73d Congress, 1st Session - - - - - House Document No. 103

COLUMBIA RIVER AND MINOR TRIBUTARIES

LETTER

FROM

THE SECRETARY OF WAR

TRANSMITTING

PURSUANT TO SECTION 1 OF THE RIVER AND HARBOR ACT APPROVED JANUARY 21, 1927, A LETTER FROM THE CHIEF OF ENGINEERS, UNITED STATES ARMY, DATED MARCH 29, 1932, SUBMITTING A REPORT, TOGETHER WITH ACCOMPANYING PAPERS AND ILLUSTRATIONS, CONTAINING A GENERAL PLAN FOR THE IMPROVEMENT OF THE COLUMBIA RIVER AND MINOR TRIBUTARIES FOR THE PURPOSES OF NAVIGATION AND EFFICIENT DEVELOPMENT OF WATER-POWER, THE CONTROL OF FLOODS, AND THE NEEDS OF IRRIGATION

IN TWO VOLUMES

VOLUME I

MARCH 29, 1932.—Referred to the Committee on Rivers and Harbors
JUNE 10, 1933.—Ordered to be printed (*see* H.Res. 178) with 2 illustrations

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1933

For sale by the Superintendent of Documents, Washington, D.C.
Price 50 cents

CONTENTS—VOLUME I

	Page
Letter of transmittal	VII
Letter of the Chief of Engineers, United States Army	1
Report of the Board of Engineers for Rivers and Harbors	6
Part 1. Report of the division engineer, North Pacific Division:	
I. Introduction	16
Authority	16
Composition of report	17
General	18
II. Discussion	22
A. General description of Columbia River and its basin	22
B. Navigation	23
General	23
Terminals	28
Navigation possibilities of an open river	28
Benefits to navigation obtainable from power dams	30
C. Power development	34
Power market	34
General	34
Conclusions as to future power market	44
Economics of power production	47
Power transmission	48
Power generation	50
General	50
Possibilities of the Columbia	53
Grand Coulee	56
Foster Creek	56
Chelan	56
Rocky Reach	57
Rock Island	57
Priest Rapids	57
The Dalles	57
Warrendale	58
D. Flood control	69
General	69
Lands along the tidal section subject to overflow	70
E. Irrigation	73
General	73
Irrigable tracts above the mouth of the Snake	74
Rathdrum prairie tract	74
Marginal areas	74
Little Spokane valley tract	74
Methow-Okanogan tract	74
Greater Wenatchee or Quincy tract	74
Priest Rapids tract	75
Pasco tract	75
Palouse tract	75
Lind tract	75
Columbia basin irrigation project	75
Combination of areas	75
Hanford tract	75
Irrigable tracts below the mouth of the Snake	75
Cold Springs tract	75
Horse Heaven tract	75
Willow Creek tract	76
Arlington tract	76
Roosevelt tract	76
Economic features	76

Page
III. Conclusions 81
IV. Recommendations 84
Appendix I. Essential facts concerning electro-chemical and other major power consuming industries 85
Appendix II. Report on power transmission study 456
Report of the Bureau of Reclamation, Department of the Interior 479
Report of the Department of Agriculture 538
Parts 2 and 3.—Reports of the district engineers at Seattle, Wash., and Portland, Oreg ..... Vol. II

LIST OF TABLES MADE IN CONNECTION WITH REPORT OF DIVISION ENGINEER

Number Title Page
A. Revenue of electric light and power industries of the United States by sources, 1920–30 37
B. Distribution of central station energy to ultimate consumers in the United States, 1920–30 38
C. Energy delivered to ultimate consumers in 1929 38
D. Rate per kilowatt-hour (in cents) 39
E. Number of residential consumers of electric power 40
F. Average sales for residential use in kilowatt hours per year per consumer 40
G. Electrical requirements of electro-chemical processes in the United States during 1929 43
H. Estimated future electrical production within marketing distance of Columbia River power site 45
I. Cost of steam power per kilowatt-hour 47
J. Construction cost of double circuit, 220,000 volts, transmission line with terminal equipment 48
K. Annual fixed charges for two methods of financing 49
L. Annual charges for double circuit, 220,000 volts, transmission line with terminal equipment 49
M. Cost of transmission per kilowatt-hour for 220,000 volt line of different length, 4 percent money 49
N. Cost of transmission per kilowatt-hour for 220,000 volt line of different length, 6 percent money 49
O. Capacity and output of generating stations in public service within marketing area for Columbia River power 51
P. Undeveloped potential water powers of rivers other than the main Columbia in Washington and Oregon 52
Q. Plans for ultimate development between tidewater and the international boundary 53
R. Records of flow on Columbia River and corresponding natural water surface elevations 58
S. Design of dams 59
T. Limiting conditions controlling power output of 17-year period from April 1913 to March 31, 1930, as assumed by district engineers 60
U. Estimated investment at power sites 61
V. Estimated annual charges, available prime output and cost per kilowatt-hour, installed generating capacity, as given in table T 62
W. Comparison of investment and operating results for power sites at Grand Coulee and at The Dalles estimated to operate at 79.5 percent load factor 64
X. Cost per kilowatt-hour with capacity of power plants adjusted to generate the given prime power but at different load factors 65
Y. Estimated cost per kilowatt-hour of energy generated at Grand Coulee and The Dalles power sites and delivered at the load centers 66
Z. Estimated cost per kilowatt-hour of energy generated by steam power with fuel oil at $1 per barrel compared with weighted average of estimated cost per kilowatt-hour generated at Grand Coulee and The Dalles power sites and delivered to load centers in the proportion indicated 67
AA. Ultimate prime power possibilities of the comprehensive plan 69
I. Summary of costs and annual charges, irrigation from Columbia River 77

ILLUSTRATIONS IN MAIN REPORT OF DIVISION ENGINEER

Plate no.		Page
I.	Map of Columbia River basin	22
II.	Chart showing growth of electrical generation in market area for Columbia River power	46

ILLUSTRATIONS MADE IN CONNECTION WITH APPENDIX I

[These illustrations are not printed. Copies thereof may be procured at cost of reproduction from the division engineer, Pacific Division, San Francisco, Calif.]

Graph no.

I. New aluminum production in the United States in last 18 years.
II. Sources of commercial fertilizer in the United States in 1928.
III. Ferro-alloy production in last 17 years compared with production of alloy steel ingots and castings.
IV. Primary zinc production in last 18 years.
V. Production of caustic soda and chlorine in last 11 years.
VI. Comparison of production and consumption of wood pulp, newspaper, and all paper in the United States in last 20 years.
Map—Bauxite mining regions, aluminum production plants, and consumption areas in North America.
Map—Fertilizer resources, nitrogen and phosphoric acid plants, and fertilizer market.
Chart—Principal nitrogen compounds and their uses.
Chart—Principal phosphatic compounds and their uses.
Map—Copper mining regions, reduction and refining plants, and consumption areas.
Chart—Major stages in copper ore reduction.
Map—Zinc mining regions, reduction plants, and consumption areas.
Chart—Major stages in zinc ore reduction.
Map—Brine sources, chlorine and caustic soda production and consumption.
Chart—Products of cellulose solutions.
Map—Newsprint timber resources, newsprint paper mills, and chief consuming centers.
Map—Rayon materials, mills, and consuming centers.
Map—Iron and steel works, ferro-alloy plants, and areas producing minerals essential to iron and steel production.

ILLUSTRATIONS MADE IN CONNECTION WITH APPENDIX II

[These illustrations are not printed. Copies thereof may be procured at cost of reproduction from the division engineer, Pacific Division, San Francisco, Calif.]

Figure no.

1. Economical RI_{rms} drop for A.C.S.R. cables.
2. Mean daily load curve, 1929, city of Seattle.
3. Mean daily load curve, 1929, Puget Sound Power & Light Co.
4. Mean daily load curve, 1929, Washington Water Power Co.
5. Economical line voltage public money.
6. Economical line voltage private money.
7. Approximate power, limit curves.
8. Cost of transmitting energy.
9. Cost of transmitting energy.
10. Weight of steel in towers.
11. Cost of towers and insulators in place per mile of line.

ILLUSTRATIONS ACCOMPANYING REPORT BY THE BUREAU OF RECLAMATION, DEPARTMENT OF THE INTERIOR

[These illustrations are not printed. Copies thereof may be procured at cost of reproduction from the respective departments]

Drawing no.	Title
222-D- 5.	Pumping plan.
222-D- 6.	Power market studies.
222-D- 7.	Cost of generating steam power.
222-D- 8.	Annual cost of steam standby.
222-D- 9.	Cost of transmitting energy to load center without steam stand-by.
222-D-10.	Cost of transmitting energy to load center with steam stand-by.

Drawing no. Title
222-D-11. Value of power at power plant without steam stand-by.
222-D-12. Value of power at power plant with steam stand-by.
222-D-13. Financial operation of power development.
222-D-14. General map.
222-D-15. Columbia River Dam and power plant.
222-D-16. Columbia River power plant, general plan.
222-D-17. Columbia River power plant, partial plans.
222-D-18. Columbia River power plant, typical section.
222-D-19. Columbia River power plant, longitudinal sections.
222-D-20. Columbia River pumping plant, typical sections.
222-D-21. North Grand Coulee Dam.
222-D-22. South Grand Coulee Dam.
222-D-23. Existing power systems.

ILLUSTRATIONS ACCOMPANYING REPORT SUBMITTED BY THE SECRETARY OF AGRICULTURE TO THE BOARD OF ENGINEERS FOR RIVERS AND HARBORS, WAR DEPARTMENT

[These illustrations are not printed. Copies thereof may be procured at cost of reproduction from the respective departments]

Figure no.
1. Population increase in the United States, 1921–31.
2. Changes in consumption of food products per person total and six principal products, United States, 1909–30.
3. Birth rates: Five countries of northwestern Europe.
4. Approximate acreage required to produce net exports, major farm products, 1897–1930.
5. Agricultural production, crop land, farm labor, and population, 1897–1930.
6. Index of total meat, milk, and egg production, animal units on farms January 1 and crop feed consumed, 1897–1929.
7. Less productive compared with more productive crops per acre and meat and milk animals per unit of feed consumed percentage change in acreage or number, 1900–30.
8. Distribution of land in farms by use in 1929 compared with our total land area.
9. Forest and cut-over land available for crops without drainage, approximate acreage, 1923.
10. Wet lands in need of drainage, approximate acreage, 1919.

LETTER OF TRANSMITTAL

WAR DEPARTMENT,
Washington, March 29, 1932.

The SPEAKER OF THE HOUSE OF REPRESENTATIVES

DEAR MR. SPEAKER: I am transmitting herewith a report dated March 29, 1932, from the Chief of Engineers, United States Army, on the Columbia River and minor tributaries, made under the provisions of House Document No. 308, Sixty-ninth Congress, first session, which was enacted into law with modifications in section 1 of the River and Harbor Act of January 21, 1927, together with accompanying papers and illustrations.

Sincerely yours,

PATRICK J. HURLEY,
Secretary of War.

COLUMBIA RIVER AND MINOR TRIBUTARIES

WAR DEPARTMENT,
OFFICE OF THE CHIEF OF ENGINEERS,
Washington, March 29, 1932.

Subject: Report on the Columbia River and minor tributaries.

To: The Secretary of War.

1. I submit for transmission to Congress, my report with accompanying papers and illustrations on Columbia River and minor tributaries, made under the provisions of House Document No. 308, Sixty-ninth Congress, first session, which was enacted into law with modifications, in section 1 of the River and Harbor Act approved January 21, 1927. As defined in the document and in the River and Harbor Act of March 3, 1925, the primary purpose of this report is "the formulation of general plans for the most effective improvement of the river for the purposes of navigation, and the prosecution of such improvement in combination with the most efficient development of the potential water power, the control of floods, and the needs of irrigation." The survey is sufficient for the general purpose indicated.

NAVIGATION

2. Columbia River from a standpoint of navigation may be divided into three sections; namely, the tidal or lower section extending from the mouth to a point about 140 miles from the mouth; the middle section extending from the head of tidewater to the mouth of Snake River, a distance of about 180 miles; and the upper section extending from the mouth of Snake River to the international boundary, about 424 miles.

3. The project now authorized by Congress for the tidal section provides for a channel through the ocean bar at the mouth of the river 40 feet deep and not less than one half a mile wide; for a channel thence to the mouth of the Willamette River 500 feet wide and 35 feet deep, to be provided in cooperation with the improvement by the port of Portland of the Willamette River to Portland, Oreg.; and for a channel 25 feet deep and 300 feet wide to Vancouver, Wash., 4½ miles above the mouth of the Willamette River, to be provided in cooperation with the port of Vancouver. In a separate report submitted to Congress, February 12, 1932, modification of the project to provide a depth of 28 feet to Vancouver, with suitable turning basins, is recommended. If so modified the present project for navigation on the tidal section will be adequate. The effective improvement of the tidal section for navigation cannot be combined with the development of potential water power, the control of floods, or the needs of irrigation. This project for navigation needs no further mention at this time.

4. The middle section is obstructed by rapids. The Cascade Gorge at the head of tidewater completely blocked navigation before improvement. Navigation past the rapids of the gorge is now afforded by a canal with a lock affording a depth of 8 feet, which was completed in 1896. The next major obstacle to navigation is the Celilo Falls, 200 miles from the mouth. Navigation past the falls is provided by a lateral canal known as The Dalles-Celilo Canal, completed in 1919, with 5 locks with chambers 45 by 265 feet in dimension and affording a depth of 8 feet. From Celilo Falls to the mouth of Snake River the existing project provides for removing obstructing boulders and ledges to provide safe navigation of such channels as exist. The controlling depth over the shoals is about 4 feet at low water. Channels through all of the rapids are generally 100 feet or more in width. Because of the swift currents in the middle section of the river, including the approaches to the Cascade Locks, it can be navigated only by high-powered boats of relatively small-cargo capacity, and is not suitable for modern barge navigation.

5. There is no project for navigation above the mouth of Snake River except in the reach, Wenatchee-Bridgeport-Kettle Falls, about 240 miles in length, where open-river work has been prosecuted to obtain a depth of 5 to 7 feet. Rapids and swift water make navigation in this reach a difficult and costly means of commercial transportation. Such traffic as there is on the river is local, and under present conditions there is no prospect of developing a water-borne commerce on the upper Columbia.

6. The tidal lower section of the Columbia has a large and important commerce. The present commerce on the middle section is unimportant, but there is every reason to anticipate a substantial commerce with large transportation economies if the river is improved for efficient and economical barge navigation. While the amount of this commerce, and the savings in transportation costs cannot be certainly estimated, yet the figures presented by the district and division engineers are considered a suitable basis for determining the value of the improvement from a navigation standpoint. These figures show a movement of 600,000 tons of freight, with an estimated saving of somewhat more than $1,000,000 per annum. The effective method for improving the middle section of the river for navigation is in combination with the development of potential water power. The estimated cost of the locks and channel enlargement necessary for navigation in such combined development is $16,100,000. The potential navigation on the middle section is of such value as to warrant the requirement that power developments be designed on the general lines recommended by the Board of Engineers for Rivers and Harbors to provide pools suitable for navigation; and the public benefits from navigation are sufficient to warrant the assumption by the Federal Government of the entire cost of the necessary locks and channel enlargement.

POWER DEVELOPMENT

7. The Columbia River and its tributaries are susceptible of being developed into the greatest system for water power to be found anywhere in the United States. The power can be developed at low cost. The sites determined by the Board of Engineers for Rivers and Harbors as most promising, all things considered, are at 10 localities, namely:

(1) Head of Grand Coulee, Wash.
(2) Foster Creek, Wash.
(3) Chelan, Wash.
(4) Rocky Reach, Wash.
(5) Rock Island Rapids, Wash.
(6) Priest Rapids, Wash.
(7) Umatilla Rapids, Oreg.
(8) John Day Rapids, Oreg.
(9) The Dalles, Oreg.-Wash.
(10) Warrendale, Oreg.-Wash.

8. Of these, the one at Rock Island Rapids is under construction by private enterprise.

9. The structures contemplated in the scheme for power development are all on a large scale, some on a grand scale, and the conditions at some of them as to foundations and flood discharge over the dams are without precedent. There is nothing, however, to cause a belief that the engineering difficulties cannot be surmounted.

10. There is a desire, which is natural, to make more extended engineering investigations at this time. I believe that there are enough data on hand on which to base any major decisions that may be required by Federal authority. Detailed investigations will be in order following these decisions, or they may be unnecessary.

11. The cost of this development will exceed that of any other single development of any kind for power that has ever been made. Assuming money at 4 percent the estimated costs of these power installations including interest during construction are as follows: Grand Coulee, $204,500,000; Foster Creek, $49,000,000; Chelan, $39,000,000; Rocky Reach, $38,000,000; Priest Rapids, $63,000,000; Umatilla Rapids, $60,000,000; John Day Rapids, $110,000,000; The Dalles, $89,000,000; Warrendale, $59,000,000. Total of these developments about $711,000,000. If money is 6 percent the total would be about $772,000,000. The Grand Coulee and The Dalles installations are outstanding because of size. The ultimate development to be foreseen would have an installed capacity of about 8,000,000 kilowatts. The Grand Coulee development alone would be able to meet any probable increase in power needs of the accessible area for a period of 30 years in the future.

12. There is evidence in this report to show that the power of the Columbia River may be developed economically, provided it be done in such increments as not to outrun the demands of the market. A combination or close coordination of the entire power industry in the region is necessary to secure economic results by guarding against overproduction.

13. The power interest on the Columbia River above the tidal or lower section is by far the most important feature in the development of the river.

FLOOD CONTROL

14. There is a problem of flood control on the lower Columbia. It is independent of other interests, though it will be ameliorated somewhat by the large power installations if they are made with provisions for storage. It can be solved by local interests whenever the economics of the situation justify the building of better levees.

IRRIGATION

15. From the data at hand about 2,000,000 acres of land along the Columbia River in the United States are susceptible of irrigation from that river.

16. The irrigation of the bulk of this land in the most economical manner depends on cheap power for pumping. Irrigation therefore depends on power installation to that degree.

17. There is a much more serious question of the economic feasibility of irrigation here than there is of power development. In fact the local reports demonstrate that the irrigation of land as pertains to the Columbia River area under consideration is not an economical proposition at this time and should await the future.

18. The policy of bringing more land under cultivation at present by large expenditures of general funds and in competition with other lands already under cultivation is questioned by agricultural authorities of the general government.

CONCLUSIONS

(*a*) Navigation interests on the lower Columbia River at present are sufficiently served by the projects heretofore adopted or recommended.

(*b*) Power development on the Columbia River is feasible and the economy of the development appears favorable, provided all power development in the region is coordinated to insure against overproduction.

(*c*) Irrigation as a part of the combined development of the Columbia River is not at the present time economical, considered alone. In the power development there should be a reservation placed on power at the cost of production for purposes of irrigation in the future.

(*d*) Flood control is a minor interest and susceptible of easy solution by local interests.

19. I recommend as follows:

(*a*) That the project for the improvement of navigation on the lower Columbia River be as heretofore adopted or recommended.

(*b*) That the existing projects for the improvement of the Columbia River between Vancouver and the mouth of Snake River be modified to provide for the construction by the Federal Government of locks having a depth of not less than 9 feet over the sills at low water and of suitable dimensions for modern barge traffic, at any dams built in this section of the river under authority of the Federal Water Power Act and in accordance with the comprehensive plan of improvement for navigation in combination with the development of water power; together with a channel enlargement for navigation purposes, all at an estimated cost of $16,100,000, with $300,000 annually for maintenance and operation.

(*c*) That the project for navigation on the upper Columbia River, the section between the mouth of the Snake River and the international boundary, remain as adopted at present, except that power installations, which shall be made on this section, shall conform to such requirements as to navigation in the future with a view of slack-water navigation of a depth of not less than 9 feet, as the Secre-

tary of War on the recommendation of the chief of engineers may prescribe.

(*d*) That the power developments on the Columbia River shall be made on application of local governmental authority or private interest under restriction of the Federal Water Power Act with the prescription of reserved demands of power at cost of production, in such amount as may be made and determined in the interest of irrigation by the Secretary of the Interior.

(*e*) That Federal projects for works for irrigation to be supplied with water from the Columbia River or its tributaries, shall be prepared by the Secretary of the Interior, when their preparation is authorized by direction of law.

(*f*) That no license be issued for the purpose of constructing dams or for power development on the Columbia River which is not in accordance with the general plan for combined development for navigation and power as recommended by the Board, subject to such modifications as may be approved by the chief of engineers and the Secretary of War in conformity with the purpose of that plan to secure the most effective improvement best adapted to the purposes of navigation in combination with water-power development.

20. This report has been submitted to the Commissioner of Reclamation of the Department of the Interior who concurs generally with the views expressed therein. The following letter from the Commissioner of Reclamation expresses his views:

March 19, 1932.

MY DEAR GENERAL BROWN: The opportunity you have given me to read your report on the development of the Columbia River made by the Corps of Engineers of the Army, is highly appreciated and in response to your invitation, I submit the following comments:

The only portion of the investigations dealt with in this report which concerns the work of the Bureau of Reclamation is that relating to the utilization of the river at Grand Coulee, through the construction and operation of power and irrigation works. With your conclusions regarding this, I am in accord and it is a pleasure to be able to state that there is a complete agreement between the engineers of the War Department and those of this Bureau regarding the plans which should be adopted for irrigation and power development, and the estimates of cost.

To your views of conditions as they exist at this time, I should like to add my belief that no development of the land and water resources of the arid region equals this in importance and in the beneficial results which would come. It will enable the largest single water supply of the arid region to be utilized to give cheap power to industries, and make feasible the irrigation of the largest and finest body of unreclaimed land left in the arid region.

I am in agreement with your conclusions that this development to be solvent must be based on the revenues from power and that these revenues must contribute to the cost of the irrigation works to avoid injurious burdens on irrigation farmers; also, that there is not at present a demand for these farms or for the crops to be grown on them. Development, if inaugurated immediately, would not, however, be in opposition to this view. It will require at least 10 years after the works are authorized, to build the dam and the power plant, and another 10 or 15 years to absorb the power thus made available. These things must precede the large expenditure to build the works required for irrigation. By that time the increase in population of the cities of Spokane, Seattle, Tacoma, and Portland, and all the other cities and towns of the Northwest, will provide a local market for the products of these farms. They will be an essential element in the economic and prosperous development of this region.

Very truly yours,

(Signed) ELWOOD MEAD, *Commissioner.*

LYTLE BROWN,
Major General, Chief of Engineers.

REPORT OF THE BOARD OF ENGINEERS FOR RIVERS AND HARBORS

SYLLABUS

The Board of Engineers for Rivers and Harbors presents a general plan for the ultimate improvement of the Columbia River for navigation in connection with power development, flood control and irrigation, but reports that the Federal Government would not be justified at the present time in adopting any further plan for improvement than that covered by the existing navigation project or in participating in the cost of any of the portions of such plan other than to bear the cost of the construction of the navigation features of the plan for the development of the river below the mouth of the Snake. It recommends—(*a*) that the existing projects for the improvement of the Columbia River between Vancouver and the mouth of Snake River be modified to provide that if dams be built in this section of the river under authority of the Federal Water Power Act and substantially in accordance with Plan A of the division engineer's report, the United States shall construct the necessary locks thereat, and enlarge the channel section above the Warrendale Dam, at an estimated cost of $16,100,000, with $300,000 annually for maintenance and operation; (*b*) that additional studies of certain engineering features of the general plan be made, and (*c*) that the reports be published.

[Second endorsement]

BOARD OF ENGINEERS FOR RIVERS AND HARBORS,
Washington, D.C., February 23, 1932.

To the Chief of Engineers, United States Army.

1. The following is in review of the report on Columbia River, Washington and Oregon, submitted under the provisions of House Document No. 308, 69th Congress, 1st Session, which was enacted into law, with modifications, in section 1 of the River and Harbor Act of January 21, 1927.

2. The reports herewith contain information concerning existing and prospective developments for navigation, power development, flood control and irrigation, and for certain important combinations thereof. A comprehensive plan for the ultimate utilization of the water resources of the river is presented by the division engineer. The principal considerations upon which this plan is based and its more essential features are summarized in paragraphs 3 to 15 below.

3. In the tidal section of the river the present and immediately prospective needs of navigation are sufficiently provided for by the existing project.

4. In the nontidal section below the mouth of the Snake River, prospective commerce is not assured to a sufficient extent to justify the cost of an adequate improvement for navigation alone. The benefits to navigation afforded by the construction of power dams providing slack water throughout this section, are sufficient to justify the United States in constructing or paying for the construction of the necessary locks. In addition, the United States might be justified in contributing a sum not in excess of $5,000,000 toward the cost of constructing the dams.

5. Above the Snake River conditions are not favorable to the development of any considerable amount of commerce, but the in-

terests of navigation should be safeguarded by reserving to the United States the right to construct or to require the construction of locks in power dams built in this section.

6. In the nontidal section there are no serious flood problems, and works for flood control either alone or in combination with other developments are not necessary.

7. In the tidal section considerable areas are subject to flooding. The most important areas have been protected by levees constructed by local interests, but many of these levees do not afford complete protection against the highest floods. It is considered that the parties interested would be justified in increasing the extent of existing protection and extending it somewhat to unprotected lands, but that this is an independent problem which cannot profitably be combined with navigation, power development, or irrigation. In case power development in the upper river with extensive development of storage should be carried on in the future along the lines discussed in this report, some minor degree of flood protection for these lands will be an incidental result.

8. Power development is not feasible in the tidal section.

9. In the nontidal section the development of power is of paramount importance. It will have no adverse effect on navigation in the tidal section; it can and should be made to aid navigation in the nontidal section. Irrigation development will need the economic support of power developed for the general power market.

10. A large amount of water power could be developed at low cost, but only by the construction of very large projects. The comprehensive plan of the division engineer includes 8 dams, utilizing a little more than 92 percent of the available head and providing for an ultimate installation of more than 8,500,000 kilowatts or 11,330,000 horsepower. Of these dams, 2 are located below the Snake River and 6 above. One of the latter is now under construction at Rock Island Rapids as a private development.

11. Of the seven undeveloped sites, the three of special interest in connection with combined development, and in the order of their location going upstream are:

a. At or near Warrendale, at the foot of the Cascade Rapids.

b. At the Dalles, about 3 miles above the city of The Dalles.

c. At the head of Grand Coulee in the State of Washington.

12. Dams at the first and second sites will develop a large amount of power and will afford canalization of the river from tidewater to the mouth of the Snake, but will not provide slack water during freshets; some of the power can probably be used for irrigation by pumping. The dam at the Grand Coulee will be primarily for power development and irrigation. Full power development at any one of the three sites should properly defer power development at the others until the growth of the power market justifies further development. Prime power from either The Dalles or the Grand Coulee sites can be delivered in large quantities at the load centers in the Pacific Northwest at relatively low cost.

13. Irrigation has already been provided for most of the land which can be irrigated at low cost and its extension to the remaining lands of this type will be substantially independent of other uses of the waters of the river. One large area of upland, known as the "Columbia Basin", could be irrigated by gravity diversion from the Clark Fork and Spokane River or by pumping from the Columbia River by means of secondary power developed at the plant on the Columbia River near Grand Coulee. The feasibility of the pumping plan is dependent on the possibility of selling practically the entire output of primary power from this plant at a remunerative rate. Various smaller but still important areas might also be irrigated by pumping, chiefly by secondary power. None of those projects is considered economically feasible if it be required that the payments for irrigation water be sufficient to repay the construction cost of the pumping and distributing systems within 40 years with interest at 4 percent. If a combined power and irrigation development at Grand Coulee were built by the United States, the receipts from power and from reasonable charges for irrigation water might, under certain specified conditions, be sufficient to repay the construction cost within a period of from 60 to 90 years with interest at 4 percent. The district engineer states that the plan proposed amounts to some extent to assessing the adjacent region to pay for the indirect benefits which might accrue to it from the irrigation development, the payments being made in the form of increased rates for power rather than by direct assessment.

14. The division engineer concludes that the most feasible plan for ultimate utilization of the resources of the Columbia River is as follows:

a. A system of 8 dams along the main stream located at:
Head of Grand Coulee, Wash.
Foster Creek, Wash.
Chelan, Wash.
Rocky Reach, Wash.
Rock Island Rapids, Wash. (under construction).
Priest Rapids, Wash.
The Dalles, Oreg.-Wash.
The foot of Cascade Rapids (Warrendale), Oreg.-Wash.

b. Additional dams, with locks, for navigation only, at points 14 and 40 miles above the mouth of the Snake, to be constructed when justified by the needs of navigation.

15. He states that the power dams in *a* above would develop 92.3 percent of the total head between the international boundary and tidewater. This system would receive full benefit from such storage and regulation in the tributaries as may be created in the future. It would furnish slack-water conditions, except at high water and thus benefit navigation. It would permit irrigation of large tracts of land in Oregon and Washington and would reduce flood heights in the tidal section of the river. He states that provision should be made for locks through the dams below the mouth of the Snake River to be installed simultaneously with the construction of the dams, and through the dams above the Snake when river traffic justifies the cost of locks. He recommends that this plan be adopted by the United States as its guide in controlling and supervising development of the Columbia River above tidewater, navigation being considered chargeable with the cost of locks through dams below the mouth

of Snake River and subject to contribution of not over $5,000,000 toward the cost of these dams; and that the plan for the tidal section of the river remain as at present.

VIEWS AND RECOMMENDATIONS OF THE BOARD

16. As stated in the act of March 3, 1925, the primary purpose of this survey was: "The formulation of general plans for the most effective improvement of the river for the purposes of navigation and the prosecution of such improvement, in combination with the most efficient development of the potential water power, the control of floods and the needs of irrigation."

17. Based upon the information now available, the Board concurs in general in the views of the division engineer as to the best general plan for a comprehensive development of this river except as to the number of dams which should be constructed between the mouth of Snake River and tidewater. In this section the plan of the division engineer provides for an extremely high dam and large reservoir at The Dalles and a relatively low dam at Warrendale. An alternative plan, designated in the report as "Plan A", develops the head in this section of the river by four dams of moderate height located at Umatilla Rapids, John Day Rapids, The Dalles, and Warrendale. Although this plan would not develop as much total power as the one recommended by the division engineer, the Board prefers it as being better suited to progressive development to meet the growth of the power market.

18. The Board desires, however, to point out the fact that considering the limited time and money available, the length and character of the river, the multiplicity of available dam sites and the various combinations possible of consideration, the reports, voluminous as they are, must still be considered as general in character only, and not sufficiently complete to permit of definite recommendations for construction even were the Board otherwise prepared to make such recommendation.

19. For the proper development of the Cascade Rapids section, a dam at Warrendale with a head of about 50 feet, appears to offer the most satisfactory solution. Yet this involves a structure that must provide safely for a possible flood discharge of 1,400,000 cubic feet per second, and must be built upon a foundation of sand and gravel. The Board has found no precedent for such a structure, and could not endorse the plan proposed as sound from an engineering standpoint without further field investigation and extended and detailed studies. Likewise the dam proposed at The Dalles, which requires the closure of a channel 500 feet wide and 150 feet deep with very high velocities, involves methods of construction without precedent, and would require further investigation and detailed studies. At other places, notably Rocky Reach and Chelan, further investigation of foundation conditions would be required to determine beyond question the feasibility of the constructions proposed.

20. The Department of the Interior, through the Bureau of Reclamation is charged with the development of irrigation projects and copies of the portions of the reports covering the proposed Columbia Basin project, including the dam at Grand Coulee, were furnished that Bureau for its information. In a report dated January 7, 1932, to the

Commissioner of the Bureau, the chief engineer thereof, while suggesting certain modifications in the project works and submitting certain different estimates of cost and concurring generally in the views of the reporting officers as to the economic feasibility of the project, makes the following statement in which the Board concurs:

> In order to perfect final construction plans it will be necessary that further information be secured by diamond drilling of the foundation of the Columbia River Dam; that additional field exploration and laboratory tests be made to determine the amount and source of supply of the concrete aggregates for the Columbia River Dam; that a topographic survey and land classification be made of the irrigable area of the project; that test pits and borings be made to determine the classification of material to be excavated in the main canals of the project distribution system for use in final designs and estimates; and that a survey be made to determine the cost of irrigating land by pumping water from the Spokane River and using Columbia River Dam power.

21. Also, the question of the necessary provision for the passage of fish over the dams or other provision therefor will require more definite determination. The salmon fishing industry is of great importance to the States of Oregon and Washington, and should not be endangered. For moderate heights of dams, fish ladders may provide for the passage of fish upstream for spawning, but for dams of 100 feet or more in height no feasible plans have as yet been fully developed.

22. Irrespective of the points above referred to, the Board's views are substantially as follows.

23. In the tidal section of the river the existing project is sufficient for the present and immediately prospective needs of navigation, and future needs can be met independently of any other use of the stream. Further flood control measures are primarily of local importance and can be taken independently of other developments. No power and no important irrigation developments are possible in this section.

24. Above the tidal section the river is naturally divided into two sections, one below and one above the mouth of the Snake. There are no important flood problems in either of these sections.

25. In the section below the Snake River improvements for navigation have included open channel work and the construction of lateral canals at the Cascades and the Dalles-Celilo section, at a total cost of approximately $8,975,000. The chief difficulties of navigation in this section are due to the swift currents. These could not be eliminated by further work of open river improvement, and the most satisfactory plan for providing for barge navigation as desired by local interests, appears to be the construction of the series of dams above indicated, together with enlargement of the channel section above the Warrendale dam to reduce the velocity at high stages. Logically, if this work were undertaken, it should start with the lower dam and proceed progressively upstream. The estimated cost of the navigation features only of this system is $16,100,000 ($14,600,000 for locks and $1,500,000 for channel enlargement), and the carrying charges would be approximately $900,000 per annum. The figures submitted by the district and division engineers indicate a maximum gross saving of transportation costs by water over existing rail charges as a little over a million dollars per annum, based on the movement of 600,000 tons an average distance of 200 miles, with a saving of 0.9 cent per ton-mile. The Board notes that with an estimated saving of 20 percent of the cost of rail haul, which is the rate generally fixed

for barge navigation on the Mississippi and Warrior systems, this gross saving would be reduced to about $600,000, which is less than the annual carrying charges. The Board is therefor of the opinion that the United States would not be justified in expending for navigation more than the amount above indicated ($16,100,000) as the cost of the features required solely for navigation.

26. The estimated cost of the dams and power installations in this section, exclusive of the navigation features, is $317,320,000. While there is also a possibility of the ultimate irrigation of approximately 375,000 acres by pumping, such development is not urged at this time, and it is therefore clear that the primary feature of the proposed plans for this section of the river is the development of a large amount of potential water power. Local interests urge that this development be undertaken along the general lines adopted for the Colorado River at Boulder Canyon, involving as the chief feature a provision that no work shall be done until contracts for all of the power to be developed have been made. Suggestions have also been made to the effect that in order to secure for the people the maximum possibilities of cheap power, it might be desirable for the United States to construct transmission lines to the chief centers of population or industry. The Board is not prepared to recommend development on such basis. It does not understand that the action of Congress in the Boulder Canyon case was intended to be considered as a precedent in the establishment of a policy for the development of water power by the Federal Government on its navigable rivers. On the contrary, it believes that the policy set forth in the Federal Water Power Act is the adopted policy for such development. This view is supported by the action taken in the case of the Tennessee River where there is also a large amount of potential power. The report thereon (H.Doc. No. 328, 71st Cong., 2d sess.) was under the same provision of law as in this case. It submitted a comprehensive project for the development of the river and recommended in substance that the power be developed under the provisions of the Federal Water Power Act by private interests, States, or municipalities. This project was adopted by Congress in the River and Harbor Act of 1930. There does not appear to be any insuperable difficulty in the development of the Columbia River power on the same basis at any time when it can be demonstrated beyond question that the value of the power is such as to justify its development on a purely business basis.

27. In the Columbia River above the mouth of the Snake, expenditures for navigation have been limited and navigation has in recent years been negligible in amount. As indicated in the reports of the district and division engineers, there is little prospect that any considerable amount of navigation would be developed even were a complete system of dams and locks constructed. The Board concurs in the views of the division engineer that were such dams constructed, the United States would not be justified at the present time in bearing the cost of constructing locks therein, but should reserve under the terms of the Federal Water Power Act the right to install such locks or to require them to be installed when needed in the interests of navigation.

28. Local interest in this section of the river is centered in the Columbia Basin project, which involves the construction of a dam for the development of a large amount of power at the Grand Coulee

site, and the irrigation of a very large tract of land by pumping from the river. The economic feasibility of the plan is largely based on subsidizing irrigation by profits from the sale of power. The Board expresses no opinion as to the wisdom of this policy, which is presumably based on the theory that the consumers of the power would be justified by the indirect benefits which they might receive from the settlement of the areas proposed to be irrigated in paying higher rates therefor then would otherwise be required to carry the power project only. The economic feasibility is also dependent upon the future growth of power demand over a period of years. This is a question involving many uncertain factors and obviously impossible of exact determination. The Board does not undertake to make a definite prediction, but is of the opinion that the estimates of the reporting officers that the growth in power demand will be such that the entire prime output would be absorbed in a period of 15 years after 1940 and that this output would amount to only about 37 percent of the total increase in demand is unduly optimistic. Should the period required to build up a load for this plant be as much as 25 years or more, as has been estimated by the present division engineer, the capital charges would probably be so increased that the profits from the sale of power at the proposed rates would be insufficient to finance the irrigation project by the method set forth by the district engineer or by that proposed by the Bureau of Reclamation in the report referred to in paragraph 20. Furthermore, in view of the existing world-wide overproduction of agricultural products and of the extensive and long-continued depression in the farming industry, it does not seem that at this time expenditures of this magnitude can be justified for the purpose of bringing new land under cultivation. The Board is in receipt of a letter from the Secretary of Agriculture, dated January 30, 1932, with appendices, supporting this view and stating in very positive terms his opinion that the Federal Government should not now undertake to further enlarge the areas devoted to agriculture in this country. While local interests have submitted a brief in opposition to this statement, the Board accepts the views of the Secretary and is unable to recommend the adoption of this project at the present time.

29. In view of the above, the Board reports that, based on present information, the best general plan for the comprehensive utilization of the natural water resources of the Columbia River and for its ultimate improvement for the purpose of navigation in combination with the efficient development of the potential water power, the control of floods and the needs of irrigation is substantially as follows: (For general estimates of cost see table, pp. 14 and 15.)

a. A system of 10 dams for the development of water power, located along the main stream at the following sites:

Warrendale.
The Dalles.
John Day Rapids.
Umatilla Rapids.
Priest Rapids.
Rock Island Rapids (under construction).
Rocky Reach.
Chelan.
Foster Creek.
Head of Grand Coulee.

Locks and other facilities needed solely for navigation to be provided at all dams below the mouth of the Snake at the same time the dams are constructed. The provision of locks and dams above the mouth of the Snake to be deferred until it is apparent that prospective traffic will justify their construction.

b. Two low navigation dams with locks between the mouth of Snake River and the Priest Rapids site, to be built when justified by the prospective traffic.

c. Channel enlargement above the Warrendale Dam to reduce velocities at high stages.

d. Irrigation on a large scale by pumping from the river at the Grand Coulee Dam and similar irrigation on a smaller scale at some or all of the other sites.

e. Maintenance, strengthening, and possible extension by local interests of the flood control works which they have built in the tidal section of the river, the only one having serious flood problems.

f. Improvement of the tidal section below Vancouver as provided by existing Federal projects, or as may be authorized by future modification thereof.

30. The Board further reports that in its opinion the Federal Government would not be justified at the present time in making any improvement of the river other than as authorized by existing projects, nor would it be justified in participating in the cost of any portion of the comprehensive plan above outlined other than to bear the cost of the construction of the navigation features of the plan for the development of the river below the mouth of the Snake.

31. The Board therefore recommends:

a. That the existing projects for the improvement of the Columbia River between Vancouver and the mouth of Snake River be modified to provide that, if dams be built in this section of the river under authority of the Federal Water Power Act and substantially in accordance with "plan A" of the division engineer's report, the United States shall construct the necessary locks thereat, each 60 feet wide, 360 feet long, and having 9 feet of water on the sills at low water, or of such other dimensions as may be approved by the chief of engineers, and shall enlarge the channel section above the Warrendale Dam, all at an estimated cost of $16,100,000, with $300,000 annually for maintenance and operation.

b. That, with the object of more definitely determining the engineering features (pars. 19 and 20) of the general plan presented above, further investigations and studies be specifically authorized. The Board suggests that the investigations of the irrigation features of the Columbia Basin development might appropriately be made by the Bureau of Reclamation of the Department of the Interior.

c. That the reports of the district and division engineers, forwarded herewith, with plans and appendixes, be printed, since they contain information of value to State, municipal, and private interests, and to agencies of the United States in connection with future development on this river.

For the Board:

WM. J. BARDEN,
Colonel, Corps of Engineers,
Senior Member.

Estimates of cost of the comprehensive plan for the ultimate development of the Columbia River for the improvement of navigation in connection with the development of water power, the control of floods, and the needs of irrigation.

Power and navigation costs

Site and item	Interest rate on power projects	
	4 percent	6 percent
Warrendale (elevation 54):		
Dam and reservoir	$24,100,000	$24,800,000
Power house and machinery (660,000 kilowatts)	32,450,000	33,350,000
Total construction cost for power	56,550,000	58,150,000
Carrying charges	2,320,000	3,480,000
Total investment for power	58,870,000	61,630,000
Navigation facilities (see note A):		
Locks	3,100,000	3,100,000
Channel improvement	1,500,000	1,500,000
Total investment for power and navigation	63,470,000	66,230,000
The Dalles (elevation 150):		
Dam and reservoir	22,050,000	22,700,000
Power house and machinery (1,370,000 kilowatts)	61,990,000	63,700,000
Total construction cost for power	84,040,000	86,400,000
Carrying charges	4,490,000	6,740,000
Total investment for power	88,530,000	93,140,000
Navigation facilities	2,100,000	2,100,000
Total investment for power and navigation	90,630,000	95,240,000
John Day Rapids (elevation 258):		
Dam and reservoir	45,600,000	46,000,000
Power house and machinery (1,080,000 kilowatts)	57,200,000	59,700,000
Total construction cost for power	102,800,000	105,700,000
Carrying charges	7,060,000	10,600,000
Total investment for power	109,860,000	116,300,000
Navigation facilities	5,400,000	5,400,000
Total investment for power and navigation	115,260,000	121,700,000
Umatilla Rapids (elevation 330):		
Dam and reservoir	26,300,000	26,900,000
Power house and machinery (910,000 kilowatts)	30,790,000	31,550,000
Total construction cost for power	57,090,000	58,450,000
Carrying charges	2,970,000	4,470,000
Total investment for power	60,060,000	62,920,000
Navigation facilities	4,000,000	4,000,000
Total investment for power and navigation	64,060,000	66,920,000
Lock and marginal canal at Richland	800,000	800,000
Lock and marginal canal at 40 miles above Snake	950,000	950,000
Priest Rapids (elevation 540):		
Dam and reservoir	41,301,632	43,178,978
Power house and machinery (648,000 kilowatts)	16,590,710	17,344,833
Total construction cost for power	57,892,342	60,523,811
Carrying charges	4,956,196	7,772,216
Total investment for power	62,848,538	68,296,027
Navigation facilities	5,400,000	5,400,000
Total investment for power and navigation	68,248,538	73,696,027
Rock Island (elevation 599): Navigation facilities	1,800,000	1,800,000
Rocky Reach (elevation 665):		
Dam and reservoir	23,682,057	24,559,171
Power house and machinery (336,000 kilowatts)	12,931,840	13,410,797
Total construction cost for power	36,613,897	37,969,968
Carrying charges	1,420,923	2,210,325
Total investment for power	38,034,820	40,180,293
Navigation facilities	2,300,000	2,300,000
Total investment for power and navigation	40,334,820	42,480,293

Power and navigation costs—Continued

Site and item	Interest rate on power projects	
	4 percent	6 percent
Chelan (elevation 762):		
Dam and reservoir	22,676,864	23,516,747
Power house and machinery (450,000 kilowatts)	14,968,465	15,522,853
Total construction cost for power	37,645,329	39,039,600
Carrying charges	1,814,149	2,822,010
Total investment for power	39,459,478	41,861,610
Navigation facilities	3,000,000	3,000,000
Total investment for power and navigation	42,459,478	44,861,610
Foster Creek (elevation 928.6):		
Dam and reservoir	24,524,372	25,639,116
Power house and machinery (691,000 kilowatts)	21,696,684	22,682,897
Total construction cost for power	46,221,056	48,322,013
Carrying charges	2,942,924	4,615,041
Total investment for power	49,163,980	52,937,054
Navigation facilities	5,400,000	5,400,000
Total investment for power and navigation	54,563,980	58,337,054
Grand Coulee (elevation 1,287.6):		
Dam and reservoir	138,736,160	147,180,969
Power house and machinery (1,575,000 kilowatts)	32,450,617	34,425,872
Total construction cost for power	171,186,777	181,606,841
Carrying charges	33,296,676	52,985,149
Total investment for power	204,483,453	234,591,990
Navigation facilities	11,000,000	11,000,000
Total investment for power and navigation	215,483,453	245,591,990
Grand total:		
Power development (7,720,000 kilowatts)	711,310,269	771,856,974
Navigation facilities (see note B)	46,750,000	46,750,000
Power and navigation	758,060,269	818,606,974

NOTE A.—The interest on navigation facilities during construction not included.
NOTE B.—The cost of the navigation facilities below the Snake River is $16,100,000.

Irrigation costs

Based on 4 percent money, settlement at a rate of 50,000 acres per year

Columbia Basin project (plan 4), 1,199,430 acres:	
Pumping plant at Grand Coulee	$15,631,300
Distributing works	165,194,030
Total	180,825,030
Carrying charges	40,896,850
	221,721,880
Smaller projects below mouth of Snake River, 378,060 acres:	
Capital cost	38,789,965
Carrying charges	6,956,304
Total	45,746,269
Total for irrigation	267,468,149

Flood control costs

Raising 216 miles of levees 2 feet above crest of 1894 flood	1,665,000
Alternate project, raising 216 miles of levees 4 feet above crest of 1924 flood	6,705,000
New levees to protect 23 square miles	1,179,000

REPORT OF THE DIVISION ENGINEER, NORTH PACIFIC DIVISION

WAR DEPARTMENT,
OFFICE, DIVISION ENGINEER,
NORTH PACIFIC DIVISION,
Portland, Oreg., July 31, 1931.

Subject: Report on the Columbia River and minor tributaries, covering navigation, flood control, power development, and irrigation.
To: The Chief of Engineers, United States Army.

I. INTRODUCTION

1. *Authority.*—The River and Harbor Act approved March 3, 1925, contains an item reading:

> The Secretary of War, through the Corps of Engineers of the United States Army, and the Federal Power Commission are jointly hereby authorized and directed to prepare and submit to Congress an estimate of the cost of making such examinations, surveys, or other investigations as, in their opinion, may be required of those navigable streams of the United States, and their tributaries, whereon power development appears feasible and practicable, with a view to the formulation of general plans for the most effective improvement of such streams for the purposes of navigation and the prosecution of such improvement in combination with the most efficient development of the potential water power, the control of floods, and the needs of irrigation * * *.

2. The resulting report, containing a list of the streams proposed for examination, the character of the investigation considered appropriate and estimates of cost, was submitted to Congress by the Secretary of War April 12, 1926, and printed in House Document No. 308, Sixty-ninth Congress, first session. The River and Harbor Act approved January 21, 1927, directed that surveys be made in accordance with the provisions of the house document.

3. Among the streams listed in the house document as coming within the purview of the act of March 3, 1925, that is "those navigable streams of the United States, and their tributaries, whereon power development appears feasible and practicable", and on which investigations were called for by the act of January 21, 1927, are:

Columbia River and minor tributaries as follows: Cowlitz, Lewis, Willamette, John Day;

Snake River and tributaries.

4. This report deals with the Columbia proper. The named tributaries, Snake, Cowlitz, Lewis, Willamette, and John Day Rivers are reported on separately. The report on Cowlitz River has been printed as House Document 666, Seventy-first Congress, third session; that on Lewis River as House Document 680, Seventy-first Congress, third session. The report on Snake River has not yet been transmitted to Congress. That on Willamette River is being printed in House Document No. 263, Seventy-second Congress, first session. Completion of the report on John Day River has been deferred until that of this Columbia River report owing to the dependence of the former report on the findings of the latter. Unnamed tributaries of the Columbia are considered only insofar as they affect the problem of the main Columbia.

5. By direction of the chief of engineers the investigation and report upon the Columbia was assigned as follows:

To the district engineer, War Department, with headquarters at Seattle, Wash., the section of the river above the mouth of the Snake.

To the district engineer, War Department, with headquarters at Portland, Oreg., the section of the river below the mouth of the Snake.

To the division engineer, North Pacific Division, War Department, was assigned supervision over and coordination of the office and field work of the two districts.

Map entitled "Columbia River Basin", being plate I of this report, parts 2 and 3 are printed in volume II of this document shows the river above and below the mouth of the Snake.

6. *Composition of report.*—This report, of the division engineer, is part 1 of the combined report of the three offices on the investigation. The report of the district engineer, Seattle district, on the section of the Columbia between the international boundary and the mouth of the Snake constitutes part 2, and the report of the district engineer, Portland district, on the section from the mouth of the Snake to the sea constitutes part 3 of the combined report. Parts 2 and 3 are printed in volume II of this document. As used hereinafter the word report, unless otherwise defined, means the combined report consisting of parts 1, 2, and 3.

7. Part 1, this division report, serves to introduce the detailed district reports, parts 2 and 3, to give their salient data and findings and to present the subject matter briefly, considering the river, its basin, and its tributary region as a whole.

8. Four basic matters are considered: navigation, power development, irrigation, and flood control. These are treated in the district reports separately under those four heads, and there follows a consideration of those elements in combination, with a view to devising as required by House Document 308, Sixty-ninth Congress, first session, a general plan or scheme of improvement embracing the four features.

9. Chapter I of each of the district reports is introductory. Chapter II of each report is in effect a reservoir of data, including opinions, relating to the respective portion of the Columbia (above or below the mouth of the Snake) and pertiment to the various elements of the report. These data have been derived from original field and office work done expressly for this report and, to avoid duplication of field and office work and resultant unnecessary expenditure of time and money, from earlier authoritative reports on the subject, published and unpublished, produced by Federal, State, and special agencies. All pertinent useful data so obtainable within the limitation of time and funds, have been sought to be included in chapters II of the two district reports. These data form the support of the succeeding chapters of the district reports.

Chapter III consists of a discussion leading to chapter IV, which contains a plan for utilization and control of the waters of the Columbia. Chapter V contains the conclusions reached by the district engineers.

10. Throughout the compilation of his report, each district engineer has borne in mind that his report was to be a part of a report on the river as a whole. During the progress of the survey data secured by one district and needed in the other was made available to the other.

11. The district reports are accompanied by their respective appendixes, as listed in those reports. This report (pt. 1) is accompanied by:

Plate I. Map of Columbia River Basin.

Plate II. Chart showing growth of electrical generation in market area for Columbia River power.

Appendix I. Essential facts concerning electro-chemical and other major power consuming industries.

Appendix II. Report on power transmission study.

12. *General.*—The following paragraphs of this section (I) of this division report state various matters pertinent to the report and considered in its preparation.

13. This report is, by the terms of the act calling for it, predicated upon the Columbia River's possessing a navigable status. This it does as a matter of fact throughout most of its extent, but there are rapids and falls in the upper reaches through which navigation is impossible and will continue so to be until dams have been constructed for navigation, power development, or other purposes, and facilities for movement of craft through or past such dams have been provided.

14. Navigability of the Columbia having been accepted as warranting a report under House Document 308, Sixty-ninth Congress, first session, it may be noted that the benefits to navigation resulting from power structures alone or with assistance of navigation structures becomes a matter of prime importance in the study under the terms of the basic act. See paragraph 24, below. Power structures in this case are dams and reservoirs created by the dams.

15. To determine the benefits to navigation derivable from power dams and reservoirs it is necessary to prepare: first, an estimate of the potential traffic on the waterway (there is practically no actual traffic above the tidal section); second, an estimate of the probable savings in cost of moving such potential traffic over the river improved by power structures as compared with the cost of moving it over the river in its present condition or improved without dams; and third, the savings by river over movement by land carriage. This has been done so far as practicable, but determination of prospective river traffic is impossible of attainment with accuracy in a region not fully developed yet well supplied with railways and highways.

16. Benefits to navigation expressed in estimated total savings may be considered the maximum amount that the United States might, in the interest of navigation, contribute to a power or combination power and navigation project or other combination project. But, as there will be no actual savings due to the improvement if prospective savings in costs of freight carriage through navigation of an improved waterway are applied wholly to the navigation improvement itself, it is unwarranted in the general case so to apply the full amount of prospective savings. What would be accomplished with such complete consumption of anticipated savings is merely improvement of the waterway and facilitation of water shipments over a new or improved route with no resultant economic gain. If, further, the water route is so situated that it becomes a competitor of one or more land systems of freight movement the result would be a multiplication of facilities. One of these may be superior to the others. All may be needed, but creation of multiple facilities, unless each is more suitable and needed for certain classes of freight than the other is, or unless the prospective tonnage is great enough to employ both or all routes to full capacity, would require special justification.

17. The test of meeting successfully a public necessity should be applied in the establishment or improvement of a water route as in the cases of land carriers. Railroads and through highways are national assets. The establishment or improvement of competing river routes that would depreciate such assets is undesirable and should be avoided unless some benefit to the general public is to be derived.

18. The expenditure of funds, Federal or other, on river improvement for navigation whose only or main effect will be a reduction of rail or truck rates with the river failing to carry its quota of freight is a cumbersome and uneconomic procedure. Reduction of such rail or truck rates to a proper point should be accomplished by other means. There is no gain in national assets to offset Federal funds consumed in a river improvement that leaves the river unused for actual freight movement, though there may be a benefit to a fortunate section of the public. In determining the amount of contribution of Federal funds appropriate to a river improvement no credit should be taken for freight savings unless effected on freight actually moved on the waterway.

19. Savings in freight carriage costs resulting from an improved river based on freight tariffs of competing carriers attain their maximum only as the river traffic reaches the expected maximim and then only if competing carriers do not reduce their rates. These elements introduced uncertainty as to the appropriate amount of Federal exenditure and should be met by conservation in estimating such amount.

20. In making comparison of costs of moving freight by different means of transportation to determine choice of means for an undeveloped country or to determine if multiplication of means is justified when there are already existing facilities, all costs of carriage and a fair profit should be considered. In the case of a railroad the first costs include those of financing, rights of way, roadway, equipment and terminals, and the cost of carrying the investment during the period of construction and of development of traffic; the carrying costs include maintenance, depreciation, operation, taxes and interest. For a waterway improvement there are corresponding costs, except that no right-of-way costs are usually incurred, and there are no taxes or costs of financing in connection with the improvement works if created by the United States; but the other classes of costs, including interest, are present in the case of movement of freight by the waterway, and should be reflected in the estimates on which conclusions are based.

21. In a case where there are existing railroads and truck lines, as along the Columbia River below the mouth of the Snake, a measure of cost of freight movement by land is furnished by the rail or truck tariffs. But in that section of the Columbia, and above tidewater, there are no common carriers on the river, and no river tariffs. Consequently, freight costs by river for comparison with costs over competing rail and truck lines to determine potential savings by using river craft must be constructed and should include the items mentioned above. Equipment costs include the cost of craft and operation costs include those of operating the craft and terminals and take

into consideration the cost of freight movement between the river and the inland points of origin and destination.

22. The Columbia is a stream of vast power possibilities. Practically no power is as yet being developed on the main stream. One plant of considerable size is under construction at Rock Island, below Wenatchee, Wash.

23. The power possibilities of the stream may be considered the basis of this report. The navigation possibilities sanction the report. Very considerable time and care have accordingly been put on the consideration of power development possibilities. The results are mentioned in the section below on power development and given in detail in the district reports. The important divisions of the study in respect to power are power development proper, and transmission and utilization of power, or power market.

24. House Document 308, Sixty-ninth Congress, first session, above referred to, recognizes differences among streams in the benefits to navigation derivable from power development. A classification of streams, and of investigation of streams, is predicated upon the comparative benefits. Class (*a*) streams are defined as those streams "the improvement of which by power developments, alone or in connection with navigation structures, would benefit navigation sufficiently to justify the Federal Government in sharing in the cost of the improvements." Class (*b*) streams are those "the improvement of which by power development would be of considerable benefit to navigation but not sufficient in the light of present information to warrant large expenditures by the Federal Government on that account." Class (*c*) streams are the streams upon which "the apparent benefits to navigation that could be derived from power developments would be insignificant".

25. The section of the Columbia below the mouth of the Snake may be fairly considered as falling within class (*b*) as defined above. Above the mouth of the Snake the stream may rather, at the present time, be classified as a class (*c*) stream. Power development on this latter part of the stream and development of the tributary territory must needs occur to a considerable extent over probably a long term of years, before the stream above the Snake can be held to fall in class (*b*). This is especially true of the part of the Columbia above Bridgeport, Wash.

26. The introduction of a power dam in a navigable stream may be of advantage to navigation through creation of slack water by which navigation may be facilitated. Slack water would not, however, be provided on the Columbia at high stages, except to some extent through regulation of flow by storage above, as the channel cross section is such that flood velocities would be but slightly reduced below those obtaining in the open river. At low stages the dams would reduce the considerable velocities now found at many points along the Columbia above tidewater. A power dam may further serve navigation by increasing depths over shoals above and this would be true in the Columbia.

On the other hand, a power dam across a navigable stream is a complete bar to such navigation as might otherwise have used the stream, necessitating locks or other means of passing the dam if navigation is to be created or continued. Cost of providing locks or

other installations for passing boats should be divided fairly between navigation and power developments in any case according to the particular conditions of that case.

27. In the estimates contained in this report, and in the estimates of the district reports on which this report is based, interest on money, whether Federal or other, has necessarily been taken into consideration, that a presentation of true costs might be made, and correct conclusions as to the economic soundness of a plan might be reached. To furnish Federal money toward a project interest free is to subsidize the project, and unless the remitted interest is calculated the true cost of the project is not known and the economic soundness of the project may be unestablished.

28. Field operations carried on in connection with this report have been limited to those needed for the purpose of the report. The extensive explorations of dam and reservoir sites and the detailed plans needed for actual inauguration of a construction project have not been made. Further, there is a multiplicity of available dam sites and the cost in money and time of making detailed surveys would have precluded such operations. Sufficient exploration and investigation has been done in connection with this report to permit decision between alternative plans and to form the basis for the comprehensive plan developed and stated below in the section (IV), conclusions, of this report.

29. It should be stated that no claim is made that the comprehensive plan for utilization and control of the water of Columbia River contained in this report is the only feasible plan, or will ultimately prove to be the best plan in all particulars. From the data forming chapter II of the two district reports other plans can readily be deduced. The plan announced purports merely to be the best plan disclosed by careful study of the complex problem.

30. The plan is presented as an orderly and comprehensive one believed to possess merit as a basis for, especially, hydroelectric development on the river. Actual power development, owing to the tremendous potential power and the progressive character of the growth of a power market, must be spread over a considerable period, and the order of undertaking individual projects will be dictated or influenced by the conditions that obtain from time to time.

31. Use of Columbia River water for irrigation has received much study in connection with this report and is dealt with in considerable detail below and in the district sections of this report.

32. Flood control is found to be of minor importance in a plan for comprehensive development of the river. However, there are areas of low land in the tidal section of the Columbia that are exposed to damage by floods, and the matter of flood control is included below in this report—not as a part of a comprehensive plan but as a separate feature.

33. In general, this report is submitted as one whose primary function is to present the economic feasibility of the plan, and of the parts of the plan, for utilization of the waters of the river. Engineering considerations are given due weight, but they must be and remain secondary until economic justification of the project is established.

II. Discussion

A. General description of Columbia River and its basin

34. Columbia River is about 1,210 miles long. Four hundred twenty-five miles of its course is in the United States between the international boundary and the mouth of Snake River, and 323½ miles between the latter point and the Pacific Ocean. (See pl. I, entitled "Columbia River Basin.") Its basin has an area of about 259,000 square miles, including about 39,000 square miles in Canada. About 64,000 square miles of the Columbia's basin above the Snake lies within the United States and embraces all of Washington east of the Cascade Range except the southeastern corner, northern Idaho, and Montana west of the Rockies. The basin of the Snake, the longest tributary of the Columbia (1,036 miles), covers about 109,000 square miles, embracing the extreme western part of Wyoming, southern Idaho, eastern Oregon, southeastern Washington, and small parts of Utah and Nevada. Below the mouth of the Snake the basin of the Columbia includes about 46,500 square miles in Washington and Oregon. About 27,000 square miles of this area lies between the Snake Basin and the Cascade Range, about 1,000 square miles through the Cascades and 18,500 square miles west of the Cascades. About 11,000 square miles of the last-mentioned area is in the basin of Willamette River.

35. Three principal systems form the headwaters of the Columbia River: First, the Columbia River proper, which, rising in Columbia Lake in British Columbia near the international boundary, flows northwesterly for nearly 200 miles then turns abruptly to the west and south, circling Selkirk Range, and enters the United States at the northeastern corner of Washington; second, Kootenai River (spelled Kootenay in Canada) which also rises in British Columbia near the source of the Columbia proper, but flows in an opposite direction (southeasterly), paralleling the Continental Divide, enters the United States at the Idaho-Montana-British Columbia corner for a short curved course of 167 miles, and empties into Columbia River proper about 30 miles north of the international boundary after flowing through Lake Kootenay in Canada; and third, Clark Fork, which, with its tributaries, drains the strip of Montana between the Continental Divide and Idaho. Clark Fork rises in western Montana, flows northwest between the Continental Divide and Bitterroot Mountains, crosses the panhandle of Idaho and the northeast corner of Washington, and, after a short course in British Columbia, empties into Columbia River very close to the international boundary and a short distance below the mouth of Kootenai River.

36. Columbia River thence flows southwest and south through northeast and central Washington, is joined by Snake River at Pasco, Wash., and a short distance below Pasco turns west, forming the Washington-Oregon boundary to the Pacific Ocean.

37. A description of the Columbia above the mouth of the Snake and of its headwaters and tributaries is given in part 2 of this report, and of the Columbia below the Snake and of its tributaries in that section is given in part 3, and printed in volume II of this document.

38. The outstanding characteristics of the Columbia and its basin are:

(*a*) The great fall in the river, amounting at low water to 975 feet between the international boundary and the mouth of the Snake, and 309 feet from the latter point to tidewater. This condition, with the existence of dam sites and usable low water flow is the basis of a large potential hydroelectric development, but the swift water resulting from the fall makes it adverse to navigation above tidewater.

(*b*) The large area of semiarid country in the basin, partly within economic reach of irrigation waters from the Columbia, a condition that, with the fertility of the soil, offers considerable possibilities of irrigation.

(*c*) The minor extent of area subject to flood damage.

These noteworthy characteristics are treated in detail in the district reports, wherein for the section of the river above the mouth of the Snake and that below, the four subjects of this report, viz: navigation, power development, flood control and irrigation, are discussed in turn and in combination.

Repetition here of the data relating to the basin and the river given in the district reports is unnecessary. Attention is invited to chapter II in each of the district reports (pts. 2 and 3 of the combined report (printed in vol. II of this document) of which this is pt. 1) for detailed physical data.

B. Navigation

39. *General.*—This section of this division report is intended to give a general picture of Columbia River from a navigation point of view. Such matter is included as is pertinent to the discussion of the benefits to navigation that might be conferred by power development of the stream. The subject of navigation is treated in detail in the district reports, parts 2 and 3 of this report, as to, respectively, the section of the Columbia above the mouth of the Snake and the section below. Attention is invited to the district reports.

40. Before any work was done on the Columbia to improve navigation conditions the entrance into the river from the sea was obstructed by a shoal across which there were one or more channels with unstable depths up to about 20 feet at mean lower low water. The channels were unstable also as to position; they shifted between Cape Disappointement on the north and Cape Adams on the south, a distance of about 6 miles.

41. The river channel from the entrance to Vancouver, Wash. (mile 105),[1] was, prior to improvement, obstructed by numerous sand bars, through which the channel or channels were comparatively narrow, with depths varying from 10 to 15 feet at low water. Vancouver was then, as now, the head of ocean navigation on the river proper, and Portland on the Willamette.

42. From Vancouver upstream to the foot of Cascade Gorge (mile 143), the head of tidewater, the controlling depth at low water was about 8 feet, adequate for river craft.

43. Through Cascade Gorge and at numerous points above to the international boundary (mile 749) the river in its natural condition was obstructed by falls and rapids. At many places the depth at low water was less than 5 feet. The principal obstructions below the mouth of the Snake (mile 323½) were the rapids, about 5 miles long, in Cascade Gorge (mile 143 to 148) and the falls and rapids between

[1] Distances given thus (mile —), are distances by river above the mouth of the Columbia.

The Dalles, Oreg., (mile 188) and Celilo, Oreg., (mile 200). Priest Rapids (mile 396) was the first of several serious rapids and falls in the Columbia between the mouth of the Snake and the international boundary.

44. Columbia River has been navigated since the early days of explorations in the Northwest. Below Vancouver, which includes the 99½ mile stretch from the sea to the mouth of Willamette River on which Portland, Oreg., is located, seagoing traffic has been continuous since 1792. The improvement of this stretch, below Vancouver and Portland, has been progressive, to keep pace with the growing needs of an important commerce. The works of improvement are described later in this and report in more detail in the district reports.

Above Vancouver (or rather above Camas, Wash., 14 miles above, over which 14 miles there has been and is special traffic in connection with pulp and paper manufacture at Camas) the Columbia has experienced several vicissitudes of navigation.

45. In the days of exploration and of fur trading the Columbia and Snake Rivers were the only highways through the Northwest. Early navigation was by canoes and batteaux, and usually, as to the upper rivers, was carried on during the higher river stages. This form of navigation disappeared many years ago. The next phase of navigation in the upper river was by flatboats, sailed or "lined" uptream and drifted down. With the introduction of steamboats on the rivers in the 1850's flatboat transportation was discontinued.

46. The advent of steamboats led to construction of portage roads past the obstacles to navigation formed by the rapids in Cascade Gorge and between The Dalles and Celilo. At first these two portages were pack roads, then vehicle roads and finally railroads. The one at the gorge was about 5 miles long; that between The Dalles and Celilo about 13 miles. Use of portages and of the river above Vancouver was discontinued temporarily on the completion of a railroad in 1882 along the river from Portland to Wallula, Wash. Later the portage railroads were reconstructed by the State of Oregon pending construction of the two canals, at the Cascade rapids and at the Dalles-Celilo rapids, and were again discontinued on the completion of those canals.

47. The section of the Columbia from tidewater to the town of The Dalles was used for boat service from the beginning of steamboat navigation (1850) to 1923, with one major interruption, 1882 to 1891. In 1923 the service was discontinued as a losing business and has not since been revived.

48. Navigation above the portage between The Dalles and Celilo began in 1858. It was never continuous for any considerable period. It was carried on mostly in combination with navigation of the Snake. Freight service above The Dalles was at its peak during the mining excitement on Clearwater River in Idaho in 1861–64. It was discontinued in 1882 upon the completion of the railroad from Portland along the river to Wallula.

49. Several attempts have been made to restore navigation on the Columbia River and on the Snake but none have been successful even though the Dalles-Celilo Canal, constructed by the United States and completed in 1915, eliminated the last portage. However, no attempts have been made by companies well equipped and financed.

50. The head of through navigation by steamer on the Columbia may be considered to be at Priest Rapids (mile 396). In only one reach above Priest Rapids and below the United States-Canada line, viz: between Wenatchee (mile 465) and Bridgeport, Wash. (mile 542), has navigation by steamer been more than an occasional trip or short series of trips. In this reach the river had been improved by the removal of obstructive rocks from the channel and was used for transportation for a number of years prior to the completion in 1913 of the railroad from Wenatchee to Brewster, at the mouth of Okanogan River, 10 miles below Bridgeport, where the railroad leaves the Columbia and goes up the Okanogan Valley. A boat line, operating launches, the only boats now in service on Columbia River above the Snake and below the international boundary, operates in the upper end of this Wenatchee-Bridgeport section, from Pateros on the railroad 7 miles below Brewster, to Bridgeport, about 20 miles by river above Pateros. These boats serve the farmers along a stretch of river which is not provided with rail facilities, and move by launch or barges towed by launch, small quantities of agricultural products and general merchandise.

51. The continuous navigation of the Columbia below Portland, Oreg., and Vancouver, Wash., and the intermittent navigation above Vancouver, led to various Federal projects for improvement of sections of the river.

52. At the mouth of the Columbia the original project, adopted in 1884, contemplated a channel 30 feet deep at mean lower low water, to be obtained by a south jetty 4½ miles long. Active construction work occurred during the period April 1885 to October 1895. Later, under the present project for a low-water depth of 40 feet and a width of not less than one half mile, the south jetty was lengthened to about 7 miles, and a north jetty, 2½ miles long, terminating 2 miles north of the end of the extended south jetty, was built. All the jetty work was completed in 1918. A depth in excess of the project depth and a width of at least one half mile were secured and have been continuously maintained by the jetties. Dredging was carried on prior to the completion of the jetties and will be done again as required to supplement the jetty action.

53. Some relief dredging was done as early as 1866 at various bars in the river above the mouth and below Portland and Vancouver for the aid of sea-going traffic. The original regular project for improvement below Portland, approved in 1877, has been followed by modifications from time to time. The first regular project contempleted a depth of 20 feet at low water to be obtained by means of dikes and revetments. Later, in 1892, the project was modified to provide for a depth of 25 feet. In 1912 the channel project depth was increased to 30 feet. The latest revision was in 1930 when the project dimensions of 35-foot depth and 500-foot width were adopted. Various acts of Congress related to the Columbia Channel between the Willamette River and Vancouver and have resulted in a present project for a channel 25 feet deep and 300 feet wide.

In the various projects in the lower Columbia and at its mouth the Port of Portland has made substantial contributions of funds and work. The Port of Vancouver has assisted in the section of the Columbia between the mouth of the Willamette and Vancouver (4½ miles).

There has never been a project for improvement of the Columbia between Vancouver (mile 104½) and the head of tidewater (mile 143).

54. From the head of tidewater to the head of the Cascade Gorge (about 5 miles) the river has a fall of 37 feet at low water. The main rapids at the head of the gorge presented a complete obstruction to navigation. A project was adopted in 1878 for the construction of a canal (the Cascades Canal) around the main rapids. This canal was completed in 1896 and is described below.

55. No project has been adopted for the section of the river from the head of Cascade Gorge to the foot of Three-Mile Rapids (mile 189½) about 1½ miles above the town of The Dalles, Oreg., owing to relatively deep water and moderate currents in this section.

56. Between the foot of Three-Mile Rapids and the head of Celilo Falls (mile 200) the river has a fall of 81 feet at low water. The lower 2½ miles of this section is covered by an existing project providing for a depth of 10 feet in a channel 250 feet wide to be secured by open river work. This project also covers the remainder of the section by the provision of a lateral canal. This canal, the Dalles-Celilo Canal described below, is 8.6 miles long, and was opened to navigation in 1915.

Between Celilo (mile 200) and the mouth of Snake River (mile 323½) there is a project for open river work consisting of the removal of obstructing boulders and ledges and raking of gravel bars.

57. There is at present no project for river improvement between the mouth of Snake River and Wenatchee, Wash. (mile 465). A small amount of work was done in this stretch under past projects. This work consisted of the removal of some of the more dangerous rocks from the channel and placing of ring bolts to aid boats in lining through the rapids.

The section of river from Wenatchee to Bridgeport, Wash. (mile 542) was improved by 1912 for a 5-foot depth. From Bridgeport to Kettle Falls (mile 707) a project was adopted with a view to a 7-foot channel depth. That depth was not secured in all places.

58. From the foot of Kettle Falls to the international boundary (mile 749) there has been no project for improvement. The foot of Grand Rapids (mile 700) has been considered the head of navigation, but navigation is possible above the head of Kettle Falls for about 40 miles in the United States, except at high stages when Little Dalles Falls forms an obstacle, and for several hundred miles in Canada.

59. All improvement of the Columbia River that has been carried on has been by open river improvement methods except at the two localities, Cascade Gorge and between The Dalles and Celilo. At these places lateral canals, with locks, have been constructed, as stated above, and are in serviceable condition.

60. The canal at the Cascades has a length of 3,000 feet, a clear bottom width of 90 feet throughout. There is one lock, located at the lower end of the canal. It has two chambers in flight, with usable lengths of 462 feet in the upper chamber and 469 feet in the lower chamber. The controlling depth of the canal system is that over the upper mitre sill, which at adopted low water stage is 8 feet. The river at times falls below that stage as much as 2½ feet. The total lift of the lock is 24 feet at low water and about 14 feet at high water.

61. The Dalles-Celilo Canal has a length of 8.6 miles and includes four locks, of which the lowest (downstream) lock has two chambers in flight. All the locks have a usable length of 265 feet and a width of 45 feet. The controlling depth of the canal system is 7 feet at low water, and occurs at lock sills. The canal trunk has a clear bottom width of 65 feet.

62. As a result of the improvements that have been made in the river and at its mouth, seagoing vessels drawing up to 29 feet navigate at low tide to Portland on the Willamette. The channel is now being deepened to 35 feet under a project adopted July 3, 1930. The channel above the mouth of the Willamette to Vancouver, 4½ miles, permits a draft of 23 feet at low tide. These sections of the Columbia are navigated by all types of seagoing and river craft.

63. Above Vancouver (mile 105) and to The Dalles (mile 188) navigation is wholly by river boats drawing less than 7 feet, for which there is adequate depth throughout the year. Above The Dalles, to the mouth of Snake River (mile 323½), the limiting draft for all year navigation is 4½ feet. The craft generally used (there is practically no navigation at the present time above tidewater except by launch) was the so-called Columbia River type of stern-wheel steamer. A typical vessel (the *Twin Cities*) had a length of 151 feet, a width of 32 feet, a depth of hold of 4.8 feet, and 600 horsepower; at full load (200 tons freight) the draft was about 4½ feet. The *Twin Cities* was one of the later vessels in service, built in 1908, and was engaged in the Columbia-Snake River trade.

64. During the calendar year 1930 seagoing traffic, inbound and outbound, of the Columbia River amounted to 6,767,165 tons, valued at $316,933,691, of which 5,041,243 tons valued at $276,909,527 passed over the river to and from Portland, and 95,604 tons valued at $3,040,479 to and from Vancouver. In general, the seagoing tonnage over this lower part of the Columbia has been steadily increasing, from about 3,000,000 tons in 1920.

65. In the calendar year 1930 inland river vessels handled, exclusive of rafted timber, 1,952,235 tons valued at $30,594,441 in the Columbia below Vancouver and Portland, and 4,076,937 tons of rafted logs for sawmills on the river, valued at $14,747,192. Tonnage moved by river vessels has likewise shown progressive increase for many years. Above Vancouver, as far as Camas, Wash., about 14 miles, there is considerable special freight movement in connection with paper and pulp mills at Camas.

66. On the river above Camas the tonnage always has been quite insignificant. During the 27 years from the date of the opening of the Cascades canal in 1896 and until 1923, when regular boat service was discontinued, the total tonnage through the canal was 794,896 tons, or an average of 29,500 tons annually. Since 1923 the average tonnage through the Cascade Canal, exclusive of rafted and floated logs and piling, was about 5,000 tons, with an average value of about $600,000. This tonnage moved partly between Portland and the city of Hood River and the remainder between Portland and The Dalles. The quantities have fluctuated widely during the period since 1923 owing to suspensions and brief resumptions of boat service. Relatively large movement of floated logs and piling began in 1926, and in the past 5 years has averaged 55,000 tons valued at $260,000. The logs and piling originated on the north side of the river within

these are general in character, though intermittent, as interference caused by ice. Swift currents are found over most of the tidewater to Snake River section at all or nearly all stages. Other obstacles like crooked and narrow channels and shoals are peculiar to particular localities or reaches.

72. From Bonneville, the head of tidewater, to the Cascades Canal, 4½ miles, the currents are so swift at all stages that only relatively high power boats can stem them going upstream and be controlled going downstream. The controlling depth at low water is not less than 7 feet.

73. Through the canal navigation is provided for with a minimum controlling depth of about 6 feet up to a stage of 42 feet (in the lower pool), above which stage the canal is closed to navigation. This closure occurs in the summer time during the regular freshets of the river caused by melting of snow in the headwaters. Drowning out of the canal occurs about 6 years out of 10 and lasts from a few days to a month at a time. At these high stages the current velocity below the canal is so great as to interrupt navigation; the canal design was based on that condition. During the periods the canal is drowned out, downstream navigation in the river proper is possible but extremely hazardous.

74. Between the Cascades Canal and the foot of Three Mile Rapid, just above The Dalles, a distance of 43 miles, the conditions for navigation are favorable at all stages with a controlling depth of about 12 feet at low water. The channel has ample width. The slope in this section is slight and no excessive velocities are present at any stage.

75. From the foot of Three Mile Rapid to the lower entrance of The Dalles-Celilo Canal, about 2½ miles, the conditions again become unfavorable for navigation. This is due to the fact that the river in this short section flows through a narrow rocky gorge with a sharp reverse curve at its lower end terminating in Three Mile Rapid. The navigation conditions are best during low stages due to absence of excessive velocities. The depths are ample. At high stages navigation is hazardous on account of the velocities and the sharp bends.

76. The Dalles-Celilo Canal offers 8½ miles of slack water with a controlled depth of 7 feet. The canal was designed for use by steamboats, the type of boats operating on the river. It was not designed for barge navigation. The canal is narrow and presents some difficulty to boats passing through it when subject to strong flank winds, a not unusual condition.

77. From the head of the canal to the mouth of Snake River, 124 miles, the controlling low water depth is not less than 6 feet, except at one point, Homly Rapids, 6 miles below the mouth of Snake River, where the depth is 4½ feet over a rocky bottom. The channel width is adequate. There are numerous rapids in this reach. The total fall is about 186 feet, largely concentrated at the rapids. These total about 18 miles in length. The rapids offer serious difficulties to open river navigation on account of strong currents, and, in the case of Homly Rapids, insufficient depth. Formerly the various rapids presented additional hazards in the form of pinnacles of ledge rock. Under the existing and former projects the most dangerous pinnacles have been removed from the navigation channel, but further removal of pinnacles and ledge is needed to rectify the channel to make navi-

gation easier and safer, and to permit night navigation over some stretches where it is not now possible.

78. Freshets are not, in general, obstacles to navigation on the Columbia, but they do cause excessive currents at places and at times drown out the canals. The latter, as stated above, is not important as the excessive velocities, not the drowning out, control the situation at those localities.

79. Ice is almost annually a complete obstruction to navigation in the section under consideration (tidewater to Snake River). The duration varies from a few days to about a month.

80. From the foregoing it may be noted that, except when interrupted by ice or by swift currents and canal closure due to freshets, boats drawing 6 feet can navigate from head of tidewater (and below) to Snake River, except at Homly Rapids and occasionally at the Cascades Canal at extreme low water. At Homly Rapids the controlling low-water depth of 4½-feet might be increased to 6 feet by rock excavation and closure of secondary channels. Even for 6-foot nagivation considerable removal of pinnacles and ledge would be needed at the various rapids to make navigation easier and safer. No open river improvement can reduce the excessive currents.

81. To provide for even slightly greater draft at low water would require modification of both canals and considerable rock excavation from the river channel. Depths throughout the tidewater-Snake River section adequate for 8-foot draft, the probable least draft for economical movement of large tonnages, could not be secured by open river methods.

82. *Benefits to navigation obtainable from power dams.*—Potential commerce on Columbia River is of importance in connection with this report, as the tonnage is the principal factor in determining the total acceptable probable savings to shippers through use of the river improved by power developments. These developments would be located in the section of the river above the head of tidewater and their effect on ease of navigation would not extend into the tidal section. That section of the river need not, therefore, be considered in connection with savings to shippers.

83. From Vancouver, Wash. (mile 105), to the city of Hood River, Oreg. (mile 167), the potential commerce will depend upon industrial development rather than directly upon the resources of the territory tributary to the river. This region is mountainous and its resources almost entirely timber. The timber is mostly included within the limits of the National forest reserves. Only small areas are actually tributary to the Columbia River. Some timber now being cut below Hood River is being rafted to the lower river.

84. The country tributary to the river between Hood River and the headwaters of the Columbia is generally open, and is in part suitable for dry farming or irrigation. There are no important mineral deposits near the river from which a large tonnage may be expected.

85. Wheat is the principal extensive agricultural product of the basin of the Columbia. Its production amounts to about 80 million bushels annually. Of this quantity, about 37 million bushels have been going to Portland and part, about 21 million bushels, to Puget Sound for shipment by water. The remainder is used locally for seed and milling. Barley and oats are raised, but only small quantities are shipped.

86. Rail rates are devised to give Portland a differential on the wheat raised in all that part of the Columbia Basin south of a line approximately described as running east and west through Lewiston and extending eastward to the Continental Divide; parity of rates to Portland and Puget Sound in an area north of the Portland differential area and east of Pasco and Spokane; and a differential in favor of Puget Sound points in the area in Washington west of the Pasco-Spokane line and north of the Portland differential area.

87. There is no commerce on the Columbia above the mouth of the Snake at the present time except a little local traffic by launch over 20 miles of the river just above the mouth of the Okanogan River. Commerce in earlier years was over a greater stretch—from Wenatchee to Bridgeport—but this was discontinued over the Wenatchee-Pateros section with the advent of the railroad. The past tonnages were small, averaging for the years 1904 to 1912, the only years of record, about 35,000 tons.

88. Little commerce can be expected to develop on the Columbia above Pasco at the mouth of the Snake with the river in its present condition, or even with additional open river work in reaches where such method of improvement is feasible. Such commerce as would develop could be only local except that for a few miles above the mouth of the Snake it could form part of through commerce below Pasco. Only by canalization can through navigation over the upper river be made possible. And even in such event potential river commerce remains a matter of conjecture. The topography of the river and adjacent land does not favor movement of freight between the farms and the river. The favorable Puget Sound rail differential of much of this territory is not conducive to use of the river and shipment in export via Portland. The country is well supplied with main and branch-line railroads, and with highways. Nor does possible increase of agricultural products, through increased irrigation, offer much, if anything, in the way of potential river tonnage.

89. The district engineer, Seattle, estimates in chapter III of his report, part 2 of this report, that the shipments on the river in and out of the territory above the mouth of the Snake River would not exceed 250,000 tons annually with a completely canalized river, and that with such tonnage the cost of transportation by water would represent no saving to producers, shippers or consumers over rail haul from points above the Snake to Portland. He is of the opinion that no river commerce will develop above Wenatchee even with a canalized river. He does not believe that expenditures, except for locks when needed through power dams, to canalize the river to permit through traffic on the Columbia above the Snake are justified by any reasonable expectation of water shipments in and out of the territory. This view of the district engineer is concurred in by the division engineer.

The ton-mile rate for rail haul used by the Seattle district for comparison with estimated cost of water haul is believed to be too low, as it is the average for the State and does not represent the local rates. There is no railroad along the Columbia River from Wenatchee to Kennewick or Pasco, and to get to Portland, shipments by rail must go via Everett and Seattle, a distance of 341 miles, passing nearly all of the Puget Sound shipping ports enroute or via Adrian and Pasco, a distance by rail of 392 miles. The distances by river

from Wenatchee to the mouth of the Willamette River is 365 miles, and to Portland on the Willamette is 376 miles. The rail haul from Wenatchee by Great Northern Railway to tidewater at Everett is only 131 miles and to Seattle 159 miles. It is, therefore, not probable that shipments originating in the vicinity of Wenatchee would go by water to Portland for transhipment to seagoing vessels nor is it likely that such shipments would go to Portland for local consumption there. It is doubtful if Portland could compete with Puget Sound in the Wenatchee territory on account of more favorable freight rates from Puget Sound points to Wenatchee, so that there would be but little if any up or downstream water-borne commerce.

Shipments originating from points below the foot of Priest Rapids to the mouth of the Snake are more likely to go downstream by water than from points above the foot of Priest Rapids, as the railroad freight rates are generally more favorable to Portland. The freight rates from Pasco to Portland are the same as those to Seattle. The territory tributary to the river between Snake River and Priest Rapids is mostly included in the report on the Columbia below the Snake River, part 3 of this report, so that no appreciable amount of tonnage in addition to that given in part 3 would be added by the section of river between Snake River and Wenatchee.

90. Satisfactory determination of potential tonnage on the Columbia below the mouth of the Snake to head of tidewater is almost as difficult as of that above the mouth of the Snake. Here, as above Pasco, there is no river traffic at the present time. The history of navigation on this lower part of the Columbia is not helpful in making forecasts for the future. Such improvements as have been made for the benefit of river commerce have not produced commensurate returns—except through reduction of rail-freight rates. The costly Cascades and The Dalles-Celilo Canals are unused.

91. The section of the Columbia below the Snake, combined with the Snake itself up to about Lewiston, Idaho, is held by some to offer an important future avenue of commerce of the Northwest. This claim is based mainly on the large wheat production in the territory tributary to Portland, a product suffering at present from low market value. The belief is held by some that navigation of the Snake and Columbia will be the salvation of the wheat grower, whose product is generally not suited to domestic distribution, except as used locally, but is dependent on foreign markets and cannot meet rail rates to the coast.

92. In chapter II, part 3 of this report, the district engineer, Portland, states that the total tonnage reported moved by rail for the fiscal year 1928–29 in and out of counties contiguous to the Columbia below the mouth of the Snake amounted to 1,956,292 tons. Of this total 392,707 tons was eastbound and 1,563,585 tons was westbound. About 60 percent of the westbound freight was wheat. Improvement of the river would not develop any new tonnage in the territory served. Any tonnage shipped by river from this territory would have to be diverted from the railroads or from truck lines. The latter carriers move some freight into and out of the territory, but the quantities are not of available record; this freight, paying relatively high rates and being usually of the kind requiring dispatch, is not important to the matter now being discussed.

93. Various estimates have been made of the tonnage that might move on the Columbia below the Snake.

The Columbia Valley Association, with headquarters in Portland, solicited promises of freight for movement on the river. Promises were forthcoming to a total of 400,000 tons, upstream and downstream combined, between Portland and Lewiston on the Snake. About 100,000 tons of this promised tonnage is tributary to Lewiston, but its movement over the Columbia would be contingent on improvement of the Snake. The promised tonnage tributary to the Columbia, 300,000 tons, is conditional on establishment of a reliable river freight service, on improvement of the river channel to 7-foot depth (5 feet at Homly Rapids), and on freight charges by river being at least 20 percent less than rail charges.

The district engineer (pt. 3, vol. II of this document) believes, from studies made by him, that this estimate of 300,000 tons is too liberal under the condition of river improvement desired and that 100,000 tons annually is more reasonable. He believes that with greater improvement of the Columbia to the mouth of the Snake (through increased lateral canal provisions at the gorge and at the Dalles-Celilo rapids) the potential tonnage may increase to 200,000 tons annually; and to 600,000 tons annually in the event of creation of through slack-water conditions from tidewater to the Snake, as by power dams. The last estimate in particular is germane to this report, as it is related to potential power development.

94. The district engineer estimates that if 600,000 tons of freight moves annually on the river, improved by power dams, up and downstream, between the mouth of Snake River and Portland, the total gross savings to shippers over existing freight charges would amount to about $1,100,000 annually. The cost of freight movement on which this estimated saving is based includes the cost of providing and operating the vessels, the terminal charges and the expense of moving freight between the river bank and the inland points of origin and destination. The cost of freight movement, however, does not cover the first cost of the navigation features through the dams, nor their maintenance and operation. The costs of this annual operation and maintenance, and the interest on the first cost of the navigation features through the dams, required for handling the 600,000 tons, total about $900,000. The net saving would, therefore, be about $200,000 per year, but with no provision for amortization.

95. The costs and savings of an open river improvement would depend on the useful life of such improvement. This life depends, not on ordinary depreciation of works which would be minor in amount, but on the length of time elapsing before the power dams would be built and the open river navigation works be rendered obsolete by the slack-water improvement.

The district engineer finds that with the open river improvement desired by the Columbia Valley Association (par. 93 above) the net savings on the district engineer's estimate of 100,000 tons would amount to $15,000 annually, with no consideration being given to amortization of the first cost of the open river works. In this computation the first cost of the two canals, Cascades and Dalles-Celilo, and also of the past works of open river improvement have been considered as written off; the operation and maintenance of these two

canals is taken into consideration. The $15,000 is comparable with the $200,000 given above as savings from slack-water improvement.

96. The difference between the annual saving, $200,000, estimated for the slack-water improvement, and $15,000, the savings through further open river improvement, or $185,000, amounts, capitalized at 4 percent, to $4,625,000. This sum may be considered the maximum (see par. 16 above) that the United States might contribute toward power development on the Columbia below the mouth of the Snake in return for expected benefits to navigation.

In view of the uncertainty of the figures used in this study as to potential tonnage below the mouth of the Snake, and of the possible development of additional lower Columbia River tonnage originating at or be destined to points above the mouth of the Snake (omitted from consideration in calculating the savings referred to in this paragraph because of their conjectural nature), it is believed reasonable that the United States may contribute not to exceed the amount of $5,000,000 (in addition to providing the navigation features through the dams) toward the cost of the two power dams between tidewater and the mouth of the Snake contemplated in the comprehensive plan stated at the conclusion of this report.

C. POWER DEVELOPMENT [2]

97. Construction of dams on Columbia River will be controlled primarily by considerations of power development. Navigation, irrigation, and flood control will receive benefits from the reservoirs formed by the dams and from the developed power, but in general the benefits may be regarded as collateral or incidental. One exception exists in the case of the so-called "Columbia Basin" irrigation project in the State of Washington which has induced special consideration of a combination power-irrigation development at the head of Grand Coulee as a means of supplying water to the area from the main Columbia for comparison with gravity supply of irrigation water from Clark Fork, a tributary of Columbia River.

98. Power development, in turn, will be controlled by the demand for electrical power. Accepting the existence of large hydro-power development potentialities on Columbia River and feasibility of transmission of energy to appropriate points for use, the primary element of power study is the amount of hydroelectric power that can at present and within a reasonable future be utilized in the Northwest. This section of this report (power development) is treated under three major headings: Power market, power transmission, and power generation.

POWER MARKET

99. *General.*—Consideration of physical conditions in the Northwest leads to the conclusion that the principal market for hydro-electric power from the Columbia River will be found in the States of Oregon and Washington, together with that part of Idaho lying north of Salmon River and the northwestern corner of Montana, now served by the Thompson Falls plant of the Montana Power Co. Present practice and limitations usually confine direct transmission of large quantities of power to distances under 300 miles. By interconnection

[2] Prepared in collaboration with Barry Dibble, consulting engineer.

and substitution the effects of distance can be lessened and the marketing range extended.

100. The international boundary between Canada and the United States has for the purpose of this study been considered the northern limit of the power market. Interconnection and interchange with Canadian power systems is now of minor amount and will probably so continue as political reasons are likely to prevent the development of large blocks of power on one side of the line for use on the other. British Columbia contains many excellent power sites capable of meeting all probable needs of the province for many decades.

101. Existing interconnections between the system of Washington Water Power Co. in Washington and Idaho and the Thompson Falls (Montana) generating station of the Montana Power Co. result in important interchanges between the two most important properties in those regions. Thompson Falls station, which supplies much of the Montana territory west of the Rockies, is interconnected with other stations of the Montana Power Co. only through the transmission lines of the Chicago, Milwaukee, St. Paul & Pacific Railway, and it has therefore been possible to secure separate records of consumption in the market supplied by that plant. Practically all the electrical energy used in northern Idaho is generated by either the Washington Water Power Co. or the Thompson Falls plant. All this area is within transmission distance of Grand Coulee and other power sites on the upper Columbia River in Washington. Therefore, it is desirable and convenient to include these parts of Idaho and Montana in the market study. The remaining parts of both States are omitted from the Columbia River power market as their load centers are located relatively far from the Columbia and they have their own large sources of power supply.

102. Present power requirements are small in the part of Oregon that lies east of the Blue Mountains. Part of the energy now used is supplied directly by The Idaho Power Co. and part is sold by the Idaho company to the Eastern Oregon Light & Power Co. There is no immediate prospect of a market condition that will warrant the construction of a transmission line to connect this system with that in the Columbia River country. However, it has been convenient in this study to use statistics prepared by the Bureau of the Census, United States Geological Survey, and others; these follow State lines. The figures for this part of eastern Oregon are so small that they have no appreciable effect upon the total and therefore the statistical information has been allowed to stand without attempting a minor change.

103. The system of the California-Oregon Power Co. is partly in California and partly in Oregon. It is interconnected with the Mountain States Power Co. which operates in Oregon and through it to the Portland General Electric Co. Examination of the records shows that about the same amount of power crosses the California-Oregon boundary line in each direction. This condition makes the State boundary a convenient dividing line for the market study and it has so been used. The influence of Columbia River power might be extended into California either by direct transmission or by using it to replace power which now moves northerly in Oregon. Replaced power would be available to transmit southerly in California. The possibilities under either method are somewhat limited and have not

been used in preparing estimates. On the west the definite line of the Pacific coast has been taken as the boundary of the market area.

104. Power sites on the Columbia, with one possible exception, are located east of the Cascade Mountains in an arid country largely agricultural through dry farming and irrigation. In this basin an important power load has been created by pumping water for irrigation where a gravity supply cannot be obtained. Mining and lumbering in the mountains north and east of the basin are also large power users. Spokane is the principal business center of the region.

105. The Cascade Mountains separate the arid inland basin from the well watered country on their west in which are located a number of tidewater cities including Seattle, Tacoma, and Portland. Those mentioned seem destined to be the principal commercial centers of the Northwest. Within and surrounding them are many industrial plants. The timber resources of the country are the basis for a large percentage of the manufacturing. However, a number of secondary industries have been established and are of growing importance.

106. The population of the States of Washington and Oregon increased from 2,140,010 in 1920 to 2,517,182 in 1930, a gain of 17.6 percent. Of this total population that portion east of the Cascade Mountains increased from 601,300 to 645,567 or 7.4 percent in the decade, while in the counties west of the Cascades the growth was from 1,538,710 to 1,871,615 or 21.6 percent.

107. The falls of Willamette River at Oregon City and West Linn, about 14 miles above Portland, were used for power development as early as 1842. In that year Dr. John McLoughlin, chief factor of Hudson's Bay Co., at Fort Vancouver, utilized the falls to furnish motive power for a sawmill and other industries which were established to supply the needs of the growing population in the "Oregon Country." This location, where the river drops 42 feet at low water, offered conditions similar to those at New England and other eastern water powers about which mills clustered before the electric era. Here on the Oregon City side of the river there was built in 1889 by Willamette Falls Electric Co., a predecessor of the present Portland General Electric Co., one of the earliest commercial hydroelectric power plants in the United States. It had a capacity of over 1,000 kilowatts divided among 19 machines. The power was transmitted to Portland at 4,000 volts. This plant was operated until 1897. The Oregon City Woolen Mills, and two large paper mills which are now located at these falls use in part the original water rights granted by Congress by act of September 27, 1850. At West Linn in 1894 the present "station B" of the Portland General Electric Co. was put into service.

108. In 1882, the same year that Edison built his first central station—Pearl Street in New York City—Charles Hanson installed a small steam engine and electric generator at Tacoma to furnish light in his flour mill and elsewhere. Tacoma's present municipal system is an outgrowth of the flour mill lighting plant.

109. Lumbering, the dominating industry of the Northwest, originally developed its own power with steam engines driving long lines of shafting. Sawdust and waste wood were used as fuel. It is only in recent years that the convenience and flexibility of electric motors have led to the electrification of sawmill machinery and the construction of steam turboelectric power plants by the principal sawmills.

110. Wood pulp and paper manufacture have grown to importance in the past decade. Large blocks of electric power are utilized. Much of it is developed by steam turbines using waste wood as fuel. The remainder is developed by water powers owned by the companies or is purchased from public utility companies.

111. The utilities of the Northwest in general have depended upon water power for their production of energy with steam as a stand-by for peaks and periods of low water. As the market has expanded it has become economical to develop sites with increasingly larger capacities and of reservoirs for the regulation of stream flow.

112. In the United States the first commercial applications of electricity were solely to lighting. Later, small motors were introduced in order to use power-generating equipment that otherwise was idle in the daylight hours. Electro-chemical industries grew up around Niagara Falls before the days of long-distance transmission. Each year has brought new and larger applications and a rapid expansion of earlier uses, extending into industries, the farm, and the home. It was 1902 before the generation and consumption of electricity had gained sufficient importance to be reported upon as a separate industry by the Bureau of the Census. Since that time it has made a steady and rapid growth, reaching out into all departments of human activities until it is now one of the most important industries of the United States, with an annual revenue from the sale of electric service estimated to have been $2,155,000,000 in 1930. In the State of Washington the 1930 revenue was about $31,000,000; in Oregon, $17,000,000.

113. No segregation of revenue to different classes of load is available for northwestern utilities. In general, trends in the Northwest are similar to those in the Nation. Table A shows for the United States the total revenue for each year from 1920 to 1930 and its percentage distribution among the several classes of service. The figures emphasize the increasing importance of small consumers who are classified in the columns headed "Residential" and "Retail light and power—commercial." Together these paid 46.6 percent of the utility revenue in 1920 and increased their portion to 61.7 percent in 1930. On the other hand, the revenue from "Wholesale power and light", which includes the large industries, was 38.3 percent of the total 1920 revenue but only 23.7 percent of the 1930 total.

TABLE A.—*Revenue of electric light and power industry of United States by sources, 1920–30* [1]

Year	Total revenue for electric service (millions of dollars)	Percentage of total					
		Residential	Retail light and power—commercial	Wholesale power and light	Municipal	Railway	Other electric service
1920	882.7	25.4	21.0	38.3	4.4	4.7	6.2
1921	911.5	27.0	22.4	32.3	4.8	4.9	8.6
1922 [2]	1,020.4	27.0	22.8	32.8	4.8	5.0	7.6
1923	1,180.8	27.4	23.4	33.3	4.6	4.4	6.9
1924	1,322.0	28.8	25.0	30.5	4.6	4.1	7.0
1925	1,425.2	29.6	26.1	29.7	4.1	3.7	6.8
1926	1,621.5	30.0	26.9	28.2	4.2	3.6	7.1
1927 [2]	1,802.7	30.4	27.7	26.5	4.3	3.6	7.5
1928	1,941.9	30.9	27.6	26.4	4.3	3.3	7.3
1929	2,105.9	31.0	28.1	26.2	4.4	3.1	7.2
1930	2,155.0	32.7	29.0	23.7	4.5	3.0	7.1

[1] Compiled from statistics in Electrical World, Jan. 3, 1931, p. 28. [2] United States census.

114. Table B gives corresponding information on the distribution of energy delivered to the several classes of ultimate consumers by public utilities operating in the United States during the period 1920–30. Small consumers, residential and commercial, used 21.8 percent of the energy sold to ultimate consumers in 1920. In 1930 their use increased to 36.6 percent of the greater total. The large industries classified under wholesale power and light consumed 61.3 percent of the total in 1920. Their portion was reduced to 51.6 percent in 1930.

TABLE B.—*Distribution of central-station energy to ultimate consumers in the United States, 1920–30* [1]

Year	Total (millions of kilowatt-hours)	Percentage of total				
		Residential	Retail light and power—commercial	Wholesale power and light	Municipal	Railway transportation
1920	32,530	9.1	12.7	61.3	2.2	14.7
1921	30,700	10.7	15.4	56.3	2.6	15.0
1922	35,822	10.3	14.5	57.0	2.5	15.7
1923	42,220	10.5	15.1	58.4	2.5	13.5
1924	45,000	11.5	16.8	56.5	2.6	12.6
1925	50,221	11.8	17.7	56.5	2.7	11.6
1926	56,964	12.2	18.5	56.0	2.7	10.6
1927	63,612	12.7	19.6	54.4	2.7	10.6
1928	68,695	12.9	19.4	55.5	2.6	9.6
1929	77,062	13.4	20.0	54.9	2.6	9.1
1930	76,120	15.3	21.3	51.6	2.8	9.0

[1] Compiled from statistics in Electrical World, Jan. 3, 1931, p. 28.

115. Figures for 1929 in table C show the distribution of the energy delivered to the different classes of consumers by seven of the large utilities operating in Washington and Oregon compared with corresponding percentages in the United States.

TABLE C.—*Energy delivered to ultimate consumers in 1929*

Class	In Washington and Oregon		In United States, percent of total
	Kilowatt-hours, millions	Percent of total	
Residential	469	19.7	13.4
Retail light and power—commercial	396	16.7	20.0
Wholesale power and light	1,325	55.8	54.9
Municipalities	82	3.4	2.6
Railway transportation	103	4.4	9.1
Total	2,375	100.0	100.0

116. The residential consumer appears to be relatively more important in the Northwest than in the country as a whole. Here he utilized 19.7 percent of the total energy sold during 1929 compared with 13.4 percent in the country as a whole. This is counterbalanced by a smaller percentage used by retail light and power consumers. Electric railway transportation in 1929 used only 4.4 percent of the

total energy in Washington and Oregon as compared with 9.1 percent in the entire Nation.

117. Lack of information as to the segregation of revenue of northwestern utilities does not permit calculation of the average rates per kilowatt-hour paid by consumers of different classes, but such average rates for the United States as a whole are given below (table D) for the years 1920 and 1930. The average rate per kilowatt-hour appears to have slightly increased during the decade. This is due to the greater importance in 1930 of the small customer, who pays a relatively high rate for his service.

TABLE D.—*Rates per kilowatt-hour (in cents)*[1]

Class	Cents per kilowatt-hour		Change in decade, (+) increase, (−) decrease
	1920	1930	
			Percent
Residential	7.50	6.05	−19
Retail light and power	4.46	3.85	−16
Wholesale power and light	1.69	1.30	−23
Municipal	5.40	4.55	−16
Railway	.87	.95	+9
Weighted average	2.70	2.83	+5

[1] Computed from data contained in Electrical World, Jan. 3, 1931, p. 28.

118. The increasing importance of the small consumer has had a stabilizing effect upon both output and revenue of electrical utilities. While the large industrial loads are adversely affected by periods of depression, residential and retail commercial loads have uniformly progressed steadily upward. In the year 1930, when in the United States the industrial load dropped 7.7 percent, domestic consumption increased 12.8 percent and that of small commercial light and power customers increased 5.9 percent. The result was that the gross revenue of the utilities increased in spite of the industrial depression.

119. Increase in load comes both from new customers and from additional requirements by old customers. The latter source is the more important. It is estimated that, in 1930, 70.5 percent of the population of the United States lived in electrically lighted homes. Perhaps one third of the remainder were within reach of transmission lines. The other two thirds, about 20 percent of the total population, were mostly in rural districts as yet remote from such facilities. It is probable that these percentages are also fairly representative of conditions in the Northwest at the present time. The number of small consumers has increased faster than the growth of population and will probably continue to do so, though at a declining rate. The greatest rate of growth comes from increased consumption by the small consumer. These conditions are illustrated by statistics concerning residential consumers reported by seven leading utilities of Oregon and Washington, as given below in tables E and F.

TABLE E.—*Number of residential consumers of electric power*

Utility	1925	1926	1927	1928	1929
Puget Sound Power & Light Co.			105,335	108,354	120,919
Portland General Electric Co.	72,252	79,915	84,085	88,181	89,762
City of Seattle	32,206	35,190	75,083	80,540	82,824
Pacific Power & Light Co.			37,350	48,045	49,063
Washington Water Power Co.					43,399
City of Tacoma			31,122		32,002
Northwestern Electric Co.	16,079	18,857	20,423	21,880	23,786
Total					441,755

TABLE F.—*Average sales for residential use in kilowatt-hours per year per consumer*

Utility	1925	1926	1927	1928	1929
Puget Sound Power & Light Co.			726	529	1,011
Portland General Electric Co.	546	596	697	771	870
City of Seattle			853	925	1,018
Pacific Power & Light Co.	454	533	620	778	890
Washington Water Power Co.					1,799
City of Tacoma			1,050		1,161
Northwestern Electric Co.	669	814	936	1,019	1,058
Weighted average					1,037

120. It is the general opinion among utilities that the residential market can be greatly expanded. The increase from 1920–30 was 295 percent. A recent statistical study concludes that there is possible an annual "economic domestic use of 40,000 kilowatt-hours per home for a large percentage of the customers." Results similar to those for residential service are being secured in the growth of the load of small commercial light and power consumers. It increased 293 per-cent from 1920–30. Municipal uses have been increasing at a pace somewhat faster than the average advance in the use of electricity. From 1920–30 the consumption for municipal purposes increased 194 percent. In all of these fields population is a factor, though at the present time its influence in the trend is minor. The trends are well defined and will probably continue in the immediate future much as they have in the past.

121. The amount of power used by electric railways has been practically stationary for the past 4 years. There is no reason to expect much change in the requirements of street railways in the near future. Electrification of additional steam railways will probably occur from time to time. The general growth of the use of electricity has been so great that possible steam railway electrification is not now relatively such an important factor as it would have been a few years ago.

122. The future of electricity in the major industries is less easily predicted. In the United States, during the decade 1920–30, consumption in the usual classification "Wholesale power and light" increased 96 percent. The requirement of the average consumer of this class is not very large. He uses only 75,000 kilowatt-hours per annum, equivalent to about 35 motor horsepower for 8 hours a day, 300 days per year. Included are many small consumers whose businesses probably partake of the character of those included in the class designated "Retail light and power—commercial" in which little fluctuation of power consumption is caused by periods of depression.

On the other hand, the "Wholesale" classification does not record the many large industries which have their own generating stations. The output of such stations is not reported to the usual statistics-collecting agencies except as to the part that is sold and enters into "public use." Census reports for 1929 show 20,100,000 horsepower for motive power developed in factories and mills having their own power plants, while the motors driven by purchased energy had a rated capacity of 22,700,000 horsepower. In other words, the industries themselves generate almost as much power as they buy.

123. Timber is the raw material for the largest manufacturing industry of the Northwest. In 1927 the lumber business accounted for $189,000,000 or 42.5 percent of the value added by manufacture [3] to the products of Washington and Oregon. Another 4 percent is added by the pulp and paper business. Both of these industries use large amounts of electric power. Much of it is generated in the steam plants operated by the companies with wood waste as fuel. Several of the pulp and paper mills secure energy from water power plants owned and operated by the manufacturing company. The aggregate installed power capacity of the lumber and paper companies is very large. Two concerns alone have major installations totaling 84,000 kilowatts (113,000 horsepower) of which 59,000 kilowatts is steam-electric and 25,000 kilowatts is hydro-electric. They have some smaller power plants, of which statistics are not available. Large quantities of energy are also purchased by them from utility companies.

124. In addition to the wood used for fuel by the manufacturing companies, other large quantities of waste material are sold to be used as fuel in power plants of the electrical utility companies and for heating office buildings and residences. The United States Geological Survey reports that in 1930 wood fuel was used to produce 362,900,000 kilowatt-hours for public use in Oregon and Washington. It is estimated that the wood refuse now available annually is sufficient to produce 750,000,000 to 1,000,000,000 kilowatt-hours.

125. At the present time a number of processes are being developed to convert waste wood into byproducts which will give it a higher value than it has for fuel. These include the use of chips for paper, the manufacture of fiber board, and other articles. On the Atlantic coast the rayon industry is using wood fiber. Resins and various products can be obtained by distillation. As the waste is graudally absorbed for such treatment, hydroelectric power or other fuel must take the place of the wood that is now burned.

126. A study of the timber industry [4] indicated that the lumber business in the Northwest has passed its peak, but that the reproductive power of the timber lands of Washington and Oregon is such that lumber will always be an important product. The industry will probably find a profitable field in the further manufacture of lumber into many articles of commerce instead of shipping rough lumber to be manufactured elsewhere. Paper manufacturing will probably continue to increase in importance for many years. It should remain one of the basic industries of the region.

[3] "Value added by manufacture," as used by the Bureau of the Census, is the value of the product less the cost of raw materials, containers for products, fuel, and purchased electrical energy. Its use in these statistics eliminates the duplication that otherwise enters the figures because of the use of the product of one process as the raw material of another.

[4] See appendix 4, by R. R. Montell, of pt. 2 of this report. (P. 1211, vol. II of this document).

127. Around the lumber, paper, and other basic industries are grouped many secondary industries designed to supply material and service of various kinds. Other important industries serve the population. As industry and population gradually grow they in time create an actual or potential demand which makes it economically possible to establish factories to supply articles which were formerly imported. This cumulative effect is of extreme importance in the growth of communities having varied natural advantages, such as those of the Pacific Northwest. Such expansion serves to diversify the market for electric power and adds to its stability. Development of any industry along any line leads both directly and indirectly to increased demands for power. However, the absorption of large blocks of power comparable with the sizes of the enterprises adapted to the major sites on the Columbia, will be facilitated if advance contracts can be made with industries which themselves will use energy in large quantities. Most prominent among these are industries involving electro-chemical and metallurgical processes.

128. For the purposes of this report B. Nienburg, economic consultant, Washington, D.C., has made a special study of these industries to learn their history, methods, requirements for raw material, consumption of electric power, costs, and amount of production and location and size of their markets insofar as such information has been found available. Statements for the separate industries accompany this report as appendix I. A résumé of these individual reports is also included in that appendix. The local availability of minerals useful as raw material for manufacturing processes have been investigated for this report by Dean Henry Landes, consulting geologist, Seattle, Wash., and Mr. Ira Williams, consulting geologist, Portland, Oreg., and their discussion appears in papers which are included as appendices to the reports of the Seattle and Portland districts (pts. 2 and 3 of this combined report, printed in vol. II of this document). With the Seattle report there is also included a study of the timber industry of Washington and Oregon by Mr. R. R. Montell, consulting engineer, Seattle, Wash., in which is contained a discussion of the waste material available for byproducts.

129. Outgoing shipments from Puget Sound and Columbia River ports consist largely of lumber, other wood products, wheat, and flour. These are distributed to all the world. Return cargoes are relatively small. In 1930 foreign imports received at Columbia River ports amounted to only 8 percent of the export tonnage. California fuel oil, gasoline, and distillate constitute the bulk of the receipts from coastwise commerce. They are shipped in barges and tankers, which are generally not suited to carry cargoes of lumber on the return voyage to California ports. Coastwise receipts other than petroleum products entering Columbia River are only 33.5 percent of outgoing coastwise tonnage. Commerce of Puget Sound ports includes imports from and exports to nearby Canadian ports. Many of the coastwise receipts and shipments move between ports within the Sound. If such cargoes are eliminated, the lack of balance between outgoing and incoming shipments is found to be much the same as for the Columbia River. Such a condition favors the possibility of obtaining low freight rates on bulky ores or other raw materials which can be brought to these ports as ballast by incoming vessels. This has an important bearing on the feasibility of obtaining needed raw

material for electro-chemical and metallurgical processes where these are not conveniently and cheaply available from local sources.

130. Constantly changing conditions in those manufacturing industries which use large quantities of electricity make it futile to attempt to predict what new enterprises may ultimately be influenced to locate in the Pacific Northwest by the availability of hydroelectric resources and by other advantages. Pertinent data adapted from appendix I is given in table G to show the relative importance of the principal electro-chemical processes in the United States in 1929, the latest year for which figures are available. It therefore gives an idea of the outlet which they might afford as a market for Columbia River power. In excess of 7,000,000,000 kilowatt-hours were consumed in the United States during 1929 in the production of some 50 chemical substances. Many of the processes used such small amounts that they are not separately reported. Appendix I contains much detailed information concerning the world production and power requirements of these and other industries.

TABLE G.—*Electrical requirements of electro-chemical processes in the United States during 1929*

Product	Process	Kilowatt-hours required per short ton	Kilowatt-hours consumed in United States during 1929 in 1,000's	Principal competing processes in United States or other countries
Aluminum	Electrolytic reduction of alumina to aluminum.	19,000–25,200	2,519,375	None.
	Electrothermal reduction of bauxite to alumina.	4,082	None.	Alkali reduction of bauxite to alumina.
Ferro-alloys:				
Ferro-silicon, 50 percent.	Electrothermal smelting	5,000	994,011	By product of fused alumina production. Blast furnace reduction for less than 12 percent silicon.
Ferro-molybdenum, 70 percent.	do	8,000– 9,000	228,258	None.
Ferro-uranium	do	6,000–10,000		
Ferro-chromium, 60 percent.	do	6,000		
Ferro-tungsten	Electrothermal smelting and refining.	7,600	26,395	Do.
Ferro-vanadium, 30 to 35 percent.	Electrothermal smelting	6,800	13,035	Thermit reduction.
Ferro-manganese, 80 percent.	Electrothermal reduction	4,400	None.	Blast furnace reduction.
Calcium carbide	do	2,600– 3,200	720,000	None.
Caustic soda and chlorine	Electrolytic reduction of brine.	[1] 2,328– 2,984	660,000	Lime-soda ash process.
Copper	Precipitation from oxide and mixed ores.	1,700– 2,625	62,849	Flotation and reverberatory smelting.
	Electrolytic refining	141– 233	309,351	None.
	Electric furnace smelting for alloying.	200– 300	[2] 220,000	Fuel fired pit furnaces.
	Annealing	50– 100		Fuel fired furnaces.
Zinc	Electrolytic precipitation	2,206– 3,200	[3] 507,115	Retort distillation.
Steel:				
Castings	Electric melting solid charge.	500– 760	281,594	Open hearth furnace. Bessemer furnace. Crucible furnace.
Ingots	Electric melting or refining or super-refining of molten charge.	210	125,219	Open hearth furnace. Bessemer furnace. Crucible furnace.
Treatment	Electric annealing or hardening.	182– 286		Fuel fired furnaces.
	Electric galvanizing or electro-zincing.	101– 230		Fuel, hot process.

[1] Per ton of caustic soda.
[2] 1927 figures.
[3] Includes power required in operations immediately essential to electrolytic precipitation of zinc.

TABLE G.—*Electrical requirements of electro-chemical processes in the United States during 1929*—Continued

Product	Process	Kilowatt-hours required per short ton	Kilowatt-hours consumed in United States during 1929 in 1,000's	Principal competing processes in United States or other countries
Crystalline graphite	Electrothermal reduction	7,600	91,200	None.
Phosphoric acid	do	5,400	81,000	Sulphuric acid process.
Oxygen (compressed)	Electrolytic reduction of water.	[4] 250	50,575	Blast furnace reduction. Liquefaction process.
Hydrogen	do	[4] 140		Water, gas and iron contact processes.
Fused alumina	Electrothermal fusion	2,000–2,540	[5] 43,318	None.
Carbon bi-sulphide	do	850	30,179	Do.
Silicon carbide	Electrothermal reduction	6,666–8,333	[6] 23,655	
Potassium hydroxide	Electrolysis of potassium chloride.	2,100–2,300	15,831	Chemical process.
Synthetic ammonia	Electrolytic hydrogen; pressure synthesis.	12,055	13,140	Water gas hydrogen; coke oven gas hydrogen; by-product hydrogen.
Metallic magnesium	Electrolysis of magnesium chloride in brine.	16,000	10,640	Electrolysis of magnesium chloride from mineral magnesite plus chlorine requiring 17,000 kilowatt-hours.
Lead	Electrolytic refining	95–111	6,180	
Cadmium	Electrolytic precipitation of zinc residue.	2,000–2,500	2,730	None.
Silver	Electrolytic refining	316–714	1,283	Sulphuric acid process.
Phosphorus	Electrothermal reduction	9,000	1,250	None.
Gold	Electrolytic refining	266	45	Sulphuric acid process.
Metallic sodium	Electrolysis of fused caustic soda.	13,000	[7]	Electrolysis of fused sodium chloride.
Fused quartz	Electrothermal fusion	10,000–16,000	[8]	None.
Silicon	Electrothermal reduction	12,000	[8]	Do.
Potassium chlorate	Electrolysis of potassium chloride.	1,350	[8]	Chemical process.
Iron	Magnetite ore reduction in arc furnace.	2,000–2,500	None.	Blast furnace. Electro-deposition.
	Electro-deposition from ore.	900	None.	Blast furnace. Electric furnace reduction.
Sponge iron	Electrothermal low temperature ore reduction.	400	[8]	Oil or gas low temperature reduction.
Iron castings	Electric melting Duplex systems, continuous.	115–550	[8]	Fuel fired cupola melting.
Nitric acid	Arc	61,000	None.	Oxidation of ammonia.
Calcium cyanamide	Electrothermal reduction	2,830	[9] None.	None.

[4] Kilowatt-hour per 1,000 cubic feet.
[5] Canadian and United States consumption in 1929 was 152,489,000 kilowatt-hours for production of fused alumina.
[6] Canadian and United States consumption in 1929 was 227,000,000 kilowatt-hours for production of silicon carbide.
[7] United States production not officially recorded. Estimated world consumption in 1927 was 375,000,000 kilowatt-hours for manufacture of metallic sodium.
[8] Not reported.
[9] The amount of calcium cyanamide shipped into the United States required 84,900,000 kilowatt-hours to produce.

131. *Conclusions as to future power market.*—Estimates of the future always involve many uncertainties. In the electrical industry 5 years ahead is as far as plans can usually be prepared with any definiteness. A 10-year estimate is hazarded only with reservations. However, in connection with the preparation of a comprehensive plan for the development of the Columbia River it is necessary to make comparisons between many possible alternatives, and the amount of power that is involved is so great that the comparisons require a forecast of the probable rate at which the power market can absorb electrical

energy over a long period of years. Therefore, the conclusions of this study have been carried beyond the usual limits.

132. Study of available data leads to the conclusion that there is not likely to be a sudden change in the general trend of growth in the market for electrical energy in the Northwest. Conditions prevailing during the business depression of 1930–31 tend to support this conclusion. Production of energy has been growing at the average rate of approximately 9.5 percent per year compounded. At this rate the business doubles in 7.6 years. In 15.2 years it quadruples. Yet in spite of past trends it is difficult to conceive that consumption of electrical energy will continue indefinitely to increase at the rate of 9.5 percent per year. Electric power has greatly changed modern methods. It is within the bounds of possibility that the progress of science and invention may bring forth other sources of energy for the service of mankind and that these will in time supersede the generation of electricity as we know it.

133. The estimates for the future consumption of electricity proposed in the district reports are concurred in. These assume that the rate of increase of production will gradually decrease following a smooth curve until at the end of 30 years (1960) the rate will be 4.75 percent per year instead of 9.5 percent. After 30 years it is assumed that the rate of increase will continue to decline along the same smooth curve until at 60 years (1990) growth ceases. Table H gives the estimated figures at 5-year intervals from 1930 to 1960.

TABLE H.—*Estimated future electrical production within marketing distance of Columbia River power sites* [1]

Year	Kilowatt-hours	Average	Installed capacity	Year	Kilowatt-hours	Average	Installed capacity
	Millions	*Kilowatts*	*Kilowatts*		*Millions*	*Kilowatts*	*Kilowatts*
1930	4,041	461,333	922,877	1950	22,930	2,617,000	5,234,000
1935	6,480	740,000	1,480,000	1955	31,830	3,633,000	7,267,000
1940	10,230	1,168,000	2,336,000	1960	41,630	4,752,000	9,504,000
1945	15,650	1,787,000	3,574,000				

[1] Includes Washington, Oregon, that part of Idaho which is north of the Salmon River and that part of Montana now served by the Thompson Falls plant of the Montana Power Co.

134. Plate II shows separately the growth from 1907 to 1930 in the generation of electricity by public utilities as compiled by the Bureau of the Census and the United States Geological Survey for the United States, the Pacific States, Washington and Oregon. It also shows the growth of generation during the same period in the area south of the international boundary where electric energy produced by the Columbia will probably be marketed. This area includes the States of Washington and Oregon, that part of Idaho which lies north of Salmon River, and the northeastern corner of Montana which is now served by the Thompson Falls plant of the Montana Power Co. There has been indicated graphically and numerically on plate II the normal trend of growth during the past decade or more. The graph of generation in the market area for Columbia River power has been extended from 1930 to 1960 in conformity with the estimates of table II. In the district reports (see vol. II of this document) there will be found comparable data for

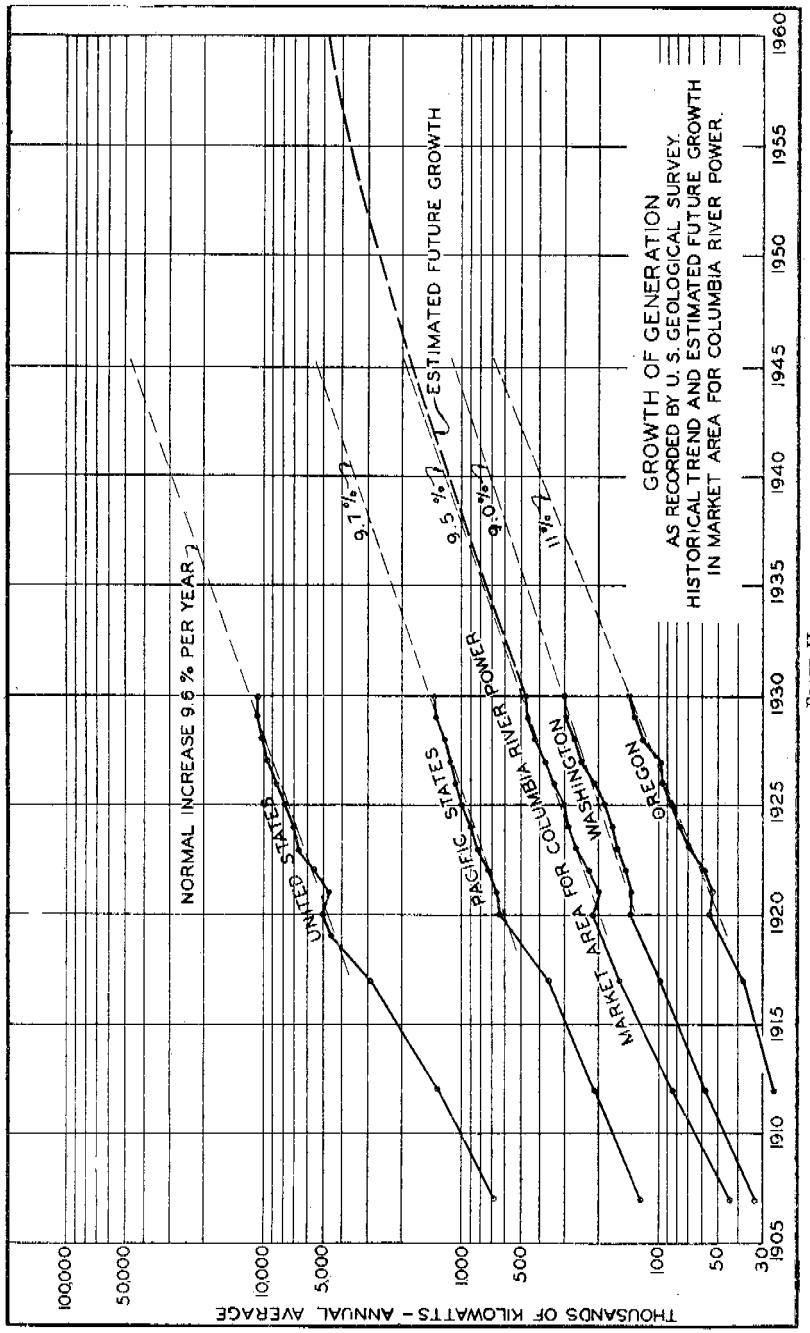

GROWTH OF GENERATION
AS RECORDED BY U. S. GEOLOGICAL SURVEY.
HISTORICAL TREND AND ESTIMATED FUTURE GROWTH
IN MARKET AREA FOR COLUMBIA RIVER POWER.
ESTIMATED FUTURE GROWTH
NORMAL INCREASE 9.6 % PER YEAR
9.7 %
9.5 %
9.0 %
11 %
UNITED STATES
PACIFIC STATES
PACIFIC NORTHWEST POWER
COLUMBIA RIVER
MARKET AREA FOR COLUMBIA RIVER POWER
WASHINGTON
OREGON
THOUSANDS OF KILOWATTS - ANNUAL AVERAGE
100,000
50,000
10,000
5,000
1000
500
100
50
30
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960

PLATE II.

the individual utilities and other information which has been used in arriving at the conclusion represented by table II.

135. These estimates appear to give reasonable and consistent results satisfactory for the purpose of this report. Should growth continue as it has in the past the estimates will be exceeded. Should the industry fail to continue its progress or should it be detrimentally affected by some new discovery, it may fall considerably short of the estimate.

136. *Economics of power production.*—Economic justification for the construction of large dams for the development of power on Columbia River depends upon successfully marketing the power at a price and in the large quantities necessary to pay all fixed charges, including interest and operating expenses, and to insure the return within a reasonable time of the original investment either directly or by setting up ample reserves for depreciation and obsolescence. The range of the selling price will lie between the minimum that will meet these requisites and a maximum controlled by competitive prices and also by the amount industries can afford to pay for power.

137. It is assumed that in general any water-power sites in the Northwest that could produce power more cheaply than the sites on the Columbia River would be put to use before development of the Columbia is undertaken. In steam power also will be found a potential competitor worthy of consideration when any project is debated.

138. The basis for determining the cost of energy produced in a large steam turbine electric station, constructed at the load center by a utility company, is discussed in some detail in the district reports. With fuel oil costing $0.50 and $1 per barrel it is estimated that the cost per kilowatt-hour for different load factors will be as given in the ollowing table:

TABLE I.—*Cost of steam power per kilowatt-hour*

Annual load factor	Fuel oil $0.50 per barrel	Fuel oil $1 per barrel
Percent	*Mills per kw.-hr.*	*Mills per kw.-hr.*
40	4.38	5.46
50	3.70	4.77
55	3.46	4.51
65	3.08	4.13
75	2.80	3.84
85	2.59	3.62
100	2.35	3.38

139. Quotations for fuel oil during 1930 and early 1931 with barge deliveries in the Northwest have ranged from $1.10 down to $0.75 per barrel. One dollar per barrel is a reasonable and convenient figure to take for determining competitive prices. Annual load factor varies greatly for different classes of service. For a large system with usual commercial diversity it is approximately 55 percent. Under such a condition the estimated cost of steam power is 4.51 mills per kilowatt-hour when fuel oil costs $1 per barrel delivered at the steam plant. Should the service be to a large industrial plant which uses power quite uniformly throughout the 24 hours of the day and 365 days of the year it is not improbable than an annual load factor of 85 percent might be attained. This would reduce the cost of steam generation to 3.62 mills per kilowatt-hour. Future variations in the cost of fuel

will, of course, affect the price at which steam power can be produced with corresponding effect upon the maximum limit at which large blocks of hydroelectric power can be sold when delivered at the load centers.

POWER TRANSMISSION

140. Hydroelectric power can be generated only where a natural fall or a suitable site for a dam exists. This is usually at some distance from the place where the electric power is to be used. Columbia River sites are no exception. Some industries may find it economical to locate close to the generating stations, but the bulk of the energy will require long-distance high-tension transmission for delivery to the points at which it can be used most conveniently.

141. Present transmission lines are shown on plate 101,[1] electric power systems of Pacific Northwest—1930, in the report of the district engineer, Portland, Oreg., which is part 3 of this report. These lines have been designed and constructed to serve the present needs of the utilities to which they belong. They have insufficient capacity to transmit or distribute the power which the Columbia River is capable of producing. The distances involved and the amount of energy to be transmitted will require the construction of a new system of high-voltage circuits which will be superimposed upon the present or then existing systems. Appendix II of this report is a study by E. A. Loew, professor of electrical engineering, University of Washington, of the type and cost of such circuits. The probable voltage is determined to be 220,000. Double-circuit steel towers would be used. The estimates of cost include rights of way, towers, conductors, and telephone lines. Substation building and synchronous condensers are included at the delivery end of the circuits; and transformers, circuit breakers, and switches at both ends. Allowances have been made for contingencies, overhead charges, and interest during construction. A comparison is made between the cost when financed with money borrowed by a utility company at 6 percent and the cost with 4 percent public money. The cost of one double circuit, 220,000-volt line, with its terminal equipment, is estimated for several circuit lengths as shown in table J below.

TABLE J.—*Construction cost of double circuit 220,000-volt transmission line with terminal equipment*

[Line designed for maximum economy of transmission] [1]

Length of line	Peak capacity (receiver end)	Investment when financed by [2]	
		4 percent money	6 percent money
Miles	*Kilowatts*		
100	325,000	$8,078,200	$8,183,100
150	271,000	8,495,700	8,605,700
200	216,000	9,144,400	9,263,200
250	162,000	9,933,600	10,062,600

[1] For the sake of brevity and simplicity certain refinements are omitted which enter the economic study for the final design of the line. The present study is sufficiently accurate for purposes of comparison. Line conductors have been estimated on the basis of copper cable at 17 cents per pound. This is higher than current prices. The cost of conductors is 17.4 percent of the total cost of the 100 mile line; 17.8 percent of the 150 mile line; 19.7 percent of the 200 mile line and 22.7 percent of the 250 mile line.

[2] Assumed construction period is 16 months. Interest during construction is computed at 4 and 6 percent on the entire cost for one half this period.

142. Annual fixed charges for the two assumed methods of financing are made up as shown in table K which follows:

[1] Not printed in this document.

TABLE K

4 percent money	Percent	6 percent money	Percent
Interest	4.00	Interest	6.00
Depreciation reserve	1.78	Depreciation reserve	1.27
Amortization	1.05	Taxes	1.50
Total	6.83	Total	8.77

143. Annual expense of operation and maintenance is estimated at $150 per circuit mile. For the lines estimated in table J the total annual charges are given in table L below.

TABLE L.—*Annual charges for double circuit, 220,000 volt, transmission line with terminal equipment*

[Line designed for maximum economy of transmission]

Length of line (miles)	Annual expense of operation and maintenance	Annual fixed charges		Total annual charges	
		4 percent money	6 percent money	4 percent money	6 percent money
100	$30,000	$551,700	$717,700	$581,700	$747,700
150	45,000	580,300	745,700	625,300	790,700
200	60,000	624,600	812,400	684,600	872,400
250	75,000	678,500	882,500	753,500	957,500

144. Assuming that the transmission lines are properly proportioned for the peak loads which they will carry (in which case the load factor is equal to the capacity factor) the cost of transmission per kilowatt-hour for various load factors will conform approximately to the figures in tables M and N below. These transmission costs must be considered in determining the cost of energy delivered at the load center or in estimating the value of the energy if it is sold at the switchboard of the hydroelectric generating station.

TABLE M.—*Cost of transmission per kilowatt-hour for 220,000-volt lines of different length*

[4 percent money]

Load factor	Length of line in miles				Load factor	Length of line in miles			
	100	150	200	250		100	150	200	250
	Mills	*Mills*	*Mills*	*Mills*		*Mills*	*Mills*	*Mills*	*Mills*
50	0.409	0.527	0.724	1.060	75	0.272	0.351	0.483	0.707
55	.372	.479	.657	.965	85	.241	.310	.426	.625
65	.314	.405	.556	.817	100	.204	.264	.362	.530

TABLE N.—*Cost of transmission per kilowatt-hour for 220,000-volt lines of different length*

[6 percent money]

Load factor	Length of line in miles				Load factor	Length of line in miles			
	100	150	200	250		100	150	200	250
	Mills	*Mills*	*Mills*	*Mills*		*Mills*	*Mills*	*Mills*	*Mills*
50	0.525	0.675	0.921	1.350	75	0.350	0.449	0.615	0.898
55	.477	.615	.838	1.225	85	.309	.396	.542	.797
65	.403	.518	.709	1.037	100	.262	.337	.461	.675

POWER GENERATION

145. *General.*—In the early days of the electrical industry, both steam and water power plants were limited to capacities that now seem very small. This was necessary in order that initial investment might be in keeping with the market for power. It is usually true that water power sites of large capacity, when they are fully utilized, show a lower unit cost of production than do sites of smaller capacity. When, however, large dams and expensive hydraulic construction have been prematurely undertaken, carrying charges have sometimes placed heavy burdens on the financial structure of utilities before the market has been developed sufficiently to permit the accruing costs to be distributed to the consumers. As the power business has grown from year to year, the average annual increase in load has become greater. Therefore, the productive capacity of the larger power sites is now more quickly absorbed than it would have been in an earlier period. The growth of the power market, as estimated in this report, assumes the continuance of this trend. In the future it will undoubtedly become economically feasible to develop power sites which are larger than would be warranted at the present time.

146. It is a desirable condition precedent to the construction of a large power plant that it serve the needs of as large a market as possible. The principal Columbia River sites are within reasonable transmission distance of all the more important load centers of Oregon, Washington, northern Idaho, and western Montana. It is logical to consider the utilities occupying this region as forming a single market to be supplied by radiating transmission lines. Such an arrangement makes it possible to draw on a single source for all or a large part of the growth of the power sales until the capacity of that particular power site has been fully utilized. A long step in this direction has already been made by interconnection of the systems of independent and related power companies.

147. The following table O gives the total and average output of generating stations for 1930 and the installed capacity of generating equipment of the principal utilities within the area in which Columbia River power would be marketed. It also shows the totals of the United States Geological Survey as reported for Oregon and Washington. Provision for carrying peak loads, for irregularities in stream flow, for stand-by service and for caring for the normal growth of business causes the total rated capacity of generating equipment to be maintained at more than double the average output. In order to make the figures of the table comparable the installed generating capacity has been given as of December 31, 1930. This will account for some differences which will be found between these figures and those contained in the district reports as in the latter power plant capacities include installations made during 1931 insofar as information has been available.

TABLE O.—*Capacity and output of generating stations in public service within marketing area for Columbia River power*

Reported by	Output, 1930	Average output, 1930	Installed generating capacity Dec. 31, 1930	System capacity factor
LARGER UTILITIES	*Kilowatt-hours, thousands*	*Kilowatts*	*Kilowatts*	*Percent*
Puget Sound Power & Light Co	891,812	101,800	262,735	38.7
Washington Water Power Co	843,376	96,200	202,535	47.5
Portland General Electric Co	600,861	68,600	181,480	37.8
City of Seattle	380,749	43,500	128,300	33.9
City of Tacoma	219,655	25,000	91,000	27.5
Northwestern Electric Co	257,036	29,400	59,000	49.8
Montana Power Co. (Thompson Falls plant)	201,646	23,019	35,000	65.8
Pacific Power & Light Co	138,760	15,900	34,735	45.8
Mountain States Power Co	12,767	1,460	24,889	
Washington Gas & Electric Co	92,848	10,600	24,000	44.2
Grays Harbor Railway & Light Co. and associated companies	37,913	4,650	12,900	36.0
City of Eugene	32,007	3,660	8,950	40.9
City of Centralia (from October only)	1,760	201	4,000	
Eastern Oregon Power Co	9,698	1,110	3,580	31.0
Total of separate reports	3,720,888	428,980	1,082,276	39.6
MARKET AREA				
Washington total, reported by United States Geological Survey	2,555,233	293,177	784,435	37.4
Oregon total, reported by United States Geological Survey	1,219,250	139,137	315,075	44.2
Thompson Falls	201,646	23,019	35,000	65.8
Lewiston and Grangeville	52,560	[1] 6,000	10,625	56.5
Total for market area	4,028,689	461,333	1,145,135	40.3

[1] Estimated.

148. The business of all these utilities is growing rapidly. Frequent increase in generating capacity and other facilities for securing electric power is required to meet the needs of the consumers. Construction programs are constantly under way.

149. Puget Sound Power & Light Co. is now constructing under Federal license a dam and power plant at Rock Island near Wenatchee, Wash. This is the first dam to be built on the Columbia River. Two 15,000 kilowatt units are to be in service by January 1, 1932. The entire capacity of 150,000 kilowatts to 200,000 kilowatts is expected to be needed by 1937.

150. Washington Water Power Co. has applied for a Federal license to develop Kettle Falls on the Columbia 41 miles south of the international boundary. Plans propose an ultimate capacity of 230,000 kilowatts. The original program contemplated completion prior to 1940. The application has been held pending the completion of this report.

151. Portland General Electric Co. is beginning the development of storage on Clackamas River, a tributary of Willamette River, which will increase the firm output of its power plants on that stream. This company has tentative plans for the construction of power plants at other sites on the Clackamas as they are needed to meet its requirements.

152. Seattle has a program for developing the Skagit River with reservoirs and power plants to provide 783,000 kilowatts which it is estimated will meet the growth of the city load for about 15 years.

153. Tacoma, since December 31, 1930, has completed a steam plant with a capacity of 25,000 kilowatts. It is also installing a

second unit with 27,000 kilowatts capacity in the Cushman no. 2 power plant.

154. Inland Power & Light Co. is constructing under Federal license a storage dam and power plant at Ariel on Lewis River, about 36 miles from Portland, Oreg. One 45,000 kilowatt unit will be ready for service in the autumn of 1931. This power site is planned for the installation of three additional units of the same size. The power will be supplied to Northwestern Electric Co. and Pacific Power & Light Co. at Portland, Vancouver, Condit, and elsewhere. Preliminary plans of the company contemplate the progressive development of a number of power and storage sites on Lewis River with a possible ultimate capacity of 1,200,000 kilowatts.

155. Montana Power Co. is constructing under Federal license a 100,000 kilowatt power plant on Flathead River 4 miles below the outlet of Flathead Lake in Montana. This plant is to be completed in 1933 or 1934.

156. Rivers other than the Columbia in the States of Washington and Oregon have undeveloped potential water-power capacities somewhat as indicated in the following table P. The figures in this table have been collected from a number of different sources, official and unofficial. They do not purport to be final and are given merely to show the general extent of available hydropower in the Northwest. The possible sites vary greatly in commercial desirability. On many streams, little is known of the probable cost of developing the potential power. It is to be expected that at many sites the costs will be so great as to make them uneconomical of development in competition with other means of securing power under present conditions or those likely to exist in the future. Insofar as the information is available the figures in table P are given on the basis used by the United States Geological Survey, which assumes 70 percent efficiency and uniform output of 90 or 50 percent of the time. The proper installed capacity would be quite different and would be determined by considerations which are too complicated for inclusion at this time.

TABLE P.—*Undeveloped potential water powers of rivers other than the main Columbia in Washington and Oregon*

River	Estimated potential powers at 70 percent efficiency		River	Estimated potential powers at 70 percent efficiency	
	90 percent of time	50 percent of time		90 percent of time	50 percent of time
	Kilowatts	*Kilowatts*		*Kilowatts*	*Kilowatts*
Tributaries to Columbia:			Other streams:		
Kootenai	154,000	266,000	Skagit	490,000	644,000
Clark Fork	1,140,000	1,950,000	Stilaguamish	79,000	99,000
Spokane	57,000	75,000	Snohomish	168,000	284,000
Wenatchee	195,000	195,000	Puyallup	16,000	24,000
Yakima	97,000	197,000	Siuslaw	39,000	39,000
Snake (below Huntington)	964,000	1,455,000	Umpqua	260,000	410,000
White Salmon	64,000	96,000	Coquille	27,000	27,000
John Day	34,000	48,000	Rogue	292,000	370,000
Deschutes	500,000	540,000	Klamath (Klamath Lake to Oregon boundary only)	76,000	112,000
Klickitat	114,000	161,000	Other streams	194,000	680,000
Willamette Basin	403,000	783,000			
Kalama		22,000			
Lewis	217,000	232,000	Total other streams	1,641,000	2,689,000
Cowlitz	300,000	353,000			
Minor tributaries	536,000	919,000	Combined total	6,416,000	9,961,000
Total tributaries	4,775,000	7,252,000			

NOTE.—On the same basis Columbia River power within the United States has been estimated to be 3,577,000 kilowatts 90 percent of the time and 5,951,000 kilowatts 50 percent of the time.

POSSIBILITIES ON COLUMBIA RIVER

157. The district engineers submit plans for an ultimate development of Columbia River between tidewater and the international boundary which include power dams at the sites named in table Q and creating maximum heads as there shown.

TABLE Q

Site	Miles from international boundary	Miles from Pacific Ocean	Normal Forebay elevation m.s.l.	Minimum tailwater elevation m.s.l.	Head at natural low water
					Feet
Above the mouth of Snake River:					
Grand Coulee	151	597	1,287.6	933.0	354.6
Foster Creek	202	546	928.6	764.6	164.0
Chelan	244	504	762.0	667.0	95.0
Rocky Reach	274	474	665.0	604.0	61.0
Rock Island	295	453	599.0	548.0	51.0
Priest Rapids	351	397	540.0	405.0	135.0
Below the mouth of Snake River:					
The Dalles (or Big Eddy)	556	192	330.0	54.0	276.0
Warrendale	608	140	54.0	1.0	53.0
Total					1,189.6

158. Plans for the river above the mouth of Snake River have been prepared by the district engineer of the Seattle district (see pt. 2, vol. II of this document). Plans below the mouth of the Snake have been prepared by the district engineer of the Portland district (see pt. 3, vol. II of this document). With one exception each dam as planned will back water practically up to the dam next above, thus making available for power production almost all the head that can be obtained at each site without interference with the next. The exception occurs in the stretch of river between Priest Rapids and Pasco, Wash. It is proposed by the Portland district that The Dalles Dam will back water up to elevation 330. The next dam above, as proposed by the Seattle district is at Priest Rapids where the natural low water is at elevation 405. This leaves a gap of 75 feet between the two elevations. There are no favorable power sites between Priest Rapids and the mouth of Snake River, a short distance below Pasco. Raising the water to an elevation greater than 330 at any site below Pasco will flood part or all of the towns of Pasco and Kennewick, besides causing extensive damages to other property. This has been an important factor in the decision to omit from present consideration the development of the fall existing in this section of the river.

159. Where the Columbia crosses the international boundary the water surface elevation is 1,288.4 at the minimum stage of record (14,000 second-feet). The maximum head proposed to be utilized occurs at natural low water with the ponds full at each dam as shown in table Q. This is the time when high efficiency is particularly important with the unregulated stream, since low water then determines the minimum potential power which is available. The total head utilized at low water is 1,189.6 feet or 92.3 percent of the 1,288.4 feet which the river falls between the Canadian boundary and the Pacific Ocean.

160. It is planned that at each site pondage will be available for use in supplying daily variations of the load. At Grand Coulee and at

The Dalles seasonal storage is provided for increasing the flow of the river during low water stages. The drawing down of the ponds will decrease the head that is utilized. This might be offset in part by making some of the dams slightly higher. At higher stages the total fall from the international boundary to tailwater at Warrendale remains about the same, but the gradient of the river between the dam sites is steepened. This causes the tailwater surface at each site to rise, resulting in a decrease of the head available. Except at locations such as Rocky Reach and Rock Island where at high water the fall will be insufficient for the effective production of power and at sites with seasonal storage, the minimum potential output occurs at time of low water and high head. When higher stages cause the head to be less, it is possible to maintain the output and carry the same peak loads as under low water conditions provided sufficient turbine capacity is installed.

161. With the information now available a combination of the plans of the two districts seems well suited to conserve and develop the potential power of the waters of the Columbia and to form a comprehensive plan for the river as a whole.

162. The flow of the Columbia is contributed by watersheds differing widely in character. The low flow is tripled and the flood flow nearly doubled by tributaries which enter between the Canadian boundary and tidewater. Proportionately its variation between extreme maximum and minimum is less than for other rivers of the western portion of the United States. The principal run-off comes from melting snow fields in high mountainous areas. Flood stages normally occur during May and June in the upper river and in June and July in the lower river. The flow is well maintained throughout the summer. Low water occurs during the winter months. Occasional brief periods of severely cold winter weather in the interior valley are the usual cause of extremely low stages of the river.

163. During recent years the West has received an annual precipitation markedly lower than the recorded average. This is directly reflected in the run-off of the Columbia on which records have been kept at The Dalles since 1878. Such changes in precipitation appear to be more or less cyclic in character. Present scientific knowledge is not sufficient to make it possible to determine the length of time during which drouths will continue nor when they may recur. For the purpose of this report estimates of the amount of electrical energy which may be secured from the Columbia have been based on the records of the 17-year period from April 1, 1913, to March 30, 1930, excluding the years prior to 1913 with their larger run-off. Spillways for dams have been designed to carry floods 25 per cent or more in excess of the maximum known flood which was recorded in June 1894.

164. Irrigation is important in the arid valleys east of the Cascades. The irrigation season is more or less coincident with the period when natural stream flow is above its average. Much of the water diverted for irrigation returns slowly to the river by percolation. This has an equalizing effect upon the flow. Diversions decrease the floods. Percolating waters increase the low water flows.

165. On the headwaters of the Columbia and its northern tributaries are a number of large lakes which act as natural detention reservoirs to equalize the flow. Their possibilities are described at some

length in the report of the Seattle district. Principal among them are the following:

Lake	River	Location	Lake	River	Location
Upper Arrow	Columbia	British Columbia.	Priest	Priest	Idaho.
Lower Arrow	do	Do.	Coeur d' Alene	Spokane	Do.
Kootenay	Kootenay	Do.	Okanogan	Okanogan	British Columbia.
Flathead	Flathead	Montana.	Chelan	Chelan	Washington.
Pend Oreille	Clark Fork	Idaho.	Wenatchee	Wenatchee	Do.

166. Coeur d' Alene and Chelan Lakes are now regulated in the interests of power development. Construction has been begun which will regulate Flathead Lake. Each of the lakes has further possibilities as a controlled reservoir to maintain the flow of the Columbia River for power production beyond the effect of natural regulation. It is possible to create a large reservoir by a dam on the south fork of Flathead River, a tributary to Clark Fork, at the Hungry Horse site in Montana. A smaller reservoir can be constructed on the Chiwawa River in Washington. Some pondage, enough for daily regulation, will be available at each of the power dams proposed for the Columbia. In addition, important quantities of water to aid in maintaining the power supply during the winter months can be stored in the reservoirs created by the proposed dams at the Grand Coulee and The Dalles sites.

167. The plans for Columbia River proposed in the district reports contemplate that ultimately storage will be available for use as needed for irrigation and power to the following extent:

Reservoirs	Useful storage	Reservoirs	Useful storage
	Acre-feet		*Acre-feet*
Hungry Horse	1,100,000	Chelan	665,000
Flathead	1,540,000	Wenatchee	1,000,000
Priest	569,000	Chiwawa	482,000
Pend Oreille	1,610,000	The Dalles	4,625,000
Kootenay (British Columbia)	715,000		
Couer d'Alene	430,000	Total	17,764,000
Grand Coulee	5,028,000		

168. A number of possible power sites have been investigated and considered, but have not been included because they do not fit into the most desirable plan. The sites thus eliminated are listed below. Some of them have characteristics which make them physically good as independent dam and power sites. Others lack essential or important qualifications.

Site	Miles from international boundary	Miles from Pacific Ocean	Site	Miles from international boundary	Miles from Pacific Ocean
Little Dalles	15	733	Blalock Rapids	514	234
Kettle Falls	41	707	Four o'Clock Rapids	516	232
Gaviota	188	560	Squally Hook Rapids	525.5	222.5
Wells	231	517	John Day Rapids	532	216
Vantage	325	423	Biggs Rapids	541	207
Homly Rapids	430	318	Five Mile Rapids	554.5	193.5
Wallula	435	313	Three Mile Rapids	558	190
Umatilla Rapids	456	292	Wind Mountain	593	155
Canoe Encampment Rapids	484	264	Cascade Rapids	601	147
Arlington	506	242	Bonneville	605	143

169. The following paragraphs contain a brief description of the physical conditions at the power sites which are incorporated in the plans proposed by the districts.

170. *Grand Coulee.*—This site is of particular importance in connection with the comprehensive plan because of its location at the head of an ancient water course known as the Grand Coulee, a prominent topographic feature of the vicinity. It is proposed to use this old channel as a storage reservoir and canal in connection with the pumping plan for irrigation of the lands of the Columbia Basin irrigation project. The floor of the Coulee is at elevation 1,500 or about 600 feet above the present channel of the Columbia. A dam at this site not only serves to provide power for pumping, but by raising the natural water surface of the river it decreases the pumping lift. The drainage area of the Columbia River above this site is 74,000 square miles. The canyon is 700 feet deep, 2,000 feet wide at the bottom, 1 mile wide at top. Granite outcrops on the canyon walls with basalt on rim of left bank. Average elevation of natural river bed is 910 feet. Natural low water elevation 933. Subsurface conditions have been investigated with 16 drill holes. Bedrock (granite) extends across the river at about elevation 870 for 2,500 feet and rises with 2:1 slopes on the canyon sides. The granite is dense with few seams. Overburden is 40 feet thick in center of stream and 200 feet thick at toes of slopes. It consists of 40 feet of blue clay next to the bedrock covered by boulders, gravel, and sand. Proposed dam will raise water surface to elevation 1,287.6 feet. At this elevation length of pool will be 151 miles and the area of water surface 74,900 acres. Land overflowed is mostly barren canyon and damages to property will be comparatively small (estimated at $6,661,200).

171. *Foster Creek.*—Drainage area is 75,500 square miles. At low water the river is 500 to 600 feet wide. Natural low water surface elevation is 765 feet. The south (left) bank is fairly flat and irregular and is composed of solid granite bedrock with little overburden. The north (right) bank rises about 250 feet above the water on a steep slope to a comparatively level bench. Six drill holes were put down at or near the site to explore subsurface conditions. Granite with some overburden apparently is continuous across the channel. On the north bank the granite bedrock extends horizontally beneath the bank at an average elevation of 755 feet. It outcrops three quarters of a mile north of the river at an elevation of 1,100 feet. The overburden above the granite is a glacial till composed of heterogeneous mixture of boulders, gravel, and sand, and contains enough clay to insure the closing of the voids and prevention of water percolation. The proposed dam will raise the water surface to elevation 928.6 feet. At this elevation the length of the pool will be 51 miles and the area 7,400 acres. Land overflowed is mostly in the canyon and valueless. The total damages are estimated at only $50,000.

172. *Chelan.*—Drainage area is 85,500 square miles. The main valley is about 2,200 feet wide, the low water channel from 500 to 600 feet wide and is close to the east (left) bank. Natural low water elevation is 667 feet. Test borings indicate that bedrock is probably continuous across the valley at elevation between 500 and 600 feet. It consists mainly of gneiss with minor quantities of mica schist and granite. Overburden is principally sand and gravel intermixed

with cobblestones and small boulders. Further investigation is necessary to determine definitely the porosity of the material and the suitability of foundation conditions for the construction of a dam. The proposed dam will raise the water surface to elevation 762 feet. At this elevation the pool will be 42 miles long and have an area of 9,200 acres. The land overflowed is mostly barren sagebrush desert, and with the exception of about 16 miles of railroad to be relocated the damages are small. The damages are estimated at $1,200,000.

173. *Rocky Reach.*—Drainage area is 87,200 square miles. The natural channel is 1,200 to 1,500 feet wide. Natural low water elevation is 604 feet. An isolated butte of gneiss and granite rising to an elevation of about 1,150 feet, east of the present channel, separates it from a dry channel which is about 75 feet above the present low water. A test hole drilled on the right bank opposite the upstream end of this butte shows the overburden to be 100 feet deep. Further investigation is necessary to determine the feasibility of this site. The proposed dam will raise the water surface elevation to 665 feet. At this elevation the pool would be 30 miles long and have an area of 5,400 acres. Construction of this dam would require the revision of about 5 miles of railroad and highway. Damages are estimated at about $400,000.

174. *Rock Island.*—Drainage area is 88,700 square miles. The local formation is a basalt resulting from lava flows of unusual thickness. Rock Island divides the river into two channels each approximately 200 feet wide at low water. The site is now being developed by Puget Sound Power & Light Co. under license 943 of the Federal Power Commission. The proposed dam will raise the water surface elevation to 599. At this elevation the pool will be 20 miles long and have an area of 2,250 acres.

175. *Priest Rapids.*—Drainage area is 95,400 square miles. Except at extreme high water, the river is divided into two channels at this site by Panhandle Island. The low water channel just below the site is about 2,000 feet wide. Natural low water elevation is 405 feet. The country rock in the vicinity is basalt. Test borings by a private company several thousand feet upstream from the present site have been made available, but no subsurface data are available at this site. The proposed dam will raise the water surface elevation to 540 feet. At this elevation the pool will be 57 miles long and have an area of 34,200 acres. Damages are estimated at $3,063,000.

176. *The Dalles.*—Drainage area is 237,000 square miles. Columbia River basalt, with no overburden, occurs along the margin of the river on both sides and in the channel. At the dam site the channel has a depth of 150 feet at low water. Natural low water elevation is 46 feet. Test holes put down at this site penetrated successive flows of basalt for over 260 feet. At this depth they were 90 feet below the bottom of the channel and 190 feet below sea level. The proposed dam will raise the water surface to elevation 330 feet. At this elevation the pool will be 147 miles long and have an area of 140,000 acres. The area inundated at this elevation contains several small towns, about 7,000 acres of irrigated farm land, and would require the revision of 323 miles of railroad and 103 miles of main highway. Damages are estimated at $71,300,000.

177. *Warrendale.*—Drainage area is 240,000 square miles. The river is divided into a main and a secondary channel by low sand islands or bars. The main channel next to the Oregon shore is 800 to 1,400 feet wide, and the secondary channel is about 500 feet wide at low water. The greatest depth at low water in the main channel is 40 feet and the average depth 25 feet. The secondary channel carries very little water at low stages. Extreme low water elevation is 1 foot above mean sea level. Beacon Rock, an andesite upthrust, is a prominent landmark which stands practically at the water's edge on the Washington shore. There is no surface indication that rock of any kind is to be found at reasonable depth anywhere in the river bed. One test hole drilled on the north side of the main channel went to elevation −144 in sand and sand and gravel. This material is unconsolidated river-carried sediments filled into the buried former channel of the Columbia River. The proposed dam would raise the water-surface elevation to 54 feet. At this elevation the pool would be 50 miles long and have an area of 22,000 acres. Property damage would be comparatively small, including the moving of the Oregon State fish hatchery, the purchase of a private cannery, and the revision of 17 miles of railroad and 2 miles of main highway. Total damages are estimated at $3,600,000.

178. Selection of an ultimate plan for their respective sections of the Columbia River development was one of the last steps in the studies made by the district engineers. From a consolidation of these a comprehensive plan for the entire river has been prepared. Time has not permitted a revision and recomputation of all district estimates to put them on the basis of the comprehensive plan. However, it is believed that the data given in parts 2 and 3 of this combined report and summarized in the following pages give a fair picture of the results which may be expected from the plan.

179. Extremes of flow and the mean flow, as used in the preparation of the district engineer's studies of each of the sites, are shown in table R, together with the corresponding natural water surface.

TABLE R.—*Records of flow on Columbia River and corresponding natural water surface elevations*

Location	Period April 1913 to March 1930					June 1894, maximum record for all time	
	Minimum record		Mean	Maximum record			
	Flow	Elevation	Flow	Flow	Elevation	Flow	Elevation
	Sec.-ft.	*M.S.L.*	*Sec.-ft.*	*Sec.-ft.*	*M.S.L.*	*Sec.-ft.*	*M.S.L.*
International boundary	14,000	1,288.4	99,000	450,000	1,333.3	700,000	1,347.5
Grand Coulee	17,000	933.0	109,000	462,000	948.0	725,000	1,003.0
Foster Creek	17,000	764.6	109,000	492,000	798.6	725,000	814.0
Chelan	17,600	667.0	113,000	500,000	713.0	735,000	724.0
Rocky Reach	20,300	604.0	117,000	510,000	641.5	735,000	665.7
Rock Island	21,000	548.0	121,000	528,000	589.5	740,000	600.0
Priest Rapids	21,000	405.0	121,000	528,000	431.0	740,000	445.0
The Dalles	40,000	43.0	185,000	800,000	[1] 94.0	1,170,000	[1] 110.0
Warrendale	43,000	1.0	190,000	800,000	37.5	1,170,000	47.6

[1] Natural water surface at The Dalles site for 800,000 second-feet is 102.5; for 1,170,000 second-feet it is 114.5. The proposed design diverts flood water from the present channel. Due to this change there would be less back water at the power house, and it is estimated that the results shown in the table will be obtained.

180. Preliminary designs of dams have been made for each of the sites included in the proposed plan and also for a number of other sites that were considered. While the available data are insufficient to permit final conclusions on the best designs and methods of construction, it is believed that the present studies give a reasonable basis for estimating the cost of the structures and the time which will be needed for their construction. This statement should be qualified as to the sites known as Chelan, Rocky Reach, and Warrendale, for which the studies and subsurface explorations have been insufficient to establish with finality their suitability as dam sites. A dam at Rock Island is now being constructed by the Puget Sound Power & Light Co. under Federal license. It is therefore omitted from the estimates which follow, although other data concerning it are included where appropriate. Table S, which follows, summarizes some statistical data contained in the reports of the district engineers.

TABLE S.—*Design of dams*

Site	Type of section	Length	Maximum height to walkway		Minimum free board [1]	Spillway		Depth on crest designed capacity
			Above foundations	Above low water		Designed capacity	Clear length	
		Feet	*Feet*	*Feet*	*Feet*	*Sec.-ft.*	*Feet*	*Feet*
Grand Coulee	Gravity overflow	2,800	490	370	13	910,000	700	16
	Bulkhead	1,490			13		1,680	23
	Total	4,290					2,380	
Foster Creek	Gravity overflow	1,390	220	179	15	910,000	1,064	35
	Canal Gate section	320			15			
	Earth fill	290			15			
	Total	2,000					1,064	
Chelan	Combination	4,540	150	95	13	940,000	1,770	28
Rocky Reach	Curved gravity overflow	2,500	100	81	3	960,000	1,950	43
Priest Rapids	Gravity overflow	3,270	202	145	10	1,000,000	2,460	22
	Bulkhead	700			10			
	Earth fill	6,580			10			
	Power-house intake	1,150			10			
	Total	11,700						
The Dalles	Bulkhead	4,900	440	294	10			
	Power-house intake	2,700			10			
	Multiple arch	5,200			10			
	Gravity overflow	2,500			10	1,400,000	2,210	30
	Earth fill	4,700			15			
	Total	20,000						
Warrendale	Spillway section	2,200				1,400,000	2,200	30
	Power-house section	1,800	101	84	3			
	Abutment section	2,000			3			
	Total	6,000						

[1] Figures given for minimum free board show clearance above water surface when spillway is discharging at designed capacity.

181. The comprehensive plan contemplates that ultimately 5,764,000 acre-feet of storage capacity will be provided on tributaries of the Columbia above Grand Coulee. With these reservoirs it is estimated that the minimum flow of the river at Grand Coulee can be increased from 17,000 second-feet to 32,900 second-feet. The Seattle district has drawn comparisons of the power sites above the mouth of Snake River based on this regulation. (See table T.)

182. Without assuming any benefit from upstream regulation of the flow of the river, the Portland district has determined that the minimum daily flow at The Dalles can be increased from 40,400 second-feet to 70,000 second-feet by the use of 4,625,000 acre-feet of storage contained in the upper 40 feet of the reservoir which would be created by The Dalles dam. This regulation may be used to produce 1,450,000 prime kilowatts. The same minimum flow at Warrendale would produce 240,000 prime kilowatts. The Portland district has prepared estimates based on this regulation.

183. The figures presented by the districts to illustrate the power possibilities of the several sites under the above conditions are given in table T.

TABLE T.—*Limiting conditions controlling power output of 17-year period from April 1913 to Mar. 31, 1930, as assumed by district engineers. (See pts. 2 and 3, Vol. II of this document)*

Power site	Average natural flow for maximum month	Head corresponding to flow of (2)	Hydraulic capacity of plant with head in (3)	Full gate capacity of installation at head in (3) limiting peak load	Average regulated flow in minimum month [1]	Head corresponding to flow in (6)	Average output in month of minimum flow, prime power	Minimum load factor for prime power	Installed capacity used in layout and estimates
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Sec.-ft.	*Feet*	*Sec.-ft.*	*Kilowatts*	*Sec.-ft.*	*Feet*	*Kilowatts*	*Per-cent*	*Kilowatts*
Above Snake:									
Grand Coulee	436,000	307.5	65,000	1,359,000	32,900	351.4	785,000	58.0	1,575,000
Foster Creek	436,000	132.4	76,000	684,000	32,900	163.8	366,000	53.5	691,200
Chelan	455,000	62.0	100,000	354,000	34,500	92.1	216,000	61.0	450,000
Rocky Reach	466,000	26.2	100,000	178,000	36,600	58.5	146,000	82.0	336,000
Rock Island	480,000	25.0	85,000	145,000	39,400	50.0	134,000	82.5	180,000
Priest Rapids	480,000	110.7	83,000	625,000	39,900	131.3	356,000	57.0	648,000
Below Snake:									
The Dalles	[2] 800,000	234.5	140,700	2,900,000	70,000	272.5	1,450,000	50.0	3,800,000
Warrendale	[2] 800,000	31.5	254,500	480,000	70,000	50.0	240,000	50.0	836,000

[1] For sites above the mouth of the Snake this flow is taken as conforming to the Seattle district plan for regulation with reservoirs on tributary streams but no use of Columbia River storage (designated in part 2 as plan 4, case 6). For sites below the mouth of the Snake this flow assumed use of storage created by the Dalles dam but no benefit from other storage.

[2] Flow for maximum day of 17-year period.

184. Details of the estimates of cost of the dams and power plants for which data has been given in tables S and T will be found in the district reports. For each site estimates include cost of flowage rights and damages in connection with the acquisition of rights of way for the reservoirs; preliminary and construction costs of dam, power house, and all accessories; an allowance of 10 percent for contingencies and a further allowance of 12.5 percent for engineering and overhead expenses. The length of time required for construction is estimated, and interest during construction is computed for both 4 and 6 percent money.

185. In comparing sites of such widely different productive capacities, it is necessary to take into account the length of time that the market may require for absorption of the possible output. This is done by capitalizing the "carrying charges" or interest that will accumulate on part of the investment between the time that operation is begun and the time when the growth of the market is sufficient to absorb all the prime power. For this purpose it has been assumed that beginning with 1940 one half of the estimated growth of the power

market in the Pacific Northwest would be available to load any one plant.

186. A brief summary of the estimated investment required for power sites which are part of the comprehensive plan is given in table U. No investment in reservoirs on tributary streams is included.

TABLE U.—*Estimated investment at power sites*

[Installed generating capacity as given in table T]

Site and item	Investment	
	4 percent money	6 percent money
Grand Coulee:		
Dam and reservoir	$138, 736, 160	$147, 180, 969
Power house and machinery	32, 450, 617	34, 425, 872
Total construction	171, 186, 777	181, 606, 841
Carrying charges	33, 296, 676	52, 985, 149
Total investment	204, 483, 453	234, 591, 990
Foster Creek:		
Dam and reservoir	24, 524, 372	25, 639, 116
Power house and machinery	21, 696, 684	22, 682, 897
Total construction	46, 221, 056	48, 322, 013
Carrying charges	2, 942, 924	4, 615, 041
Total investment	49, 163, 980	52, 937, 054
Chelan:		
Dam and reservoir	22, 676, 864	23, 516, 747
Power house and machinery	14, 968, 465	15, 522, 853
Total construction	37, 645, 329	39, 039, 600
Carrying charges	1, 814, 149	2, 822, 010
Total investment	39, 459, 478	41, 861, 610
Rocky Reach:		
Dam and reservoir	23, 682, 057	24, 559, 171
Power house and machinery	12, 931, 840	13, 410, 797
Total construction	36, 613, 897	37, 969, 968
Carrying charges	1, 420, 923	2, 210, 325
Total investment	38, 034, 820	40, 180, 293
Priest Rapids:		
Dam and reservoir	41, 301, 632	43, 178, 978
Power house and machinery	16, 590, 710	17, 344, 833
Total construction	57, 892, 342	60, 523, 811
Carrying charges	4, 956, 196	7, 772, 216
Total investment	62, 848, 538	68, 296, 027
The Dalles:		
Dam and reservoir	190, 297, 000	198, 950, 000
Power house and machinery	83, 743, 000	87, 600, 000
Total construction	274, 040, 000	286, 550, 000
Carrying charges	70, 460, 000	110, 450, 000
Total investment	344, 500, 000	397, 000, 000
Warrendale:		
Dam and reservoir	23, 020, 000	23, 660, 000
Power house and machinery	40, 970, 000	42, 140, 000
Total construction	63, 990, 000	65, 800, 000
Carrying charges	3, 010, 000	4, 560, 000
Total investment	67, 000, 000	70, 360, 000
Grand total investment	805, 490, 269	905, 226, 974

187. The estimates of the annual charges for the several sites are contained in table V. Allowances for interest, amortization, and tax items for the sites above Snake River as contained in the estimates of the Seattle district (pt. 2) have been increased to cover the extra investment represented by "carrying charges." The annual charges are given for both 4 percent money, corresponding to public construction, and 6 percent money, corresponding to construction by a large corporation. The estimated available prime output in kilowatt-hours per year is also given. From the annual cost and output the cost per kilowatt-hour is directly computed and shown in the final column of table V. In presenting these figures certain differences in the basis of estimate should be noted. The installed capacity of the power plants on which the estimates have been based does not bear a uniform relationship to the amount of prime power that can be produced by the sites. (See table T.) This is illustrated by the load factors necessary to be maintained to produce the prime power with the installed equipment. Estimates of output at sites above the mouth of Snake River reflect benefits assumed to be received from regulatory storage on tributary streams, but the cost of this storage is not included. At the Grand Coulee site a large storage reservoir is created on Columbia River. The figures include the cost of this reservoir but do not reflect any use of it except as the high dam increases the head on the power plant. At The Dalles also the proposed dam creates a large reservoir. In this case both the cost of the reservoir and its use to regulate the flow and increase the prime power are reflected in the estimates. At Warrendale it is assumed that regulated flow from The Dalles will be available.

TABLE V.—*Estimated annual charges, available prime output, and cost per kilowatt-hour installed generating capacity as given in table T*

Site	Load factor	Operation and maintenance	Depreciation	Interest	Amortization	Taxes	Total cost	Annual prime output	Cost
	4 percent money								
	Percent							*1,000 kw.-hr.*	*Mills/kw.-hr.*
Above Snake River:									
Grand Coulee	79. 5	$151, 758	$665, 239	$8, 179, 338	$2, 147, 076	----------	$11, 143, 411	7, 945, 000	1. 40
Foster Creek	53. 5	148, 616	402, 934	1, 966, 559	516, 222	----------	3, 034, 331	3, 206, 160	. 94
Chelan	61. 0	148, 616	279, 753	1, 578, 379	414, 325	----------	2, 421, 073	1, 892, 160	1. 28
Rocky Reach	82. 0	148, 616	247, 072	1, 521, 393	399, 366	----------	2, 316, 447	1, 278, 960	1. 81
Priest Rapids	57. 0	148, 616	325, 905	2, 513, 942	659, 910	----------	3, 648, 373	3, 118, 560	1. 17
Below Snake River:									
The Dalles	50. 0	760, 000	1, 566, 000	13, 780, 000	3, 618, 000	----------	19, 724, 000	12, 702, 000	1. 55
Warrendale	50. 0	380, 000	744, 000	2, 680, 000	703, 500	----------	4, 507, 500	2, 102, 400	2. 14
	6 percent money								
Above Snake River:									
Grand Coulee	79. 5	$151, 758	$454, 680	$14, 075, 519	----------	$3, 518, 880	$18, 200, 837	7, 945, 000	2. 29
Foster Creek	53. 5	148, 616	289, 740	3, 176, 223	----------	794, 056	4, 408, 635	3, 206, 160	1. 37
Chelan	61. 0	148, 616	198, 695	2, 511, 697	----------	627, 924	3, 486, 932	1, 892, 160	1. 84
Rocky Reach	82. 0	148, 616	172, 915	2, 410, 817	----------	602, 704	3, 335, 052	1, 278, 960	2. 62
Priest Rapids	57. 0	148, 616	225, 740	4, 097, 762	----------	1, 024, 440	5, 496, 558	3, 118, 560	1. 76
Below Snake River:									
The Dalles	50. 0	760, 000	1, 130, 000	23, 820, 000	----------	5, 955, 000	31, 665, 000	12, 702, 000	2. 49
Warrendale	50. 0	380, 000	538, 400	4, 222, 000	----------	1, 055, 000	6, 195, 400	2, 102, 400	2. 95

188. In view of the differences cited it is apparent that the figures of tables U and V, and particularly the unit costs per kilowatt-hour, are not directly comparable. They do not represent the results to be secured at an individual site if it were developed independently. However, they do indicate that any of the sites, but particularly Foster Creek and Priest Rapids, can produce power very cheaply as part of a general plan in which the flow of the river is regulated by large reservoirs. When the decision was reached to include, as part of the comprehensive plan, a high dam at Grand Coulee which would back the water of the Columbia River to the international boundary, it became apparent that the 5,028,000 acre-feet of useful storage which would be made available in the upper 80 feet of the reservoir thus created would make regulation of the river possible without depending upon the construction of upstream reservoirs. The Seattle district engineer estimates that with this 5,028,000 acre-feet the minimum flow at Grand Coulee can be increased to an average of 40,400 second-feet during the 182-day period from October 1, 1929, to March 31, 1930, which is the controlling low-water period of the 18 years from April 1913 to March 31, 1931. This minimum is obtained after allowing 1,000 second-feet for winter diversion to the Columbia Basin irrigation project. This gives a basis for considering the economics of the Columbia River Dam and power plant at Grand Coulee as a source of electric power independently of other construction included in the comprehensive plan. It also makes it possible to compare the economics of this site and of the site at The Dalles.

189. This comparison is of particular value because among the seven undeveloped power sites included in the comprehensive plan, Grand Coulee and The Dalles are of outstanding importance, not only on account of their size and the regulatory storage which they provide, but because of their strategic location. The Columbia River Dam at Grand Coulee is essential to the Columbia Basin irrigation project for reducing the pumping lift and supplying power for pumping. The Dalles Dam would reduce the pumping lift to irrigation projects below the mouth of the Snake and could supply power for pumping to these and other projects. It would improve the navigability of the Columbia and Snake Rivers by submerging all obstructions between The Dalles and the mouth of Snake River by raising the low-water surface at the latter point about 17 feet. Regulatory storage at Grand Coulee would benefit all the other power sites on the river. Storage at The Dalles would be beneficial at the Warrendale site. The relative distances of the two sites from the principal prospective power markets are not greatly different.

190. To secure a direct comparison of Grand Coulee and The Dalles developments with each other, each as an independent entity, though, in fact, elements of the comprehensive plan, the estimates that immediately follow do not take into account any benefit which may ultimately be secured from upstream regulation nor any abstraction of power for irrigation use.

191. At Grand Coulee the regulation is assumed to be for an average flow of 40,400 second-feet during the 182 days above mentioned and for the equivalent of prime power of 907,000 kilowatts, or an annual prime output of 7,945,000,000 kilowatt-hours. The average flow for the maximum month of the 17-year period from April 1, 1913, to March 31, 1930, was 436,000 second-feet. The corresponding head

is 307.5 feet. At this head the full gate capacity of the turbines and generators included in the estimate is computed to be 1,359,000 kilowatts. However, the assumptions made involve an 80-foot draw-down of the reservoir. With the reservoir empty the head will be reduced to 270 feet.[5] At a head of 270 feet the 15 generating units would have a full gate capacity of 1,140,000 kilowatts. This, then, determines the limiting peak load of the installation, and makes 79.5 percent of the minimum load factor for prime power under the stipulated conditions. The estimated investment for this installation is given in table U. The estimated annual charges are given in table V.

192. At The Dalles the regulation is assumed to be for an average flow of 70,000 second-feet during the minimum month and for prime power of 1,450,000 kilowatts, or an annual prime output of 12,702,000,000 kilowatt-hours. The maximum flood for the 17-year period from April 1, 1913, to March 31, 1930, was nearly 800,000 second-feet. The corresponding head is 234.5 feet. At this head the capacity of the 38 turbines and generators included in the Portland estimate is 2,900,000 kilowatts. At this site the assumptions involve a 40-foot draw-down of the reservoir. Under this condition the head will also be 234.5 feet.[6] In order to modify the figures for The Dalles and put them on a basis comparable with those for Grand Coulee, advantage has been taken of the flexibility of the Portland methods to reduce the size of the Dalles power plant to 24 units, with a peak output of 1,987,000 kilowatts at 234.5-foot head, such as would be appropriate for producing the prime power of 1,450,000 kilowatts at a minimum load factor of 79.5 percent. The Portland district has prepared estimates of investment and annual charges to apply to this condition at The Dalles. These figures are shown in table W with the corresponding figures for Grand Coulee in parallel columns.

TABLE W.—*Comparison of investment and operating results for power sites at Grand Coulee and at The Dalles estimated to operate at 79.5 percent load factor*

Item	4 percent money		6 percent money	
	Grand Coulee	The Dalles	Grand Coulee	The Dalles
Investment:				
Dam and reservoir	$138,736,160	$193,520,000	$147,180,969	$202,370,000
Power house and machinery	32,450,617	54,040,000	34,425,872	56,490,000
Total construction	171,186,777	247,610,000	181,606,847	258,860,000
Carrying charges	33,296,676	69,600,000	52,985,149	109,100,000
Total investment	204,483,453	317,210,000	234,591,990	367,960,000
Annual charges:				
Operation and maintenance	151,758	480,000	151,758	480,000
Depreciation	665,239	1,040,000	454,680	734,000
Interest	8,099,338	12,688,000	14,075,519	22,078,000
Amortization	2,147,076	3,331,000		
Taxes			3,518,880	5,519,000
Total	11,063,411	17,539,000	18,200,837	28,811,000
Prime output per year—1,000 kilowatt-hours	7,945,000	12,702,000	7,945,000	12,702,000
Cost per kilowatt-hour—mills	1.40	1.38	2.29	2.27

[5] At the estimated maximum flood stage of 910,000 second-feet for which the spillway is designed the head available at the power house would be 267.6 feet.

[6] At the estimated maximum flood stage of 1,400,000 second-feet the head would be reduced to 222 feet. At this head the capacity of the 38 units would be 2,850,000 kilowatts. Such a flood has not occurred since records were begun in 1878. During the June 1894 flood, which reached a peak of 1,170,000 second-feet, the minimum head would have been 225 feet and the peak capacity of the 38 units 2,919,000 kilowatts. The average occurrence of floods greater than 800,000 second-feet is less than 2 days per year. The studies made in both districts have disregarded such extremes in the computation of prime power output.

193. The above figures should be used only for the purpose for which they are intended—namely, for a comparison of the probable cost of power generated at the two sites under the specified conditions. A load factor of 79.5 percent is too high to be commercially attainable under ordinary conditions. It is here used for comparison because of the limited number and size of units included in the estimate for Grand Coulee.

194. The annual load factor on large utility systems with the usual commercial diversification in types of service is ordinarily not in excess of 55 percent. Detailed estimates have not been made to determine the amount of the expenditure that might be necessary to increase the power-house installation at Grand Coulee to a size appropriate for producing, at 55 percent of other load factors, the prime power which would be available if the controlling low flow of the Columbia were regulated to 40,400 second-feet. However, the uncertainty due to lack of these estimates involves a relatively small part of the total cost of the Grand Coulee development. Under the existing conditions a reasonable approximation of the effect which such a change in the power-house installation might have upon the cost per kilowatt-hour can be obtained by adjusting the cost to compare with the analysis which has been made in Portland for The Dalles. These costs per kilowatt-hour for various load factors at Grand Coulee and The Dalles are given in table X. Here again it is assumed that one half the estimated growth of the power market will be taken by the plant. Beginning on this basis in 1940, it would take 12 years to absorb the prime output at Grand Coulee and 17 years at The Dalles.

TABLE X.—*Cost per kilowatt-hour with capacity of power plants adjusted to generate the given prime power but at different load factors*

Load factor	Grand Coulee (prime output, 7,945,000,000 kilowatt-hours)		The Dalles (prime output, 12,702,000,000 kilowatt-hours)	
	4 percent money	6 percent money	4 percent money	6 percent money
	Mills	*Mills*	*Mills*	*Mills*
100	1.34	2.21	1.33	2.20
85	1.38	2.26	1.36	2.26
79.5	1.40	2.29	1.38	2.28
75	1.42	2.31	1.40	2.30
65	1.46	2.35	1.45	2.36
55	1.52	2.43	1.51	2.44
50	1.55	2.47	1.55	2.48

195. The figures in table X show the cost of energy delivered at the switchboard of the generating station. Table Y has been prepared for a wide range of load factors to show the cost of energy from Grand Coulee and The Dalles when delivery is made at load centers. (For transmission costs see tables M and N.) Comparison is made for areas centering at Seattle, Portland, and Spokane.

TABLE Y.—*Estimated cost per kilowatt-hour of energy generated at Grand Coulee and The Dalles power sites and delivered at the load centers*

Load center	Load factor	Grand Coulee			The Dalles		
		Cost of generation	Cost of transmission	Total cost at load center	Cost of generation	Cost of transmission	Total cost at load center
		4 percent money					
	Percent	*Mills*	*Mills*	*Mills*	*Mills*	*Mills*	*Mills*
Seattle	100	1.34	0.36	1.70	1.33	0.53	1.86
	85	1.38	.43	1.81	1.36	.62	1.98
	79.5	1.40	.45	1.85	1.38	.66	2.04
	75	1.42	.48	1.90	1.40	.70	2.10
	65	1.46	.55	2.01	1.45	.81	2.26
	55	1.52	.66	2.18	1.51	.96	2.47
	50	1.55	.72	2.27	1.55	1.02	2.57
Portland	100	1.34	.53	1.87	1.33	.18	1.51
	85	1.38	.62	2.00	1.36	.22	1.58
	79.5	1.40	.66	2.06	1.38	.23	1.61
	75	1.42	.70	2.12	1.40	.25	1.65
	65	1.46	.81	2.27	1.45	.29	1.74
	55	1.52	.96	2.48	1.51	.33	1.84
	50	1.55	1.02	2.57	1.55	.35	1.90
Spokane	100	1.34	.18	1.52	1.33	.47	1.80
	85	1.38	.22	1.60	1.36	.56	1.92
	79.5	1.40	.23	1.63	1.38	.59	1.97
	75	1.42	.25	1.67	1.40	.63	2.03
	65	1.46	.29	1.75	1.45	.72	2.17
	55	1.52	.33	1.85	1.51	.86	2.37
	50	1.55	.36	1.91	1.55	.95	2.50
		6 percent money					
Seattle	100	2.21	.47	2.68	2.20	.67	2.87
	85	2.26	.55	2.81	2.26	.79	3.05
	79.5	2.29	.58	2.89	2.28	.84	3.12
	75	2.31	.62	2.93	2.30	.90	3.20
	65	2.35	.70	3.05	2.36	1.00	3.36
	55	2.43	.85	3.28	2.44	1.22	3.66
	50	2.47	.94	3.31	2.48	1.30	3.78
Portland	100	2.21	.67	2.88	2.20	.24	2.24
	85	2.26	.79	3.05	2.26	.28	2.54
	79.5	2.29	.84	3.13	2.28	.30	2.58
	75	2.31	.90	3.21	2.30	.32	2.62
	65	2.35	1.00	3.35	2.36	.37	2.73
	55	2.43	1.22	3.65	2.44	.44	2.88
	50	2.47	1.35	3.82	2.48	.48	2.96
Spokane	100	2.21	.24	2.45	2.20	.58	2.78
	85	2.26	.28	2.54	2.26	.71	2.97
	79.5	2.29	.30	2.59	2.28	.76	3.04
	75	2.31	.32	2.63	2.30	.80	3.10
	65	2.35	.37	2.72	2.36	.90	3.26
	55	2.43	.44	2.87	2.44	1.09	3.53
	50	2.47	.48	2.95	2.48	1.16	3.64

196. At present about twice as much electrical energy is consumed in the Puget Sound (Seattle) area as is used in the area of which Portland is center. Assuming the power output of either Grand Coulee or The Dalles to be divided in this proportion between these load centers, the weighted average cost per kilowatt-hour for the two sites is given in table Z. For comparison there are also given in table Z corresponding average costs assuming the energy is divided equally between the Seattle and Portland centers.

TABLE Z.—*Estimated cost per kilowatt-hour of energy generated by steam power with fuel oil at $1 per barrel, compared with weighted average of estimated cost per kilowatt-hour generated at Grand Coulee and The Dalles power sites and delivered to load centers in the proportion indicated*

Load factor	Energy generated by steam power	Energy delivered			
		⅔ at Seattle, ⅓ at Portland		½ at Seattle, ½ at Portland	
		From Grand Coulee	From The Dalles	From Grand Coulee	From The Dalles
	6 percent money	4 percent money			
	Mills/kw.-hr.	*Mills/kw.-hr.*	*Mills/kw.-hr.*	*Mills/kw.-hr.*	*Mills/kw.-hr.*
100	3.38	1.76	1.74	1.78	1.69
85	3.62	1.87	1.85	1.90	1.78
79.5	3.72	1.92	1.90	1.95	1.83
75	3.82	1.97	1.95	2.01	1.88
65	4.15	2.09	2.09	2.14	2.00
55	4.53	2.25	2.26	2.33	2.15
50	4.75	2.37	2.35	2.42	2.24
		6 percent money			
100	3.38	2.75	2.73	2.78	2.65
85	3.62	2.89	2.88	2.93	2.79
79.5	3.72	2.97	2.94	3.01	2.85
75	3.82	3.02	3.01	3.07	2.91
65	4.15	3.15	3.15	3.20	3.09
55	4.53	3.40	3.40	3.46	3.27
50	4.75	3.48	3.51	3.57	3.44

197. It is of interest to note in the foregoing tables that the unit costs for power delivered from either Grand Coulee or The Dalles are nearly the same. Should the market for electrical energy absorb the possible output less rapidly than estimated, the carrying charges will become more of a burden, and consequently the cost per kilowatt-hour will be increased. Such a change would affect the unit costs at The Dalles with its greater initial investment proportionately more than it would those at Grand Coulee. Should construction be undertaken by one of the present utilities of the Pacific Northwest to secure power for distribution in its own relatively limited market area, it is probable a site of smaller capacity than either The Dalles or Grand Coulee would be more practical from an economic standpoint, even though the initial construction cost per kilowatt of capacity might be considerably greater.

198. The margin of economic feasibility of the development of one of these large sites is increased if there be concentrated upon it a large part of the growth of the power market of the Northwest until its total potential output is absorbed. Several years will be required for preliminary work and construction at any of these sites. It has been assumed that 1940 is about as early as first-power production would begin. By that time most of the present construction programs of the several utilities will be completed and their power plants loaded. It should not be impossible to find a plan under which these public-service organizations could pool their interests to the extent of draw-

ing upon a single large development for the supply of a major part of the prospective growth of their business over a term of years, especially if such a plan would result in lower cost to them and would help the expansion of business in the whole region. There is enough of an analogy between the separation of the electrical business into generation, transmission, and distribution and the customary division of merchandising into manufacturing, transportation, and retailing to establish the possibility of mass production of power and its disposal in wholesale quantities to large distributing organizations.

199. The above discussion has concerned the cost of power. There is a considerable margin between the estimated cost of production at Grand Coulee or The Dalles and the competitive cost of steam power in favor of hydroelectric power. This margin represents the limit of possible profit. It is illustrated in table Z, which shows in parallel columns the cost of energy delivered at the principal load centers. It is neither necessary nor desirable that the initial selling price of the hydroelectric energy be kept down to absolute cost provided it is kept within reasonable limits. Should the selling price be fixed somewhat above the estimated cost, one or all of several things can be accomplished. Among them are: First, the undertaking can be made a financial success even though sales are less than estimated; second, reserves can be built up to be used in advancing additional development; third, applying particularly where public credit has been used, the investment can be retired or amortized in less than the 40 years estimated.

200. Tables X, Y, and Z show costs at annual load factors ranging from 50 to 100 percent. The tables illustrate the variations that may be expected between these limits. Service to a utility having a well-diversified commercial load and a load factor of 55 percent would cost the power-producing organization about 1.52 mills per kilowatt-hour if construction has been financed with 4 percent money and 2.44 mills per kilowatt-hour if financed with 6 percent money. In both cases delivery of energy is assumed to be made at the power house. Similarly, if energy is delivered to a large electrochemical industry which maintains an 85 percent load factor, the cost per kilowatt-hour would be 1.38 mills per kilowatt-hour with financing at 4 percent and 2.26 mills per kilowatt-hour at 6 percent. Should power be sold at a flat rate under which the customer may take energy continuously, the rate for 100 percent load factor may be applied. This is equivalent to an annual rate of $11.74 per kilowatt (or $8.76 per horsepower) of peak demand with 4 percent financing and $19.26 per kilowatt ($14.44 per horsepower) with 6 percent financing. In a similar manner the additional cost of transmission for different load factors and different distances may be estimated to determine the cost of energy delivered at the load center.

201. The comprehensive plan contemplates pumping water from the Columbia River at Grand Coulee and Priest Rapids for the irrigation of the Columbia Basin irrigation project, as distinguished from an alternative irrigation scheme under which diversion would be made by gravity from Clark Fork and Spokane River. Studies made by the Seattle district develop the fact that withdrawal of water by gravity for the Columbia Basin irrigation project results in a reduction of the prime hydroelectric power that can be generated with the falling water. Floods in the Columbia come at such a time of the year that irrigation pumping can be done with seasonal or secondary

power and thus will not encroach on the primary power. Including the power possibilities at Z Canyon and Clark Fork, at the sites on the Spokane River, and at those on the main Columbia from Grand Coulee to Warrendale, there can be produced for sale under the comprehensive plan about 400,000 kilowatts more prime power than if the gravity plan for irrigating the Columbia Basin irrigation project were adopted.

202. Completion of the comprehensive plan would undoubtedly be accomplished step by step over a long period of years. If properly coordinated, each step would increase not only the yield of power but also the economy and flexibility of operation. This would be particularly true if the entire river were controlled and managed as one system. In order to produce the entire quantity of available prime power at commercial load factors, the installed generating capacity at each site would need to be increased materially above that included in the foregoing estimates. Some provision for additional capacity should properly be made at the time of original construction, although the length of time which must elapse before completion of the proposed system of reservoirs is so great that the extent of such expenditure should be carefully controlled and limited. The enormous potentialities of the plan are well illustrated by the totals in table AA. The total prime output of 41 billion kilowatt-hours per year or 4.7 million average kilowatts is sufficient to meet the estimated growth of the power demands in the Pacific Northwest (see par. 133) over a period of 30 years. In the entire United States the 1930 production of public utilities was 90 billion kilowatt-hours. Total production in 1930, including that of plants operated by manufacturers, was estimated at 125 billion kilowatt-hours. The Columbia can produce prime power equal to one third of this quantity and in addition can supply secondary power to meet all the probable requirements for irrigation pumping.

TABLE AA.—*Ultimate prime power possibilities of the comprehensive plan*

Site	Kilowatt-hours per year	Mean output	Probable requirements for peak capacity of generating
		Kilowatts	*Kilowatts*
Grand Coulee Foster Creek Rocky Reach Rock Island Priest Rapids	24, 440, 000	2, 790, 000	5, 580, 000
The Dalles	14, 279, 000	1, 630, 000	3, 260, 000
Warrendale	2, 365, 000	270, 000	540, 000
Total	41, 064, 000	4, 690, 000	9, 380, 000

D. FLOOD CONTROL

203. *General.*—The Columbia above tidewater flows through a well-defined and deep channel with only occasional places where there are low lands subject to overflow. The areas of these low lands are small. The problem of flood protection of these areas is wholly local and by reason of the absolute and relative unimportance of the lands is not considered in this report.

204. The tidal section of the river includes the lower 140 miles between Warrendale and the sea. In this section the immediate valley floor of the Columbia differs from that above tidewater, being wider. Between the mouth of Sandy River, a minor tributary which empties into the Columbia 19 miles below Warrendale, and the sea the valley floor includes numerous areas of low lands subject to overflow. This section of the river is further considered below.

205. There are records of floods on the tributaries of the Columbia; but except for the Snake, mentioned below, these floods do not affect the flood problem of the Columbia. Some of these tributary floods are locally quite serious, as those sometimes following so-called "cloudbursts." Local flood conditions at Flathead Lake, Pend Oreille Lake, and Coeur d'Alene Lake and on the lower Kootenai are discussed in the Seattle district report (pt. 2, printed in vol. II of this document).

206. By far the greater part of the drainage basin of the Columbia lies in the basins of the upper Columbia and Snake. These contribute the flows that produce the annual freshets of the Columbia below the mouth of the Snake. These freshets occur during the period May to July and are due to the melting of snow in the headwaters, combined with spring precipitation. The flood of 1894, the greatest of record, both above and below the mouth of the Snake, was produced by unusual combination of melting snow and heavy spring precipitation. This flood was exceptionally large below the mouth of the Snake, due to the approximate coincidence at the mouth of the Snake of the flood peaks of the upper Columbia and Snake.

207. In addition to these periodic freshets of various stages from upstream sources, the Columbia, in its lower reaches where precipitation is relatively heavy, shows the effects of winter and spring snows and rains in those lower areas in the form of minor increases in river stage. These rises occur during the winter and spring. The Willamette is the principal contributor, but there are others, like the Cowlitz and Lewis. While the flood discharges of these streams are considerable, they reach the Columbia at its lower stages and are not important as to flood heights or flood effects on marginal lands.

208. The peak flow of the annual freshets of record in the lower river, measured at The Dalles, varied from about 332,000 second-feet in June 1930 to 1,170,000 second-feet in June 1894. These discharges corresponded to stages, respectively, of 11 feet and 33 feet on the gage at Portland and 6.3 feet and 26 feet on the gage at Longview.

209. Actual flooding of unleveed lowlands along the tidal section of the Columbia begins when the discharge reaches about 600,000 second-feet, corresponding to about 11.2 feet on the gage at Longview. As the flood height rises, a greater area of land is inundated, increasing the potential damage. Little actual damage on such lands occurs before the discharge reaches 700,000 second-feet. Such a flood may be expected to occur once in about 3 years. Floods of 700,000 or more second-feet have durations from 4 to 42 days.

210. *Lands along the tidal section subject to overflow.*—As stated above, only lands along the Columbia below the head of tidewater are considered in this report. These lands are included, not because they can be economically protected through a comprehensive development of the river for the various purposes of navigation, power

development and irrigation, but because of the importance of the lowlands to the States of Oregon and Washington as present and prospective agricultural lands of high value. It is deemed proper that this report should set forth the conditions that exist and the steps that may be taken by interested parties for protection against floods.

211. Detailed consideration of the flood control problem in the tidal section of Columbia River is contained in the Portland district section of this report. (Pt. 3, printed in vol. II of this document.) The principal features of this section follow.

212. There is about 266 square miles of arable lands below the crest elevation of the 1894 flood, distributed in small parcels along the Columbia between the mouth of Sandy River and the Pacific Ocean. About 226 square miles of these areas are below the crest elevation of floods occurring as often as once in 3 years. About 119 square miles of this latter area are now more or less protected by dikes of various heights. About 8 square miles of the diked area includes the cities of Longview and Kelso. About 2 square miles of Portland's industrial area along the Willamette which is affected by backwater from Columbia River floods is partially protected by a seawall with crest elevation 4 feet below the plane of the 1894 flood. Map showing the lowlands and the existing levee system along the tidal section of the Columbia is contained in the district report (pt. 3, printed in vol. II of this document).

213. About one third of the levees protecting land along the tidal section of the river have been built to a height about 2 feet above the crest elevation of the 1894 flood. The remaining levees have elevations, in many cases, little higher than ordinary flood crests. In general, the levees on the river front are constructed of material dredged from the river side of the levees and the levees are close to the river bank. Portions of the levee lines, aggregating about 17 miles of levee, are exposed to eroding or caving banks.

214. There have been no floods of height sufficient to overtop the higher levees, all of which have been built since 1894. However, the lower levees have been frequently overtopped. The district engineer estimates that the probable annual damages from overflow, including damage to levees, throughout the leveed and unleveed areas will not exceed about $150,000 with the levee system left in its present condition. This damage would occur principally in the areas now partially protected by levees of inadequate height. The damage would be much higher were it not that the inhabitants have advance notice of impending floods and probable flood heights and can take appropriate measures to safeguard livestock and other property. Further, the duration of many floods is so slight that excessive loss to crops is not entailed.

215. The district engineer estimates that the cost of raising the existing low levees and reconstructing levees exposed to attack of caving and eroding banks to an elevation 2 feet above the 1894 flood plane, would be about $1,665,000. This sum includes only the cost of substantial levees. Pumping and other auxiliaries are in the main already provided.

216. Of the 266 square miles of arable land below the 1894 flood plane, 147 square miles are unprotected by levees of any height. This land is mostly in small isolated parcels, the protection of which by

levees would not, in general, be justified at present. However, some 23 square miles could be leveed as parts of existing leveed areas, or as independent areas. The cost of leveeing this 23 square miles, exclusive of bank revetment, but including pumping facilities and tidegates, would be about $1,200,000.

217. Raising or reconstruction of levees to a height of 2 feet above the 1894 flood plane would provide ample protection against all but exceptional floods occurring probably not oftener than about once in 50 years.

218. The district engineer considers in his report various possible methods of control of floods other than levees, or dikes as locally termed, and concludes that leveeing is the most suitable method for protection of the lands in the tidal area. This view of the district engineer is concurred in. Raising of existing low levees and moving back those now too near caving banks appears to be economically justified at this time by the additional protection they would afford, and some extension of the levee system to include additional areas may likewise be justified. These conclusions, however, are based on estimates of damages due to inadequacy of the present levee system and of costs of current repairs to levees. Both of these basic figures are indefinite because of meager records.

219. Flood control on the Columbia is not susceptible to inclusion in an economically feasible combined project for utilization of the waters of the river for navigation, power development, and irrigation. It cannot be combined with a navigation project to the benefit of navigation, but dredging for navigation improvement could aid levee construction by furnishing levee material, usually, however, at cost greater, often considerably greater, than for the navigation work alone. A project of power development or irrigation or the combination of the two as may be adopted for the river above would automatically give some benefits to the lowlands of the tidal section through regulation of discharge and resultant lessening of flood heights, but the cost of storage or regulation for flood control alone would be far greater than the benefits to the lowlands would justify.

220. While flood protection of the lowlands along the tidal section of Columbia River is a matter of concern to the owners and cultivators of the land and of importance to the States of Oregon and Washington through affording means of augmenting the assets of those States, national interest justifying expenditure of funds of the general public in works for flood control or protection of these lands is not present. This case is unlike that of the lower Mississippi Valley, where the area of land subject to overflow is enormous, occurring in many States, and where works of flood protection in one State have adversely effected the conditions in another. In the lower Columbia case both Oregon and Washington and their citizens can proceed with flood-control plans without fear of adverse effects produced by or in the other State. Nor does the fact that the waters of the lower Columbia come from several States constitute a reason why the general Government should participate in the cost of flood control in the tidal section of the river. No upstream State or agency will, in connection with river flow or works, take action adversely affecting the right of the lowlands in the lower river. On the other hand, some benefits, as stated, may flow from power development and irrigation in the upper river.

E. IRRIGATION

221. *General.*—Over most of the area of the Columbia Basin east of the Cascades, except in general in the higher altitudes at the headwaters where topographic conditions are unfavorable to agriculture, rainfall is insufficient for crops other than wheat and grass, and for wheat only under dry-farming methods in selected areas. Precipitation in the mountains traverses the arid regions, as rain and melted snow run-off, through the well-defined channels of the Columbia and its tributaries. This fact has from early days challenged the settler to apply the water to the arid land. But existence of land and a nearby source of water do not alone warrant irrigation. Cost of works, with its related matters of capital and credit, is an important feature, as is reasonable assurance of adequate water supply, of fertility and other fitness of the land for irrigation, of the existence of a favorable climate and growing season, and of a market for the products; and finally, of great importance, is settlement of the land. These are essentials to the success of irrigation of an area, and deficiencies in one or more of these respects have led to failure or partial failure in some cases where irrigation has been undertaken in the Columbia Valley and elsewhere.

222. In the district reports, herewith, parts 2 and 3 of this combined report,[1] the various potential irrigation projects of the basin are treated in considerable detail. The potentialities of these areas are considered from the point of view of the areas themselves in order to determine the promise of success of irrigation by a study of costs and returns.

223. It appears evident that as time goes on the area of cultivable land in the United States will need to be extended unless increased production through improved fertilization, intensified crops, raising of products for domestic consumption instead of for export, further motorization of agriculture and consequent decrease in demand for feed, possible changes in the American dietary, or stabilization of population cause the present cultivable areas to be adequate. Recommendations as to the broad questions of increasing the area of cultivable land in the United States, of the time for such increase and of the propriety of the expenditure of national funds on development of further irrigation projects are matters of policy beyond the scope of this report, and are not made. These are matters for the attention of Congress. This report attempts to point out irrigation possibilities along the Columbia River, and to show the economic features of the possible developments.

224. It may be expected from the history of irrigation in the basin that national participation, already a fact in certain areas, will be urged more and more. Briefly stated, the history is as follows:

225. Lands suitable for development from an irrigation point of view are found in one or another of three situations. The problems involved in their conversion to farms have depended on such circumstance.

First, there are the small tracts onto which water could be diverted by individuals from nearby streams. Such local irrigation was begun by the earliest settlers, and almost all suitable lands of this class in the Northwest were taken up between 1850 and 1890.

[1] Printed in vol. II of this document.

Second are low bench lands that could be watered from nearby streams by small canals within the capacity of local organized effort of corporate enterprise. Almost all of the less expensive of the larger developments have been of this type. Although from necessity, prior to 1900, such lands were the principal additions to the areas farmed, they were not all so developed, and a large aggregate of work by small organizations is being carried on to this time.

By far the greatest areas are of the third type. These are vast plains—remains of old lake beds or the gently sloping ridges into which they have been eroded; high benches, wide alluvial cones at the debouchment of streams from the mountains, and finally, various lands for which works are required of a magnitude and cost not warranted by return expected under the other conditions. An essential feature to be noted in the case of land of this third type is that its settlement is impracticable until after the irrigation works are well on their way toward completion. After 1903, when the United States through the United States Bureau of Reclamation began to construct projects, these enormous undertakings became possible. Even today, however, the problems of colonization and repayment are more complex than those of construction.

226. Notes on western system of water appropriation and on formation of irrigation districts are given in part 3 of this report, chapter II E.

227. In this report the following irrigable tracts have been considered. The acreages given do not include areas, which, while irrigable, have poor soils.

IRRIGABLE TRACTS ABOVE THE MOUTH OF THE SNAKE

(For details see report of district engineer, Seattle—pt. 2, vol. II of this document.)

Rathdrum prairie tract.—This tract is located in north Idaho and consists of 40,000 acres. It can be irrigated by a pumping diversion from Pend Oreille Lake or by a gravity diversion from Priest River. These two possible methods are discussed in a general way in the Seattle report, as the water used would affect the supply available for tracts along the main stream, the primary subject of the report, and because of the importance to Idaho of the Rathdrum prairie tract.

Marginal areas.—There are various small areas marginal to the section of Columbia River between the international boundary and the mouth of the Snake. These areas aggregate about 52,000 acres. Irrigation by pumping diversion from the Columbia River, the only source of water supply, is considered.

Little Spokane valley tract.—This tract consists of about 30,000 acres which can be reclaimed only as a part of the gravity plan of the Columbia Basin irrigation project. (See Combination of Areas, below.)

Methow-Okanogan tract.—This tract consists of 18,000 acres in Methow and Okanogan Valleys. A gravity diversion from Methow River is discussed.

Greater Wenatchee or Quincy tract.—This has a total area of about 340,000 acres of which 20,000 is located in Wenatchee Valley and the remainder on the Quincy Flats, a high tableland east of the Columbia River and south of Quincy and Ephrata. Reclamation by a gravity

diversion from the Wenatchee River is discussed. The Quincy division of this tract may be irrigated in connection with and as part of the Columbia Basin irrigation project. (See Combination of Areas, below.)

Priest Rapids tract.—This area consisting of about 140,000 acres, located between Saddle Mountains and Columbia River, is irrigable by a pumping diversion from the Columbia River near Bend, Wash. This tract also enters into the combination of areas forming the Columbia Basin irrigation project.

Pasco tract.—This area, north and east of Pasco, Wash., consisting of about 102,000 acres, is irrigable by a pumping diversion from Snake River as an individual unit and also as a member of the combination of areas forming the Columbia Basin irrigation project.

Palouse tract.—This area lying between the Snake and the upper Columbia consists of about 100,000 acres. It is irrigable independently by a gravity system making a diversion from the Palouse River. It also forms part of the combination constituting the Columbia Basin irrigation project.

Lind tract.—This tract, consisting of 784,260 acres, is the largest tract included in the Columbia Basin irrigation project (see next item below) under the scheme of gravity diversion from Clark Fork. It is located east of the Quincy Flat and Palouse tracts listed above.

Columbia Basin irrigation project.—See next item.

Combination of areas.—The Columbia Basin irrigation project includes Lind, Palouse, Pasco, Priest Rapids, and Quincy tracts. Various combinations of these and two plans of water application (by gravity and by pumping) are considered in detail in the Seattle district report.

Hanford tract.—An area in the northern portion of Benton County consisting of about 40,000 acres that can be reclaimed only as an individual unit, by pumping from the Columbia.

IRRIGABLE TRACTS BELOW THE MOUTH OF THE SNAKE

(For details see report of district engineer, Portland, pt. 3, vol. II of this document.)

Cold Springs tract.—This is an area of about 67,000 acres in Umatilla County, Oreg., of which 50,000 acres is considered irrigable. It lies east of the United States Bureau of Reclamation Umatilla project. The upper and easterly boundary of the area lies at about 1,000 feet elevation above sea level. The area extends about 15 miles southerly from Columbia River.

Horse Heaven tract.—This is an area of about 200,000 acres in Benton and Klickitat Counties, Wash., of which about 142,000 acres is considered irrigable. It is bounded on the north by elevation 1,000 feet above sea level, and on the south by elevation 350 feet, near Columbia River. It extends from Spaw Canyon (mile 303, Columbia River) on the east, to Alder Creek (mile 257) on the west. The extreme width east and west is about 40 miles and the greatest north and south is about 18 miles.

Irrigation of Horse Heaven area is considered in three divisions: Division A between elevations 350 and 575; division B between elevations 575 and 800; and division C between elevations 800 and 1,000.

Horse Heaven area has also been considered for irrigation from Klickitat and Cispus Rivers, by gravity. This plan of irrigation is not considered feasible.

Willow Creek tract.—This is an area of about 207,000 acres in Umatilla, Morrow, and Gilliam Counties, Oreg., of which 173,060 acres is considered irrigable. The area extends from elevation 350 feet above sea level near Columbia River on the north, to elevation 1,000 feet on the south. It is bounded on the east by Butter Creek, Umatilla River and the Westland irrigation district, and on the west by Willow Creek and Eightmile Canyon. The greatest width of the area from north to south is about 17 miles.

Willow Creek area is considered for irrigation in three parts: Division A between elevations 350 and 616; division B between elevations 616 and 800; and division C between elevations 800 and 1,000.

Irrigation of this area and Arlington area, described below, by gravity from John Day River has been considered in a separate report. A comparison of cost estimates shows that the pumping plan is less expensive than the gravity.

Arlington tract.—This is an area of about 18,000 acres in Gilliam County, Oreg., of which about 11,500 acres is considered irrigable. It is located on a high bench near Arlington, Oreg., and extends south from Columbia River about 7 miles. It is bounded on the east by Willow Creek and Eightmile Canyon, and on the west by Alkali Canyon.

Roosevelt tract.—This is an area adjacent to Columbia River in Benton County, Wash., near Roosevelt, Wash. The total area of this tract is about 2,000 acres, of which 1,500 acres is considered irrigable.

228. *Economic features.*—Eliminating duplications of acreage in the tracts described above, the area of irrigable land in the Columbia Basin above Snake River and irrigable from the Columbia includes approximately 1,560,000 acres, and the area in the Columbia Basin below the mouth of the Snake, also irrigable from the Columbia, includes approximately 378,000 acres, making a total of 1,938,000 acres. With the exception of a portion of the Lind tract, which lies at a higher elevation above sea level than the remainder of that and other tracts, the various areas are essentially the same so far as climate, soils, and water supply are concerned. All tracts, with the exception of the Lind area, have similar ranges of crop adaptability, will produce three cuttings of alfalfa on the average in a season, and will return approximately the same yields per acre, since areas of poor soil are not considered in the report. The cost of land, land leveling, farm buildings, and other permanent improvements have been estimated to be approximately $100 per acre on the average in all of the areas considered.

229. Markets are essentially the same for agricultural products of the entire Columbia Basin. Studies of markets for the products of irrigated areas have been made by the Seattle and Portland districts and appear in chapter II E of parts 2 and 3[1] of the combined report. The study of the Seattle district is based on the Columbia Basin irrigation project possibilities. That of the Portland district is more general. From these studies the general conclusion may be drawn that, assuming increase in the area of cultivable land in the United

[1] Printed in vol. II of this document.

States is desired (see par. 223 above) the desirable rate of accretion to areas of irrigated lands of the United States depends on the prospective market growth and on the feasible rate of efficient settlement of the irrigated lands. In the case of the areas considered in this report the latter controls.

230. A rate of settlement of 50,000 acres of irrigated land a year has been used as reasonable for the portion of the Columbia Basin lying within the States of Washington and Oregon. In determining the costs of irrigation the rate of interest on construction costs is uniformly figured at 4 percent, while the farmer's return is in all cases taken as 6 percent on his investment (other than construction costs). Table I below gives a summary of costs and annual charges for the various tracts considered in this report. For purposes of comparison a uniform period of 40 years after construction is complete is assumed for repayment of construction costs, with repayments figured on an amortized basis.

TABLE I.—*Summary of costs and annual charges,*[1] *irrigation from Columbia River*

Name	Irrigation plan	Irrigable area, acres	Construction cost [2]		Annual costs per acre			
			Total	Per acre	Interest and repayment [3]	Electrical energy	Operation, maintenance and depreciation	Total
Greater Wenatchee-Quincy tract.	Gravity	320,310	$94,896,200	$296.26	$14.97		$3.00	$17.97
Priest Rapids tract	Pumping	140,520	15,092,800	107.40	5.43	[4] $1.59	3.00	10.02
Pasco tract	do	102,000	15,355,030	150.54	7.61	[4] 2.04	3.00	12.65
Lind tract	Gravity	784,260	257,491,560	328.32	16.59		3.00	19.59
Hanford tract	Pumping	40,000	5,176,200	129.40	6.54	[4] 1.44	3.00	10.98
Columbia Basin irrigation project.	Gravity	1,519,890	598,285,020	393.63	19.89		3.13	23.02
Do	Pumping	1,174,630	207,397,120	176.56	8.92	[4] 1.28	3.00	13.20
Cold Springs tract	do	50,000	7,975,000	159.60	8.06	[5] 4.13	3.00	15.19
Horse Heaven tract, division A.	do	28,500	3,933,000	138.00	6.97	[5] 1.52	3.00	11.49
Horse Heaven tract, division B.	do	47,500	6,574,000	138.40	6.99	[5] 2.20	3.00	12.19
Horse Heaven tract, division C.	do	66,000	10,091,000	152.90	7.73	[5] 3.79	3.00	14.52
Willow Creek tract, division A.	do	37,940	5,209,000	137.30	6.94	[5] 2.64	3.00	12.58
Willow Creek tract, division B.	do	103,770	13,270,000	127.95	6.46	[5] 3.06	3.00	12.52
Willow Creek tract, division C.	do	31,350	4,751,000	151.54	7.66	[5] 3.63	3.00	14.29
Arlington tract	do	11,500	1,427,000	124.07	6.27	[5] 2.73	3.00	12.00
Roosevelt tract	do	1,500	170,000	113.37	5.73	[5] .92	3.00	9.65

[1] Does not include any part of cost of power dams, electrical energy being purchased at the rates given.
[2] Includes interest during construction and period during settlement.
[3] Interest at 4 percent with amortized payments covering a period of 40 years. Annual payments equal 5.0524 percent of principal.
[4] Assumed price of power $0.00075 per kilowatt-hour.
[5] Assumed price of power $0.001 per kilowatt-hour.

231. Comparing various tracts, differences are found in the cost of construction, the pumping lift, operation and maintenance charges, and the rate for power. All of these except pumping lift appear in the table. The effect of the rate of settlement varies with the size of the project. Small projects bear a comparatively small carrying charge for interest during the construction period because the period is relatively short. Small projects, for the same reason, have a

decided advantage over large projects in that they allow an elasticity in stage development which is not permitted in projects requiring large investments of capital to cover the essential construction program.

232. Independent studies have been made in the Seattle and Portland districts of the economic feasibility of irrigation developments. While the Seattle district has referred particularly to areas above the mouth of the Snake and the Portland district to areas below, it is in the method of analysis rather than in the basic characteristics of the areas that the two studies differ.

233. The study made in the Seattle district (pt. 2 of this combined report) [1] indicates that the following yields and prices represent a reasonable expectation over a period of 30 years, or a period required for the construction of the larger projects involved:

Crop	Yield	Price	Returns per acre
Alfalfa (representing all forage crops and alfalfa) ..... tons	3.75	[1] $14.00	$52.50
Small grain and corn ..... bushels	40	[2] 1.00	40.00
Potatoes ..... tons	5.75	20.00	115.00
Beans and peas ..... pounds	1,200	.04	48.00
Fruit ..... tons	10	25.00	250.00

[1] Fed to cows. [2] Fed to hogs.

In this Seattle district study an analysis of the probable market conditions indicates that livestock products, including dairy and poultry products, will form an important part of the demand. Fruit, which offers the highest returns per acre, cannot be indefinitely planted on account of the restricted market. Although the exact demand cannot be anticipated, a study of the present per capita consumption of products raised in the Columbia Basin applied to the estimated increase in population indicates that the following distribution of crop acreage will approximately meet the increased demand during the next 30 years, assuming 1,000,000 acres as a possible combined total of newly irrigated land: Forage and hay crops and pasture 60 percent, small grains and corn 24 percent, beans and peas 8 per cent, truck crops 6 percent, fruit 2 percent.

234. Assuming the above distribution and applying these percentages to the crop yields and prices given above, the per acre income will be approximately $54 per year. This figure is based on the definite elimination of all areas where soil conditions and topography are not sufficiently favorable to produce satisfactory yields. This matter is emphasized because of the prime importance of yields in projects having high construction costs. If any large areas of second-class land are included, the returns will be appreciably less than the assumed figure.

235. The permissible charge for water, based on the returns given in the table in paragraph 233 above, has been estimated in the Seattle report to be $6 per acre. This is considerably higher than the average charge made by the Bureau of Reclamation, but the figure is approximately equal to the average charge in irrigation districts in the West. If returns per acre are lower than the estimated production indicates, the permissible charge for water will also be lower. In the interest of rapid and successful settlement, it is entirely possi-

[1] Printed in vol. II of this document.

ble that the charge should be reduced. The "permissible charge for water", as used in the Seattle report, is the amount the farmer can pay for water from his returns from sale of crops after meeting all other production costs, including interest on his investment (other than costs of irrigation works) and $75 per month for his own time.

236. The Seattle district concludes that, comparing this permissible charge for water with the per acre cost of construction, operation and maintenance and cost of power, no project in the Columbia basin above the mouth of the Snake is economically feasible if the cost of construction of irrigation works must be paid wholly from the returns from the sale of water for irrigation.

237. The study made in the Portland district shows that in addition to the total construction costs shown in table I following paragraph 230 above, which the farmer would have to invest in pumping plant and canals to get water to his land, he would have to meet the costs of farm buildings, expense of leveling, ditching, and other permanent improvements, cost of farm implements, and have a capital investment in livestock and an operating fund. These additional items are estimated at $161 per acre by the Portland district.

238. On such basis the total investment per acre in the areas below the mouth of the Snake would vary from $274 per acre to $320 per acre. Allowing 6 percent return on the $161 item of the total investment, and adding this to the annual charges as estimated in the above table for the irrigation system for each of the areas below the mouth of the Snake would give a fixed charge varying from $19.31 per acre to $24.85 per acre, which would have to earned each year over and above other production costs, if the costs of irrigation are to be paid from the returns from the sale of farm products.

239. The Portland district holds that if the gross returns do not exceed the costs of production other than the fixed charges by an amount sufficient to cover the fixed charges, the project is not economically sound, and, like the Seattle district, arrives at the conclusion that under present agricultural conditions the fixed charges on none of these tracts could be met from the direct returns from sale of agricultural products. Considering the similarity of tracts above and below the mouth of the Snake as to matters affecting economic justification of irrigation, the views reached independently by the two district engineers are corroborative.

240. The Portland district is of the opinion that under favorable conditions returns from irrigated areas in the future may justify the expenditures for irrigation indicated for the tracts below the Snake. Such conditions include fair prices, reasonable production costs, careful selection and rotation of crops. Under present conditions of overproduction and general agricultural depression, it is felt that it would be unwise to develop any of the areas until prices for farm products and costs of production are such that net returns of $19.31 to $24.85 as described above can be secured.

241. There are benefits flowing from irrigation that are not used above in the test for economic justification. Such benefits have been made the subject of a study in the Seattle report. They can be grouped into two distinct classes:

The first result from increased production and are reflected in reduced prices to the consumer. This class of benefits may be considered as indirect and may form a proper basis for public subsidy if there is a general need for increased production.

The second class of benefits results from the activities created because of the buying power of the farmer and are reflected in increased land values, increased profits and, in the case of public utilities, in increased franchise values. This class of benefits may be considered the basis for a determination of economic feasibility, because these benefits are direct, are more or less specific and are assessable insofar as they affect local and regional interests. The benefits to interests outside of the State or States involved are direct and specific but too widely scattered to be assessable.

The method used in the Seattle study above referred to, while made specifically for tracts above the mouth of the Snake, is applicable equally to tracts below the mouth of that river. The Seattle report concludes that some irrigation projects, otherwise not feasible, may be classed as economically justified through recognition of the collateral benefits.

242. Another classification of benefits divides them into three: first, the return to the farmer from the sale of his product; second, the benefit to the general public through the expected lowering of price of foodstuffs; and, third, the incidental benefits to the inhabitants of the region through increase in value of lands and in commercial activity. The first one, should, it is thought, be the test of economic feasibility of and measure of general interest in a project and control the choice of the project to be adopted when several are under consideration, due regard being paid to the question of size of tract desired to be irrigated; the second relates to general interest, but is too indeterminate to appraise; the third should be held a measure of the local interest which may properly be recognized by local support and local funds.

243. It has been proposed by various interests that, in the case of the Columbia Basin irrigation project, the profits from the sale of power developed by the Grand Coulee Dam be used to subsidize the irrigation project. This could be done, by charging enough for the power to cover the costs of the irrigation project. Such subsidy of irrigation projects by the use of revenue from power is equally applicable to The Dalles power project in the section of the river below the mouth of the Snake.

244. The Columbia Basin irrigation project has an area in excess of 1,000,000 acres within easy reach of Grand Coulee dam site. Part 2 of this report estimates the cost of irrigation construction for this area at $176.56 per acre, with annual charges of $13.20 per acre for irrigation, including interest and repayment, and operation and maintenance. In the section below the mouth of the Snake nine irrigable areas are considered conveniently located with respect to The Dalles dam site, totaling about 375,000 acres. Separate costs for the nine areas are estimated in part 3[1] of this report; the average cost per acre for the entire area being $141. The estimated average annual charge for irrigation of these nine areas is $13.22 per acre.

245. The estimates of annual costs of irrigation of the various tracts considered in this report have been based on availability of large quantities of low-cost (about 1 mill per kilowatt-hour) secondary power. Large quantities of cheap power could be made available by construction of one or more of the dams described in this report. There is a limited supply of cheap power from existing plants. It

[1] Printed in vol. II of this document.

would be adequate for only the Hanford tract, of the three to which water could be pumped from unregulated river levels. This tract is favorably situated for irrigation from a construction point of view, but not favorably from others. Neither of the other two tracts irrigable by pumping from present river levels, the Pasco and the Priest Rapids, are considered feasible for irrigation with power from existing plants.

Even with such cheap power none of the projects is economically justified under present conditions.

246. Table I, in paragraph 230 above, includes all tracts along the Columbia believed worthy of consideration for irrigation with water from the main river. These are discussed in detail in the district reports. There are other tracts, on the tributaries of the Columbia, that present opportunity for irrigation. Consideration should be given to these before decision is reached to irrigate any of the tracts listed. Except as to the Rathdrum Prairie tract they are not discussed in detail, as not falling within the scope of this report. Attention is invited to reports under House Document 308, Sixty-ninth Congress, first session, on Snake, John Day, Willamette, Cowlitz, and Lewis Rivers, and to various reports listed in the district sections of this report.

III. Conclusions

247. Below are given the conclusions of the division engineer based on the matter presented in brief above and in detail in the reports of the Seattle and Portland district engineers, herewith as parts 2 and 3 of this combined report on Columbia River. (Printed in vol. II of this document.)

AS TO THE TIDAL SECTION OF THE RIVER

(*a*) Columbia River below Vancouver, Wash., and Portland, Oreg., is primarily of value as an avenue of commerce and in that respect ranks high among the waterways of the United States; it will continue to merit favorable consideration by the Federal Government in the matter of maintenance and improvement of the navigation channel.

(*b*) No power development is feasible in the tidal section of the river.

(*c*) There are areas of fertile low lands along the tidal section of the Columbia that are worthy of protection against the flood effects of the river. These areas have in part been protected to some degree; in some cases they have been fully protected. The most suitable method of securing protection is the one already adopted—by levees (or dikes as locally called). The present levee system is inadequate in places through deficient levee heights and improper levee location, and in extent. Raising of low levees, reconstruction of levees when too close to the river bank, and some extension of levee lines, while desirable, cannot be absolutely declared justified at this time. Works on the upper river specifically for flood protection of these areas or works for flood control in combination with navigation, power, or irrigation are not feasible, but some decrease of flood effects will be produced by any power or irrigation development that may be installed in the upper river. Finally, flood protection of the low lands in the tidal section of the Columbia is of local and State concern and not a matter for Federal control or the expenditure of Federal funds.

(*d*) No irrigation use of the water of the tidal section of the river is needed.

AS TO THE NONTIDAL SECTION OF THE RIVER UP TO THE INTERNATIONAL BOUNDARY

(*e*) While navigation of the river between the head of the tidal section and the mouth of the Snake is at the present time practically nonexistent, any dam erected across that section of the river for power development purposes should be provided with locks for the passage of water craft appropriate to that part of the river. Such locks, although made necessary by the bar to navigation created by the dam, should be paid for by the United States as compensation for the benefits to navigation conferred by the power reservoirs through creation of slack water and increase of depths over shoals. Commerce on the river between the head of tidewater and the mouth of the Snake is not assured to an amount sufficient to justify the expenditure of more than $5,000,000 of Federal funds as a navigation contribution on a power development (other than for locks) if such power development is at expense other than Federal, nor to justify charging more than $5,000,000 of the cost of a power development to navigation (other than for locks) if such power development is made with Federal funds contributed or loaned.

(*f*) Future navigation in the section of the Columbia between the mouth of the Snake and the international boundary is even less assured than in the nontidal section below the mouth of the Snake. There is a rather remote promise of through navigation as far up as Wenatchee, Wash., and above that point future navigation, except local, may be said to be exceedingly unlikely. In the section of the Columbia above the mouth of the Snake no steps should be taken in the interest of navigation in connection with power development except to reserve to the United States the right to install locks or similar works or require them to be installed when navigation requires them, leaving to the future the question of the time such works should be installed and the allocation of costs.

(*g*) The Columbia in its nontidal section is primarily a power stream and other uses should, in general, be subordinated to power development, provided always that development above the head of tidewater shall not adversely affect the rights of navigation in the tidal section.

This conclusion is reached with full acceptance of the principle that irrigation is a preferred use of the water, and is not incompatible with that principle. The conclusion is believed sound as irrigation development would need the economic support of power developed for the general power market of which irrigation is only a part.

The conclusion that power development is paramount in the nontidal section is reached with full appreciation of the just claims of navigation, and is not inconsistent with due regard therefor. Dams for navigation alone would not be justified. No works for navigation alone, other than dams, would on this steep river, adversely affect power development. Power development through creation of reservoirs by means of dams can be made to serve navigation. Power considerations should, in the main, control the location and height of the dams. At the appropriate time due provision should be made for passing navigation through or past the power dams, as stated in (*e*) and (*f*) above, and power pool levels and regulation of flow should always be so controlled that navigation will not be unduly and adversely affected.

(*h*) The great power potentialities of the Columbia can be increased by the use of reservoirs on the main stream and its tributaries by which the minimum natural low flow can be doubled at The Dalles and tripled at Grand Coulee with corresponding increase in the potential prime power. With such regulation the Columbia can be made to produce prime power amounting to 41 billion kilowatt-hours per year.

(*i*) This potential output is sufficient to meet the normal increase of power demand in the Pacific Northwest for about 30 years unless the growth of market be accelerated by the exceptional introduction of new industries requiring cheap power. On the other hand, the programs of the utilities, including power developments existing or under construction on the Columbia (at Rock Island) and on the tributaries (notably on Flathead River, Lewis River and on Willamette River and its tributaries) will provide for a considerable part of the prospective market until about 1940.

(*j*) There are numerous sites for power development on the Columbia. Three of these are of especial interest for the reasons given below:

1. The Dalles site about 3 miles above the city of The Dalles. This site has good foundations and a power dam would serve both navigation and irrigation.

2. At the head of Grand Coulee in the State of Washington. A dam at this point might be constructed for power alone, or for power and irrigation of the large area of land in Washington known as the Columbia Basin irrigation project. A dam at this isolated point would serve only a local river traffic, which may not occur.

3. At or below the foot of the rapids through the gorge. This location is of importance mainly because of the benefits it, in conjunction with a dam at The Dalles, might confer on through navigation from tidewater to the mouth of the Snake. It has the advantage of proximity to power market (Portland and vicinity) and to tidewater; and the disadvantage of uncertain foundations and higher unit costs than the other two dams.

Dams at the two sites, 1 and 3, may be built to heights affording canalization of the river from tidewater to the mouth of the Snake. Slack water, however, would not obtain during freshets. Such system of two dams would give pronounced benefit to navigation if it is revived and might bring about resumption of navigation.

Plans for dams at various sites along the Columbia are given in detail in the district reports, in part 2 as to the river above the mouth of the Snake and in part 3 as to the Columbia below that point. Statistics relating to the dams at the three sites, 1, 2, and 3 above, are given in tables Q and S, following paragraphs 157 and 180 of this report.

(*k*) Full power development at any one of the three points listed in (*j*) above should properly defer power development at the others until the growth of the power market justifies the inception of a second project. Benefits to navigation would not justify the construction of a second dam before it is needed for power development. Choice of the dam that should be built first may be based on considerations foreign to this report and no recommendation is made.

(*l*) Prime power from either The Dalles or Grand Coulee sites can be delivered in large quantities at the load centers in the Pacific Northwest at one half or two thirds the cost at which steam power

can be produced in large modern generating stations when the price of fuel oil is $1 per barrel.

(*m*) Works for flood control alone or for flood control in combination with navigation, power development or irrigation are neither needed nor feasible.

(*n*) The results of studies made by both the Seattle and the Portland districts of irrigable areas along the Columbia, not now irrigated, listed in table I in paragraph 230 above, definitely demonstrate that none of those areas can be considered as economically feasible of irrigation at this time with repayment of costs plus interest chargeable against the returns to the farmer from the sale of crops. The smaller tracts of land have an advantage in the economy represented by possible stage developments.

(*o*) Revenue from the sale of power could be applied as a subsidy for irrigation development. Such use of power revenue might perhaps be the best to which it can be applied, but the most beneficial use could be determined only by analyses and appraisals of the benefits that would flow from all possible uses.

(*p*) The so-called "pumping plan" for irrigating the Columbia Basin irrigation project would make possible the production of 400,000 kilowatts of prime power that would be lost should the "gravity plan" of development be adopted. Irrigation by the "pumping plan" would be served wholly by secondary power.

(*q*) As the development of the potential power of the river, the control of floods, the diversion for water for irrigation all depend largely on the quantity of water flowing in the stream and its tributaries, it is highly important that adequate records of stream flow should continue to be obtained.

IV. Recommendations

248. From the studies made it is concluded that the most feasible plan for ultimate utilization of the resources of Columbia River is as follows:

(1) A system of 8 dams along the main stream located at:

Head of Grand Coulee, Wash.
Foster Creek, Wash.
Chelan, Wash.
Rocky Reach, Wash.
Rock Island Rapids, Wash. (now under construction).
Priest Rapids, Wash.
The Dalles, Oregon-Washington.
At the foot of Cascade Rapids, Oregon-Washington.

Such system would develop for power purposes 92.3 percent of the total head between the international boundary and tidewater and all of the head economically developable. It would receive full benefit of storage and regulation in the tributaries, as may be created in the future. It would benefit navigation by furnishing, except at high water, slack-water conditions. It would permit irrigation of large tracts of land on both sides of the river in Oregon and Washington. It would confer incidental benefits upon lowlands along the tidal section of the river through reduction of flood heights.

Provision should be made for locks through the dams below the mouth of Snake River to be installed simultaneously with the con-

struction of those dams and through the dams above the mouth of the Snake when river traffic justifies the cost of locks.

(2) Additional dams, with locks, for navigation only, at points 14 and 40 miles above the mouth of the Snake. These will be contingent on the development of a commerce justifying through canalization above the mouth of the Snake to the vicinity of Wenatchee, Wash.

249. It is recommended that the above-stated plan be adopted by the United States as its guide in controlling and supervising development of the Columbia River above tidewater, navigation being considered chargeable with the cost of locks through dams below the mouth of Snake River and subject to contribution of not over $5,000,000 toward the cost of those dams; and that the plan for the tidal section of the river remain as at present, viz: Improvement as needed to meet the requirements of seagoing and river traffic.

G. R. LUKESH,
Colonel, Corps of Engineers, Division Engineer.

APPENDIX I

CONTENTS

		Page
1.	Résumé of essential facts concerning electrochemical and other major power consuming industries	85
2.	Power in aluminum production	108
3.	Power in fertilizer-material production	133
4.	Power in copper and copper-alloy production	196
5.	Power and zinc and lead production	244
6.	Power in the manufacture of chemicals and metals from brine	280
7.	Power in the cellulose industries	309
8.	The electric furnace in the iron and steel industry	384
9.	The original and some new electric-furnace products	426
10.	Electric reduction of gold and silver and rare or minor metals	445

RÉSUMÉ OF ESSENTIAL FACTS CONCERNINGEL ECTRO-CHEMICAL AND OTHER MAJOR POWER CONSUMING INDUSTRIES

1. Electrochemistry was first applied commercially to the manufacture of products which required temperatures too high to be achieved successfully with fuels or which could be dissociated from other materials only by electric current. The products which were rendered commercially available by electrochemical processes at the close of the nineteenth and at the beginning of the twentieth century, namely, aluminum, fused aluminous abrasives, calcium, calcium carbide, calcium cyanide, artificial graphite, silicon, silicon carbide, ferro-silicon, sodium, phosphorus, and refined copper are still manufactured solely by such processes. To their ranks have been added other ferro-alloys, metallic magnesium, fused quartz, fused mullite, tungsten, cadmium, bismuth, and a number of other substances, all requiring electrochemical treatment but for which there is still limited demand. In the last 15 years, electrochemical processes have also been extended to the manufacture of products long made by other processes, either because greater purity of product could be achieved by electrical methods or because such methods proved more economic under specific conditions. Today, caustic soda, phosphoric acid, potassium hydroxide, carbon bisulphide, the chlorates and hypochlorites, as well as the gases hydrogen and oxygen, are

produced electrochemically as well as by other methods. Today, zinc from complex ores and copper from mixed ores are precipitated electrochemically. There is a steadily mounting tonnage of steel ingots and castings, of iron castings, of copper alloy ingots and castings, that is either melted or heat-treated electrically.

2. The trend toward wider use of electricity has gone so far that it would be difficult to determine what industries should be classed as electrochemical industries. On the other hand, electrochemical processes remain sharply defined. Therefore, this study deals with the position of electrochemical processes and products in industry as organized and operating in 1929 and 1930, without attempting to draw lines of demarkation between electrochemical and other industries.

RELATIVE IMPORTANCE OF ELECTROCHEMICAL PRODUCTS IN POWER CONSUMPTION

3. Electrochemical processes consumed more than a tenth of the total electricity generated for industrial purposes in 1929. In excess of seven billion kilowatt-hours (7,000,000,000 kilowatt-hours) were consumed in the electrochemical processes required to produce 50 substances. As the total number of products manufactured in the United States runs into many hundreds, the importance to power markets of products requiring electrochemical processes is obvious.

4. But the significance of individual electrochemical products in power development varies greatly. Industries whose products can be manufactured solely by electricity necessarily carry a stable current load and require a reliable current supply. But at least 22 electrochemical products out of the 50 covered by this report are manufactured in such small quantities today, that, individually, they have little present power market value save as they may add to a specific power load by being manufactured along with other electrochemical products. Each represents a potential power load, however. As a contrast, ideal products from the viewpoint of power development such as aluminum and ferro-alloys, require large amounts of current per ton so that a cheap and abundant source of power is a manufacturing essential; they are produced in large manufacturing establishments, have developed markets, and give promise of expanding markets.

5. While only aluminum and ferro-alloys can be said to meet all these conditions following the year of general business depression, 1930, other products meet the first three specifications—large unit consumption, large productive capacity, established markets—while a question mark would be placed as to the date when markets may expand beyond present plant capacities. The electrolytic precipitation of zinc from complex ores with the recovery of cadmium and other metals, the precipitation of copper from oxide and mixed ores, the manufacture of calcium carbide, silicon carbide and fused alumina, necessarily require heavy unit and heavy total current loads. The electrochemical manufacture of caustic soda and phosphoric acid must compete with other methods of manufacture, but such electrical production already consumes large amounts of electricity. Growth will depend upon the success with which electrochemical processes meet competition from fuel and chemical processes. On the other

hand, the electrolytic production of oxygen and hydrogen has not yet assumed large proportions although future conditions may make such production feasible in competition with other methods.

6. The electrolytic refining of copper, the electric melting and heat-treatment of copper alloys, the electric melting and heat-treatment of steel ingots and iron and steel castings require a much smaller number of kilowatts of electricity per ton handled than do other electrochemical processes, but the tonnage of these industries is so great, the operating units so large, that total current requirements are heavy. All copper, except pure Lake copper, is already electrolytically refined; only an expansion in amount of copper produced will materially increase the market for current in copper refineries. In copper alloy mills, in steel works and rolling mills, however, the electric furnace is replacing coal, oil, or gas fired equipment; replacements in themselves will add greatly to the electric load carried by such mills in the future.

7. Consideration of electrochemical processes in steel works and rolling mills draws attention to industries whose installed horsepower is very large even though no manufacturing processes are electrochemical. First among such industries is paper and wood pulp manufacture, which is exceeded only by steel works and rolling mills in total installed horsepower as well as in total installed electric horsepower. Power is required for steam and for mechanical purposes only. Its cost forms about 7 percent of the market price of manufactured paper as compared with power costs of 8 percent to 14 percent for electrochemical products which are dependent upon electric heat or electric deposition. As power forms but 3 percent of the market value of products in all manufacturing establishments, power costs are almost as important in the production of some types of paper and wood pulp as they are in some electrochemical products. Total electricity consumed in pulp and paper mills is also greater than in many electrochemical factories. Paper consumption is increasing. It seems advisable, therefore, to include pulp and paper along with electrochemical products when considering probable future industrial power needs of the country.

8. Other industries whose total installed horsepower is large but which consume electricity chiefly for mechanical purposes, such as cotton goods manufacture, lumber and lumber products, foundry and machine shops, railroad car and general shop construction and repair are organized in many units so that the power requirements per plant are small. Power costs form 2 percent or less of the value of marketed products. Obviously, location near a large power supply is not a consideration in these industries.

SPECIFIC POWER REQUIREMENTS OF ELECTROCHEMICAL PRODUCTS AND PULP AND PAPER

9. Power requirements of electrochemical processes employed in the United States or in Canada and Europe are listed on pages 93 and 94. The arc process securing nitrogen from air for use in the manufacture of nitric acid and nitrate fertilizers requires by far the largest number of kilowatt hours per short ton of any electrochemical process. Since the original arc process plants were built in Norway, however, less costly methods of nitrogen fixation have been developed; nitric acid is made

by the oxidation of ammonia in the United States. The arc process is now regarded as uneconomical and new arc plants will probably not be built.

10. *Aluminum.*—But even in Europe, as in the United States, the largest total power load in electrochemical industries is carried by aluminum. In 1929 in this country, over 2,500,000,000 kilowatt-hours were consumed in the electrolytic reduction of aluminum from its oxide, alumina. This reduction also requires more power per ton than any other product manufactured in the United States, or from 19,000 to 25,200 kilowatt-hours per short ton. Latest developments in aluminum plants, here and abroad, indicate that power requirements of aluminum plants will be increased. Whereas the oxide of aluminum has been extracted from the ore bauxite by chemical methods until a year or two ago, new plants are extracting the oxide by electrothermal processes requiring 4,000 kilowatt-hours of current and more. Furnace electrodes and furnace linings are also being produced electrothermally at newly constructed aluminum plants. Mechanical operations are all electrified. Wherever it is feasible to install rolling mills at aluminum reduction works, the power load is further increased by electrically heated melting furnaces and heat treatment ovens as well as by the additional mechanical load.

11. *Ferro-alloys.*—The ferro-alloys rank second in importance among electrochemical products in total energy demands. Ferro-silicon containing 12 percent or more silicon, ferro-tungsten, ferro-chromium, ferro-molybdenum, and other alloys of these substances required by the steel industry are smelted only electrothermally. Ferro-vanadium is produced in the electric furnace and also by the thermit process. Ferro-manganese, alone of all the alloys which serve as scavengers in removing undesirable elements from steel or which improve the properties of steel, is not produced electrothermally in this country although it is so manufactured in Canada and Norway by American capital. The total energy consumed in ferro-alloy furnace smelting in 1929 was in excess of 1,260,000,000 kilowatt-hours. Almost 1,000,000,000 kilowatt-hours were consumed in ferro-silicon smelting, each ton requiring about 5,000 kilowatt-hours of current. Power forms from 13 to 14 percent of the market price of this alloy. Other ferro-alloys consume from 6,000 to 10,000 kilowatt-hours of electricity per ton but production is small; it is increasing, however.

12. *Newsprint paper.*—The newsprint paper industry in the United States including therein the mechanical and sulphite pulp manufactured at such paper mills, consumed almost 2,000,000,000 kilowatt-hours of electrical energy in 1929. Largest consumption occurs in the manufacture of mechanical pulp, approximately, 1,280 kilowatt-hours of current being essential to reduce pulp wood to 1 ton mechanical pulp. When considered in terms of newsprint paper, the electric requirements for mechanical operations per ton of newsprint averages 1,340 kilowatt-hours. Such paper also requires from 8,000 to 14,000 pounds of low steam pressure per ton which is still secured by fuels except in plants where hydraulic turbines drive the main electric generator. But electrical costs alone form over 11 percent of the cost of manufacturing newsprint paper, and 10 percent of the price at which newsprint paper is marketed. While the unit electric requirements per ton of newsprint paper are much lower than the unit current

requirements of many electrochemical products, the larger tonnage of newsprint paper, the regular daily demand for paper, the long contracts entered into between newsprint paper mills and newspaper publishers, make a modern newsprint mill manufacturing its mechanical pulp almost as constant a power load as are the major electrochemical factories.

13. *Caustic soda and chlorine.*—In spite of the fact that less than a third of caustic soda consumed in the United States is manufactured by the electrolysis of brines, approximately 660,000,000 kilowatt-hours of energy were consumed in such production in 1929. The passage of 2,328 kilowatt-hours or more current through purified brine solutions produces simultaneously 1 ton caustic soda, approximately nine-tenths ton chlorine, and approximately 8,100 cubic feet hydrogen. If power costs are charged against caustic soda alone, they form 14 percent or more of the market price of soda; but if they are divided proportionately with chlorine, power costs are reduced to 8 percent of the combined marketable yield.

14. *Other brine products.*—In 1930, all metallic magnesium manufactured in the United States was secured from the magnesium chloride extracted from well brines before such brines were electrolyzed into caustic soda and chlorine. Metallic magnesium is exceeded only by aluminum in the amount of current required per ton produced. It is still manufactured in pounds, however, rather than in tons, so that total power consumption in 1929 was but approximately 11,000,000 kilowatt-hours. Metallic sodium, also produced at electrochemical caustic soda plants, requires 13,000 kilowatt-hours of energy per ton. This, together with such sodium hypochlorite and such sodium chlorate as may be produced by electrolysis at electrochemical caustic soda and chlorine plants increases the power consumption of these plants. Separate industries have not been developed in the United States for the electrolytic manufacture of these three sodium products.

15. *Calcium carbide.*—The production of calcium carbide, the basic material for acetylene and for calcium cyanamide, required almost 750,000,000 kilowatt-hours of electricity in 1929. Unit consumption varies from 2,600 kilowatt-hours to 3,200 kilowatt-hours in different furnaces. All calcium carbide manufactured in the United States is for acetylene, the acetylene being used for welding and cutting, for lighting, and as a basic chemical for acetic acid and other synthetic organic chemicals. Calcium carbide for calcium cyanide, used in fertilizer and other chemical production, is manufactured in Canada and in Europe. Had the cyanamide shipped to the United States been manufactured here, an additional 85,000,000 kilowatt-hours of energy would have been required for its production in this country.

16. *Zinc and cadmium.*—Zinc is the principal metal secured from its ores by electrolysis. Although 70 percent of marketed zinc is still extracted by retort distillation, the zinc content of complex ores in the Northwest has been made available only through flotation and electrolytic processing. Zinc precipitation already ranks fifth among electrochemical processes in total amount of current consumed. In 1929, more than 507,000,000 kilowatt-hours were consumed in zinc electrolytic precipitation, from 2,206 to 3,200 kilowatt-hours being required per ton at electrolytic tanks.

17. The power load at zinc plants is being increased by a recent demand for cadmium as a protective coating for other metals. Cadmium must be removed from zinc concentrates before zinc can be secured. Consequently, its electrolysis from zinc concentrate residue adds a valuable byproduct to electrolytic zinc production. Cadmium production required almost 3,000,000 kilowatt-hours of current in 1929.

18. *Copper.*—The electrolytic refining of copper dates from 1885. Such refinement was essential for the recovery of valuable metals such as gold and silver and for the removal of objectionable metals such as bismuth and antimony from western copper. Today, all copper, save a small tonnage from the Lake Superior peninsula in Michigan, is refined electrolytically. As such refinement requires only from 141 kilowatt-hours to 233 kilowatt-hours of electricity per ton, power is not a large item in the unit cost of copper refining. However, copper tonnage is sufficiently large to give copper refinement sixth place in total power consumption among electrolytic and electrothermal processes.

19. A more promising power load is being developed in the Southwest by leaching and electrolytic precipitation of copper from oxide and mixed copper ores. Such precipitation requires from 1,700 to 2,625 kilowatt-hours per ton. In 1929, two American plants that have adopted this method consumed almost 63,000,000 kilowatt-hours of electricity.

20. *Lead, gold, and silver.*—Lead electrolytic refining required over 6,000,000 kilowatt-hours. Such refining competes with pyrometallurgical and chemical refining processes but has the advantage of removing bismuth which may be electrolytically refined for pharmaceutical purposes.

21. Four fifths of all silver and one fourth of all gold is secured through the refining of copper, lead, or zinc ores. The precious metals are cast into anodes to be electrolytically refined chiefly at a few large copper or lead refineries, and at United States mints. While the refining of silver and gold requires more kilowatt-hours per ton than the refining of copper or lead, gold and silver are produced by the fine ounce. As far as it is possible to determine, together, their refinement required but a million and a third kilowatt-hours of energy in 1929.

22. *Copper alloy rolling mills and foundries.*—The power consumption in brass, bronze, and other copper alloy rolling mills has approximated that required in copper refineries and is increasing. Until 1917, all melting and heat-treatment of copper and copper alloys was done in fuel-fired furnaces or ovens. Today, almost all brass and bronze melting in rolling mills and much in foundries is done in electric furnaces, the energy required varying with the alloy made from 195 kilowatt-hours to 300 kilowatt-hours per ton alloy melted. Such melting operations required in excess of 220,000,000 kilowatt-hours of electricity per year. Pure copper ingot is only melted in electric furnaces to a limited extent as present electric furnace lining life is short with metal containing more than 90 percent copper.

23. In the process of drawing, rolling, or piercing copper and copper alloys into wire, tubes, and sheets, the semi-finished product must be softened by annealing. In products such as hard-drawn wire and tubing, careful temperature control is essential and electric annealing furnaces are displacing wood-fired muffles. Such annealing furnaces

consume from 50 to 100 kilowatt-hours per ton of copper-alloy handled. While data concerning the actual number of installations of electric annealing ovens is not available, it is obvious that any general adoption of electric annealing furnaces would bring about a heavy increase in the power load of copper alloy rolling mills.

24. *Steel.*— Blast furnaces, steel works, and rolling mills outrank all other industries in installed horsepower, only three fourths of which is electric horsepower. This ranking position is due to the fact that iron and steel tonnage exceeds all other metal, chemical, or paper tonnage by many millions, rather than to unit power requirements of iron and steel products. But electrification of steel works and rolling mills is proceeding rapidly not only for mechanical operations but for heating processes. In 1929, 1 percent of steel ingots were refined in electrically heated furnaces requiring approximately 210 kilowatt-hours per ton molten charge. Such electric refinement consumed 125,000,000 kilowatt-hours of energy. Twenty-six percent of steel castings were melted in electric furnaces, consuming from 500 to 760 kilowatt-hours per ton cold charge. An increasing number of electric furnaces are employed in the heat-treatment of alloy steels and carbon steels, specific operation requiring from 50 to 500 kilowatt-hours of current. Electro-galvanizing, electrozincing, and electroplating are also increasing. Probably the best measurement of the part all power, regardless of source, plays in steel works and rolling mills today and the part which electrical power and heat may play in the future is gained by a comparison of the present cost of fuels and electricity in steel works and rolling mills and the market value of all manufactures. Electricity and fuels form 6.6 percent of the total market value of products today.

25. *Artificial abrasives and refractories.*—Closely associated with the development of hard alloy steels is the manufacture in electric furnaces of fused alumina and of silicon carbide, the latter being second only to the diamond in hardness. Both serve to grind metals and other substances and as refractories where high temperatures and difficult heating conditions must be met by furnace linings and equipment. Silicon carbide requires from 6,666 to 8,333 kilowatt-hours of energy per ton and fused alumina from 2,000 to 2,540 kilowatt-hours. American firms manufacture both abrasives in plants located in the United States and in Canada. While the crude materials are converted into marketable abrasives in this country, electrothermal processes are carried on more extensively in Canada than in the United States. Crude silicon carbide and fused alumina produced in electric furnaces in the United States in 1929 required less than 70,000,000 kilowatt-hours of energy whereas crude abrasives produced in both countries and consumed largely in the United States required 380,000,000 kilowatt-hours. Silicon, requiring approximately 12,000 kilowatt-hours per ton, is produced in small quantities at silicon carbide plants.

26. *Graphite.*—Crystalline graphite in powdered and electrode form requires approximately 7,600 kilowatt-hours of electricity per ton. Although manufactured by one firm only until recently, firms engaged in the manufacture of other electric furnace products are now offering it for sale, while firms requiring graphite electrodes in quantity for electrochemical production are manufacturing their own electrodes where petroleum coke is easily available.

27. *Phosphoric acid and phosphorus.*—Although phosphoric acid has been manufactured electrothermally for only 10 years chiefly for food and chemical industries, it already ranks eleventh among electrochemical industries in the total amount of electricity consumed. Current consumption totaled approximately 81,000,000 kilowatt-hours in 1929, while unit consumption averaged 5,400 kilowatt-hours. Electrothermal phosphoric acid production will have to compete with blast furnace phosphoric acid in markets requiring a pure acid, while chemical phosphoric acid still controls the fertilizer market. Phosphorus has been made in an electric furnace for many years. While power consumption is heavy, quantities produced are small.

28. *Industrial gases and synthetic ammonia.*—The electrolysis of water produces approximately 2 parts of hydrogen and 1 part oxygen, 1,000 cubic feet of hydrogen requiring 140 kilowatt-hours and 1,000 cubic feet of oxygen about 250 kilowatt-hours of electricity. These gases may each be manufactured by other methods. As manufacturing plants requiring large amounts of either gas produce their own gases, such production is not recorded and any electricity consumed is reported along with total power consumption of the specific product manufactured. We know only that about a sixth of the oxygen offered for sale was produced electrolytically and that such production consumed more than 50,000,000 kilowatt-hours of electricity, and that synthetic ammonia made from electrolytic hydrogen at ammonia plants in the United States consumed over 13,000,000 kilowatt-hours of energy.

29. *Potassium compounds.*—Potassium hydroxide used in the manufacture of soft soaps, dyes, and other potassium compounds required over 2,000 kilowatt-hours of electricity to produce by electrolysis. Total power consumption in its manufacture exceeded 15,000,000 kilowatt-hours. Potassium chlorate requires approximately 1,350 kilowatt-hours per ton. Potassium permanganate and potassium persulphate are also produced electrolytically in this country but in small quantities.

30. *Carbon bisulphide.*—Carbon bisulphide manufacture consumed approximately 36,000,000 kilowatt-hours of current in 1929. This chemical is used as an insecticide, as a solvent of caoutchouc and fats and also in the extraction of essential oils.

31. *Rare or minor electrochemical products.*—Fused quartz is finding extended application not only in equipment that must resist acids and sudden heat, but also in the manufacture of telescope and photograph lenses and in window glass which transmits ultra-violet and infra-red rays. Its production required from 10,000 to 16,000 kilowatt-hours per ton. Production is still on a poundage basis, however.

32. Demand for materials reduced only at high temperatures and employment of high pressures in chemical industries have brought into the market several new electric furnace refractories. Mullite, electrically sintered magnesite, and other electrically combined substances, are being tried out in industry.

33. Pure tungsten, for electric lamp filaments and for ignition contact points, also requires large amounts of power per unit and hydrogen atmosphere furnaces, but production is still in small quantities. Molybdenum, tantalum, and barium, are finding application in radiotube manufacture. Cobalt is being alloyed with other metals to

produce machine tools and acid-resistant equipment. Beryllium, cerium, and lithium are also alloyed with other metals. Each product is manufactured electrochemically with high unit-current consumption. But each product is manufactured in small quantities today and has only potential significance in the development of the Nation's water power.

Power requirements of electrochemical processes and consumption of electricity by such processes in the United States in 1929 [1]

Material	Process	Kilowatt-hours required per short ton	Total kilowatt-hours consumed in 1929 in United States	Principal competing processes in United States or other countries
1. Nitric acid	Arc	61,000	None	Oxidation of ammonia.
2. Aluminum	Electrothermal reduction of bauxite to alumina.	4,082–?	None	Alkali reduction of bauxite to alumina.
3.	Electrolytic reduction of alumina to aluminum.	19,000–25,200	2,519,375,000	None.
4. Metallic magnesium.	Electrolysis of magnesium chloride in brine.	16,000	10,640,000	Electrolysis of magnesium chloride from mineral magnesite plus chlorine requiring 17,000 kilowatt-hours.
5. Metallic sodium	Electrolysis of fused caustic soda.	13,000	[2]	Electrolysis of fused sodium chloride.
6. Synthetic ammonia.	Electrolytic hydrogen; pressure synthesis.	12,055	13,140,000	Water-gas hydrogen; coke-oven gas hydrogen; by-product hydrogen.
7. Fused quartz	Electrothermal fusion	10,000–16,000	[3]	None.
8. Silicon	Electrothermal reduction	12,000	[3]	Do.
9. Phosphorus	do	9,000	[4] 1,250,000	Do.
10. Crystalline graphite.	do	7,600	[4] 91,200,000	Do.
11. Ferro-tungsten	Electrothermal smelting and refining.	7,600	26,395,000	Do.
12. Silicon carbide	Electrothermal reduction	6,666–8,333	[5] 23,655,000	Do.
13. Ferro-molybdenum 70 percent.	Electrothermal smelting	8,000–9,000	[6] 228,258,000	Do.
14. Ferro-uranium	do	6,000–10,000		
15. Ferro-chromium 60 percent.	do	6,000		
16. Ferro-vanadium 30 percent–35 percent.	do	6,800	[4] 13,035,600	Thermit reduction.
17. Phosphoric acid	Electrothermal reduction	5,400	81,000,000	Sulphuric acid process. Blast-furnace reduction.
18. Ferro-silicon 50 percent.	Electrothermal smelting	5,000	994,011,000	Byproduct fused alumina production; less than 12 percent silicon blast-furnace reduction.
19. Ferro-manganese 80 percent.	Electrothermal reduction	4,400	None	Blast-furnace reduction.
20. Calcium carbide	do	2,600–3,200	720,000,000	None.
21. Calcium cyanamide.	do	2,830	[7] None	Do.
22. Zinc	Electrolytic precipitation	2,206–3,200	[8] 507,115,192	Retort distillation.
23. Copper	Copper precipitation from oxide and mixed ore.	1,700–2,625	62,848,806	Flotation and reverberatory smelting.
24. Caustic soda	Electrolytic reduction of brine.	[9] 2,328–2,984	660,000,000	Lime-soda ash process.
Chlorine				
25. Cadmium	Electrolytic precipitation of zinc residue.	2,000–2,500	2,730,200	None.
26. Fused alumina	Electrothermal fusion	2,000–2,540	[10] 43,318,000	Do.
27. Potassium hydroxide.	Electrolysis of potassium chloride.	2,100–2,300	15,831,000	Chemical process.

[1] Does not include 15 rare metals or chemicals, the production of which is still on a very small scale.
[2] United States production not officially recorded. Estimated world electricity consumption in manufacture of metallic sodium in 1927 was 375,000,000 kilowatt-hours.
[3] United States production too small to be officially recorded.
[4] Estimated.
[5] Canadian and United States consumption in 1929 was 227,000,000 kilowatt-hours.
[6] Includes minor quantities of other ferro-alloys.
[7] The amount shipped to the United States in 1929 required 84,900,000 kilowatt-hours.
[8] Includes power required in operations immediately essential to electrolytic precipitation.
[9] Per ton caustic soda.
[10] Canadian and United States consumption in 1929 was 152,489,000 kilowatt-hours.

Power requirements of electrochemical processes and consumption of electricity by such processes in the United States in 1929—Continued

Material	Process	Kilowatt-hours required per short ton	Total kilowatt-hours consumed in 1929 in United States	Principal competing processes in United States or other countries
28. Iron	Magnetite ore reduction in arc furnace.	2,000–2,500	None	Blast furnace. Electrodeposition.
29. Potassium chlorate.	Electrolysis of potassium chloride.	1,350	[3]	Chemical process.
30. Iron	Electrodeposition from ore.	900	None	Blast furnace. Electric furnace reduction.
31. Carbon bisulphide.	Electrothermal fusion	850	30,179,250	None.
32. Sponge iron	Electrothermal low temperature ore reduction.	400	[3]	Oil or gas low temperature reduction.
33. Steel castings	Electric melting solid charge.	500–760	[4] 281,594,000	Open-hearth furnace. Bessemer furnace. Crucible furnace.
34. Steel ingot	Electric melting or refining or superrefining of molten charge.	210	125,218,590	Do.
35. Steel	Electric annealing or hardening.	182–286		Fuel-fired furnace.
36.	Electric galvanizing or electrozincing.	101–230		Fuel hot process.
37. Iron castings	Electric melting: Duplex system	115	[3]	Fuel-fired cupola melting.
	Continuous	550		
38. Copper	Electrolytic refining	141–233	309,351,900	None—Lake copper is not refined.
39. Copper ingot	Melting	310		Fuel-fired ovens.
40. Copper alloy	Electric furnace melting	200–300	[11] 220,000,000	Fuel-fired pit furnaces.
41.	Annealing	50–100		Fuel-fired ovens.
42. Silver	Electrolytic refining	316–714	1,283,460	Sulphuric acid process.
43. Gold	do	266	45,300	Do.
44. Lead	do	95–111	6,180,000	
45. Oxygen, compressed.	Electrolytic reduction of water.	[12] 250	50,575,000	Liquefaction process.
46. Hydrogen		[12] 140	[13]	Water-gas. Iron contact processes.

[3] United States production too small to be officially recorded.
[4] Estimated.
[11] Figures are for 1927.
[12] Kilowatt-hours per 1,000 cubic feet.
[13] Process employed chiefly in plants where hydrogen is consumed in major manufacturing processes.

PRESENT LOCATION AND STATUS OF MAJOR POWER CONSUMING INDUSTRIES

34. The most favorable location for any large power-consuming industry is one in which power site is within easy access of essential raw materials and in close proximity to consuming markets. As all new plants in power-consuming industries control mechanical operations electrically, such industries are no longer dependent upon a labor supply trained through years of actual experience for specific processes. The general levelling of wage rates in the industrial East and West has narrowed the differences in labor cost in all sections of the United States save in the South.

35. In the past, power supply, sources of raw materials, and available labor have determined plant locations in Eastern and Central States. In a period such as the present, when manufacturing capacity in many industries exceeds market demands, markets stand out as one of the most important factors in determining locations of new or branch plants. The advantages to be obtained through easy contact with customer industries, the lessened risk involved where companies are not entirely dependent upon conditions in one locality, and the

wisdom of distributed investments is tending more and more to the establishment of branch factories in consuming areas. The heaviest markets for electrochemical and paper products are in East Central and Lake States. The general movement of population westward brings with it an increase in service industries. But the development of basic industries in a given locality due to a dependence on bulky low-cost raw materials has tended to bring related industries to specific sections. Even so, production costs of manufactured products are seldom sufficiently low to offset heavy freight charges from western raw-material sources to eastern markets. Manufacturing costs are being lowered, however, by the integration of a number of related industries so that present waste is eliminated and overhead costs greatly reduced.

36. In the following pages are outlined briefly, factors entering into the establishment of existing major electrochemical and paper plants, present sources of raw materials, possible future sources, as well as conditions affecting prevailing markets and industrial control.

THE ALUMINUM INDUSTRY

37. *Plant location.*—Aluminum manufacture as practiced in the United States involves two processes, the chemical extraction of aluminum oxide from the ore bauxite and the electrolytic reduction of the oxides to metallic aluminum. When hydroelectric service was first available at Niagara Falls, aluminum-reduction works were put into operation at the Falls. The chemical-extraction plant was placed at East St. Louis, Ill., near coal fields and where bauxite could be shipped via water from Arkansas bauxite mines to it. As markets for aluminum expanded, additional reduction works were constructed at Massena, N.Y., where power is secured from waters of the St. Lawrence River; at Shawinigan Falls, Quebec, on the St. Maurice River; at Badin, N.C., where power is gotten from the Yadkin River; at Alcoa, Tenn., which is served by power from a number of developments in the Great Smokey Mountains of Tennessee; and in 1926 construction was started at Arvida, Quebec, on the Saguenay River. The Massena reduction works is the largest plant in the United States. Plans for developments at Arvida, Canada, contemplate a capacity almost equal to present total production in the United States.

38. Until 1928, aluminum oxide for all North American reduction works was supplied by the East St. Louis factory. By 1929, the Arvida plant had succeeded in meeting almost all its own needs by the electrochemical extraction of aluminum oxide from bauxite shipped to it from the British and Dutch Guianas. Should electrothermal reduction of bauxite be able to compete with the long-established chemical reduction which resulted in locating one unit of aluminum production near coal fields, all processes in the manufacture of aluminum from its ores can be carried on at power sites.

39. While present power developments along the Saguenay River will provide 500,000 horsepower at Arvida, completed construction will make available 1,000,000 horsepower. The Aluminum Company of America, sole producer of virgin aluminum in the United States and in Canada since 1886, holds riparian rights near Long Sault Rapids in the St. Lawrence River which it has not been able to develop

due to lack of coordinate legislation on the part of the United States and Canada, the State of New York, and the Province of Ontario. It also has undeveloped power sites in the Great Smoky Mountains of Tennessee.

40. *Expanding markets.*—Continuous research has brought about an expanding market for aluminum. Not only has it held well established markets in cooking utensil and electrical conductor industries, but strong aluminum alloys have found large markets in transportation industries and in electrical apparatus manufacture while beginnings have been made in structural fields. With the exception of post war years, aluminum production has increased steadily in the United States. The very rapid expansion since 1923 is shown on Graph I.[7]

41. *Control of production.*—World aluminum production is also increasing. Such production is controlled by two groups, the Aluminum Company of American with Canadian and other foreign holdings operated by Aluminum Limited and the International Aluminum Cartel made up of four principal producing companies in France, Germany, Great Britain, and Switzerland. In 1929, the Aluminum Company of America produced 51 percent of the world's supply of aluminum, 38 percent being manufactured in the United States. Germany produced 13 percent of the world's supply, France 11 percent.

42. *Sources of raw materials.*—Bauxite, a hydrated oxide of aluminum containing 50 percent to 60 percent aluminum oxide, is the source of all commercial aluminum today. It is mined principally in southeastern United States, in British Guiana and Dutch Guiana, in France, Hungary, Italy, and Yugoslavia. Extensive deposits are believed to exist in Africa and India. As the large world aluminum manufacturers control extensive bauxite deposits, it is not believed that the very abundant aluminous clays containing lesser amounts of aluminum oxide will be used in aluminum production for many years.

43. However, Italy is experimenting with the commercial production of aluminum oxide and potash from leucite ores containing both minerals. This experiment is of importance to Wyoming where geologists estimate 2,000,000,000 tons of leucite ore containing 200,000,000 tons of aluminum oxide and a like amount of potash are available.

PHOSPHORIC ACID, NITROGEN, AND POTASH PRODUCTION

44. *Sources of potash and phosphates.*—The undeveloped potash resources of Wyoming call sharply to attention the research that is being carried on by two Federal departments to develop methods of making available to agriculture and industry the potash resources of the country. The American farmer applies approximately 343,000 tons of pure potash to farm lands each year along with 345,000 tons of nitrogen and 808,000 tons of phosphoric acid. The phosphoric acid was produced in the United States from native phosphate rock; 53 percent of available nitrogen was manufactured in the United States; while but 16 percent of available potash was American production.

45. The Wyoming potash in leucite rock is not water soluble as is German and French potash and, therefore, must be chemically

[7] Not printed.

treated before it is available as plant food. As yet, no process has been developed which will permit potash so treated to meet foreign fertilizer prices unless the aluminum contained in the ore is also marketed. Development of this potash along with nearby phosphate deposits for baking powder and chemical industries has just begun. Experiments are also under way using this potash silicate as a flux in electrothermal phosphoric acid manufacture. Government geologists and metallurgists, however, are working at present with potash from well deposits in Texas and New Mexico. As the Wyoming deposits of potash are believed to be the largest in the United States and as the largest known world deposits of high grade phosphate rock are located in Idaho, Wyoming, Utah and Montana, the Nation will eventually depend upon these States to supply much of its phosphate and potash requirements.

46. At present, Florida supplies the largest amount of phosphate rock; Tennessee ranks second in production, while but a small amount is mined in Idaho, Wyoming, and Montana.

47. *The fertilizer market.*—More than 90 percent of phosphate rock sold enters the fertilizer trade. This rock is manufactured into phosphatic fertilizer, not at the mines, but in fertilizer consuming centers. The reason is obvious. The prevailing phosphatic fertilizer, superphosphate, is made by mixing one part of phosphate rock with one part of sulphuric acid producing a product containing 16 to 18 percent phosphoric acid and a large quantity of gypsum. The original phosphate rock from which this fertilizer was produced contained 30 to 34 percent phosphoric acid. As value is based on phosphoric acid content rather than on bulk, it is cheaper to ship rock containing over 30 percent phosphoric acid to fertilizer consuming districts than to manufacture the fertilizer at the mine and ship the finished product containing only 16 to 18 percent phosphoric acid.

48. Fertilizer manufacturing located in the South, as cotton fields consume 31 percent of all fertilizer, and also near corn, potato, wheat, and tobacco regions. Such manufacturing involved the production of superphosphate and mixing it with foreign potash and, until recent years, with foreign nitrogen materials. In this mixed fertilizer the farmer paid not only for 17 percent available plant food but the cost of bagging, handling, and hauling the other 83 percent almost valueless filler. Obviously, Rocky Mountain phosphate rock or Rocky Mountain superphosphate could not be shipped profitably to southern and central fertilizer markets.

49. *Transitional period.*—The costliness of such practices, as well as the waste involved in diluting phosphate rock with sulphuric acid and the danger of permitting the country's agricultural development to be largely dependent upon foreign sources of nitrogen and potash is nationally recognized. Fertilizer manufacture and the production of the three chemicals entering into such manufacture are passing through a transitional period in the United States.

50. The percentage of plant food in fertilizer increased from 14 percent in 1920 to 17.6 percent in 1929. Some phosphate rock is being treated with phosphoric acid in place of sulphuric acid in order that both rock and reagent may furnish plant food. This product, known as double superphosphate, contains from 45 to 50 percent plant food as against 14 to 18 percent in regular superphosphate. Phosphoric

acid is also used as the carrier of nitrate ammonia fertilizer, thereby creating a 2-plant food fertilizer. Instead of forcing the producer of ammonia to manufacture ammonium sulphate with its useless sulphate radical for the fertilizer market, this practice permits anhydrous or aqua ammonia to be shipped to fertilizer plants to be combined directly with phosphoric acid fertilizer.

51. *Competition between phosphoric acid manufacturing processes.*—But this phosphoric acid is still produced mainly by the sulphuric acid process. Electrothermal phosphoric acid manufacture began in 1920, blast furnace phosphoric acid manufacture in 1929. As these methods produce a pure acid more easily than the sulphuric acid process, pyrolytic phosphoric acid has served the baking powder, pharmaceutical, and other industries in which a pure acid is essential. The pure acid required by these markets brings a price of $170 to $180 per ton whereas the phosphoric acid in superphosphate fertilizer is worth only $50 a ton of acid. It is obvious why pyrolytic producers of phosphoric acid have given first attention to markets other than the fertilizer market.

52. But as the industrial market is small, normal growth will force pyrolytic phosphoric acid into the fertilizer market. All furnace processes have advantages over the sulphuric acid process. Low-grade ores may be treated along with high-grade ores making unnecessary the washing and screening of ores essential for the chemical process. Much present waste of phosphate rock is avoided. Again, any degree of concentration of phosphoric acid may be obtained directly by furnace methods so that the expense involved in the sulphuric-acid process of evaporating weak solutions is eliminated.

53. In regions where a market must be found for waste sulphur fumes, as near sulphide ore smelters, sulphuric acid may be a very cheap reagent. More labor is required by this chemical process than by other processes. Where coke is cheaply available, blast-furnace reduction may prove to be more economical, whereas an abundance of electrical power may make the electrothermal process more advantageous.

54. *Chemical nitrogen production.*—Other technical developments which may lead to the production of high-analysis fertilizers and thereby permit a development of western phosphate and potash deposits, are also of recent date in the United States. The direct synthetic ammonia process for nitrogen fixation was first put into operation at Syracuse, N.Y., in 1921. In 1929 a sixth of the available nitrogen supply was secured from air nitrogen fixation plants, this production representing a 350 percent increase in 2 years. Building of additional plants during 1929 and 1930 will bring the direct synthetic ammonia plant capacity of the United States close to 200,000 tons.

55. *Ammonia plant location.*—Largest present production takes place at Hopewell, Va., and at Belle, W.Va., where water-gas is employed as the hydrogen source. Near Seattle, Wash., electrolytic hydrogen is employed. Recently, an electrolytic plant has been erected at Trail, British Columbia, for the pressure synthesis. A plant building at Brose, Calif., will secure its hydrogen from natural gas. Four electrolytic caustic soda plants are manufacturing by-product hydrogen into ammonia. In Europe, coke-oven hydrogen has proved a cheap source of supply.

56. As shown on graph II,[8] by far the larger amount of domestic nitrogen was secured as a by-product of coke production. As coke is sold primarily to iron and steel mills, any production of ammonia at coke ovens depends on the demands of iron and steel mills for coke rather than upon the market demand for ammonia. Chilean nitrate, until 1926 our prevailing nitrogen source, still ranks second as a source of supply. Ten percent of our available nitrogen was imported from Canada in the form of calcium cyanamide and cyanide. Much of the cyanamide imported is manufactured into ammonia and ammonium phosphate.

57. *Competitive conditions.*—Successful competition of the several nitrogen compounds depends not only on the cost of differing manufacturing methods at particular plant locations, but upon the derivatives obtainable from the initial nitrogen products and upon the markets for by-products. In the electrolytic-hydrogen ammonia process, power is the major operating cost. As 1 part of oxygen is produced with every 2 parts of hydrogen, a profitable market for this oxygen, such as the oxidation of ammonia to nitric acid, reduces the cost of manufacture materially. Then, too, electrolytic hydrogen costs would be reduced if such manufacture were carried on with off-peak power as the electrolytic hydrogen cells operate efficiently under great load variations. The cyanamide process requires large amounts of power per ton of nitrogen fixed as well as coal, coke, and limestone. The cyanamide is not only converted into ammonia and all ammonia compounds, but into the fertilizer area containing 45 percent nitrogen, into calcium cyanide for metallurgical reductions, into hydrocyanic acid for plant fumigation, and into ferrocyanide used in dye manufacture. Methanol used in the production of formaldehyde, insolvents and in other chemicals is the principal by-product of water-gas ammonia.

58. *Industrial control.*—The two largest producers of direct synthetic ammonia are the Atmospheric Nitrogen Corporation, a subsidiary of the Allied Chemical & Dye Corporation, and the E. I. du Pont de Nemours & Co. The latter company oxidizes much of its ammonia to nitric acid for use in the explosives, nitrate plastics, and nitrocellulose lacquers it manufactures. The American Cyanamide Co., producing cyanamide at Niagara Falls, Canada, phosphoric acid at Tampa, Fla., and ammonium phosphate and other chemicals in New Jersey, owns controlling cyanamide patents.

59. All nitrate-producing countries save the United States have entered into an agreement concerning production quotas, export quotas, and prices, such agreement becoming effective in August 1930.

FERRO-ALLOYS AND THE IRON AND STEEL INDUSTRY

60. *Ferro-alloy plant -Location.*—Original plants for the electrothermal manufacture of ferrosilicon and ferrochromium were located at Holcomb Rock, Va., and at Kanawha Falls, W.Va., during and immediately after the Spanish American War. Ten years later production began at Niagara Falls. But foreign competition hindered extensive development of all ferro-alloy manufacture until the outbreak of the European war. The demand for alloy steels, the employment of ferrosilicon to supply hydrogen for aircraft, caused

[8] Not printed.

the United States Government to encourage the building of ferro-alloy plants in States where alloying minerals were available. Under this stimulus, plants were built in Washington, Oregon, California, Montana, Colorado, Alabama, Tennessee, as well as in Iowa, Pennsylvania, Maryland, and New York. From 1915 to 1917, production of ferro-alloys increased 184 percent. With the cessation of hostilities, all far-western plants were forced to close down. But the ferro-alloy industry had been firmly established in this country. Ferrosilicon production was 88 percent more in 1929 than in 1919. From 1928 to 1929 it increased 12 percent while production of the rarer alloys such as ferrochromium, ferrovanadium, ferrotungsten, and ferromolybdenum increased 24 percent.

61. The largest manufacturer of electrothermal ferro-alloys in the United States is the Electro-Metallurgical Co., a unit of the Union Carbide & Carbon Corporation. This company has a large factory at Niagara Falls where a number of ferro-alloys are manufactured. It produces ferrovanadium in Ohio and operates the original ferrosilicon and ferrochromium plants in Virginia and West Virginia. It is completing the construction of a hydroelectric power plant on the New River, W.Va., which will furnish 80,000 horsepower to a new unit of the company erected at Boncar, W.Va. The Union Carbide & Carbon Corporation manufactures ferromanganese electrothermally in Norway.

62. The Vanadium Corporation of America is especially interested in the manufacture of ferrovanadium and the rarer alloys, although it also manufactures ferrosilicon and ferrochromium at Niagara Falls. Other electrothermal ferrosilicon plants are located at Keokuk, Iowa, and near Chattanooga, Tenn. A small amount of this alloy is produced as a by-product of artificial abrasive manufacture. Several smaller plants are making a specialty of specific rare ferro-alloys and are located near consuming markets.

63. *Sources of alloy materials.*—Although the United States has achieved virtual independence in the manufacture of ferro-alloys, imports being chiefly of electrothermal ferromanganese from Canada and Norway, it is still largely dependent on foreign countries for all alloying minerals save silicon and molybdenum. Manganese ore is imported principally from Soviet Russia, Brazil, India, and British West Africa; chromite is shipped from Rhodesia and Cuba; tungsten comes from China, vanadium from Peru, and uranium from the Belgian Congo. Reserves of chromium, tungsten, uranium, and vanadium are located in Pacific Coast or Rocky Mountain States. Reserves of high-grade manganese are not extensive in the United States but large reserves of low-grade ores are found in these Western States and in Minnesota. Efforts to concentrate these ores to the purity demanded by steel manufacturers have reached the trial commercial plant stage.

64. *Ferro-alloy markets and location of iron and steel industry.*—At present, largest markets for ferro-alloys are in Pennsylvania and Ohio where almost 60 percent of all steel is produced. Indiana and Illinois manufacture about 20 percent of all steel. The iron and steel industry is located in coking coal regions because it is less costly to bring iron ore to coal than coal to iron. Only in Alabama do coking coals and iron ore occur in adjacent fields.

65. *Iron ore supply.*—Seven eights of all iron ore consumed in the United States comes from the Lake Superior region. As the estimated life of these deposits is drawing to a visible end at present consumption rates, radical changes may occur in the iron and steel industry in another quarter century. A large iron and steel firm has already secured control of some iron-ore deposits in South America. Some experts believe China will export iron ore to this country. Others believe that the exhaustion of hematite ores in the United States will bring with it the abandonment of the blast furnace and the adoption of low-temperature reduction furnaces operated by gas, oil, or electricity on magnetite iron ores of far Western and Eastern States. If any one of these predictions prove correct, the iron and steel industry will tend to move to locations that can be reached by ocean shipment. Under existing conditions, it is gradually moving westward.

66. *Increased use of electricity in iron and steel.*—Electric-furnace production of iron from its ores is carried on in Norway, Sweden, and Italy. While iron and steel of high quality has also been produced in this country, there is so small a market for the product that manufacture has not been able to proceed on a commercially profitable scale.

67. The increased production of alloy steel is, however, bringing with it new installations of electric melting and refining furnaces as well as expanding ferro-alloy manufacture. The relationship between alloy-steel production and ferro-alloy production is clearly shown on graph III. Although only 1 percent of steel ingots produced in 1929 was melted or refined in the electric furnace, this constituted a 17 percent increase in electric furnace ingots in 1 year. Electric furnace iron and steel castings formed 26 percent of castings produced. Approximately seven tenths of all alloy steel is consumed by the automobile industry.

68. *Markets.*—The building and construction industry vies with the automotive industry for first place in steel consumption. Railroads afford the third largest outlet for rolled products. These three industries absorb approximately 50 percent of all rolled steel. Oil, gas, and water companies are heaviest consumers of pipe and rank second in the use of plates. Almost three fourths of all tin plate is made into metal containers. Agriculture requires approximately 18 percent of all steel wire produced.

69. While major consuming markets are in the East and Middle West, the purchase of Pacific coast iron and steel mills in 1929 by the two largest steel corporations is indicative of the increasing demand for steel on the Pacific coast. Only a sixth of Pacific coast steel market needs are met by existing Pacific coast States. One fifth of all tin plate produced in the United States is consumed by canning industries on the Pacific coast, while but 10 percent of these needs are supplied by local mills. None of the pipe and seamless tubing, rail, and plate requirements of this region are met by Pacific coast plants.

70. Exports of iron and steel are chiefly in the form of finished rolled products; tinplate, terneplate, and structural shapes exceed all other forms. Tinplate and terneplate are shipped principally to Japan and Canada, to China, Argentina, Mexico, British India, Siam, Cuba, and South American countries. Structural

shapes go chiefly to Canada. Plates and sheets go in largest measure to Canada, Japan, and the Philippine Islands.

71. *Control.*—More than 80 percent of the steel ingot capacity in the United States is controlled by 11 steel companies. The United States Steel Corporation produced 41.6 percent of the iron ore of the country, 29 percent of the coke, and 39 percent of our steel ingots and castings.

ZINC AND CADMIUM REDUCTION

72. *Plant location.*—The location of zinc reduction plants in the United States has been determined by the character of ore treated and the specific reduction process employed. As fuel is essential to zinc distillation, zinc retort plants are located in coal mining or in natural gas regions. Zinc-lead ores of Oklahoma, Kansas, and Missouri are smelted at natural gas fields in Oklahoma and Kansas or are shipped to Arkansas gas fields or to Illinois coal fields. One electrolytic plant is located in Illinois near a large steam power plant. Zinc oxide ores of New Jersey are sent for distillation to Pennsylvania coal fields. Southern States ship to either middlewestern or Pennsylvania smelters, although new construction is taking place in West Virginia coal fields. Complex ores of the Rocky Mountain region are reduced by flotation and electrolysis near zinc mines as abundant power is obtainable near largest zinc mining regions.

73. *Production and consumption.*—In 1929 there were four electrolytic zinc plants, producing 23 percent of the zinc, and 21 operating retort smelters. Zinc production in 1929 was the largest in the history of the industry, although smelters were operating at less than 60 percent capacity. The apparent consumption in 1929 was approximately 15 percent less than production. In 1930 production fell to its lowest level since 1922.

74. Forty-six percent of zinc consumed in the United States is used in galvanizing sheets, tubes, and other iron and steel products. Twenty-nine percent is mixed with copper to produce brass. Eleven percent is rolled into zinc sheets or strips for roofings, boilerplate, electrotype, and dry batteries. Pigments, paints, and rubber consumed less than 10 percent. Die castings made of a zinc-tin-aluminum-copper alloy are finding a market in the automobile hardware industry. Efforts are being made to introduce this alloy into building hardware manufacture and to find new markets for zinc. Exports of zinc are small.

75. *Industrial control.*—The largest production of metallic zinc in 1929 occurred at the two electrolytic plants of the Anaconda Copper Mining Co. in Montana. This company has also operated since 1929 large zinc properties in upper Silesia, ceded to Poland by the Treaty of Versailles. Here zinc is not only mined, smelted, and manufactured into finished products, but pig lead and lead products, sulphuric acid, superphosphate, and mixed fertilizers, as well as coal, brick, lumber, porcelain, paper, and explosives are produced.

76. The New Jersey Zinc Co. not only mines and distills zinc, but produces finished products and sulphuric acid. Subsidiaries of the United States Steel Co. produce zinc ore in the Tri-State District and in Tennessee. The Grasselli Chemical Co., a subsidiary of E. I. du Pont de Nemours & Co., operates two zinc plants and is also producing sulphuric acid from zinc fumes. A number of other com-

panies operate in the Tri-State District. The only other western zinc electrolytic plant is located at Kellogg, Idaho, and is operated by the Sullivan Mining Co.

77. *Competitive processes.*—Supplies of zinc in the United States and in other countries are abundant. The existing plant capacities in the United States and in Europe exceed demands. Sharp competition between zinc companies has resulted.

78. The electrolytic process has marked advantages over the old retort distillation methods. Not only is a zinc of higher quality produced, and a higher extraction of zinc secured, but elements lost in distillation operations are saved. Gold and silver are recovered in a lead concentrate and are shipped to lead smelters and refineries; residue copper is sent to copper refineries. Cadmium, used to electroplate ferrous materials and as a primary wash for automobile parts that are to be chromium or nickel plated, is necessarily precipitated before the electrolysis of zinc. It also is recovered by electrolysis. Cobalt, now alloyed with tungsten carbide in high-speed machine tools, and with chromium and tungsten for acid and heat resistant equipment, is a recoverable byproduct. Cobalt is secured for its oxide, electrothermally. Arsenic, thallium, and other elements are recoverable whenever a market is found for these substances. Sulphur dioxide fumes may be collected from either electrolytic or distillaton processes wherever a market exists for sulphuric acid. This acid is now consumed principally in fertilizer manufacture and in petroleum refining (in which fields it is meeting competition from other acids or by new production methods), in chemicals, metallurgical reduction, paints, pigments, explosives, paper, rayon, and textiles.

Improvements are being made in retort distillation methods, however, and several new processes are being tested.

CAUSTIC SODA AND CHLORINE PRODUCTION

79. *Plant location.*—The cost involved in evaporating dilute solutions of caustic soda to concentrated form for shipment only to be diluted again in actual application, the difficulty, only recently overcome, of shipping corrosive chlorine, has caused caustic soda and chlorine plants to be established close to consuming markets. In fact, manufacturers requiring large amounts of chlorine have frequently established their own electrolytic chlorine plants, while others requiring caustic soda, only have installed equipment to manufacture the caustic from sodium carbonate.

80. The electrolytic branch of the industry has been fortunate in finding its largest markets close to power supplies and to brine sources. Five plants are located at Niagara Falls, near brine wells and near New York pulp and paper plants and other consuming industries. Michigan electrolytic plants are located above brine wells and serve principally Michigan and Wisconsin pulp and paper industries. West Virginia plants are near organic chemical factories, the California plant sells to petroleum refineries and soap industries, while Washington electrolytic plants were established to serve the pulp and paper industry of the Pacific Northwest. While there are 19 electrolytic caustic soda and chlorine plants serving all markets, 17 other plants are operated at paper mills by paper companies.

81. *Consuming markets.*—It is estimated almost two thirds of all chlorine produced enters the pulp and paper industry. Whether in liquid or gaseous form, as a hypochlorite or in bleaching powder, some form of chlorine is used in paper manufacture to remove impurities left by all pulping processes. Twenty percent enters into textile production. Amounts of chlorine used for purifying drinking water and bathing beaches, and for other sanitary purposes are increasing. Aluminum chloride enters into oil refining. Chlorine is used to detin tin-plate scrap. It is also the basic ingredient of almost every one of modern chemical warfare agents. But the largest recent increased demand for chlorine has come from the synthetic organic chemical industry.

82. Electrolytic production of caustic soda has been hindered by lack of market for chlorine. The extended use of chlorine in synthetic organic and chemical production or expansion in industries already served will increase the demand for chlorine and at the same time increase the consumption of electrolytic caustic soda. Unless part of the cost of electrolytic production of caustic soda is borne by the chlorine produced simultaneously, such caustic cannot compete with caustic soda produced by the lime-soda process. The largest markets for caustic soda are offered, at present, by the rayon, the chemical, the petroleum, and the soap industries, each of which purchases 15 percent or more of the total amount marketed. Soda pulp for fine papers, rubber reclaiming and textiles are also products which require caustic soda. Exporting markets are in Japan, the Philippines, Mexico, Cuba, Canada, and South America, where our products come in competition with those of Great Britain, which at present supplies about three fourths of the market.

83. *Diversification of products.*—Manufacturers of electrolytic caustic soda and chlorine do not confine themselves to the production of these two chemicals. As caustic soda and chlorine are raw materials for a number of other chemicals, each electrolytic producer for the general market manufactures such sodium and chlorine compounds as his market demands. Recently other constituents of brine than sodium chloride have been utilized. Well brines containing magnesium chloride supply all metal magnesium now manufactured in the United States. Bromine and calcium chloride may also be secured by electrolytic methods. Such utilization of brine and the manufacture of related chemicals so diversifies consuming markets and so divides overhead expense as to fortify electrolytic caustic soda and chlorine production against competition from lime-caustic soda.

PULP AND PAPER AND OTHER CELLULOSE INDUSTRIES

84. The pulp and paper industry not only affords chlorine its largest market, but caustic soda, soda ash, sulphur, lime, sodium sulphate, aluminum sulphate, casein, clays, and rosins find extensive demand in the several types of pulp and many kinds of paper made. Then, too, the quantity and quality of water supply is a matter of vital importance to pulp and paper manufacture.

85. *Location of industry.*—From earliest times, pulp and paper mills located on the banks of streams where a clear, abundant water supply was available near forests supplying the pulpwood. As such locations were plentiful in New York, New England, and Pennsylvania, early paper mills were established fairly close to consuming centers. With

the westward movement of population, spruce forests of Wisconsin, Michigan, and Minnesota were cut for newsprint paper and the hardwoods of Ohio and Indiana added to the book paper pulpwood supply; paper mills were established near these sources of supply. In 1909, three fifths of all pulp and paper was produced in New England, New York, and Pennsylvania, and about one fourth in Lake States.

86. This over-centralization, combined with the heedless felling of trees, developed a shortage in the supply of spruce in these States. Paper mills turned to Canadian forests for a part of their supply. In 1910, the Government of Quebec prohibited the exportation of any wood cut from crown lands. This policy was followed by other provinces until pulpwood could only be shipped into the United States from freehold lands comprising about one tenth of Canadian pulpwood lands. Since 1911, standard newsprint paper and pulp has entered this country duty free.

87. *Imports.*—The effect of these two policies is reflected on graph VI.[1] While our imports of pulpwood have not changed, proportionately, in 20 years, our imports of wood pulp and paper have increased materially. When all paper and wood pulp imported into this country are reduced to their pulpwood content, about 60 percent of the forest material for paper used in the United States comes from outside our country. These imports are chiefly of newsprint paper or of pulp and wood for such paper, and of pulp for wrapping paper.

88. *Pulpwood reserves.*—One half the Nation's spruce reserves are in Washington and Oregon. One fourth of our pines, available for wrapping paper, are on the Pacific coast. These States possess the same natural advantages for newsprint pulp and paper manufacture as does eastern Canada; that is, extensive forests and cheap hydroelectric power. These States have demonstrated that they can produce the chemicals necessary for paper or rayon manufacture. Yet Washington State produced but 8 percent of the Nation's wood pulp and 3 percent of the Nation's paper requirements, while Oregon and California produced but 5 percent of the wood pulp and 3.7 percent of the paper requirements.

89. By correlating the lumber industry with the pulp industry, Northwestern States have been able to produce mechanical and sulphite pulp for newsprint paper more cheaply than can be done in Eastern States, but not cheaply enough to meet competition in eastern markets of Canadian and Scandinavian pulp. Sweden has been able to meet Canadian competition in American markets by so integrating her lumbering, sawmill, planing mill, and pulp-mill activities that almost all her pulp is manufactured from logging and sawmill waste. The extensive lumber industry of Washington and Oregon make similar correlation possible in these States.

90. *Consuming markets.*—Paper mills which purchase wood pulp from distant sections are located principally in New York State, Pennsylvania, Ohio, and Michigan. Massachusetts, Connecticut, New Jersey, Maryland, Indiana, and Illinois also purchase some pulp along with much waste paper and waste textiles.

91. The market for final paper product whether it be newsprint or magazine paper, paper boxes or wrapping paper, building boards or fine stationery, is dependent upon the size and character of specific

[1] Not printed.

retail purchasing markets. The New York City metropolitan area consumes far more paper than any other section. Illinois ranks second in printing and publishing of all types; Pennsylvania third, and Ohio fourth. Massachusetts and California follow.

92. Pacific coast paper mills supply paper needs of Pacific coast and Rocky Mountain States. A British Columbia paper mill ships newsprint paper via the Panama Canal to Texas, Louisiana, Oklahoma, New Mexico, Arkansas, Nebraska, and Kansas. Gulf ports and lower Mississippi ports can be reached more cheaply from Seattle than from New York, but large middle western consuming cities are served more cheaply by Lake State paper mills.

93. Paper and pulp exports are small. Export trade is chiefly with the Philippines, China, and Mexico.

94. *Newsprint paper purchasers.*—Four publishers in the United States purchase about 30 percent of all newsprint paper available in the United States. The Hearst papers require almost 15 percent, the Scripps-Howard, the Patterson-McCormick, and the Ochs papers purchasing the remaining 15 percent. Over three fourths the newsprint paper is purchased for large daily papers. These papers contract for their paper supply from 1 to 10 years. The hundreds of small daily papers and thousands of weekly papers buy through jobbers or through cooperative associations in small lots.

95. *Control of paper and pulp industry.*—Twenty-one firms operating mills in the United States and Canada have daily capacities of 500 tons or over finished paper. The largest of these, the International Paper Co., manufactures all kinds of wood pulp and many kinds of paper. It produces the larger part of its newsprint paper in Canada where it has timber rights to an extensive acreage and owns hydroelectric power systems. The Canada Power & Paper Corporation has the second largest productive capacity. The Crown Zellerbach Corporation, of Washington, Oregon, and Canada, ranks third in pulp and paper production. The next two largest companies are Canadian companies. The largest producer of newsprint paper in the United States is the Great Northern Paper Co. of Maine. The largest book paper manufacturer is the West Virginia Pulp & Paper Co. with mills in New York, Pennsylvania, Maryland, and Virginia.

96. All Canadian newsprint mills in the Provinces of Ontario and Quebec are members of the Newsprint Institute of Canada, organized through the efforts of the Prime Ministers of these provinces to bring about a more even distribution of available business.

97. *Rayon, cellulose plastics, and cellulose lacquers industries.*—The rayon, cellulose plastic, and cellulose lacquer industries are not large consumers of power in themselves although the rayon industry requires a 24-hour supply. Only when they are considered as markets for electrolytic chemicals do these cellulose industries become of interest in power development. Each ton of viscose rayon requires 2 tons of high-quality caustic soda. All rayon pulp and rayon skeins are bleached with chlorine compounds. The cellulose acetate rayon and plastics require acetic anhydride in the manufacture of which chlorine compounds are essential. The cellulose nitrate plastics and lacquers require nitric acid now made by the oxidation of ammonia, the hydrogen content of which may be obtained from the electrolytic production of caustic soda and chlorine.

98. *Sources of raw materials.*—About 80 percent of the world's rayon is manufactured from spruce pulp. American rayon mills do

not buy the spruce but purchase sulphite pulp made from it. The Canadian International Paper Co. at Temis-Kaning, Quebec, is the largest manufacturer of bleached sulphite pulp for rayon. The only large producer of such pulp in the United States is the Brown Co., of Berlin, N.H. The Rainier Pulp & Paper Co., of Shelton, Wash., is now manufacturing rayon pulp from hemlock.

99. Cotton linters, obtained from a second ginning of cotton after the staple cotton has been removed in the first ginning, also serve as a raw material for some rayon and for a number of the cellulose plastics.

100. *Plant location.*—Large American rayon factories not only produce rayon skeins but they carry on such textile operations as render the threads in condition for the knit goods manufacturer or the weaver. European firms ship rayon skeins to "converters" in this country, who dye, twist, and wind the threads in a manner desired by knitting and weaving customers. Because textile operations are a part of rayon production in this country, labor costs form from 40 to 50 percent of total costs, while engineering and administrative services add another 10 percent to the pay roll. Labor requirements have caused large rayon mills to be built in sections where no other industry is competing for semiskilled man and woman labor, woman labor forming approximately half the total amount required.

101. *Industrial control.*—It is claimed that 80 to 85 percent of the world's rayon production is controlled directly or indirectly by three companies: Courtalds, Limited, of England; Snia Viscosia of Italy, and Vereinigte Glanzstuff-Fabriken of Germany. The English company operates as the Viscose Co. in the United States and is by far the largest producer of rayon in this country. The German company operates two plants in Tennessee. The Italian company no longer operates any American plants, although a second Italian company operates one plant. The E. I. du Pont de Nemours & Co. is associated in rayon production with the leading French rayon producer.

102. While the rayon industry in the United States has been built up largely by foreign companies operating under foreign patents, the cellulose plastics industry has developed as an American industry. The E. I. du Pont de Nemours & Co. is the largest producer of cellulose nitrate and manufactures the cellulose into numerous plastic forms and into lacquers. The Eastman Kodak Co. is the largest producer of cellulose acetate plastic, its plant being located at Kingsport, Tenn.

POWER IN ALUMINUM PRODUCTION

CONTENTS

	Page
Power requirements of the aluminum industry	108
Development of aluminum industry	109
Historical setting	109
Growth of industry in United States	109
Plant and market expansion	110
Aluminum production	111
Aluminum manufacturing processes	112
Extraction of aluminum from ore	112
Bayer or alkali process	112
Electrothermal processes	112
Extraction of alumina from leucite	114
Cost of extraction	114
Production of synthetic cryolite	114
Electric calcining and baking of coke for electrodes	115

Aluminum manufacturing processes—Continued. Page
Power consumption in aluminum reduction 116
Refining and remelting pig aluminum in ingot production 116
Remelting secondary aluminum 117
Cost of producing aluminum 117
Working of aluminum 118
Sources of raw materials 118
Occurrence of metallic aluminum 118
Bauxite deposits 119
United States and South American developments 119
European deposits 120
Deposits in other countries 121
Fluorspar deposits 121
Organization and location of aluminum producing units 122
Shipment of bauxite to alumina works 122
Alumina works 123
Aluminum reduction plants and power developments 124
Rolling mills 125
Fabricating plants operated by Aluminum Company of America 126
Aluminum consumption 126
Marketed grades and prices 126
Domestic markets 126
Export markets 130
World production of aluminum 130
The European Cartel 130
World production of bauxite and aluminum 131
Bibliography 132

Aluminum reduction requires not only more electricity per unit than any other electrolytic or electrothermal process employed in manufacture in the United States, but yearly current consumption in such reduction exceeds that of any other single process. In European electrochemical industries, nitric acid manufacture by the arc process and hydrogen peroxide manufacture by electrolysis require larger amounts of current per ton, but these chemicals are not produced in sufficient quantities by such methods to even approximate the yearly current demands of aluminum reduction.

As carried on in the United States, the electrolytic reduction of aluminum from alumina requires 20,000 kilowatt hours to 25,200 kilowatt-hours electricity per ton, at the cell. In new cells in a Canadian plant reduction is attained with 19,000 kilowatt-hours of energy. The total electricity consumed in 1929 in the United States in this single electrolytic process exceeded 2,500,000,000 kilowatt-hours. To this must be added 6,000,000 kilowatt-hours of current required in the reduction of bauxite to alumina, any current consumed in carbon electrode or carbon furnace lining manufacture as well as power for mechanical service and lighting in plants and in mill villages. As rolling mills are located at three aluminum plants, their current requirements are also met from power installations for aluminum plants. Installed horsepower serving aluminum plants and villages exceeded 600,000 horsepower in 1929.

Although all countries continue to employ the original Hall-Heroult process for aluminum reduction from its oxide, three commercial plants have begun to extract aluminum oxide from the ore bauxite by electrothermal methods instead of by the prevailing alkali or Bayer process. These plants, located in Canada, Norway, and Italy, are operating on different processes and have not yet published

the results of their endeavors. The adoption of electrothermal processes will increase the electrical load at aluminum plants at least by 4,000 kilowatt-hours per ton. Add to this, the substitution of electric heated for the oil or gas fired calcining, baking, and melting ovens and furnaces now employed in older plants and the power requirements of aluminum plants are seen to be increasing in spite of a lessened need of power in new electrolytic aluminum cells. Then too, the expansion of aluminum markets has led to a steady increase in production in this country and in Europe.

Only one company has produced virgin aluminum in the United States since manufacture began in 1886. This company, the Aluminum Co. of America, is a vertical trust owning bauxite deposits in the United States, in British Guiana, in Dutch Guiana, and in Europe; coal and fluorspar mines; alumina extraction plant; aluminum reduction works; power plants, rolling mills, and aluminum fabrication factories; as well as steamships or railways connecting mines with mills. The Aluminum Co. of America produced 38 percent of the world's aluminum in its United States plants and 13 percent in its Canadian plants. It operates as "Aluminum Limited" in Canada and in all countries other than the United States. European production and prices are controlled by the International Aluminum Cartel made up of the principal producing companies of France, Germany, Great Britain, and Switzerland.

Practically all alumina for the aluminum industry is secured from the ore bauxite, a hydrated oxide of aluminum containing from 50 to 60 percent alumina. As deposits of bauxite are extensive in many countries, aluminous clays containing lesser amounts of alumina have not been employed in commercial aluminum production. Experiments are now underway in Italy to produce alumina and potash from leucite ore. This experiment is of importance to Wyoming where 2,000,000,000 tons of leucite are found containing 200,000,000 tons of alumina and 200,000,000 tons of potash.

Less than half the bauxite used in aluminum production in the United States is secured from ores in the United States; the amount mined for such manufacture is decreasing steadily. Aluminum requirements are being met by shipments from the British and Dutch Guianas.

Development of the Aluminum Industry

HISTORICAL SETTING

1. *Electrolytic process patented.*—Although aluminum was produced in 1825 by H. C. Oersted, a Danish physicist and chemist, and although it was manufactured by a chemical process in France prior to 1855, the present aluminum industry was founded upon a discovery by Charles M. Hall that aluminum could be secured by decomposing an electrolyte in which aluminum oxide had been dissolved by aluminum and other fluorides. Hall filed his process with the Patent Office in 1886 and secured United States patents on April 2, 1889. At approximately the same time, Paul L. T. Heroult had perfected the same process, quite independently, in France. But while Hall brought into being a company to finance aluminum production in the United States, Heroult first turned his attention to the manufacture of aluminum alloys in Switzerland.

2. *Commercial application in United States.*—The Pittsburgh Reduction Co. was incorporated on September 18, 1886, and started production of aluminum at a very small plant in Pittsburgh. By 1895 a new reduction works was put into operation at Niagara Falls to be followed by other additions to this plant. Litigation with the Cowles Electric Co. which had purchased patents of C. S. Bradley for keeping bath temperature up to the melting point by an electrolyzing current caused the Pittsburgh Reduction Co. to purchase these patent rights. The Hall and Bradley patents permitted this company to operate under patent monopoly until April 2, 1906, when the Hall patents expired and until February 2, 1909, when the Bradley patents expired. The name of the Pittsburgh Reduction Co. was changed to The Aluminum Co. of America in 1907.

3. *Beginnings of electrolytic reduction in Europe.*—The initial success of electrolytic aluminum production in the United States caused the abandonment of the chemical process in Europe. In 1888 electrolytic production of aluminum had begun in France and in Switzerland. As markets for aluminum expanded, reduction plants were established in Scotland, Wales, Norway, Austria, Germany, Italy, and Spain. All employ the Hall-Heroult electrolytic process of aluminum reduction.

GROWTH OF THE INDUSTRY IN THE UNITED STATES

4. *Establishment of new plants.*—Only once since the purchase of the Bradley patents in the early days of the industry has any firm other than the Aluminum Co. of America attempted the manufacture of the virgin aluminum in the United States. In 1912, the largest French aluminum producing company formed the Southern Aluminum Co. as a corporation of the State of New York. This company purchased riparian rights on the Yadkin River in Badin, N.C., and began the erection of plants for the production of alumina and aluminum. It was the intention of this organization to import bauxite from France and manufacture the alumina and aluminum at Badin. The World War necessitated suspension of building operations in October 1914. In 1915, the incomplete plant and the riparian rights were sold to the Aluminum Co. of America.

5. Prior to this date, the company had constructed reduction works at Massena, N.Y., where power is generated from the St. Lawrence River, and at Shawinigan Falls on the St. Maurice River in Quebec. More recently, reduction plants have been built at Alcoa, Tenn., power being secured from a number of developments on the Little Tennessee River in the Great Smoky Mountains. In 1926, the largest project was started at Arvida on the Saguenay River in the Province of Quebec.

6. *Aluminum market expansion.*—Such developments were made possible only through an increasing market for aluminum. From its inception, the Pittsburgh Reduction Co., and later, the Aluminum Co. of America, conducted research as to the uses to which aluminum could be put.

7. Pure aluminum is a weak material. Therefore, it was used first only for articles in which lightness, resistance to corrosion, high electrical conductivity, and ease of fabrication were essential. Discovery

that strength could be given to aluminum by alloying it with small amounts of copper, zinc, manganese, magnesium, silica, iron, or nickel opened up a vast field of new uses for the metal. Castings were now possible. As these light alloys used in automobile construction give better mileage, the automobile industry became the largest single user of aluminum.

8. The year 1929 marked the successful completion of a manufacturing technique that made possible the rolling of large structural shapes of high strength alloys. This, together with the adoption of aluminum as a decorative material in buildings, actually brings aluminum into the field of structural materials.

9. The laboratories of the Aluminum Co. of America are continuously at work discovering new properties of aluminum in its relation to other metals and finding methods by which aluminum and its alloys may be used in new industries such as aircraft, or in established industries such as paint manufacture. The extension of the field in which aluminum can serve makes its production no longer dependent upon any one market.

10. *Aluminum production.*—In 1891, but 75 short tons of aluminum were manufactured in the United States. Production increased steadily until in 1907, when the name of the sole producer was changed to the Aluminum Co. of America, it had reached 13,000 short tons. War years brought sharp demands for aluminum with the resulting increase in plant capacities. Production of primary metal in 1918 in the United States reached 72,000 short tons. This was followed by a sharp decline in production in 1921 and 1922. Succeeding years, however, have seen expansion in production until 112,500 tons was manufactured in 1929. At the same time, the amount of secondary aluminum used has increased steadily. Our importations totalled 24,000 short tons in 1929. The available supply of aluminum in the United States in 1929 was almost 177,000 short tons.

TABLE I.—*Aluminum production and supply in the United States*

Year	New production in short tons [1]	Secondary production in short tons [2]	Imports in short tons [3]	Exports in short tons [3]	Available supply
1930	114,517		12,273	5,957	
1929	112,500	50,000	24,208	9,749	176,959
1928	90,000	47,800	18,961	8,366	148,395
1927	80,000	46,200	36,366	8,026	154,540
1926	75,000	44,200	37,611	4,875	151,936
1925	73,000	44,000	20,999	6,321	131,678
1924	75,000	27,700	15,905	3,172	115,433
1923	70,000	21,300	21,238	2,770	109,768
1922	40,000	16,290	21,946	2,174	76,062
1921	30,000	8,900	16,280	1,098	54,082
1920	70,000	15,500	19,649	4,704	100,445
1919 [4]	64,000	18,691	8,822	2,510	91,513
1915 [4]	49,500	8,500	4,267		
1913 [4]	23,000	4,654	11,380		

[1] Figures estimated by "The Mineral Industry".
[2] Figures for 1920–30 from U.S. Department of Commerce, Bureau of Mines: "Bauxite and Aluminum."
[3] Figures for 1920–29 from U.S. Department of Commerce, Bureau of Foreign and Domestic Commerce, "Foreign Commerce and Navigation of the United States in 1929," and preliminary figures for 1930, U.S. Bureau of Mines.
[4] Figures for 1913, 1915, 1919 from U.S. Senate Hearings Before Committee on the Judiciary, Pursuant to Resolution 109, Sixty-ninth Congress, 1 sess.

Aluminum Manufacturing Processes

11. At present, all metallic aluminum is manufactured from the ore bauxite, a hydrated oxide of aluminum containing iron, silicon, titanium, and minor impurities. Bauxite mined in North and South America is crushed, washed, and kiln dried at the mines. Its reduction to aluminum is accomplished in two distinct stages; first, the extraction of aluminum oxide or alumina from bauxite, and second, the reduction of aluminum oxide to metal aluminum. While the original process of electrolytic reduction of aluminum oxide to metal aluminum has remained substantially the same in the last 40 years, the position of the alkali process for the extraction of alumina from bauxite has been challenged, recently, by electrothermal extraction processes. The alkali process, known as the "Bayer" process, is still the prevailing process in the United States and in Europe, but the Frary electrothermal process is being successfully employed at Arvida, Canada, the Haglund electrothermal process has been tried out in Germany and is being put into operation in Italy, and the Pedersen process is being applied in Norway.

12. Patents issued for the recovery of alumina from bauxite clays and from other aluminous minerals are very numerous. Some have been experimented with on a semicommercial basis but have failed to compete with existing production methods.

Extraction of Alumina

13. *The Bayer process.*—The Bayer or alkali process is employed at the only alumina works in the United States in East St. Louis, Ill. In this process, alumina is extracted from bauxite while most of the impurities are rendered insoluble. Although details vary as the content of bauxite to be treated changes, in general the steps in the process are as follows:

14. Bauxite is calcined, ground, and mixed with an aqueous caustic soda (sodium hydroxide). The mixture is digested under 50 pounds to 70 pounds pressure at 150° to 160° C., forming sodium aluminate ($NaAlO_2$) and water. The iron and titanium in the bauxite are not affected by caustic soda and, by adding lime to the bauxite during grinding, silica which would be dissolved in part by caustic soda, forms insoluble calcium silicate. The mass is permitted to settle while all the solid residue is separated.

15. The sodium aluminate liquor is then filtered, diluted, and sent to precipitation tanks. A small amount of aluminum hydroxide is added as a "seed" charge and gradually aluminum hydroxide is precipitated. The sodium hydroxide liquor in the tanks is evaporated for reuse in the treatment of raw bauxite.

16. After filtering and washing, the aluminum hydroxide is calcined at 1,000° to 1,100° C. in tubular rotary kilns producing alumina containing from 98 to 99.5 percent aluminum oxide with small amounts of water, sodium, iron, and silicon oxides. From the solid residue, ferro-silicon is now manufactured. It is suggested that titanium dioxide be recovered also, for use in the paint trade.

17. *Frary electrothermal process.*—Patents for the electrothermal reduction of alumina from bauxite were granted to F. C. Frary,

Director of Research, Aluminum Company of America, in 1925 and in 1926. The process is in operation at the Arvida plant of the company.

18. The bauxite used must have a sufficient iron and silicon content to dissolve all titanium. Therefore, a mixture of siliceous and ferruginous bauxite is employed. This is sintered to remove water. The sintered bauxite and coke are smelted in an electric furnace to reduce impurities to a metallic state. The molten purified alumina forms on top of this alloy and is poured off at a temperature of about 2,500° C. The impurities in the form of a ferrosilicon aluminum-titanium alloy are tapped out of the furnace.

19. As the stream of molten alumina issues from the furnace spout, it is struck by a high-pressure blast which forms it into small hollow globules. By this method, any carbon or carbide formed and any remaining iron oxide is volatilized. These globules are then leached with sulphuric acid and washed to remove lime. When dried, alumina is ready to be reduced to metallic aluminum.

20. *Haglund electrothermal process.*—Experimental work on the Haglund process was carried on at Lautawerk, Germany, in 1924, by the Vereinigte Aluminum Werke, A.G. This process has been adopted by the Società Italiana dell' Aluminio operating at Mori, Italy, a company in which German capital is interested.

21. The Haglund process differs from the Frary process only in that a sulphide of a heavy metal is added to the electric furnace charge to lower the melting point of aluminum oxide. The melting point of aluminum oxide is 2,200° C. and that of aluminum sulphide about 1,100° C. Pyrotite is the sulphide usually added to bauxite; both metals are reduced with the requisite amount of carbon. The sulphide-oxide slag produced separates completely from the other impurities. As the slag cools, the aluminum oxide crystallizes. The slag is crushed and washed. Hydrogen sulphide formed may be used for sulphurizing bauxite high in iron. This reduces the amount of pyrotite required in the charge and lessens the power consumption per short ton of aluminum oxide from 5,400 kilowatt-hours to 4,082 kilowatt-hours.

22. The remaining mixture, containing crystallized aluminum oxide, aluminum hydroxide, and small amounts of iron sulphide and titanium sulphide passes through classifiers and concentration tables. The aluminum oxide is washed in warm sulphuric acid and dried. The aluminum hydroxide may be used again in the process or may be manufactured into pure alumina, alumina salts, or into cement.[9]

23. *Pedersen process.*—The process patented by Prof. Harold Pedersen was put in operation at Hoyanger, Norway, by the Norsk Aluminum Co. owned by American and Norwegian interests. According to this process, bauxite, iron ore, lime, and coke are smelted in the electric furnace. The ferrous impurities are melted and a calcium aluminate slag is formed. The slag is tapped off, cooled, crushed, and leached with a hot dilute solution of sodium carbonate containing a small amount of caustic soda. After filtering and washing, the aluminum hydrate is precipitated from the solution by carbon dioxide. It is filtered and washed again and calcined to alumina.

This process was tested by the United States Bureau of Mines cooperating with the research bureau of the Aluminum Co. of America.

[9] Haglund, Ture R. "The Haglund Process for the Electrothermal Production of Pure Aluminum Oxide." Industrial and Engineering Chemistry, January 1926.

24. *Acid process.*—Acid processes are suggested, frequently, for the removal of alumina from clays. The Blanc process is being tried out on a semicommercial scale on leucite deposits in Italy. This ore is a double silicate of alumina and potassium (K_2O, Al_2O_3 $4SiO_2$). The success of the experiment is of special interest to western United States as the Leucite Hills in Sweetwater County, Wyo., are estimated to have almost 2,000,000,000 tons of leucite-bearing rock containing 8 to 12 percent potash and from 9 to 13 percent alumina.

25. The leucite is crushed and gangue removed by a magnetic separator. Silica remains when the ore is leached with hydrochloric or nitric acid and the solution drawn off. Potassium chloride crystallizes out as the solution is cooled. The remaining hydrated aluminum chloride is precipitated by additional acid and is calcined to alumina. As leucite contains much smaller amounts of alumina than bauxite, the success of the process depends upon the production of potash as well as of alumina.

TABLE II.—*Estimated operating cost of extracting one ton alumina from bauxite*

Cost item	Bayer process		Haglund process			
			At prices in Germany		At prices in United States	
Power consumption	208 kw.-hr. at $0.004.	$1.07	4,082 kw.-hr. at $0.0017.	$6.94	At $0.002	$8.16
Bauxite	2.2 tons at $5.60	12.32	2 tons at $5.62	11.24	At $5.60	11.20
Bituminous coal	2.64 tons at $2	5.28				
Coke and coke breeze			800 pounds at $4.32	1.72	At $4.09	1.64
Lime	0.25 ton at $7.30 [1]	4.19				
Soda ash	0.125 ton at $98.90					
Pyrolite			666 pounds at $6.48	2.15	At $2.60	.86
Electrodes			70 pounds at $75.62	2.64	At $60	2.10
Labor	24 man-hours at $0.50.	12.00	16.5 man-hours at $0.21.	3.46	11 man-hours at $0.50.	5.50
Miscellaneous supplies, repairs, and general expense.		10.00		5.62		5.62
Total operating cost.		44.86		33.77		35.08

[1] Figured on a recovery of one half sodium hydroxide.

26. *Production of synthetic cryolite.*—Cryolite is essential to the electrolytic dissociation of alumina. The only natural deposit is found at Ivigtut, Greenland. The mining is done by a Danish company under lease from the Danish Government. Since 1865 all exports to North and South America have been controlled by the Pennsylvania Salt Manufacturing Co. of Philadelphia which applies cryolite in chemical manufacture and sells it to glass and aluminum manufacturers.

27. But cryolite (Na_3AlF_6) is also made synthetically. The mineral fluorspar, consisting of 48.9 percent fluorine and 51.1 percent calcium when pure, is treated with sulphuric acid to produce hydrofluoric acid. This reacts upon alumina and soda to form cryolite which is dried and calcined. The alumina and soda may be gotten from sodium aluminate made in the Bayer process. Or, sodium carbonate and aluminum hydrate may be employed.

28. *Carbon electrode and carbon lining manufacture.*—As each ton of aluminum produced consumes about three fourths of a ton of

electrode, carbon electrodes are an essential part of aluminum manufacture. Petroleum coke or specially prepared anthracite coke is the carbon material used in their manufacture. This is crushed and calcined to remove volatile constituents and to shrink the coke. Calciners are usually gas fired, although an electrically heated calciner is employed at Arvida; required temperatures range from 900° to 1,100° C.

29. *Electric calciner.*—The electric calciner of the continuous type heats the coke, as it is fed into a vertical chamber, by electric current introduced by upper and lower electrodes. The gas formed is recirculated through the furnace after it has been washed in order to preheat the entering coke rendering it electrically conductive.

30. *Baking the electrode.*—Calcined coke is then mixed with tar, pitch, and pulverized reclaimed or rejected electrodes. The mixture is shaped into electrodes of proper size and is baked in gas-heated or electrically-heated furnaces. The electrodes are surrounded with coke dust which, in the electric furnace, acts as a resistor and carries the current. Baking is done at a temperature of from 1,000° to 1,400° C.

31. After cleaning, copper or iron suspension rods are attached to the electrodes which serve to carry the current as well as to suspend the electrode in the cell.

32. *Söderberg electrode.*—The Söderberg continuous electrode is being tried out in aluminum production. By enclosing the heated petroleum coke, tar, and pitch in an aluminum mantle, the consumption of the mantle during the process does not introduce impurities into the cell. Should this type electrode be adopted, separate baking of electrodes would be avoided, as the Söderberg electrode is baked by the heat of the electrolytic furnace into which it projects through a hole in a platform above the cell.

33. *Carbon lining.*—The electrolytic cell used in the production of aluminum is a steel box lined with a 6 to 12 inch thickness of carbon. This lining is built up of carbon blocks cemented in place with ground coke, tar, and pitch. These blocks are prepared and baked in the same manner as are the electrodes. Or, powdered coke with tar and pitch may be rammed into the cell using a steel shell for shaping. This lining is baked in the furnace at a temperature of 600° to 800° C.

34. *Reduction of aluminum.*—As has been stated, the electrolytic cell employed in aluminum reduction from its oxide is a steel cell heavily lined with carbon. Carbon anodes are suspended in the bath from aluminum or copper busbars above the cell. In beginning the cell operation some granulated carbon is placed in the cell base. The anodes are lowered and by their contact with this carbon the furnace is heated. Cryolite, a double fluoride of sodium and alumina plus calcium fluoride or other fluorides, is added slowly. The anodes are raised as the furnace is filled. After the cryolite bath has melted, alumina is added in small amounts. At a temperature slightly above its melting point cryolite dissolves from 10 to 20 percent of its weight of aluminum oxide. The current decomposes this aluminum oxide, the molten aluminum settling at the furnace bottom while the oxygen rises to the anodes.

35. The gas given off at the anodes keeps the electrolyte agitated as does the passage of the current through it from anode to cathode. This is essential in order that the alumina added from time to time does not drop to the cell bottom before it is dissolved.

36. *Power consumption.*—Aluminum reduction cells require direct currents of low voltage, 5 to 7 volts, and high amperage. As it is not economical to build generators of such low voltage, cells are arranged in series so that current passes from one to the other. Consequently, generator voltage usually lies between 200 and 600 volts and amperage from 8,000 to 30,000 amperes, depending upon the size and number of electrodes.[10] While direct-current generators may be driven directly by a prime mover, it is more usual to transmit alternating current from a hydroelectric plant to the reduction plant where it is transformed to proper voltage for rotary converters which convert it into direct current. These converters are operated in parallel on a bus system, although sometimes each converter operates one line of cells.

37. Power efficiency is affected by a number of factors. The newest plant of the Aluminum Co. of America is reported to reduce 1 short ton aluminum with a cell consumption of 18,000 to 19,000 kilowatt-hours of energy. Frary and Edwards, the director and assistant director of research for the company, report 20,000 to 24,000 kilowatt-hours per ton to be normal practice. Aluminum is tapped from the cells in small quantities, is blended with aluminum from other cells, and poured into molds.

INGOT PRODUCTION

38. *Refining aluminum.*—The aluminum produced by the Hall process is not more than 99.7 percent pure. If aluminum of higher purity is required, an electrolytic refining takes place. The refining cell, patented by William Hoopes in 1925, is divided horizontally into two electrically insulated sections. A copper-aluminum alloy forms the anode which rests at the bottom of the cell. The electrolyte is made up of alumina, cryolite, aluminum fluoride, and barium fluoride. Graphite cathodes are employed. The aluminum is dissolved from the anode into the electrolyte and is deposited at the cathode.

39. These electrolytic refining cells require about 5 to 7 volts and about 20,000 amperes. A metal of 99.99 percent purity has been obtained.

40. *Remelting.*—Pig aluminum from reduction works is usually remelted to permit casting the metal into workable form, to remove some of the oxide, or to add alloying metals. When large amounts are to be remelted, an open-hearth furnace, heated by oil or gas, has been commonly employed. Smaller amounts are melted in iron-pot or barrel type furnaces, also heated by oil or gas. Melting temperature is kept as low as is consistent with pouring requirements and does not usually exceed 732° C. The electric furnace for remelting is just beginning to be adopted in the United States, although it has been applied in specific instances since 1918.

41. *Alloying.*—Some hardening metals are added in the form of rich aluminum alloys; that is, a 50 percent aluminum—50 percent copper alloy, or a 90 percent-10 percent manganese alloy is first made, and the alloy added in proper proportion to the aluminum remelt. Such minerals as magnesium, zinc, and silicon are usually added without alloying.

[10] Frary, Francis C., and Edwards, Junius D., The Aluminum Industry, p. 319.

42. *Remelting secondary aluminum.*—In the melting of secondary aluminum in a number of forms such as borings, old castings, or sheet scrap, it is usually necessary to employ a flux to separate the aluminum from the oxide. Zinc chloride or aluminum chloride may be applied. Puddling is done in a special reverberating furnace or in an iron pot, gas or oil heated. Dross is skimmed off and the metal thoroughly mixed in order to insure uniform composition.

43. *Casting of aluminum and aluminum alloys.*—Remelted aluminum from new or secondary metal is usually cast into notched-bar ingots sold as metallurgical ingot, rolling ingot, extrusion ingot, forging ingot, or casting ingot in accordance with the purpose to be served by particular sizes and shapes. If aluminum is to be reworked at the plant, it is cast directly into desired form for the particular operation. The metal is poured slowly into molds that it may solidify as the mold is filled. The mold and hot ingot are quenched in water. When castings are to be made directly from molten metal, the metal may be transferred to iron-pot furnaces in which a variety of conditions can be effected in the metal before casting.

COST OF PRODUCING ALUMINUM

44. Table II on page 114 gives the estimated cost of extracting alumina from bauxite by the Bayer or alkali process as it is now done in the United States and estimated cost by the electrothermal process being employed in Italy. Haglund, the inventor of the second process, claims that the cost of erecting a 25,000-ton alumina extraction plant in Germany would cost $43.20 per ton for the electrothermal process and $200 per ton were the Bayer process to be applied. As the only Bayer plant in operation in the United States has been built over a period of 40 years until its capacity is approximately 400,000 tons alumina, its cost would have been less than that quoted by Haglund. Be this as it may, European and American companies are building electrothermal extraction plants rather than chemical extraction plants, indicating that electric extraction plants are cheaper, all items considered, for present-day development.

44½. The following itemization of cost of producing 1-ton aluminum from alumina includes all capital and overhead expenses necessary to the extraction of alumina as well as to the reduction to aluminum, for separate statements of capitalization and overhead are not made by aluminum producers.

TABLE III.—*Estimated cost of producing 1-ton aluminum*

Cost item	Total cost per short ton	
Factory operating cost:		
Alumina, 2 tons, at $46 [1]	$92.00	
Alumina, 2 tons, at $35 [2]		$70.00
Carbon electrodes, 0.75 ton, at $60	45.00	
Cryolite, 200 pounds, at $73.38	7.34	
Aluminum fluoride, 100 pounds, at $90	4.50	
Power, 21,000 kilowatt-hours, at $0.002	42.00	
Miscellaneous operating expenses	42.60	
Total operating cost	233.44	
Administration, depreciation, research, selling, and other overhead charges on alumina and aluminum production	120.00	
Interest on investment of $1,700 per ton, at 6 percent	102.00	
Total cost of 1 ton aluminum	455.00 to 433.00	

[1] Estimated cost of Bayer process alumina plus freight.
[2] Estimated cost by an electrochemical process carried on at aluminum plant.

Working of Aluminum

HOT WORKING

45. *Electric preheating.*—When ingots are to be hot worked into rods, bars, or slabs, they are preheated to insure even temperature throughout the ingot that will permit of most effective working. This preheating is done in soaking pits. At Massena, N.Y., 14 electric pit ovens are used requiring 3,000 kilowatts of electricity. The ingots are transported to and from the ovens by electrically operated cranes and the temperature is controlled by electrical recorders, regulators, and light indicators. Rolling temperature lies between 316° and 510° C. according to Aluminum Co. specialists.[11]

46. Hot working is accomplished by passing the heated ingot between oppositely driven rolls. The blooming mill at Massena is said to be the largest in the world having rolls measuring 38 inches in diameter by 84 inches in length. This requires a 5,000-horsepower adjustable-speed reversing unit. Instead of being operated by a feeder, 2 catchers and 2 helpers, as is usual in older mills, at Massena 2 men control all operations from an elevated platform. The product from the mill is delivered to electrically operated shears on an electrically operated table.

COLD WORKING

47. *Annealing.*—Slabs produced by hot rolling are further reduced to flat sheet or strips by passing through other rolls; rods, bars, and structural shapes may also be cold rolled. Cold worked aluminum is given a heat treatment to produce a new crystal structure in the metal. It is usually annealed at a temperature of 316° to 343° C. with higher temperatures for some alloys. Annealing furnaces may be heated by electricity, oil, or gas. At Massena, finished pieces from the structural mill pass into and through a 90-foot electric oven having 26 temperature zones, each of which can be separately controlled. Pieces come out of the annealing oven onto power operated roller tables, pass through a quenching bath to a straightening iron. They are then cut to size.

48. Annealed sheet and plate may be worked further into foil, powder, corrugated sheet, or circles for tubing. Bars and rods are fashioned into wire, the wire into cable, nails, or rivets. Hollow ingots are also made into tubing.

49. *Castings.*—Casting ingot is cast into sand castings, permanent mold castings, and diecastings according to the market to be served. A new electric furnace has been designed for heat treatment of aluminum alloy castings. A furnace designed to heat a 1-ton charge (which includes a 500-pound basket) from 316° to 510° C. required 84 kilowatts at high heat and 28 kilowatts at low heat. The heating required 1 hour and the charge was held at 510° C. for 12 hours. The radiation rate at the holding temperature was 17 kilowatt-hours.[12]

Sources of Raw Materials

50. *Occurrence of metallic aluminum.*—The element aluminum forms 8 percent of the earth's crust. It is found as a silicate in clays, feldspars, micas, leucite, and other minerals, and as an oxide in bauxite,

[11] Bakker, H. E., and Edwards, Junius D. Working of Aluminum, in The Aluminum Industry.
[12] General Electric Review, January 1930.

corundum, andalusite, diaspore, and still other minerals. In spite of its abundance, practically all alumina for the aluminum industry is secured from bauxite which is a hydrated oxide of aluminum containing minor amounts of iron oxide, silicon, titanium oxide, or other impurities. Bauxite is also used in the manufacture of aluminous abrasives and refractories, in the manufacture of cement, and in the production of aluminum sulphate for the paper industry, and of aluminum chloride for petroleum refining, as well as in the production of various alums.

51. Other aluminous minerals are employed in the ceramics and refractories industries. Low-grade aluminum silicates have been used successfully for alumina production in the laboratory, but the extensive deposits of bauxite in many sections of the world do not make any process suggested to date commercially feasible. However, a small tonnage of alumina for refractories is produced from alunite in Utah as a byproduct of potash production and a potash-alumina industry using leucite as the ore is being developed in Italy. Should the latter attempt at a combined industry prove commercially feasible, a similar development might be possible in Wyoming thereby furnishing the country with a source of potash as well as of aluminum.

52. *Leucite rock.*—The largest known area of leucite rocks in the United States is in the Leucite Hills in the north half of Rock Spring Dome, Sweet Water County, Wyo. The potash content of these rocks is 7.99 percent to 11.91 percent and the alumina content varies from 9.14 percent to 13.37 percent, according to the United States Geological Survey. Federal geologists estimate that there are almost 2,000,000,000 tons of leucite in these hills and that they contain almost 200,000,000 tons of alumina and an equal amount of potash. (See p. 114 for reduction methods.)

53. *Bauxite deposits.*—Prior to 1914 most of the world's output of bauxite was mined in France and in the United States. Since that time commercial mining has been extended and new discoveries of bauxite deposits have greatly increased the quantity available. Although estimates of exact quantity and character of the deposits have not been made, there seems no question concerning abundance of the bauxite supply. At present the chief producing countries are France, the United States, South America, Hungary, Yugoslavia, and Italy. A number of other countries are producing minor quantities.

54. *Mining of bauxite in the United States.*—The United States produced 409,670 short tons of bauxite in 1929 and imported 426,509 short tons. Only 38 percent of the domestic production was consumed by the aluminum industry, the remainder entering into other industries. A third of our imports were reexported. Actual consumption of bauxite in the aluminum industry of the United States totalled 470,476 short tons.

55. The principal producing fields are in Saline and Pulaski Counties of central Arkansas; production has been carried on since 1899. Bauxite is also found in Williamson County, Ga.; Sumter, Randolph, and Barbour Counties of southeastern Alabama; as well as in northwestern Georgia, northeastern Alabama, northeastern Mississippi, and eastern Tennessee. This field has produced steadily, but in small quantities, since 1889. Its bauxite is used, however, chiefly for the abrasive, refractory, and chemical industries rather than for aluminum manufacture. Arkansas bauxite contains slightly less than 60

percent alumina, 5 percent or more silica, and is low in ferric oxide. The Georgia-Alabama-Tennessee field has from 54 to 58 percent alumina, with a silica content ranging from 6 to 12 percent, and from 1 to 3 percent ferric oxide. Diasporic clay is found in central Missouri; while this runs as high as 70 percent in alumina content, it has been used entirely for the manufacture of refractories, abrasives, and chemicals.

BAUXITE DEPOSITS IN SOUTH AMERICA

56. *Brazil.*—Bauxite deposits are in the districts of Minas Geraes and Maranhao.

57. *British Guiana and Dutch Guiana.*—Large deposits of excellent quality bauxite run across British Guiana into Dutch Guiana. Its average composition is about 60 percent alumina, 2 percent silicon oxide, 2.5 percent titanium oxide, and from 2 to 6 percent ferric oxide. The deposits are found in small hills above the general level of the coastal plains and are from 15 to 100 miles from the coast along the rivers. Bauxite from these deposits is shipped principally to the United States and Canada for aluminum manufacture.

BAUXITE DEPOSITS IN EUROPE

58. *France.*—France is still the largest producer of bauxite. The mineral occurs in a belt almost parallel to the Mediterranean, the largest producing area being at Var. The alumina content of French ores ranges from 50 to 65 percent, but much of it contains large amounts of iron oxide. It is believed that ore reserves total 60,000,000 metric tons.[13] While much of this ore is refined in southern France, considerable amounts are shipped to Great Britain and Germany.

59. *Germany.*—There is little or no bauxite in Germany. She is, therefore, developing Hungary's deposits while at the same time importing bauxite from France, Italy, Yugoslavia, and from other sources.

60. *Great Britain and Ireland.*—Antrim Island has bauxite but it is not of good quality.

61. *Greece.*—Bauxite is produced from mines located at Distomar on the Gulf of Corinth.

62. *Hungary.*—Large deposits of bauxite lie close to the Danube River or its tributaries in western Hungary. Deposits have been recently discovered in the Vertes Mountains. Deposits are easily mined and contain alumina content of from 57 to 62 percent. This is exported to Germany for refinement as there is little or no bauxite in Germany.

63. *Italy.*—The ceding to Italy of high-grade bauxite deposits of Istria, formerly belonging to Austria, makes Italy one of the important producing countries. The Istrian deposits are similar to those in Yugoslavia. Bauxite is also found in the central Appenine Mountains, in the Province of Aquilo, and in the Province of Benevento.

64. *Norway.*—Bauxite was discovered in 1930 on a Norwegian Island, Jan Mayen, in the Arctic Ocean. The qualities of this ore are not yet known, but there are expectations that this supply will free Norway from its dependency on other countries.

---

[13] Powlowski. Les Bauxite Francaises. Paris. 1925.

65. *Poland.*—A newly-found deposit which will produce a large tonnage has been opened.

66. *Rumania.*—High-iron bauxite from large deposits are reported in the Bihrar Mountains and on the Kiratyerdo Plateau.

67. *Spain.*—Bauxite is produced near Barcelona.

68. *Yugoslavia.*—High-grade ore deposits are being mined in Dalmatia in Yugoslavia. The ore is high in ferric oxide and low in silica. It is reported that the Provinces of Herzegovina and Croatia also have large undeveloped deposits and that much ore is found along the coast of Montenegro. While much of this production reaches Germany, some has been shipped to the United States.

BAUXITE DEPOSITS IN OTHER COUNTRIES

69. *Africa.*—Although bauxite has not yet been exploited commercially, surveys indicate that it exceeds 4,000,000 tons in Ashanti and 50,000,000 tons at Mount Supirri.[14] Twenty million tons are reported in Nyassaland and indications are that other sections have ample supplies.

70. *Dutch East Indies.*—Some deposits are being developed in the Singapore district.

71. *Australia.*—In Victoria bauxite is being mined by the Sulphates Proprietary, Ltd. In Western Australia deposits have been found and the search for richer deposits is going on.

72. *India.*—At present the production is small, although there are believed to be extensive deposits not only near the west coast but also in the north, central, and southern parts. Some fields are adjacent to important prospective water-power developments.

FLUORSPAR AND CRYOLITE

73. As has been stated, only one commercial deposit of cryolite is known to exist in the world. This deposit at Ivigtut, Greenland, is controlled by the Danish Government. While 7,778 long tons were imported into the United States in 1929, the aluminum industry is turning to the use of a synthetic cryolite made from fluorspar. Such application adds to the importance of fluorspar as an essential raw material in aluminum reduction.

74. Fluorspar is composed chemically of 51.1 percent calcium and 48.9 percent fluorine. It occurs in deep vertical veins which are usually very pure, as bedded deposits, and as superficial pick-and-shovel deposits. That required for the manufacture of hydrofluoric acid, which is reduced to synthetic cryolite, must contain a minimum of 98 percent calcium fluoride and not more than 1 percent silica.

75. Fluorspar is known to occur in 21 States of the Union. It was produced, in 1929, in Illinois, Kentucky, Colorado, New Mexico, and Nevada. During 1918 production occurred also in Washington, Utah, Arizona, and New Hampshire. By far the largest amount has been mined in a belt extending from Hardin County in southern Illinois across the Ohio River into western Kentucky. This belt is said to contain the largest high-grade fluorspar deposits known.

76. *Rocky Mountain States.*—Production in Rocky Mountain States has not been extensive because the market for fluorspar in this

[14] Kitson Gold Coast Geological Survey Mining Magazine, 33. 1925.

region has been limited to the few steel plants. Fluorspar has been mined at Jamestown in Boulder County; at Rosita in Custer County; at Duffields in El Paso County; at Evergreen in Jefferson County; and at Wagon Wheel Gap, Mineral County, Colorado. It occurs also in a number of other counties in this State. The quality of fluorspar is said to be excellent. In New Mexico mining has occurred in Dona Ana, Sierra, Luna, and Grant Counties, and deposits are reported in other counties. The lack of an abundant water supply has not been conducive to fluorspar mining at some locations, water being necessary to wash the ore. Fluorspar mined in Nevada in 1929 came from Nye County and Mineral County. While most of this ore was shipped to steel plants, some fluorspar from Mineral County was used in the manufacture of hydrofluoric acid.

77. A survey of the Nation's fluorspar deposits has not been made, principally because present known resources have been regarded as adequate to meet the country's needs. And yet, while 146,439 tons were produced in this country in 1929, 54,345 tons were imported. France and Germany were the chief sources of imported fluorspar. Other countries which shipped fluorspar, chiefly to our steel mills, were Spain, Italy, the United Kingdom, and Africa. Canada produced fluorspar mainly in British Columbia.

78. The successful operation of a flotation mill on mill tailings in 1929 marks the beginning of the use of lower-grade ores for aluminum industry fluorspar.

79. The sources of the third material essential for aluminum reduction, petroleum coke, have been discussed fully in the Original and Some New Electric Furnace Products, page 440.

Organization and Location of Aluminum Producing Units

80. The Aluminum Co. of America is the sole producer of aluminum in the United States. In May 1928 its properties in Canada and in Europe were transferred to a newly incorporated company called Aluminum Limited. As, however, a large part of Canadian production is shipped into the United States and, therefore, materially affects production in the United States, operations in Canada will be considered along with those in this country.

SHIPMENT OF BAUXITE

81. *Mines.*—Less than half of the bauxite now manufactured into aluminum in the United States is secured from deposits in this country. Although the Aluminum Co. of America, through its subsidiary American Bauxite Co., owns extensive mines at Bauxite, Ark., and through a subsidiary, the Republic Mining & Manufacturing Co., owns bauxite properties in Georgia, Alabama, and Arkansas, the bauxite drawn from these properties for aluminum production is decreasing. In its stead, large quantities are being imported from Dutch Guiana and British Guiana. In Dutch Guiana the Aluminum Co. of America operates mines through its subsidiary, Surinaamsche Bauxite Maatschappij. In British Guiana its subsidiary, Demerara Bauxite Co., Ltd., owns extensive private properties and also has a concession from the British Government. The Aluminum Co. of America also owns deposits of low-grade ore in Minas Geraes, Brazil, which are not mined at present.

82. The ore consumed at the Canadian plants of the company came chiefly from the South American operations, even though a part of this was exported to American ports and then reshipped to Canada.

83. *Steamship lines.*—The Aluminum Co. of America owns two steamship lines. One, the Aluminum Line, which plies between the Guianas and New Orleans, Mobile, and Tampa; the other, the Ocean Dominion Steamship Corporation, which plies between the Guianas and Halifax, Montreal, and New York. As these are not common carriers, the Merchant Fleet Corporation reports that all rates are closed rates.

84. *Railroads.*—The Aluminum Co. of America also owns the Bauxite & Northern Railway Co., which carries bauxite and other freight from Bauxite, Ark., to the Iron Mountain Railroad. Bauxite from the Mississippi River port near St. Louis to East St. Louis is handled by a second company railroad, the Alton & Southern Railroad. A third railroad, the St. Louis & Ohio River Railroad, carries coal from the coal mines to East St. Louis. A fourth short line, the Massena Terminal Railroad Co., hauls freight from the main lines of the New York Central and Grand Trunk Railway to the company's plant at Massena and to the town of Massena. All these railroads not only carry the freight for the plants but also act as common carriers.

85. *Freight rates.*—According to the Inland Waterways Corporation, the shipping charge on bauxite from New Orleans to East St. Louis is $3 per gross ton without handling charges. The Interstate Commerce Commission quotes an all-rail rate from Bauxite, Ark., to East St. Louis, at $3.65 per gross ton.

86. The Aluminum Co. supplies its European plants in part from its own European mines. In France it owns two deposits outright and through the Norsk Aluminum Co. has half ownership in a third deposit. It also has one-half interest in Societa Anonima Mineraria Triestina, Istria, Italy. About two thirds of the stock interest of Primorski Bauxit Dioni' Co. Drustvo, in Dalmatia, Yugoslavia, is owned by the Aluminum Co. Small quantities of ore have been shipped into this country from Yugoslavia and from France.

87. *Fluorspar mining.*—The Fluorspar necessary for the manufacture of artificial cryolite is mined by the Franklin Fluorspar Co., which has a flotation mill at Rosiclare, Ill. This, too, is an Aluminum Co. subsidiary.

88. *Alumina works.*—The only alumina works in the United States is located at East St. Louis, Ill. It is operated by the subsidiary, the Aluminum Ore Co. This plant location was chosen because the process employed in alumina extraction required coal, limestone, and soda ash as well as bauxite. As required tonnage of these minerals was greater than bauxite tonnage, the plant was located near a source of these minerals. The company owns the coal mines which furnish all coal for operations of the alumina plant.

89. The East St. Louis plant has a capacity of approximately 400,000 tons alumina and supplies all reduction works in the United States and one Canadian plant with alumina. Freight rates on alumina from East St. Louis to Massena are quoted at $0.69 per hundredweight. Until the development of the Frary process of electrothermal ore reduction, it also furnished alumina to the Arvida plant. At the present time the Arvida plant is reducing alumina

from bauxite which is shipped to it directly or indirectly from South America in small ocean steamers coming through the St. Lawrence River and up the Saguenay River.

90. A second alkali alumina extraction works was started on the Chesapeake Bay in 1916, but it was not completed.

ALUMINUM REDUCTION PLANTS AND POWER DEVELOPMENTS

91. *Massena.*—The largest reduction works of the Aluminum Co. is at Massena, N.Y., where production in a single year has exceeded 50,000 tons aluminum. This plant's supply of power is partly purchased from the Cedar Rapids Manufacturing & Power Co., and partly generated by the Aluminum Co.'s own hydroelectric plant at Massena. This power plant is situated about 600 feet from the aluminum reduction room and transmits 60,000 kilowatts at 600 volts on aluminum transmission lines supported by aluminum frame structures. The water power is developed by deflecting water from the St. Lawrence River through a 3-mile canal to the Grasse River. Several smaller plants are located at points on the Raquette River. These smaller plants make available an additional 45,000 kilowatts to Massena.

92. Just recently, a blooming mill has been completed at Massena which is reported to have a capacity of 500 tons a day. It is said to be the largest structural aluminum plant in the world. In this plant all operations from the remelting of the aluminum pig to final heat treatment are carried on electrically and all mechanical equipment, temperature controls, and regulators are operated electrically.

93. *Alcoa.*—The second largest reduction plant in this country is located at Alcoa, adjoining Marysville in Blount County, Tenn. The reduction plant was built in 1914 and has been increased in size until it now has 10 pot rooms. In 1919 a plant was built to supply the carbon electrodes. In 1920 a sheet mill was added. A new rolling mill has been built which has an initial capacity of 500 tons per month with provisions for increasing this capacity to 1,500 tons per month. In 1929, an aluminum bronze powder plant was built to manufacture pigments for use in aluminum paint. The power is transmitted to Alcoa from two power houses of the Tallassee Power Co. located above Alcoa on the Tennessee River. A third source of power has just been completed further up the Little Tennessee at Calderwood. This power plant is equipped with two 56,000-horsepower units operating on 213 foot head. Provision has been made for addition of a third unit.

94. *Badin.*—The third reducton works of the Aluminum Co. of America is located at Badin in Stanly County, N.C. This has six pot rooms, and a carbon plant which supplies the necessary electrodes and pot lining material. It is served by 3 power houses, 1 at Badin, 1 at Yadkin Falls, and the third at High Falls—all on the Yadkin River.

95. *Niagara Falls.*—The fourth reduction plant is at Niagara Falls. This was the location of the company's original plant but only a small part of the entire development at this location is now operating. Power is purchased for this operation. Electrodes are made by the Republic Carbon Co., owned in part by the Aluminum Co. of America.

96. *Canada.*—The original Canadian plant of the Aluminum Co. was establishd at Shawinigan Falls, Province of Quebec. By far the larger plant, however, has been located recently at Arvida. Small ocean steamers can come up the Saguenay River to the plant while larger ones land their cargo at Port Alfred on the St. Lawrence River. This plant gets its cryolite from Greenland and its bauxite from Dutch Guiana and British Guiana. All processes in the manufacture of alumina, aluminum ingots, as well as electrodes and cell linings are carried on electrically at this factory. Power is secured from the Chute a Caron Power Co., Ltd., through which Aluminum Limited owns riparian rights on the Saguenay River. About 500,000 horsepower has been or is being developed at Isle Maligne and additional construction is under way that will bring the total horsepower available at Arvida operations to 1,000,000 horsepower.[15]

97. *Europe.*—The Aluminum Co. of America, through affiliations with the Societa dell' Aluminio Italiano, operates a reduction plant in Italy having a capacity of 5,000 to 6,000 tons per annum. Through affiliations with the Norsk Aluminum Co. and Det Norske Nitridaktieselskab it operates plants in Norway. Its relationship in Det Norski Aktiessilskat for Electrokewski Industri gives it partial rights to land for the development of two water power sites in Norway, and valuable electrode patent rights.

98. *Other power sites.*—In addition to the power plants owned at or near Massena, N.Y., in the Great Smoky Mountains of Tennessee, on the Yadkin River in North Carolina, and on the Saguenay River, Canada, the Aluminum Co. of America acquired property as early as 1906 near Long Sault Rapids in the St. Lawrence. This has never been developed due to the lack of coordinate legislation on the part of the United States Government, the State of New York, the Canadian Dominion's Government, and the Province of Ontario. It also has undeveloped power sites in the Great Smoky Mountains of Tennessee.

ROLLING MILLS

99. The following rolling mills are operated by the Aluminum Co. of America. Their estimated capacity is given.

Location	Annual capacity
United States:	
New Jersey:	
Edgewater, Bergen County	10,500 short tons.
New York:	
Niagara Falls	10,500 short tons.
Massena	175,000 short tons (reported).
Ohio:	
Cleveland	6,600 short tons. Forging capacity to be tripled.
Pennsylvania:	
Arnold, Westmoreland County	6,000 short tons. New tube mill to be added.
New Kensington, Westmoreland County.	7,500 short tons.
Tennessee:	
Alcoa, Blount County	16,500 short tons. (Provision for increase to 28,500 tons.)
Wisconsin:	
Manitowoc	Sheets for own utensil production, only.
Two Rivers	
Canada: Toronto	1,650 short tons.

[15] Edwards, Junius D., Assistant Director of Research, Aluminum Co. of America. Aluminum and its Production.

OTHER FABRICATING PLANTS

100. The company also owns plants manufacturing castings, forgings, or other aluminum articles.

Plant location	Subsidiary	Product manufactured
California: Oakland	Modern Foundry and Pattern Works	Aluminum castings.
Connecticut: Fairfield	Aluminum Manufactures, Inc	Sand castings.
Michigan:		
Detroit	do	Sand castings for automobile parts.
Do	Aluminum Co. of Michigan	Aluminum fabrications for automobiles.
New Jersey:		
Edgewater	Aluminum Index Co	Aluminum index cards.
Do	Aluminum Screw Machine Products Co.	Screw-machine products.
Garwood	Aluminum Die-Castings Co	Die castings.
New York:		
Buffalo	Aluminum Body Co	Aluminum automobile bodies.
Do	Aluminum Manufactures, Inc	Castings.
Ohio: Cleveland	do	Sand castings for automobile parts.
Pennsylvania:		
Arnold	Aluminum Seal Co	Bottle closures.
New Kensington	Aluminum Cooking Utensils Co	Cooking utensils.
Do	United States Aluminum Co	Fabricating sheets, wire, tubing, rods, and other semifinished products.
Do		Aluminum-bronze powder and foil.
Wisconsin: Manitowac and Two Rivers.	Aluminum Goods Manufacturing Co.	Cooking utensils and novelties.

European fabricating plans

Plant location	Subsidiary	Product manufactured
England	Birmingham Aluminum Castings Company, Ltd.	Castings.
France	Fondrie De Precision	Die castings.
Germany	Aluminum Spritzgriss Werke, G.M.B.H.	Do.
Italy: Milan	Anonima Italiana Conduttori Alluminio.	Transmission wire and cable.
Norway	Norsk Aluminum Company	Crude and fabricated aluminum.
Switzerland	Arbon and Rorschach, through Societi Anonyone d' Aluminum Coire.	Castings.

ALUMINUM CONSUMPTION

101. *Grades.*—Virgin aluminum is sold in ingot form in three grades. Grade A, 99 percent or more aluminum, is used for sheet and other wrought products. Grade B, 98 to 99 percent aluminum, is used largely for alloy castings. Grade C, or 94 to 98 percent aluminum, in grain or granulated form is used principally for deoxidation in steel manufacture. Grade A and an alloy containing about 1.25 percent manganese, known as "3S", are produced in all forms in which aluminum is used.

102. Grade A was quoted at $0.243 throughout 1929 and until June 26, 1930; on that date a new price, $0.233, was announced which still pertained in April 1931. Grade B dropped during the same period from $0.239 to $0.229.

103. *Domestic markets.*—Continuous research has brought about an expanding market for aluminum. As new uses for the metal have been found, its relative importance in older markets has shifted. In the early days of the industry the largest amount of aluminum was consumed in cooking utensil manufacture. As aluminum alloy castings found a market in the automotive industry this became the largest single consumer of aluminum. In 1925 cooking utensil manufacture took but 10 percent of the total aluminum produced and automo-

biles approximately 60 percent. However, with the falling off in automobile sales in 1930 and with the expansion of the aluminum market into structural and other fields, the automotive industry consumed less than 36 percent of the total 1930 production while our cooking utensils consumption increased to 14 percent.

104. The United States Bureau of Mines quotes the 1930 consumption of virgin domestic aluminum in the several industries as follows:

	Percent
Transportation (land, air, and water)	38
Electrical conductor	16
Cooking utensil	14
Machinery (electrical appliances, etc.)	9
Iron and steel metallurgy	8
Building	4
Miscellaneous foundry and metal working	4
Chemical	2
Food products	1
General miscellaneous	4

CONSUMPTION IN TRANSPORTATION INDUSTRIES

105. *Automobiles.*—As has been stated, the automotive industry consumes large quantities of aluminum-copper alloy castings as well as some aluminum-zinc and some aluminum-silicon alloy castings. These are fashioned in pistons, crank cases, cylinder heads, transmission cases, and into a number of small parts. Strong alloys are entering into truck and bus body frames, while tops and sides are also made of aluminum.

106. *Aircraft.*—Aluminum castings are also entering into aircraft construction. Not only are castings used for aluminum pistons and other aircraft engine parts, but they are also employed for aileron levers, control levers, shock absorbers, fusilage, and landing gears. Duraluminum, containing copper and small amounts of manganese and magnesium, has been used for aircraft structures. Unalloyed aluminum is used for gasoline and oil tanks. Aluminum propellers are also in use. In aircraft construction aluminum alloys must compete with magnesium alloys, for magnesium alloys not only possess equal tensile strength and ductility but also save 40 percent in weight. Some of the magnesium alloys do, of course, contain aluminum, but the amount is relatively small. (See p. 307 of Power in the Manufacture of Chemicals and Metals from Brine.)

107. In the lighter-than-air craft strong aluminum alloys have also become accepted materials. The Zeppelins have employed it as their principal construction metal not only in the internal framework but also in the covering. Duraluminum is used in the framework, whereas alclad, an alloy core covered with a layer of pure aluminum integral with the core, is used for the outer covering.

108. *Railroads.*—Strong aluminum alloys are entering also into railroad-car construction largely because of their lightness which permits a saving in power required for operation. Aluminum-tank cars resistant to certain acids have become the method of transporting such acids. Aluminum is also being applied to steam and electric locomotive reciprocating parts.

109. *Marine construction.*—Aluminum has been used in the construction of yachts and other small water craft, and it is entering into larger marine craft. The Naval Limitation of Armaments Confer-

ence which fixed the displacement limit has turned attention to aluminum alloys as metals of value in the construction of much battleship furniture and equipment.

CONSUMPTION IN THE ELECTRICAL INDUSTRY

110. Weight for weight, aluminum has twice the conductivity of copper. It has been used, therefore, for the transmission of current since 1898. It is the practice today to provide aluminum transmission lines with a steel-wire core to carry the suspended conductor. Effort is being made to introduce an aluminum alloy cable which will not require the steel core; this is marketed as "Aldrey" by a German company and as "Almelec" by a French company. Aluminum insulated cables for underground network systems as well as for automobile wiring systems were also marketed in 1930.

111. Aluminum is used for busbars in power stations and in industrial plants handling heavy currents. Outdoor busbar systems employ stranded cable, while tubing is used for rigid systems and flat strips when large currents are handled indoors. Aluminum is applied also to other electrical equipment in small quantities.

CONSUMPTION IN COOKING UTENSILS AND MACHINES

112. Not only has aluminum held its place as a material for household cooking utensils, but it is employed in restaurants, in canneries, and in packing houses, and in various food factories either because of its lightness, its heat retentivity, or its resistance to acids. Aluminum mason jar cap manufacturing is reported as a market for 10,000,000 pounds of aluminum.[16] The Norsk Aluminum Co. (affiliated with the Aluminum Co. of America) is making aluminum cans especially for use in the fish-canning industry. The major problem is one of cost. By embossing the cans the expense of labeling is saved which, it is claimed, will make aluminum cans as cheap as tin cans.

113. Aluminum is also used in machines that are handled extensively. Vacuum cleaners, typewriters, washing machines, are among the articles that are being constructed of aluminum alloy. Equipment that handles heavy weights such as cranes are also being made of aluminum.

CONSUMPTION IN METAL INDUSTRIES

114. As has been stated, grade C aluminum is applied to steel for deoxidation. It may be added as aluminum or in the form of a silicon-aluminum-iron alloy, but is usually the final deoxidizer employed.

115. Where carbon-free metals are desired, aluminum may be used as the reducing agent. This so-called Goldschmit or thermit process is employed in vanadium, chromium, cobalt, manganese, and certain alloy production. Barium peroxide and aluminum powder in capsule form and having a fuse of magnesium are employed to start the aluminum grain or shot to burning the oxide from the other metals. The same process is used in welding and repairing iron and steel, the aluminum being mixed with iron.

[16] Engineering and Mining Journal. February 1927.

STRUCTURAL USES

116. The development of a casting technique for large aluminum alloy ingots and the design of heat-treating equipment for large structural shapes made possible the completion of an aluminum structural mill in 1929 and the entrance of aluminum alloys into the structural field. The research laboratory of the Aluminum Co. of America at New Kensington was a practical demonstration of the use of aluminum alloys not only for angles, I-bars, channels, and other usual structural shapes, but also for exterior cornices, spandrels, window frames and sills, copings, and roofing accessories. Furniture and equipment as well as cranes are of aluminum alloys. Already building construction in 1930 is credited with the consumption of approximately 5,000 tons of aluminum alloying. The Empire State Building in New York City alone consumed 4,250 tons during its erection. Manufacture has begun on aluminum window screening and on woven and barbed wire for fencing.

OTHER FIELDS

117. The resistance of aluminum to corrosion by certain acids under given conditions has led to its use in construction of storage or transportation tanks for acetic and nitric acid and dilute sulphuric acid. It is also employed for roofing and tubing in plants handling acetic acid such as rayon plants. Aluminum powder is mixed with lacquer, varnishes, bodied oils, or bronzing liquids to make aluminum paint. This is regarded as an excellent priming coat for wood and for painting dark shops. It is applied to exterior steel construction, to oil tanks, and other exposed steel. As foil, aluminum replaces tin and tin-lead foil, in the confectionery, yeast, and tobacco industries.

COMPETITION

118. Aluminum competes with basic metals in each of its major consumption fields. In the electrical industry, it is a substitute for copper; in cooking utensils for iron and tin; in the structural, transportation, and machinery fields for iron and steel; in corrosion resistance equipment, in paint; and as a rubber filler, for zinc; and in foil, paint, and chemical apparatus, for lead. In aircraft it comes into direct competition with magnesium and with steel in tubing for aircraft.

119. The present advantage of the industry lies in the use of aluminum in many diverse fields of industrial activity so that depression in any one industry may not materially affect the prosperity of the entire industry.

LOCATION OF DOMESTIC MARKETS

120. Automobile castings are manufactured close to their largest consuming markets located in Michigan, Ohio, and New York. In these States and in Illinois, New Jersey, Pennsylvania, Wisconsin, Indiana, Missouri, Tennessee, Connecticut, Massachusetts, California, and Washington, alloy castings are made for this and other industries.

121. The largest plants manufacturing cooking utensils are in Pennsylvania and Wisconsin with smaller plants in Illinois and Ohio. The machinery industries which consume aluminum are located chiefly in Ohio, New York, Illinois, Connecticut, Massachusetts, and Iowa. Metallurgical consumers are located in Pennsylvania, Ohio, and New Jersey.

EXPORTS

122. Although aluminum is purchased in ingot form in the domestic market to a large extent, exports of ingot aluminum from the United States were almost negligible in 1929. Plates, sheets, bars, strips, and rods were the largest item of export, amounting to 8,209 tons. More than a third of this went to British India and another third to the United Kingdom.

123. Canada, on the other hand, exported 36,485 tons of aluminum of which 14,181 tons reached the United States, 8,758 tons were shipped to Japan, 6,100 tons to the United Kingdom, 3,443 tons to Germany, 1,596 tons to Switzerland, and less than 1,000 tons to a number of other countries.

124. Japan is dependent on imported aluminum. Although research is underway to make aluminum from clays available in the country, processes to date have been too expensive. The amount which she imports is increasing. It is fabricated at Kobe and Osaka into kitchen and other utensils, into transmission cable, into alloys and about 10 percent into automotive engine castings. The Asia Co., Ltd., of Tokio is the principal aluminum importing company. The Aluminum Co. of America has an interest in this company.

TABLE IV.—*Exports of aluminum products from the United States in 1929 by country of destination* [1] [2]

Country	Bauxite and other aluminum ores (long tons)	Ingots, scrap, and alloys (short tons)	Plates, sheets, bars, strips, and rods (short tons)	Tubes, moldings, castings, and other shapes (short tons)
Total	133,551	307	8,209	1,233
Argentina		6	196	24
Belgium	200	22	272	24
Brazil		1	247	38
British India		29	2,923	581
Canada	125,545	47	283	395
Chile		1	27	2
China		2	305	1
Germany		35	76	
Italy		10	433	48
Japan		97	47	22
United Kingdom	227	52	2,917	74
All others	7,579	5	483	24

[1] Compiled from: U.S. Department of Commerce, Bureau of Foreign and Domestic Commerce, Foreign Commerce and Navigation of the United States for 1929.
[2] Exclusive of kitchenware and miscellaneous fabricated materials.

WORLD PRODUCTION OF ALUMINUM

THE EUROPEAN CARTEL

125. The world's aluminum production is controlled by two groups, the Aluminum Co. of America with Aluminum Limited, and the International Aluminum Cartel. The latter organization is made up of the principal producing companies of France, Germany, Great Britain, and Switzerland. The European cartel was formed in 1926 to regulate production, stabilize prices, expand markets, and exchange technical information for 2 years. In 1928 the cartel was renewed for a 3-year period.

126. *French producing companies.*—L'Aluminium Francais is the selling and fabricating agent for the two French producing companies,

QUANTITIES PRODUCED

129. The foregoing table compares the bauxite production of each country with its aluminum production. The United States produced 48 percent of the world's aluminum in 1929. Including the production of its Canadian works, the Aluminum Co. of America manufactured more than half of the entire amount of aluminun in the world. Only 18 percent of the world's bauxite was mined in the United States while mines in British and Dutch Guiana produced 20 percent of the entire supply. (Bauxite mining includes bauxite for industries other than the aluminum industry.)

130. Germany had risen to second place in the production of aluminum in 1929, while France ranked third, Norway fourth, and Switzerland fifth. The only other producing countries were Great Britain, Austria, and Italy.

131. Canada and Norway export a large part of the aluminum they produce. Both countries count on Japan, Great Britain, and the United States for their principal consuming markets, although Canada ships in largest quantities to the United States, and Norway sends the largest amount of her aluminum to Great Britain. France, Hungary, Italy, and the Guianas are bauxite exporting countries, while Germany, Great Britain, and the United States are bauxite importing countries.

132. Plant expansion is going on in all European countries as well as in the United States and in Canada. Unquestionably, world aluminum producers believe the aluminum market is an expanding market.

Bibliography

Year	Author	Title
1924	Anderson, R. J	Metallurgy of Aluminum and Aluminum Alloys.
1929	Bossert, T. W	Aluminum and Its Alloys in Aircraft. In American Electrochemical Society Proceedings, Sept. 19, 1929.
1927	Edwards, J. D	Aluminum from Oersted to Arvida, in American Electrochemical Society Proceedings.
1929	do	Alumina Production in Its Present Day Aspects.
1929	Edwards, J. D., and Taylor, Cyril S.	Nominal Composition of Strong Alloys, in Transactions of the American Electrochemical Society, 1929. Vol. LVI.
1927	Edwards, J. D	Aluminum Paint, in Aluminum Catalogue.
1930	Edwards, Frary, and Jeffries	The Aluminum Industry.
1930		Massena Mill Relies Largely on Electrical Application, Apr. 12, 1930. Electrical World.
1927 1929 1930		Engineering and Mining Journal. Price quotations.
1927	Faragher, P. V	Commercial Forms and Applications of Aluminum and Aluminum Alloys. American Institute of Mining Metallurgy. Eng. Tech. Pub. 33.
1930	Frary, Francis C	Present Day Aspects of the Aluminum Industry, an address before the New York section of the American Electrochemical Society, Feb. 14, 1930.
1924	Guillet, L	History of Light Alloys of Aluminum and the Present Position of Their Manufacture. J. Inst. Met. 33.
1926	Haglund, J. R	The Haglund Process.
1930	Hobbs, Douglas B	Aluminum in 1929, in Engineering and Mining Journal.
1928		Journal du four "Electrique", no. 4.
1928	Knibbs, N. V. S	The Industrial Uses of Bauxite.
1929	Lowdon, D. S	The Aluminum Industry, in Harvard Business Review, October.
1928	Mantel, C. L	Aluminum, in Chemical and Metallurgical Engineering. August.
1927	McBride, R. S	Modern Technology in Producing Pig Aluminum, in Chemical and Metallurgical Engineering, vol. 34, no. 2. February.
1928		The Development of the Aluminum Industry, in Metal Industry, vol. 26, no. 3.

Bibliography—Continued

Year	Author	Title
1929	Roush, G. A.	The Mineral Industry During 1928, vol. XXXVII.
1930	Porter, J. D.	Aluminum in the South, Journal of Chemical Education. October 1930.
1927	Rheinboldt	Hundred Years—Aluminum, Metallwirtschaft 6: J. Inst. Met. 37.
1925	Thompson, Maurice D.	Theoretical and Applied Electrochemistry.
1928 1929	U.S. Department of Commerce: Bureau of Mines	Bauxite and Aluminum.
	Bulletin 312	Bauxite: Floating and Sink Fractionation. Flotation Experiment.
1929	Bureau of Foreign and Domestic Commerce.	Market Data Handbook of the United States.
1929	Bureau of Standards Circular No. 346.	Light Metals and Alloys.
1921	U.S. House of Representatives	Hearings on General Tariff Revision, Pt. II.
1926	U.S. Senate	The Aluminum Co. of America, S.Doc. No. 67. 69th Cong., 1st sess.
1926	----do	Hearings Before the Committee on the Judiciary Pursuant to S.Res. 109.

POWER IN FERTILIZER MATERIAL PRODUCTION

CONTENTS

Page

Present status 134

NITROGEN AND ITS COMPOUNDS

History and development of the industry 137
Sources of supply and methods of nitrogen fixation 137
World War conditions 138
Post-war world nitrogen sources 128
Nitrogen consumed in the United States 139
Production 139
Capacity of plants 141
Imports and exports 141
Air nitrogen processes and energy requirements 142
Direct synthetic ammonia process 142
Water-gas hydrogen 143
Electrolytic hydrogen 143
Coke-oven hydrogen 144
Nitrogen production 144
Arc process 145
Cyanamide process 145
Other processes 146
Conversion of initial nitrogen fixation products into market products 147
Crude cyanamide ammonia and urea 147
Ammonium sulphate 148
Ammonium phosphate 148
Ammonium nitrate 148
Calcium and sodium nitrates 149
Production costs 149
Comparison of capital costs, power consumption, and operating costs of each process 149
Possible methods of reducing electrolytic hydrogen ammonia costs 152
Markets for specific nitrogen compounds 154
The chemical market 154
The fertilizer market 155
Control of the nitrogen fixation industry and nitrogen markets in North America 156
Market value of available nitrogen in principal nitrogenous materials 156
World competitive conditions 158
Canadian construction of nitrogen plants 158

PHOSPHORIC ACID AND PHOSPHATIC COMPOUNDS

	Page
History and development of the industry	160
Phosphate rock	161
Location of deposits	161
South Appalachian region	161
Rocky Mountain region	162
Africa and Europe	163
Extent of reserves	164
World production	165
United States production	166
United States imports and exports	166
Phosphoric acid manufacture	167
Sulphuric acid process	167
Electrothermal processes	168
Continuous process	168
Phosphorus oxidation	169
Fuel-fired furnace process	169
Cost of manufacture	170
Sulphuric acid process	170
Electrothermal and fuel processes	171
Double superphosphate	173
By products	173
Consumption of phosphate rock, phosphoric acid, and phosphorus	175
In agriculture	175
In baking powders and cleansers	175
In silk manufacture and other industries	176
Market prices	177
Organization of the phosphorus and phosphoric acid industry	177
Phosphorus producer	177
Phosphoric acid producers	177
Future market for phosphoric acid	180
The fertilizer industry in the United States	181
Location of plants	181
Fertilizer consumption	182
Concentrated fertilizer development	188
Hauling and handling costs on superphosphate and concentrated fertilizer	188
Retarded development	189
Beginning of the industry	189
Ammoniated superphosphate	189
Potash	190
Production and imports	191
Domestic resources	191
Agricultural research	193
Electrolytic potassium compounds	193
Potassium compound manufactures	194
Bibliography	194

Our soils consume 808,000 tons phosphoric acid, 345,000 tons of nitrogen, and 343,000 tons of potash annually. Seventy percent of this plant food reaches the farmer in the form of mixed fertilizer, a product containing specified amounts of each plant food mixed with about 83 percent gypsum and impurities. The fertilizer price paid by the farmer includes not only the cost of 17 percent available plant food but the cost of bagging, handling, and hauling 83 percent almost valueless filler.

Manufacturing processes are also uneconomical or are not conducive to the development of all native fertilizer resources. Phosphoric acid is made available by treating phosphate rock with sulphuric acid which dilutes the phosphoric acid by half; nitrogen is secured by treating ammonia with sulphuric acid or through the use of Chilean sodium

nitrate; potash is imported largely from Germany and France. Power plays little part in such production and mixing.

As the fertility of our soils is depleted by cropping and erosion, the economical production and application of plant foods to soils become of increasing importance to national well-being. The situation is recognized nationally. The percentage of plant food in fertilizers is increasing. One hundred and ten thousand tons concentrated fertilizer was produced in 1929; a part, however, was exported. The use of high analysis fertilizers is just beginning in the United States whereas such fertilizers already hold a conspicuous place in European markets and have made extensive demands on European energy resources.

There are definite causes for the retarded development of high analysis fertilizers in this country. First, chemical engineering methods in this country are only now reaching a point where relatively cheap concentrated nitrogen compounds and concentrated phosphoric acid can be produced. Potash from our own mineral resources has not yet been produced commercially in large quantities, although by-product potash is available. Second, farm machinery for applying fertilizer has to be redesigned to distribute the smaller quantities of concentrated material used per acre. Third, the farmer must be convinced that such fertilizer is of material value to him before old machines will be scrapped and concentrated fertilizer purchased. And fourth, the more than 600 fertilizer manufacturers or mixers require assurance that the market demands concentrated fertilizer as a substitute for the traditional low-analysis material.

The fixation of air nitrogen and the production of phosphoric acid are now effected by several processes. Some require abundant electric energy, others require electricity only for motor operation. When nitrogen and oxygen are combined through the arc process as nitric acid, 61,000 kilowatt-hours energy are consumed per ton available nitrogen obtained. When nitrogen is combined with hydrogen secured through the electrolysis of water, 14,640 kilowatt-hours are required per ton available nitrogen. A ton of available nitrogen absorbed by hot calcium carbide forming calcium cyanamide demands 12,000 kilowatt-hours. Whereas, when nitrogen is combined with hydrogen produced from water-gas or from coke-oven-gas, only 2,430 kilowatt-hours and 2,000 kilowatt-hours, respectively, are required per ton of nitrogen fixed.

Concentrated phosphoric acid may be produced in an electric furnace by a continuous process which requires 5,400 kilowatt-hours per ton of available phosphoric acid. Phosphorus may be produced in the electric furnace consuming about 4,400 kilowatt-hours per ton of phosphoric acid in acid and metal and later be oxidized with steam to produce phosphoric acid. Or phosphoric acid can be manufactured in a fuel-fired furnace or by the sulphuric acid process.

Competition has practically eliminated the arc process from nitric acid production even in Norway where it was commercially profitable for many years. The successful competition of a process in industrial and agricultural markets depends upon the cost, at particular plant locations, of the major items entering into each process, of the derivatives obtainable from the initial product, and on the markets for by-products. The cyanamide process, which requires coke and coal and limestone as well as electrical energy, has flourished on this continent and abroad in spite of higher total production costs per ton of avail-

able nitrogen largely because it is the base of a number of derivatives that find ready markets in industry and mining as well as in agriculture. Other processes have been employed on this continent too short a period to determine their ultimate competitive value. Coke-oven hydrogen ammonia synthesis is used only in Europe.

As technical and industrial markets bring higher prices, concentrated phosphoric acid, ammonia, and nitric acid manufactured in this country sought these markets before entering the agricultural field. The purest phosphoric acid is used in baking powders, in drinks, and for pharmaceutical purposes. In combination with other chemicals, phosphoric acid is sold in relatively small amounts to a number of industries. Nitrogen, in various forms, is essential for explosives, for many chemicals, in refrigeration, in medicines and in numerous other products.

Continued large expansion of production, however, is dependent upon an agricultural market. Before being available for fertilizers, phosphoric acid and fixed nitrogen must be combined with a base. As the market calls primarily for mixed fertilizer, it is economical to absorb ammonia gas in phosphoric acid.

Only one firm in the United States is producing both ammonia and phosphoric acid for this two-plant food fertilizer. The possibilities of combining such production economically are numerous. The electric furnace and oxidation method of producing phosphoric acid yields sufficient hydrogen to produce the ammonia necessary to convert phosphoric acid to monoammonium phosphate. The continuous electrothermal phosphoric acid process combined with electrolytic-hydrogen ammonia synthesis creates the largest power load. Some of the by-product oxygen from the latter production could be used in the production of nitric acid explosives. Or, if the experiments now under way to use potash silicate as a flux in electrothermal phosphoric acid production prove successful, two plant foods will be obtained by one process and these may be combined with ammonia to produce a complete fertilizer. Still another suggestion combines electrothermal phosphoric acid production and electrolytic caustic soda production, ammonia being one by-product of the latter process. Plants located in coal and coke regions would use the fuel-fired methods for producing phosphoric acid and the water-gas or coke-oven hydrogen-ammonia synthesis processes.

The largest phosphate and potash deposits are found in the Rocky Mountain region. The largest fertilizer markets are in the Southeast and South Central States. The position of power in fertilizer material production will depend upon the extent to which electrothermal and electrolytic processes produce fertilizers that can be delivered to large fertilizer markets at a price per unit of available plant food that will encourage the substitution of such high-analysis fertilizers for sulphuric acid or imported fertilizers.

Nitrogen and Its Compounds

1. Indispensable as plant food, an essential element of explosives, nitrogen in usable compounds plays a vital role in peace and in war. It constitutes four fifths of the air, forms part of many animal and vegetable substances and is found as a mineral in Chile, Peru, and in certain soils in India and Ceylon. It is called an inert element because of the difficulty with which it is combined with other elements.

History and Development of the Industry

2. The history of the nitrogen industry is one of discovery of the different sources of supply and of methods of fixing air nitrogen in commercial compounds.

3. From early times, the nitrogen in animal and vegetable refuse was fed to the soil for soil fertilization. Inorganic nitrogen in the form of potassium nitrate was first found in India. The discovery of this mineral's use in the manufacture of black powder, as well as its importance as a fertilizer, created an active demand for nitrogen compounds. In 1830 the large sodium nitrate deposits of Chile were discovered. When Paul Vicille invented smokeless powder through the use of nitric acid made from Chilean sodium nitrate and the French Government, in 1887, adopted smokeless powder as its explosive, Chilean deposits assumed world importance.

4. The development of by-product coke ovens at the end of the nineteenth century afforded another source of nitrogen, for coking coals contain combined nitrogen in varying quantities, the maximum amount being 40 pounds per ton of coal.

5. *The arc process.*—It was known that the atmosphere was composed largely of nitrogen and small quantities had been made available by combining air nitrogen with other elements as early as 1777. But it was not until 1902 that a commercial reduction of atmospheric nitrogen to nitric acid was attempted. In this year the Atmospheric Production Co. took over the patents of C. S. Bradly and R. Lovejoy for the production of nitric acid by the oxidation and absorption of nitrogen in water, a process known as the arc process. In this first arc process plant, the yield was only 948 pounds of nitric acid per kilowatt-year. Plant operation was discontinued in 1904. However, in 1903 experimental plants using similar methods were operating in Norway with such success that commercial arc process plants followed. The two largest plants operated by the Norwegian Hydroelectric Nitrogen Co. (Norsk Hydro) are located at Notodden and Rjukan and in 1927 had a combined output of 38,000 tons of fixed nitrogen per year, consuming 261,100 kilowatts. The Norsk Hydro Co. is replacing its arc process capacity with direct synthetic ammonia capacity as it is estimated that even nitric acid can be produced more cheaply by this process.

6. Two other efforts were made to produce nitrogen by the arc process in the United States. A plant erected in 1913 at Nitrolee, S.C., was not a commercial success. The plant erected at LaGrande, Wash., in 1917 by the American Nitrogen Production Co. had a capacity of 1 ton of nitrogen per day, and produced sodium nitrite. It operated for 10 years until the plant was destroyed by fire.

7. *The cyanamide process.*—The development of the cyanamide process, whereby free nitrogen is absorbed by very hot calcium carbide, was based on patents taken out in 1894 by Professors Franke and Care of Germany. The first cyanamide plant put in operation in Germany in 1905 was not a success. A plant built in the same year at Piano d' Orta, Italy, however, was so efficient that other plants using the same process were built in other countries. On this continent, the American Cyanamide Co. built a plant at Niagara Falls, Canada, in 1909. This plant has been continually enlarged and is operating today.

8. *Direct synthetic ammonia process.*—Commercial interest in the production of direct synthetic ammonia was first aroused in 1910 when the Badische Anilin Und Soda-Fabrik decided to attempt production by the Haber process. Operation was begun in 1913 and was so successful that production by the direct synthetic ammonia process has been steadily increasing on both continents. The first commercial unit was put into operation in the United States in August 1921 at the Syracuse, N.Y., plant of the Atmospheric Nitrogen Corporation.

9. *World War conditions.*—Just before the World War began there were in operation throughout the world 7 arc plants with a total capacity of 20,000 tons, 15 cyanamide plants with a capacity of 66,000 tons of nitrogen per year, and 1 direct synthetic ammonia plant of 7,000 tons capacity.[17] Of a world production of 784,100 metric tons contained nitrogen in 1913, 439,800 tons was natural nitrogen while 284,100 metric tons was byproduct ammonia.[18] Obviously, nations were still depending primarily on Chile for their sodium nitrate. German cruisers were able to cut off ships carrying nitrate to England and France for 7 weeks, while the British fleet closed German ports. This brought sharply to the attention of all countries the importance of a local supply of nitrogen for both agricultural and explosive purposes. In the United States $20,000,000 was made available to the President by the National Defense Act of June 3, 1916, for the investigation of various methods of producing nitrate and other products for munitions of war and useful in the manufacture of fertilizer. A committee appointed by the Secretary of War recommended that United States Nitrate Plant No. 1 be erected at Sheffield, Ala., to produce nitrogenous compounds by the direct synthetic ammonia process. The United States Nitrate Plant No. 2, was erected at Muscle Shoals, Ala., to produce nitrogen by the cyanamide process. The United States Chemical Plant No. 4 was erected at Saltville, Va., for the production of sodium cyanide. These plants did not get beyond trial operation before the signing of the armistice.

10. Research work was undertaken by the Bureau of Soils of the Department of Agriculture in 1915 on the direct synthetic ammonia process. In 1919 this work was taken over by the Fixed Nitrogen Research Laboratory, which is still working on nitrogen fixation processes.

11. At the close of 1918 there were in operation, or in process of building, in the world 12 arc plants with a capacity of 40,000 metric tons of nitrogen, 35 cyanamide plants with a capacity of 350,000 tons, and 3 direct synthetic ammonia plants of 330,000 metric tons.[19]

12. *Postwar nitrogen sources.*—During the fertilizer year 1928–29 it is estimated that a world nitrogen production of 2,328,000-short tons [20] was obtained as follows:

[17] Ernst, Frank A. Fixation of Atmospheric Nitrogen, p. 16.
[18] Pollitt, C. P. The Synthetic Ammonia Industry. Paper given at world power conference, June 1930.
[19] Ernst, Frank A. Fixation of Atmospheric Nitrogen, p. 16.
[20] British Sulphate of Ammonia Federation, Ltd. Ninth annual report.

TABLE I

Product	Quantity (in short tons of contained nitrogen)	Percent of total production
Synthetic ammonia and other forms obtained by synthetic processes	937,000	40.3
Chilean nitrate	540,000	23.2
Byproduct ammonium sulphate and other forms of byproduct nitrogen	470,000	20.2
Cyanamide nitrogen [1]	231,000	9.9
Calcium nitrate (obtained by arc process)	150,000	6.4
Total	2,328,000	100.0

[1] Except cyanamide made in Japan which is calculated as synthetic sulphate of ammonia.

13. It is obvious, therefore, that while the World War stimulated the development of atmospheric nitrogen fixation, the postwar years are bringing about an increased use of the direct synthetic ammonia process and an ever decreasing use of the arc process.

14. *Nitrogen production in the United States.*—The following table shows the sources of industrial nitrogen available in the United States in the last 3 years. Our own production has been steadily increasing until in 1929 we manufactured 53 percent of the total available supply in the country.

TABLE II.—*Chemical nitrogen production and supply in the United States (short tons of nitrogen contained)* [1]

Source	1927	1928	1929
Production:			
At coke works	147,700	164,500	183,000
At gas works	6,200	6,500	6,000
From the air	18,000	27,000	84,000
Bone distillation, etc	200	200	200
Total production	172,100	198,200	273,200
Imports:			
Ammonium sulphate	3,900	9,600	6,000
Ammonium-sulphate-nitrate	13,000	23,800	4,000
Calcium cyanamide	26,000	32,300	45,000
Calcium nitrate	3,100	3,900	5,000
Chile nitrate	130,000	179,200	160,000
Cyanides	4,800	5,500	6,000
Miscellaneous ammonium compounds and nitrates	4,600	5,700	5,000
Nitrogeneous fertilizer mixtures (estimated)	6,000	9,000	8,500
Total imports	191,400	269,000	239,500
Grand total available	363,500	467,200	512,700
Exports:			
Ammonium sulphate	32,400	21,400	30,000
Sodium nitrate	2,200	3,200	2,000
Anhydrous ammonia	500	800	1,100
Other nitrogen compounds	2,000	10,000	11,000
Total exports	37,100	35,400	44,100
Apparent United States consumption	326,400	431,800	468,600

[1] Compiled by Chemical and Metallurgical Engineering, January 1930, p. 31.

15. The greater part of this nitrogen was in the form of ammonium sulphate or liquid ammonia, a byproduct of coke ovens operating primarily to provide coke for iron and steel mills. Byproduct coke-oven ammonia production increased by a fourth in 2 years. Pennsylvania and Ohio are the largest producing centers of coke-oven

ammonia, although it is manufactured in a number of bituminous mining States. Table III shows the amount and form of ammonia produced in 1928 at coke-oven plants. There are now 80 byproduct coke plants owned by 54 separate companies.[21]

TABLE III.—*Ammonia produced at coke-oven plants, by States, in 1928, in short tons* [1]

State	Sulphate	Liquor (NH_3 content)	Sulphate equivalent of all forms	
			Total	Per ton of coal coked
Alabama	(2)	(2)	78,888	25.4
Colorado	9,160		9,161	20.6
Illinois	(2)	(2)	55,169	23.4
Indiana	61,014	2,696	71,796	17.5
Maryland	16,917		16,917	20.7
Massachusetts	(2)	(2)	10,663	20.6
Michigan	(2)	(2)	39,002	23.0
Minnesota	(2)	(2)	8,994	20.0
New Jersey	14,222		14,222	22.7
New York	(2)	(2)	63,425	23.1
Ohio	[3] 352,735	[3] 5,578	134,568	223.5
Pennsylvania			240,479	23.7
Tennessee	1,617		1,617	21.4
Utah	6,538		6,538	29.2
Washington		264	1,057	32.8
West Virginia	23,354		23,354	23.8
Connecticut, Kentucky, Missouri, Rhode Island, and Wisconsin	(2)	(2)	23,037	23.0
Undistributed	208,391	17,697		
Total	693,948	26,235	798,887	22.8

[1] Compiled from U.S. Bureau of Mines, Coke and By-Products in 1928, p. 783.
[2] Included under "Undistributed".
[3] Figures for Ohio and Pennsylvania combined to avoid disclosing individual operations.

16. Although our air nitrogen fixation plants manufactured only 16.4 percent of the country's available nitrogen supply, this represented an increased production of 350 percent in 2 years. This manufacture was entirely by the direct synthetic ammonia process. By this process 102,565 tons of ammonia, yielding 84,000 tons of nitrogen, were produced in 1929.

17. In June 1930 the Nation's direct synthetic ammonia yearly plant capacity had been increased to 189,300 tons. A new plant was in course of construction which was reported to be designed for a 24,000-ton ammonia capacity. The plants operating or in course of construction in the United States are listed in table IV. The method of producing hydrogen is also stated.

[21] Brief of By-Product Coke Producers before Committee on Ways and Means, H.R., 17th Cong., 2nd sess., vol. 1, p. 509.

TABLE IV.—*Capacity of plants in the United States using direct synthetic ammonia process for nitrogen fixation*

Company	Plant location	Hydrogen used	Approximate annual capacity June 1930 in tons of ammonia	Output during 1929 in tons of ammonia
Atmospheric Nitrogen Corporation (subsidiary of the Allied Chemical & Dye Corporation.	Hopewell, Va.	Water-gas	108,000	54,750
	Syracuse, N.Y.	do	14,600	14,600
Du Pont Ammonia Corporation.	Belle, W.Va.	do	54,000	25,550
Great Western Chemical Co.	Pittsburg, Calif.	Byproduct of caustic soda manufacturing.	1,500	730
Mathieson Alkali Works.	Niagara Falls, N.Y.	do	4,500	4,380
Midland Ammonia Corporation.	Midland, Mich.	do	2,500	None.
Pacific Ammonia Co. (subsidiary of Du Pont Co.).	Seattle, Wash.	Electrolytic	1,200	1,095
Roessler & Hasslacher Chemical Co.	Niagara Falls, N.Y.	Byproduct of caustic soda manufacturing.	3,000	1,460
Shell Chemical Co.	Brose, Calif.	Natural gas cracking	(1)	None.
Total			189,300	102,565

[1] Building for 24,000 tons of ammonia annually.

18. Organic sources of nitrogen are no longer a large factor in the country's nitrogen production. While amounts of manure spread locally as fertilizer are not recorded, commercial tankage, dried blood, fish scrap, cottonseed meal, and other substances have such value as cattle feed that decreasing amounts enter the fertilizer field in the form of mixed fertilizer.

19. *Imports and exports.*—During 1929 imports formed 46.7 per cent of the available national supply of industrial and agricultural nitrogen. The bulk of these imports was Chilean nitrate, which ranks second as a source of our country's nitrogen supply in 1929, coke-oven nitrogen only being available in larger quantities.

20. Ten percent of our available nitrogen was imported from the Canadian plant of the American Cyanamide Co. in the form of calcium cyanamide and cyanide. While some cyanamide is consumed in mixed fertilizer and crude cyanide is used in metallurgy, the larger proportion of the imports go to the company's plant at Warners, N.J., where the cyanamide is used for ammonia and ammonium phosphate production and the cyanide enters into hydrocyanic acid and yellow and blue prussiates manufacture. The ammonium phosphate is, in turn, exported from the United States to Japan, the Philippines, Sumatra, and Java.

21. While some ammonium sulphate, calcium nitrate, and nitrogenous compounds came into this country, chiefly from German ports, they formed less than 6 percent of our available nitrogen supply in 1929.

22. Out of an available supply of 512,700 tons nitrogen content, 44,100 tons were exported. This left an apparent national consumption of 468,600 short tons of contained nitrogen in 1929, as compared with an apparent consumption of 431,800 short tons in 1928 and 326,400 short tons in 1927, or an increased consumption of 43.6 per cent in 2 years.

Air Nitrogen Processes

23. The manufacture of air-nitrogen compounds involves two steps—the fixation of nitrogen with other elements and the conversion of these initial products into compounds suitable for agricultural and industrial uses.

24. The initial or fundamental products of nitrogen fixation are these: Ammonia, resulting from the fixation of nitrogen with hydrogen through the direct synthetic ammonia process; nitric acid, the combination of nitrogen and oxygen achieved through the arc process; and calcium cyanamide, the product resulting from the absorption of nitrogen by hot calcium carbide.

25. While each of these initial products has its own markets, each also serves as the basis of a series of derivatives. Calcium cyanamide is productive of the largest number of derivatives because, in addition to those products obtainable only from cyanamide, the cyanamide may be converted into ammonia, or into nitric acid, and thus is available for the same purposes as ammonia or nitric acid produced by the other processes can be used. Ammonia may be converted into nitric acid and consequently has two sets of derivatives. Nitric acid is limited, however, to its own series of compounds, as conversion cannot be reversed.

26. Profitable production by specific methods is dependent, therefore, not only on respective fixation costs and market demand for initial products, but upon market demand for conversion products. The following discussion will deal first with the production of the initial products, then with the conversion of these products into other marketable compounds, and lastly with the costs of production of comparable products by each process and with market demands.

The Direct Synthetic Ammonia Process

27. The original process for the fixation of nitrogen with hydrogen as ammonia is known as the Haber process. Today there are a number of methods for direct synthetic ammonia production such as the Claude, the Casale, and the Fauser processes. The underlying principles of each are similar to the original process.

28. One ton of ammonia requires approximately 25,000 cubic feet of nitrogen and 75,000 cubic feet of hydrogen. These are compressed, the pressure varying in different processes from 100 to 900 atmospheres, and are passed over a catalyst at temperatures ranging from 450° to 700° C. The catalyst, at present regarded as most effective, is an iron oxide [22] to which has been added small quantities of potassium oxide and aluminum oxide or other materials useful as promoters of the synthesis. Magnetite has also been used successfully as a catalyst.

29. At best, only a small percent of ammonia is produced in a single passage of the gas over the catalyst, the amount produced being dependent upon the volume of gas per unit volume of catalyst space per hour or upon the space velocity.[23] In some processes the uncombined gases plus mixed gases equivalent to the ammonia removed

[22] U.S. Patent 1489497.
[23] Ernst, Frank A. Fixation of Atmospheric Nitrogen, pp. 54–63.

are passed through a series of catalyst chambers; in others, the gases are returned to the original chamber, the ammonia being removed following each pass.

30. Ammonia is removed by two methods. In one, the gases ascend a tower over which water or aqua ammonia is pumped. The ammonia gas is scrubbed out of the mixture and the absorbing liquid trapped while the gases return to the catalyst chambers. The resulting product may be aqua ammonia or ammonia gas depending upon the quantity of water used in relation to the amount of ammonia to be released. By the second method, the gas mixture is cooled under pressure causing condensation of some of the ammonia with a resultant production of anhydrous ammonia.

31. The plants manufacturing synthetic ammonia also manufacture their raw materials, hydrogen, and nitrogen. While nitrogen is readily obtained, the manufacture of hydrogen is one of the industry's main problems. The amount of electricity consumed in the direct synthetic ammonia process is dependent primarily upon the method employed to secure hydrogen. The water-gas hydrogen ammonia process requires about 1,500 kilowatt-hours per ton of available nitrogen; 14,640 kilowatt-hours are required when the electrolytic hydrogen process is employed; and about 2,430 kilowatt-hours per ton available nitrogen when coke-oven gas hydrogen ammonia is made.

HYDROGEN AND NITROGEN PRODUCTION

32. *Water-gas hydrogen.*—The larger plants in the United States obtain hydrogen by a water-gas catalytic process and nitrogen from producer gas or from an air liquefaction plant. Two volumes of water-gas (made by passing air and steam alternately over red-hot coke) and 1 volume of producer gas are mixed. The mixture contains 35 percent hydrogen, 20 percent nitrogen, 40 percent carbon monoxide and small parts of carbon dioxide, methane, and other gases. This is treated with steam in the presence of a catalyst at a temperature of about 500° C. The carbon monoxide combines with the steam to form hydrogen and carbon dioxide. The carbon dioxide is largely removed by scrubbing with water and the remaining dioxide as well as any remaining carbon monoxide is scrubbed out with a caustic soda solution followed by a cuprous ammonia formate solution. If the purified gas does not contain the correct proportions of hydrogen and nitrogen necessary for the ammonia synthesis, this is attained by adding pure nitrogen from an auxiliary air-liquefaction plant.

33. *Electrolytic Hydrogen.*—One plant in this country produces hydrogen by the electrolysis of water. There are two main types of electrolytic cells, the ordinary tank type and the filter press cell. While the cells in active operation in the United States are 5,000-ampere cells, single cells of 15,000 amperes are obtainable. Voltage required varies with the type of electrodes used, the electrolyte, and with the temperature at which the cell is maintained. The electrodes are usually pure iron with nickel-plated anodes. In one type tank cell they are plain metal sheets, in a second type each electrode is built up of a number of metal strips laid to form a grid. The cells contain about 150 gallons of water in which is dissolved 435 pounds of 88 to 92 percent potassium hydroxide. The temperature of about 65° C. is maintained automatically on large installations.

34. According to Frank A. Ernst of the United States Fixed Nitrogen Research Laboratory, a 5,000-ampere cell operating at 2.24 volts consumes 268.8 kilowatt-hours in the production of 1,920 cubic feet of hydrogen. Sufficient hydrogen to produce 1 ton of ammonia would require, therefore, 10,500 kilowatt-hours of energy. Sufficient hydrogen to produce 1 ton of nitrogen in ammonia would require approximately 12,750 kilowatt-hours of energy. Attempts are being made to reduce the electricity required by using a pressure cell which at 150 atmospheres requires 25 percent less energy than at one atmosphere.[24]

When nitrogen is obtained by the Linde process, the total power consumption per ton of ammonia is about 12,000 kilowatt-hours; per ton available nitrogen, it is a little less than 15,000 kilowatt-hours.

35. *Coke-oven hydrogen.*—Hydrogen may also be obtained from byproduct coke-oven gas, which contains approximately 55 percent hydrogen, 6 percent nitrogen, 30 percent methane, and 6 percent carbon monoxide. As only half the total gas produced is consumed in oven heating, and as the hydrogen furnishes only about 30 percent of the calorific value of the gas, the hydrogen may be removed from the gas without lowering the heat value of the gases below the necessary amount. In large plants the gas passes through hydrogen-separating plants before heating the ovens. When, however, a number of coke ovens are to furnish the hydrogen, the hydrogen is obtained from the surplus gas of the ovens. By the Linde-Bronn process the production of nitrogen by rectifying liquefied air is combined with the washing of coke-oven gas by means of liquefied nitrogen. The power requirements per ton of ammonium are about 2,000 kilowatt-hours; or 2,430 kilowatt-hours are required to obtain 1 ton available nitrogen by this method.

This process is growing in favor in Germany, Belgium, and Holland. In the fertilizer year 1929–30, 15 percent of the world's synthetic ammonia was made from hydrogen derived from coke-oven gas.

36. *Natural-gas hydrogen.*—Millions of cubic feet of hydrogen are wasted at our natural-gas wells. However, this waste gas contains 6 percent methane, which must be removed. The Shell Chemical Co. is constructing a plant near San Francisco which will utilize natural-gas hydrogen. The gas hydrocarbons will be cracked.

37. *Phosphorus-water hydrogen.*—In the Liljenroth process phosphorus vapor and steam are passed over a catalyst maintained at about 700° C. Phosphoric acid and hydrogen are produced. When the finished product is to be a nitrogen-phosphorus fertilizer, this process would seem of great value. Commercial operation has been hindered by the formation of phosphine. However, a German plant is now operating on the Liljenroth process.

38. *Byproduct hydrogen.*—There is a growing tendency in this country to erect synthetic ammonia plants at electrolytic chlorine and caustic soda factories, as will be seen on page 141. In the electrolytic manufacture of chlorine, 9,000 cubic feet of hydrogen is produced for every ton of chlorine. (See p. 291 of Power in the Manufacture of Chemicals and Metals from Brine.) The commercial feasibility of using this hydrogen for ammonia production depends mainly on the volume of byproduct hydrogen that can be produced.

39. *Nitrogen production.*—The production of nitrogen from the atmosphere for ammonia synthesis may be accomplished at relatively

[24] Noeggerath, J. E. Article in Chemical and Metallurgical Engineering, July 1928.

little expense by three processes, the process used at particular plants depending largely on the source of hydrogen employed. If hydrogen is obtained from water gas, nitrogen is usually gotten from lean or producer gas made by blowing air over glowing coke. This gas contains approximately 60 percent nitrogen, 10 percent hydrogen, 25 percent carbon monoxide, and small parts of other gases.

40. If, however, a plant is operating on waste hydrogen or cheap electrolytic hydrogen, it may prefer to secure nitrogen by burning hydrogen in air. The hydrogen combines with oxygen to form water, leaving nitrogen. Per ton of ammonia produced, this method would require 88,380 cubic feet of hydrogen, 75,000 cubic feet to be used as hydrogen, and 13,380 cubic feet to be employed in the production of 25,000 cubic feet of nitrogen from 32,000 cubic feet of air.

41. The third process for nitrogen production is by the liquefaction and distillation of air. The air after being scrubbed to remove impurities is compressed to 450 pounds in the Claude process and to 3,000 pounds in the Linde process, and is cooled. The larger portion is then expanded, thus cooling the remainder to the liquefying point. Both air and liquid trays are admitted to rectifying towers. The nitrogen boils off and is collected as gas at the top of the tower while the residual liquid air is allowed to escape.

ARC PROCESS

42. The primary product of the arc process is dilute nitric acid. A rapidly moving air current is passed through an electric-arc furnace of very high temperature. The gases containing nitric oxide as they leave the furnace are cooled in economizers. The cooling of the nitric oxide is continued in cooling towers. It then enters a series of towers, in the first of which the oxygen of accompanying air reacts with the nitric oxide to form nitrogen dioxide. These gases pass through other towers in which they are brought in contact with water by which the nitrogen dioxide is absorbed, forming nitric acid. About 80 percent of the oxides are obtained in the form of nitric acid, a large part of the remainder being absorbed in alkaline towers to produce sodium nitrite or a mixture of sodium nitrate and sodium nitrite.

43. The total electric energy requirements are 61,000 kilowatt-hours per ton of fixed nitrogen, over 97 percent of which is necessary to prepare and maintain conditions favorable to the formation of nitric oxide.[25] Exceedingly high temperatures are essential for nitric oxide formation in quantity, and very rapid cooling is required to prevent its decomposition into its elements.

44. Laboratory investigation with small furnaces have increased the efficiency of energy utilization greatly, but when methods are applied to large commercial furnaces the results were not achieved. Technicians are not hopeful concerning any increase in commercial operating efficiency. Commercial furnaces are of the Birkeland-Eyde, Schonherr, and Pauling types and have capacities of from 500 to 4,000 kilowatts.

CYANAMIDE PROCESS

45. The raw materials for calcium cyanamide production are calcium carbide and nitrogen. The nitrogen is run over the pulverized

[25] Ernst, Frank. Fixation of Atmospheric Nitrogen, p. 22.

carbide in an electric oven which has been previously heated to 1,000° C. The reaction generates sufficient heat so that no additional electrical heating is required and continues from 24 hours to 48 hours, depending on the size of the oven. The energy consumption in the cyanamide oven is given at 115 kilowatt-hours per ton of nitrogen fixed.

46. The nitrogen gas is absorbed by the carbide to form calcium cyanamide. The pig is removed from the furnace, cooled, powdered, and sprayed to destroy any unnitrified carbides. The crude cyanamide produced by the American Cyanamid Co. averaged 23.5 percent nitrogen content, in 1927. At the trial operation of United States Nitrate Plant No. 2 a 21.5 percent nitrogen content was obtained.

47. *Raw material production.*—The original nitrogen is obtained through the liquefaction and distillation of air, a description of which is given on page 145. This consumes about 6.5 percent of the energy required in the entire fixation process. Calcium carbide is an electric-furnace product and its production is the largest item of cost in the cyanamide process. Lime, which has been made by heating pulverized limestone and coal in lime kilns, is fused with soft-burned coke in open-top electric furnaces at approximately 3,300° C. While soft-burned coke containing not more than 6 percent ash and not more than 0.5 percent moisture is regarded as the best form of carbon for use with lime, anthracite coal or charcoal is also used.

48. The power consumed per unit of product decreases with furnace size. The furnaces at Muscle Shoals have a capacity of 60 tons crude carbide daily and require 2,962 kilowatt-hours to produce a ton of 81.5 percent carbide.[26] Mr. W. S. Landis, vice president of the American Cyanamid Co., states that his company's Canadian carbide furnaces are rated at 12,000 kilowatts, while furnaces of 15,000 kilowatts are in operation elsewhere.[27] Twenty-six hundred kilowatt-hours seems to be closer to actual commercial operating requirements, making a total power consumption of 2,830 kilowatt-hours per 1 ton calcium cyanamide containing 23.5 percent nitrogen or 12,000 kilowatt-hours per ton of available nitrogen.

The molten carbide is tapped from the furnace at approximately 35-minute intervals and run into chill cars to cool. It is then crushed and finely powdered and is ready to be charged into the cyanamide oven. The large quantity of carbon monoxide formed, approximately 735 pounds per ton of crude carbide, was not recovered until recently.

OTHER PROCESSES

49. *Bucher process.*—Much research has been done on other methods for the fixation of atmospheric nitrogen. Probably the Bucher process has received most attention. By this process briquets are made of sodium carbonate, coke and small quantities of iron. These are treated with pure nitrogen in externally heated retorts at a temperature of 1,000° C. The iron acts as a catalyst and converts the soda and carbon into cyanide and carbon monoxide. The sodium cyanide may be decomposed with steam to produce ammonia, or it may be converted into urea. This process was used

[26] Braham, J. M. Nitrogen Survey. Part III, p. 10.
[27] Paper before American Electrochemical Society, April 1927.

by the Government in 1918 at Saltville, Va., and also tried out at an experimental plant in Greene, R.I. While it was believed to have commercial possibilities as a source of cyanide, its use for ammonia production was impracticable.

50. The Air Reduction Co. of Elizabeth, N.J., has developed a similar process for sodium cyanide production, using less iron and a revolving nitrogen retort. The crude sodium cyanide is treated with carbolic acid liberating hydrocyanic acid used in fumigation of citrous fruit trees.

51. *Nitride processes.*—The Serpek process of making aluminum nitride from bauxite, coke and nitrogen heated in an electric furnace to about 1,800° C. was attempted in France. The aluminum nitride is decomposed with steam or caustic soda to yield ammonia and regenerate alumina. The formation of other nitrides such as boron, titanium, and silicon as a means of fixing nitrogen has received much attention but no commercially successful nitride plant is in operation.

52. *Explosive process.*—The Hausser process explodes combustible gas with air or oxygen to bring about a union of nitrogen and oxygen. The nitric oxide is then converted into nitric acid. This was tried out in a small scale in Germany, but the strain upon the apparatus by the explosions proved too severe.

53. Other experiments in nitrogen fixation are under way. The chief difficulties seem to be in securing either the high temperatures necessary for the reaction, economically, or the apparatus capable of continuous and lengthy operation under high temperatures.

Conversion of Initial Nitrogen Fixation Products into Market Products

CRUDE CYANAMIDE CONVERSION

54. Crude cyanamide is a fine powder very disagreeable to handle and containing some unnitrified carbide. Before being marketed as a fertilizer in this country, it is subjected to a water and oil treatment, producing the "cyanamide" of commerce. This contains 45 percent calcium cyanamide, 27 percent calcium hydroxide, and varying amounts of filler. While cyanamide is used as a fertilizer, it is a disagreeable substance to handle and it cannot be used freely in mixed fertilizers containing phosphates because it causes the acid phosphate to revert. Consequently, much is converted into ammonia products or urea for use as a fertilizer.

55. For ammonia production, 8,000 pounds of cyanamide and 300 pounds of soda ash are charged into an autoclave with approximately 19,000 pounds of filtrate liquor containing 2 percent sodium hydroxide. The charge is aerated and then subjected to steam under pressure. Ammonia with steam is drawn off.

56. In urea production the calcium cyanamide is fed into water in active agitation and carbon dioxide gas is blown into the circuit. The calcium is abstracted leaving in solution free cyanamide to which is added sulphuric acid. A 25 percent solution of urea is formed which is treated with powdered calcium carbonate leaving a clear solution of urea to be evaporated in a vacuum pan. Urea solid contains about 45 percent nitrogen.

57. Cyanide for metallurgical purposes and as a base for hydrocyanic acid used in plant fumigation is produced by fusing cyanamide

and sodium chloride in an electric furnace to form calcium cyanide which is quickly chilled after leaving the furnace.

58. *Ammonium salts.*—While ammonia is used as such in the refrigeration and chemical industries as well as for household purposes, its greatest use is as the nitrogen carrier of various fertilizers. A large number of ammonia compounds may be produced by the neutralization of various acids with ammonia.

59. Ammonium sulphate, the principal fertilizer produced by byproduct coke ovens, has gained a prominent place in fertilizer materials. Ammonia gas, obtained from the cyanamide or synthetic ammonia processes, may be converted to ammonium sulphate by a process similar to that used at some coke ovens. In the hot process an almost 100 percent ammonia gas is introduced to a saturator containing sulphuric acid and maintained at 105° C. The excess water passes off as steam and the crystals are freed of remaining liquor in centrifugal and rotary driers. One ton of sulphate of ammonia requires 515 pounds ammonia and 2,000 pounds of 60° B. sulphuric acid.

60. At some synthetic ammonia plants in Germany and England, sulphate of ammonia is produced by the use of gypsum (calcium sulphate) rather than by the use of sulphuric acid. The gypsum is ground to a very fine powder and while in suspension in water is treated with ammonia and carbon dioxide in closed vessels. This reaction forms ammonium sulphate and calcium carbonate. Evaporation gives a solid sulphate salt. Twenty-three hundred tons of gypsum are consumed per 2,000 tons sulphate of ammonia produced. This method utilizes waste carbon dioxide gas produced when hydrogen is made from water-gas. To convert ammonia to ammonium sulphate by this process is said to require 2,000 kilowatt-hours per ton available nitrogen.

61. Although the fertilizer industry uses ammonium sulphate in large quantity, the fact that sulphuric acid has little fertilizer value is tending toward the development of other carriers for ammonia. One for which there is great expectation is ammonium phosphate, which contains two plant foods, nitrogen and phosphorus. Monoammonium phosphate contains 14.7 percent ammonia and 61.7 percent phosphoric acid (P_2O_5). Other grades are produced and are marketed under trade names such as "Ammo-Phos" of the American Cyanamid Co. (See pp. 156, 157 and 189.)

62. Ammonium phosphates are made by methods similar to the manufacture of ammonium sulphate except that phosphoric acid is substituted for sulphuric acid. The phosphoric acid is distributed to the ammonia absorption towers from which the mixture goes to a saturator. If weak phosphoric acid is used, the liquor from the saturator goes directly to tanks and then to rotary driers. When concentrated acid is used a centrifuge is employed before conveying the mixture to the rotary drier. Diammonium phosphate, consisting of 23 percent ammonia and 47 percent phosphoric acid is produced by treating the monoammonium phosphate liquor with additional ammonia.

63. Ammonium nitrate, used extensively in high explosives, is also used as a fertilizer, although it is difficult to handle as a fertilizer. It is made by absorbing ammonia in 30 to 50 percent nitric acid. The solution is evaporated and crystallized. Research work is under way

to render this product less hygroscopic so that it may be handled more easily. In Germany it is mixed with potash salts or with ammonium sulphate. The ammonium sulphate-nitrate containing 28 percent nitrogen is marketed as Leuna salpeter. It contains about 1,245 pounds of sulphate and 755 pounds of nitrate. Potassium-ammonium nitrate contains 15.5 percent nitrogen and 27 percent potash. "Leunaphos" is a compound of diammonium phosphate and ammonium sulphate.

64. *Conversion of ammonia to nitric acid.*—Nitric acid, the direct product of the arc process and a direct derivative of Chilean sodium nitrate, is the base of a large number of explosives. It is essential, therefore, in war time to be able to convert ammonia into nitric acid. This is done by the oxidation of ammonia. Oxidizers are of two types, one requiring a flat gauze catalyst that is heated electrically to a reaction temperature of 700° to 1,000° C. while the other uses a circular gauze requiring no previous heating. Finely drawn platinum wires are giving best results as catalysts but research work is being conducted on base metals. Air with 10 percent ammonia is passed through the catalyst at a temperature of approximately 800° C. The hot gases are cooled in cooling towers and passed to oxidation and absorption towers. A 50-percent acid is obtained which may be concentrated further through trickling weak nitric acid and sulphuric acid over a tower packing in an absorption tower.

65. *Nitric acid compounds.*—Calcium nitrate is made by treating limestone with nitric acid. It contains 15.5 percent nitrogen and 28 percent lime and is used as a fertilizer. Synthetic sodium nitrate is produced by neutralizing the acid with soda ash, the resulting product being used in the chemical industry and recently for fertilizer. Sodium nitride is also used in the chemical industry. Ammonium nitrate and potassium nitrate have already been considered.

Production Costs

66. The comparative value of specific methods of nitrogen fixation depends in large measure upon the locality in which a fixation plant is to be built. Items constituting major factors of production costs under each process must be relatively cheap at the fixation plant in order that the specific process used may enter into effective competition with other processes.

67. In table V following, estimated costs have been based on the assumption that each type of plant was built under conditions most favorable to its erection and operation. For this reason the plant capacities, upon which costs are based, vary. Electrolytic-hydrogen ammonia plant capacity is limited at present by the size of electrolytic cells available and by the amount of electric power to be obtained cheaply at one point. The water-gas ammonia method depends for economy on large-scale operation. Coke-oven hydrogen plants, however, may be operated economically in small units. Power is the most important operating cost in the electrolytic hydrogen-ammonia process, in the cyanamide, and the arc process; coke and coal must necessarily be cheap fuels at water-gas and coke-oven gas ammonia plants and also at cyanamide plants. Consequently, power rates used in table V are lowest where power consumption is highest, and coal and

coke prices vary with their use in West Virginia coal and coke regions or at Niagara Falls.

68. It is obvious that capital costs are lowest in plants using coke-oven hydrogen. Because both hydrogen and coke are produced, the capital costs are distributed. The division of costs by different firms may easily vary. The German authority, P. Borchardt, makes such a division of capital costs between these products that the amount charged against hydrogen is much lower than given in table V. The figures used are quoted by the Englishman, Col. G. P. Pollitt, and seem more in line with prevailing material and labor costs in this country.

TABLE V.—*Estimated cost of nitrogen fixation by various processes* [1]

[The prices quoted are those obtaining in regions where specific processes are being or may be used]

Cost item	Direct synthetic-ammonia process						Cyanamide process (based on 350,000 tons cyanamide capacity)		Arc process—Nitrogen 20 percent as sodium nitrate; 80 percent as nitric acid
	With electrolytic hydrogen (based on 26,000 short tons ammonia capacity)		With water-gas hydrogen (based on 200,000 short tons ammonia capacity)		Coke-oven gas hydrogen (based on 20,000 short tons ammonia capacity)		Calcium cyanamide	Nitrogen	
	Ammonia	Nitrogen	Ammonia	Nitrogen	Ammonia	Nitrogen			
Capital cost per ton year	$200	$240	[2] $155	[2] $188	$145	$177	$85	$360	$600
Amortization, interest, taxes charged at 15 percent	$30.00	$36.00	$23.25	$28.20	$21.75	$26.55	$12.75	$54.00	$90.00
Power consumption, per ton	12,055 kilowatt-hour, at $0.002—24.11	14,640 kilowatt-hour, at $0.002—29.28	1,250 kilowatt-hour, at $0.004— 5.00	1,500 kilowatt-hour, at $0.004— 6.00	2,000 kilowatt-hour, at $0.004— 8.00	2,430 kilowatt-hour, at $0.004— 9.75	2,830 kilowatt-hour, at $0.003— 8.50	12,000 kilowatt-hour, at $0.003—36.00	61,000 kilowatt-hour, at $0.0015—91.50
Other operating and maintenance costs including royalties	18.83	22.87	26.75	32.00	31.75	38.25	12.35	52.50	60.00
Total estimated costs	[3] 72.94	[3] 88.15	[3] 55.00	[3] 66.20	[4] 61.50	74.55	33.60	142.50	241.50

[1] Based in part upon known costs and upon calculated costs. References:
Col. G. P. Pollitt, of England. The Synthetic Ammonia Industry (paper before World Power Conference, June 1930).
P. Borchardt, Germany. Gaszerlegung durch Druck und Tieftemperature (paper before World Power Conference, June 1930).
P. McMichael in Chemical and Metallurgical Engineering, August 1930.
Frank A. Ernst, Fixed Nitrogen Laboratory, U.S. Department of Agriculture. Fixation of Atmospheric Nitrogen, p. 90 (1927).
J. M. Braham, Fixed Nitrogen Laboratory, U.S. Department of Agriculture. Nitrogen Survey. Part III, 1924.
W. S. Landis, vice-president Cyanamid Co. The Cyanamid Industry, 1927.
H.R. 16396–16614. Hearings on Muscle Shoals.

[2] The high plant capacity is in part responsible for low capital cost.

[3] Does not include any allowance for by-product oxygen produced.

[4] Borchardt estimates German cost to be $51.84 and $62.40, respectively. This difference is due to a smaller capital cost charge against the product.

69. The power consumption and capital costs of arc-process plants are so great that it is evident this process cannot hold a place under present operative conditions, even when cheap power is obtainable. Until a few years ago nitric acid—the fixation form of nitrogen by this process—has been obtained in this country, not from European arc process plants but from Chilean nitrate. As a consequence a nitric-acid industry had been built up quite apart from the development of nitrogen-fixation processes. In 1921, when our first commercial nitrogen-fixation unit was put in operation, there were 56 establishments manufacturing over 50,000 tons of nitric acid. In recent years, with the aid of the fixed nitrogen research laboratory, American industry has developed a process for making nitric acid by catalytic oxidation of ammonia. (See p. 149.) Not only are plant costs for this process lower than those essential for Chilean nitrate conversion but high efficiency and safety of operation with the explosive mixture have been obtained. As a result the nitric-acid industry has been revolutionized and we are licensing use of the ammonia-oxidation process in Europe.

70. While the electrolytic-hydrogen ammonia process consumes the second largest amount of power, its other operating costs are lower than in other processes. The cyanamide process requires but 2,600 kilowatt-hours less per ton of nitrogen fixed, but it also requires over 3 tons of coal and coke, as well as limestone. The coke-oven hydrogen-ammonia-process costs depend largely upon the hydrogen content of the original gas as the quantity of coal needed will vary with the quantities of hydrogen extracted. In this table it is assumed that 15 tons of coal were necessary to produce hydrogen sufficient to fix 1 ton of nitrogen.

71. In the water-gas hydrogen process the table assumes that coke ovens are a part of the water-gas plant, the coke-oven gas being used under boilers instead of for the extraction of hydrogen. It is for this reason that coke is charged at $3 in these plants as compared with $6 market price in the cyanamide process.

72. *Possibility of reducing cost of electrolytic-hyrdogen ammonia.*—When comparing total costs of the electrolytic-hydrogen ammonia process with other processes, several matters must be given consideration. The entire cost of hydrogen and nitrogen production is charged against these gases whereas large quantities of oxygen are also produced, as will be seen in table VI. While the demand for oxygen is varied, it has been decentralized. If, however, an available market existed close to the ammonia plant so that oxygen could bear its part of the gas-production expense, the cost of electrolytic-hydrogen ammonia would be materially reduced. Even assuming that a market existed for oxygen at the low rate of 15 cents per thousand cubic feet, such a sale would reduce the production price per ton of contained nitrogen to $65.88 per ton, or within competitive range of water-gas hydrogen ammonia. The production of nitric acid by the oxidation of ammonia would seem to be one use for cheap oxygen at an ammonia plant.

TABLE VI.—*Production costs of direct synthetic ammonia process with electrolytic hydrogen* [1]

	Plant capacity 8,750 tons ammonia annually	Plant capacity 26,250 tons ammonia annually
Production and plant operation 350 days, at 90 percent ammonia-plant efficiency:		
Electrolytic cell plant:		
Hydrogen ..... cubic feet	578, 890, 000	1, 567, 357, 000
Oxygen ..... do	289, 419, 000	783, 678, 000
Nitrogen plant:		
Nitrogen ..... do	179, 900, 000	486, 850, 000
Oxygen ..... do	46, 928, 000	136, 378, 000
Ammonia plant:		
Containing ammonia ..... tons	7, 661	20, 745
Nitrogen ..... do	6, 307	17, 080
Byproduct oxygen ..... cubic feet	336, 347, 000	920, 056, 000
A. Capital cost:		
Electrolytic cell plant	$794, 000	$2, 097, 000
Nitrogen plant (Linde air cooler)	210, 500	470, 000
Ammonia plant (modified Haber)	418, 500	1, 092, 000
Miscellaneous (laboratories, office, etc.)	249, 000	433, 000
Total	1, 672, 000	4, 092, 000
Capital cost per annual ton nitrogen fixed ($265 at 15 percent and $240 at 15 percent)	$39. 75	$36. 00
B. Power consumption per year (in kilowatt-hours):		
Electrolytic cell plant	81, 680, 000	221, 170, 000
All others	13, 140, 000	28, 908, 000
Total	94, 820, 000	250, 078, 000
Kilowatt-hours consumed per ton, nitrogen fixed (15,033 at $0.002 and 14,642 at $0.002)	30. 00	29. 28
C. Other operating and maintenance costs:		
Electrolytic cell plant	$23, 606	$58, 485
Nitrogen plant and purifiers	40, 140	71, 850
Ammonia plant and compressors	45, 950	102, 200
General:		
Water	7, 560	15, 120
Labor	5, 250	15, 750
Supervision, chemists, clerks	35, 000	65, 000
Royalty at $3 per ton, ammonia	22, 983	62, 235
Total	180, 489	390, 640
Operating and maintenance costs per ton nitrogen fixed	28. 62	22. 87
Total cost per ton nitrogen fixed	98. 37	88. 15
Total cost per ton ammonia	81. 05	72. 53
Cost per ton of nitrogen fixed if byproduct oxygen sold at 15 cents per M cubic feet	90. 45	80. 00
Cost per ton of ammonia if byproduct oxygen sold at 15 cents per M cubic feet	74. 47	65. 88

[1] Production figures, capital, operating and maintenance costs based on estimates by Paul McMichael (Chemical and Metallurgical Engineering, August 1930, p. 480). Capital costs and power consumption in smaller plants are only slightly less than those quoted by Frank A. Ernst, of the United States Fixed Nitrogen Research Laboratory. Final cost of production exceeds McMichael estimates due to fact that McMichael divided electrolytic cell operations costs according to volume of hydrogen and oxygen produced and charged hydrogen cost only against ammonia.

73. Then, too, in the costs listed, nitrogen is obtained by liquefaction methods. Should the capacity of any hydrogen plant be such that sufficient hydrogen may be obtained for ammonia production and yet enough be left to burn in air to secure the necessary nitrogen, another saving would be made.

74. A third factor of importance in lessening electrolytic hydrogen costs is the feasibility of operating such cells with off-peak power. The cells adjust to rapid charges in load and operate at reasonable efficiencies under great load variations. Wherever large quantities of power are available during off-peak periods, a general reduction in power costs would result by filling up the slumps in load curves by a battery of electrolytic hydrogen cells.

Attention is called to the differences in cost between small and large plant operation shown on table VI.

75. *Water-gas ammonia byproducts.*—Methanol is being recovered as a byproduct of ammonia production by this method. The residual carbon monoxide is converted by means of a catalyst into this product. Methanol is used in the production of formaldehyde, in solvents and in other chemicals and for denaturing purposes. As the Du Ponts produced a million gallons in 1928, and a larger amount in 1929, byproduct methanol unquestionably served to lower the Du Pont cost of water-gas ammonia. American plants are also conducting research on other high-pressure synthetic products so that widest use may be made of the equipment and types of labor and supervision required by the ammonia plant.

76. *Effect on prices of byproduct ammonia.*—Although definite supplies of byproduct ammonia cannot be depended upon because their production is tied up with market conditions of other products, its presence in large quantities may have a marked effect on all prices. As it is often difficult to allot capital and general charges between principal product and a number of byproducts, the market price of byproduct hydrogen-ammonia is usually determined by competing products. As ammonia must be recovered in a number of cases, it tends to be marketed at a price that will move it quickly. However, the ammonia produced as a byproduct of coke ovens, when sold in liquid form, is considered of intermediate quality.

Markets for Specific Nitrogen Compounds

77. Nitrogen in various forms is consumed primarily by four groups of industries in the United States. In 1929 over 70 percent of all inorganic nitrogen went into fertilizer manufacture; 14 percent into chemicals, almost 5 percent into explosives, over 3 percent into refrigeration, while 5 percent of the production was distributed among manufacturers of other products.

CHEMICAL AND MISCELLANEOUS USES

78. *Ammonia.*—The only initial fixation product used for refrigeration and chemicals and acids is ammonia. That made by the direct synthetic process is marketed principally as anhydrous ammonia while the byproduct ammonia from the coke and gas industries is marketed as aqua ammonia and is usually an intermediate quality. The anhydrous ammonia is shipped in tank cars of 25 tons' capacity. It has extensive use as a synthetic reagent in the organic chemical industry. In the petroleum industry it neutralizes acids and reduces pipe corrosion. It is finding new use in the treatment of water in combination with chlorine.

79. Because ammonia easily reverts to its constituent parts, it is an excellent source of supply of hydrogen and nitrogen. By passing ammonia over an electrically treated catalyst, much of its 75 percent hydrogen content may be obtained. When nitrogen is desired, the ammonia may be cracked and the hydrogen burnt out by admixture of air. Mr. Jasper Crane, vice-president of the E. I. du Pont de Nemours Co., states that 1 cylinder of ammonia treated in the foregoing manner will yield 36 cylinders of compressed air at one ninth the cost of cylinder nitrogen, and that 1 cylinder of ammonia is equal to 17 cylinders of hydrogen.

80. In combination with other chemicals, ammonia finds use in medicine, in photography, in dyeing operations, in the textile industry, in electric batteries, and in galvanizing and other metal processes.

81. *Nitric acid.*—As has been stated on page 33, much nitric acid is made in the United States by the oxidation of ammonia. This derivative enters largely into the chemical industry as well as being the source of most explosives. It is a powerful oxidizing agent. In the pure state, nitric acid is used in medicine, and nitric oxide or "laughing gas" is well known. Use for it is also found in the manufacture of coal-tar dyes and of sulphuric acid. But its largest use is in the explosive industry. Dynamite, nitroglycerine, nitrocellulose, cordite, picric acid and trinitrotoluel are all made by combining nitric acid with other substances. In addition to military demands for these products, some are used in mining, quarrying, road building, and clearing the lands.

82. *Cyanamide compounds.*—Cyanide which may be produced through the cyanamide process when combined with sodium chloride is largely used in the extraction of gold and silver from their ores. In the form of hydrocyanic acid, it finds use in citric-fruit fumigation. And as ferrocyanide, it is used in yellow and blue prussiates manufacture.

83. *The fertilizer market.*—Nitrogenous fertilizers were purchased in the United States in the following quantities:

TABLE VII.—*Short tons of nitrogen* [1]

Materials	1913	1926	1928
Sulphate of ammonia	30,750	84,562	128,450
Nitrate of soda	52,700	113,770	120,000
Calcium nitrate		2,293	4,000
Leuna salpeter		4,576	23,000
Cyanamide	5,590	20,855	32,000
Total inorganic [2]	89,040	226,056	307,450
Percent inorganic	42	77	85

[1] Compiled by H. R. Smalley, National Fertilizer Association.
[2] The principal sources of organic nitrogen are cottonseed meal and animal tankage.

84. Only since 1926 has Chilean sodium nitrate ceased to be our principal source of fertilizer nitrogen. But because farmers are accustomed to a nitrate nitrogen fertilizer, this type continues to bring higher prices than the ammonia nitrogen. Consequently, our synthetic ammonia manufacturers have converted ammonia for the fertilizer market, not to the sulphate containing 20.5 percent, but to a synthetic sodium nitrate containing 16.5 percent nitrogen, for, according to 1930 fall prices, the latter product would bring $43, whereas ammonium sulphate was worth only from $35 to $38. Methods producing this synthetic product have been so perfected that costs do not exceed $27.50, a figure well within the range of present Chilean nitrate costs. About three fourths of the sodium nitrate used as fertilizer is applied to the soil as top dressing. Ammonium sulphate, so applied, increases soil acidity. This is overcome by the application of lime along with the ammonium sulphate.

The two other nitrate nitrogen fertilizers listed are imported from Germany. Calcium nitrate is favored in citrus culture in California.

85. The sulphate of ammonia entering our fertilizer market is chiefly obtained as a byproduct of coke ovens. The costs involved in

converting synthetic ammonia into ammonium sulphate will not make this product attractive to the synthetic industry in competition with the byproduct production. However, it has been found that the ammoniation of superphosphate fertilizer is accomplished with better results in the presence of ammonium sulphate. Consequently, some anhydrous ammonia and sulphuric acid are converted to ammonium sulphate at fertilizer plants.

86. Cyanamide is not only disagreeable to handle, but also leaves an inorganic residue in the soil which is often not permissible. Therefore, while 32,000 tons of cyanamide were used as fertilizer in this country in 1928, a large part of the cyanamide sent into this country from the Canadian Niagara Falls plant was converted into ammonium phosphate. This is manufactured at an approximate cost of $60. While it contains only 10 percent nitrogen, it combines two fertilizers which gives it a higher fertilizer value than the fertilizer containing only one plant food in small quantities. The American Cyanamid Co. has been exporting its entire product of ammonium phosphate as local markets for this valuable material are in process of developing. (For full account see p. 157.)

87. Urea is a more concentrated form of nitrogen fertilizer. The Union Carbide Co. has the United States and Canadian rights to develop urea under the J. H. Lidholm process. A pilot plant was built in 1925. The company estimated that the Cyanamid Co. could manufacture urea at Muscle Shoals for $95 per ton. Educational work is now being done to acquaint the farmer with the advantages of urea, and unquestionably it will enter into quantitative use in the years to come. Tariffs on urea and ammonium sulphate were removed in 1930, resulting in a noticeable increase in urea importations.

88. The following table gives the market values of principal nitrogenous materials. The varying values per ton of nitrogen compared with the costs of nitrogen fixation and conversion indicate clearly the products for which there is market preference.

TABLE VIII.—*Market value of available nitrogen in principal nitrogenous materials*

Nitrogenous materials	Percent nitrogen contained	Price schedule base	Price per short ton, fall 1930	Value per ton available nitrogen
Ammonia, anhydrous	82.3	Tank cars f.o.b. plant	$120.00	$145.20
Nitric acid	22.2	36° carboys--pounds	$100.00–105.00	$450.00–472.50
Cyanamide	23.5	Bulk	47.00	199.75
Chilean sodium nitrate	15.65	Per 100 pounds	39.80– 42.00	254.00–268.00
Synthetic sodium nitrate	16.47	do	42.80– 43.00	259.00–261.00
Calcium nitrate	15.5	Philadelphia	40.00	258.00
Ammonium sulphate	20.5	Bulk f.o.b. nearest seaport	35.00– 38.00	169.75–184.30
Ammonium sulphate nitrate	28.0	Philadelphia	45.00– 49.75	162.00–179.00

CONTROL OF THE FIXATION INDUSTRY AND NITROGEN MARKETS

NORTH AMERICA

89. *Cyanamide and its derivatives.*—The American Cyanamid Co., of Niagara Falls, Canada, owns all cyanamide patents. While the basic patents have expired, a series of other patents cover each improvement in manufacture. Should the United States operate the

cyanamide plant at Muscle Shoals, it can use such of the Cyanamid Co.'s patents as existed when this plant was built for a payment to the company of about $1,200,000 yearly. No private firm may operate the Muscle Shoals plant without infringing on existing patent rights.

90. As has been stated, a large part of the cyanamide is shipped in tank cars to Warners, N.J. The company owns a phosphate rock mine about 50 miles inland from Port Tampa, and has constructed a phosphoric acid factory at Tampa. From this mine phosphate rock is shipped to New York Harbor. Sulphur for the manufacture of sulphuric acid is purchased from the Freeport Sulphur Co., of Texas. Had Congress seen fit to permit the American Cyanamid Co. to operate the Muscle Shoals cyanamide plant, the company planned to manufacture urea, a concentrated nitrogenous fertilizer, as well as ammonium phosphate. The urea patents would have been turned over to it by the Union Carbide Co. in exchange for power privileges.

91. The American Cyanamid Co. owns the Calco Chemical Co. with which have been consolidated the Passaic Color Co. and the Garfield Analine Works; the Kalbfleisch Co., which has taken over the Jarecki Chemical Co. of Cincinnati, and the Superior Chemical Co., of Joliet, Ill.; and the Seldon Co. with plants at Pittsburgh and Bridgeville, Pa. The Seldon Co. of Pennsylvania, and the Calco group, with five plants in New Jersey, manufacture coal-tar products among other chemicals and may, therefore, serve as a market for the ferrocyanides produced at the Warners plant. The Kalbfleisch group manufacture nitric acids and other acids for chemical and miscellaneous uses, as well as sodium and alum compounds, solvents, and miscellaneous chemicals. The Calco Co. also manufactures nitric acid.

92. *Direct synthetic ammonia and its derivatives.*—The original Haber-Bosch patents are owned by the Chemical Foundation, which permits their use by any firm which demonstrates it is capable of manufacturing synthetic ammonia. As the Fixed Nitrogen Laboratory of the Department of Agriculture has developed and is developing methods of overcoming many difficulties and inefficiencies in these processes, expert advice and assistance is available to all manufacturers.

93. The Atmospheric Nitrogen Corporation manufactures anhydrous ammonia for chemical industries, but also produces synthetic sodium nitrate for the fertilizer market. It is a subsidiary of the Allied Chemical & Dye Corporation, which, through its mergers, manufactures the fundamental raw materials not only of the chemical industry but of many other industries. At Syracuse alone are plants not only engaged in manufacturing ammonia, but ammonia-soda and electrolytic alkalies. The General Chemical Co., one of the subsidiaries, is a large producer of nitric acid, as well as of sodium and alum compounds and miscellaneous chemicals.

94. The E. I. du Pont de Nemours & Co., in addition to its two synthetic ammonia plants, produces nitrogen compounds and compressed gases in Missouri. Its subsidiary, the Grasselli Chemical Co. manufactures nitric acid and some phosphoric acid as well as fertilizer. Unlike the Allied Chemical & Dye Corporation, much of the ammonia and nitric acid produced in these plants is manufactured into finished market products by the Du Ponts. Power and explosives, nitrate plastics such as pyroxylin, nitrocellulose fabrics, and nitrocellulose lacquers all require nitric acid.

95. Large independent manufacturers of nitric acid are: The Atlas Powder Co.; the J. T. Baker Chemical Co., of Phillipsburg, N.J.; Chas. Cooper & Co., of Newark; Hercules Powder Co.; Merck & Co., with plants in New Jersey; Monsanto Chemical Works, of St. Louis and Monsanto, Ill.; the Newport Co., with one plant at Carrollville, Wis.; and others in New Jersey; the Pennsylvania Salt Co., of Philadelphia, and with a plant in Tacoma, Wash.; and the Trojan Powder Co.

96. It is obvious that the heaviest chemical and explosive market for nitrogen compounds is to be found in New Jersey, but that a quantity is consumed in or near St. Louis.

The fertilizer market will be dealt with in detail under "Phosphates." (See pp. 180–188.)

World Competitive Conditions

97. World consumption of nitrogen has not kept pace with production. While this may be attributable in part to poor agricultural conditions, it is also due to the heavy increase of synthetic nitrate production by major powers without a corresponding diminution of Chilean nitrate production. Consequently, the I. G. Farberindustrie, of Germany, the Imperial Chemical Industries, Ltd., of Great Britain, and the Chilean Minister of Finance, representing Chilean nitrate interests, entered into an agreement on June 26, 1929, which brought about a drop in nitrogen prices.

98. The realization that synthetic nitrogen was a permanent competitor of Chilean nitrates has led to a complete reorganization of the industry in Chile. All nitrate operations are to be carried on by the Chile Nitrate Co., a semigovernment corporation. All extractions will be by the newer Guggenheim process. Government-owned nitrate lands will be made available as needed. The export tax on nitrates and iodine, in existence since 1897, is abandoned. Instead, the Chile Nitrate Co. guarantees the Chilean Government payments of sums ranging from 186,000,000 pesos in 1930 to 140,000,000 pesos in 1933, and the Government receives one half the stock of the company. After 1933 a 6 percent income tax and dividends will be relied upon for Government support.

99. The reorganization became effective July 21, 1930. The Chilean nitrate reorganization was followed by an international agreement between the Chilean interests, Germany, England, France, Belgium, Holland, Norway, Italy, Poland, and Czechoslovakia—all the nitrate-producing countries except the United States. While only the official communique has been made public, production quotas, export quotas, and prices are believed to have been agreed upon. The extension of the 1929 agreement to include the smaller countries is due in part to the fact that Belgian and Dutch producers of fertilizer from coke-oven gas have been able to underbid previous cartel prices. The agreement effective in August has a 1-year duration.

What effect this agreement will have on the synthetic industry in the United States is a matter of conjecture.

New Canadian Plants

100. Of special interest to the Pacific Northwest is the construction work under way at Trail, British Columbia, by the Consolidated Mining & Smelting Co., of Canada. The plant will produce 35 tons

of fixed nitrogen daily in the form of fertilizer salts, the hydrogen to be derived electrolytically in a plant requiring 14,920 killowatts. The nitrogen will be gotten through air liquefaction in a plant requiring 7,460 kilowatts energy. The company owns large phosphate rock deposits and is a producer of sulphuric acid.

101. Canadian Industries, Ltd., is erecting a small synthetic ammonia plant at Windsor, Ontario, to utilize byproduct hydrogen of the Canadian Salt Co. It also plans to produce mixed fertilizers at Hamilton, Ontario, and Beloiel, Quebec, which will undoubtedly affect the export fertilizer trade of the United States.

The following table indicates the world market for nitrogen:

TABLE IX.—*World nitrogen supply in 1928* [1]

[Short tons of nitrogen]

Country	Production	Imports	Exports	Apparent consumption [2]
Germany	870,000	20,800	316,500	574,300
United States	198,000	268,600	35,400	431,200
France	70,000	110,500	7,200	173,300
Japan	73,600	78,800	7,300	145,100
Belgium	50,400	50,400	6,200	94,600
Netherlands	11,100	81,800	11,500	81,400
United Kingdom	156,000	18,000	98,200	75,800
Italy	55,600	24,900	4,900	75,600
Spain	8,200	56,100	----------	64,300
Poland	45,500	21,300	4,300	62,500
Denmark	----------	34,900	----------	34,900
Egypt	----------	34,700	----------	34,700
China	2,000	33,800	2,100	33,700
Dutch East Indies	----------	31,400	----------	31,400
Java	----------	28,400	----------	28,400
Czechoslovakia	14,700	12,000	900	25,800
Sweden	7,200	13,200	200	20,200
Canada	42,900	9,500	35,400	17,000
Formosa	----------	16,800	----------	16,800
Union of Soviet Socialist Republics	7,100	3,500	----------	10,600
Hawaiian Islands	----------	10,200	----------	10,200
Korea	----------	6,700	----------	6,700
Yugoslavia	16,800	900	11,200	6,500
India and Ceylon	3,400	4,800	2,200	6,000
Philippine Islands	----------	5,800	----------	5,800
Irish Free State	300	4,700	200	4,800
British West Indies	----------	4,600	----------	4,600
Hungary	200	4,400	----------	4,600
New Zealand	----------	4,400	----------	4,400
Canary Islands	----------	3,400	----------	3,400
Cuba	----------	3,400	----------	3,400
South Africa	----------	3,100	----------	3,100
Australia	4,000	----------	1,000	3,000
Finland	----------	2,700	----------	2,700
Austria	----------	3,800	1,600	2,200
Norway	45,600	----------	43,500	2,100
Greece	----------	1,500	----------	1,500
French West Africa	----------	1,100	----------	1,100
East Coast Sumatra	----------	1,000	----------	1,000
Peru	----------	1,000	----------	1,000
Brazil	----------	700	----------	700
Fiji	----------	600	----------	600
Estonia	----------	300	----------	300
Latvia	----------	300	----------	300
West Indies (except Cuba and Bermuda)	----------	300	----------	300
Argentina	----------	200	----------	200
Newfoundland	----------	200	----------	200
Barbados	----------	100	----------	100
Bulgaria	----------	100	----------	100
Chile	553,000	----------	489,000	----------
Switzerland	7,800	1,500	9,300	----------
Manchuria	----------	----------	----------	----------
Mexico	----------	----------	----------	----------

[1] Compiled by Messrs. Howard P. Emerson and Edward T. Dunn, of the Du Pont Ammonia Corporation for Chemical and Metallurgical Engineering and printed in January 1930 issue.

[2] In computing apparent consumption, stocks on hand are not taken into account. The consumption of nitrogen in Germany is probably somewhat less than that indicated because of the large stocks of ammonium sulphate. Furthermore, there were unconsumed stocks of Chile nitrate in numerous countries on Dec. 31, 1928. Stocks on hand Dec. 31 in Chile were equivalent to 161,000 short tons of nitrogen.

Phosphoric Acid and Phosphatic Compounds

1. Elemental phosphorus does not occur in a free state in nature, nor does it find extensive industrial use today except in combination with other substances. Its great affinity for oxygen has made the product obtained by the complete oxidation of phosphorus, phosphorus pentoxide (P_2O_5), the phosphatic compound most used in the chemical industry. Consequently the grade of various phosphatic materials consumed in industry is expressed in terms of P_2O_5, which is commercially, though erroneously, called "phosphoric acid."

BRIEF HISTORY

2. While phosphorus was prepared and named as early as 1669, it was a century later before it was known to be an essential constituent of bones. Almost another century went by before an Englishman discovered that the fertilizer value of bones, fish, and guano, which had been fed to the soil for centuries, was due to their phosphoric acid content. In 1842 John B. Lawes was issued a British patent for making bone ash more available to crops by dissolving bones with sulphuric acid. A few years later the discovery of phosphate ore in England and in France occurred. From 1857, when Leibig pointed out that the phosphoric content of ores could also be made more available as plant food when dissolved in sulphuric acid, the sulphuric acid process has prevailed in preparing phosphate rock for the fertilizer market. For many years the resulting fertilizer was known as "acid phosphate" in this country, but it is now called "superphosphate."

3. In 1867 high-grade phosphate rock was located in South Carolina. For the next 20 years South Carolina furnished 90 percent of the world's supply of phosphate rock. In 1888 Florida fields were developed. Tennessee began production in 1893. As these mines could be operated more cheaply than the South Carolina deposits, the latter ceased operations in 1922. Phosphates in Tunis and Egypt were discovered in 1897, and development began in Morocco in 1917. The discovery of vast deposits in Wyoming and Idaho left no doubt as to the availability of phosphate rock for many years to come.

4. Some iron ores of Alsace-Lorraine had been considered too impure to work because of their phosphoric content. In 1871 it was discovered that by lining crucibles with lime and magnesium the phosphorus from the melted iron would be absorbed in the slag lining, thus securing a valuable phosphate fertilizer material as well as a high-grade steel. As a consequence, basic phosphate slag is an important third source of phosphatic materials in Europe. In this country, with the exception of Alabama ores, so little phosphorus is contained in our iron ores as to make its recovery inadvisable.

5. While different sources of phosphoric acid were being discovered, new uses were also found. In 1827 phosphorus was used in the manufacture of friction matches. Today, yellow phosphorus in matches is prohibited, but a nonpoisonous sesquisulphide of phosphorus heads the "strike anywhere" match.

Monocalcium phosphate baking powder was patented in 1856 by E. N. Horsford. This and other phosphatic powders were made from bone phosphate until the discovery of the pyrolytic process of

producing phosphoric acid. As early as 1888 phosphoric acid was used in optical glass, in 1893 in phosphor bronze, and in 1899 the sodium phosphate industry began.

6. Although phosphorus was prepared in commercial quantities first by treating degelatinized bones with sulphuric acid, the process was involved and costly. As early as 1867 a patent was obtained for collecting elementary phosphorus from phosphate rock, sand, and coke, heated to a high temperature. It was in 1889 that J. B. Readman suggested the use of the electric furnace for such production.

6½. Practical application was made by the Oldbury Chemical Co., which used an arc furnace to smelt raw phosphate rock, silica, and coke. Although patents were taken out for the manufacture of phosphoric acid rather than phosphorus by furnace method as early as 1895, it was 1920 before the electrothermal manufacture of phosphoric acid began, at Anniston, Ala. Only in 1929 was the production of phosphoric acid by blast-furnace methods attempted at Nashville, Tenn., by the Victor Chemical Corporation. All pyrolytic processes have furnished phosphorus or phosphoric acid only for food, chemical, metallurgical, and other miscellaneous uses until very recently. The use of phosphoric acid in fertilizer production is beginning. Whether it will replace sulphuric acid seems to be primarily a question of relative costs of the two acids and the relative prices for the respective fertilizers per unit of plant food charged the farmer.

PHOSPHATE ROCK

7. Although bone, tankage, guano, basic slag, coprolites, and apatite are sources of phosphoric acid, so large are the world's deposits of phosphate rock that these deposits are and will continue to be the principal source of the acid for many years to come.

8. The most extensive deposits are in the United States, in northern Africa, and in islands of the Pacific and Indian Oceans. Minor deposits are located in a number of other countries. In the United States large deposits are located in Florida, Tennessee, Idaho, Utah, Wyoming, and Montana, and smaller deposits are available in South Carolina, Kentucky, and Arkansas.

LOCATION OF PHOSPHATE ROCK DEPOSITS

9. *Florida.*—The deposits of Florida have been mined extensively and are still the largest present-day producers. The Florida rock is of three types—land pebble or phosphate pebbles found mixed with sand and clay in relatively level surfaces in Hillsboro, Polk, and De Soto Counties; the hard rock occurring in irregular pockets on the western part of the Florida Peninsula; and soft phosphate, at present of little commercial value.

Land pebble phosphates form over 95 percent of the total present Florida production. These beds range in thickness to 25 feet. The overburden is stripped by hydraulic methods or by drag-line excavators. Streams of water under 100 to 225 pounds pressure per square inch wash the matrix down into a sump from which it is sucked by pumps and conveyed through pipes to the washer plant. The pebble is washed, screened, and dried partly by drainage and partly in rotary oil-burning driers. Its tricalcium phosphate content ranges from 69 to 78 percent, while its phosphoric acid content

is from 30 to 34 percent. Modern mining equipment is electrically driven and handles 400 cubic yards of material per hour, as compared with 50 cubic yards handled by steam-driven equipment. There were eight producers of land pebble phosphate in 1928. As the principal operating mines are located only 20 to 40 miles east of Tampa, all phosphate pebble for Atlantic and Gulf, as well as European ports, is shipped from Tampa.

10. The hard rock is found in beds of varying thickness, and the percentage of recoverable rock differs. Only about 10 percent of the total material handled is recovered and marketed. While this rock has a greater phosphoric content than land pebble (36.39 percent), it is more expensive to mine. Three companies were mining this rock in 1928. It is transported by railroad to ports on either side of the Florida Peninsula, from which much is shipped to foreign ports.

11. *Tennessee.*—Two types of rock are marketed from Tennessee mines—brown and blue rock. The brown rock has a varying phosphoric acid content of from 30 to 38 percent, while the blue rock runs from 27 to 32 percent phosphoric acid. A white phosphate also is found but is not marketed at present. The deposits lie in the central part of the State, covering an area of approximately 7,000 square miles. The brown rock is mined in the same manner as is Florida hard rock—that is, by stripping off the overburden with steam shovel, scrapers, or hydraulic apparatus; by crushing the mechanically mined rock, grading, and drying it. The blue phosphate deposits are overlain by blue slate so that underground mining is usually done. The blue slate forms an excellent roof for such mines, so that timbering is not necessary. The rock is usually mined by drilling and blasting. This rock requires no washing, but it is dried frequently because of its high moisture content.

12. In 1929 Florida land pebble sold from $3.21 a long ton f.o.b. mines, the hard rock for $3.67, while the Tennessee brown rock, forming 90 percent of total Tennessee production, sold for $4.89 a long ton. Consequently, the 14 Tennessee phosphate-rock producers sold this product, not in the eastern seaboard market, but in the South Central and Middle Central States and to some extent in the North Atlantic States.

13. *South Carolina, Kentucky, Arkansas.*—South Carolina rock occurs in boulders, nodules, and small pebbles in sand and slag. It is prepared in the same way as Florida land pebble. Its location along the coast makes it easily accessible, but the beds are only about a foot in thickness, as compared with Florida fields running as high as 25 feet. The lower cost of mining in Florida caused mining operators to cease in South Carolina in 1921. There are believed, however, to be from 9,000,000 to 11,000,000 tons of phosphate rock unmined in this State.

Kentucky deposits are limited both as to extent and richness but are similar to the brown rock of Tennessee. Arkansas fields are too high in iron for sulphuric-acid methods but may become valuable as pyrolitic production methods are used which make use of iron in byproduct production.

14. *Western deposits.*—By far the largest known world deposits of high-grade phosphate rock are found in the Rocky Mountain region from the latitude of Salt Lake City to that of Helena, Mont. The deposits are bedded deposits, quite distinct in character from those

of the South Appalachian range. The series is 90 feet in places, and beds vary in thickness from a few inches to 10 feet. They contain gray or black rock of varying texture. Beds are frequently broken by thin layers of poorer phosphatic material, making economical processes that can utilize all grades of rock. Underground mining is essential with usual timbering requirements. An adit is driven at the base of the hill along the strike of the bed and sloping up into it. The broken rock is drawn down through chutes into 10-ton cars, which are moved out to the mill by electric storage battery locomotives.

15. The rock is clean and dry. For every ton of rock mined 94 percent may be shipped without washing and usually without drying. The phosphoric-acid content varies from 32 to 38 percent.

16. The Idaho deposits are considered the richest, although in some places Wyoming rock has as high a phosphoric content. The Idaho fields lie in the southeastern part of the State, within the Snake River drainage basin and mostly along the east side of the Snake River range. Phosphoric formation is also exposed near the south end along the western flank of the Teton Mountains.

The Wyoming rock is mostly in the Owl Creek, Wind River, Gros Vertre, and Salt River ranges. In Utah the deposits are in the Wasatele and Uinta ranges east of Great Salt Lake.

17. Deposits have been developed north of Soda Springs, Georgetown, and Montpelier, near Paris, Idaho; along the Idaho-Wyoming border in the Sublette Mountain Range, near Border Station and Cokeville; in southwest Wyoming and in northern Utah. Although phosphate has been located at Melrose, Garrison, Phillipsburg, and Cardwell, in Montana, little development has taken place.

18. As the rock comes from these western mines it is crushed and conveyed by shaking feeders to a large grizzly. A small tonnage is finely ground for direct application to some California citrus fruit soils, but the mass is shipped to phosphoric acid or fertilizer plants. Mining units are electrically driven. The western phosphate mining companies are the Anaconda Copper Mining Co., Conda, Idaho; the San Francisco Chemical Co., Montpelier, Idaho; Cokeville Phosphate Co., Cokeville, Wyo.; and the Agricultural Potassium Phosphate Co. near Paris, Idaho.

19. *Northern Africa.*—Tunisia is believed to have very extensive deposits. Developments have taken place near Safsa, from which ore is transported about 150 miles to Sfax and Sousse. Algeria also has very extensive deposits, many of which lie beyond the reach of transportation facilities at this time. Egypt, from deposits along the banks of the Nile and near the Red Sea, and Morocco, add to the sum total of northern Africa production sufficient tonnage to bring its total tonnage in excess of the phosphate rock production of the United States. These deposits range in phosphoric acid content from 22 percent in Algeria to 35 percent in Morocco.

20. *Pacific and Indian Oceans.*—Ocean Isle and Christmas Isle have the richest known deposits containing over 38 and 39 percent phosphoric acid, respectively. Naura or Pleasant Island has phosphate deposits throughout its total area of 12 square miles. Makatea and Angeaur are also small phosphate islands. Some rock is also found in Australia.

21. *Europe.*—While some phosphate rock, as well as apatite and coprolite deposits have been worked in the several European countries,

the development of the richer deposits in Africa, the islands, and this country have caused such production to practically cease.

THE WORLD RESERVES OF PHOSPHATE

22. Although geological surveys of phosphate deposits have been extensive, no attempt has been made to definitely determine the exact quantity of rich, medium, and low-grade ore still available. From the surveys and mining that has been done, estimates have been made by Mr. George B. Mansfield, of the United States Bureau of Mines, which, while not exact, indicate, in general, the extent and location of the important reserves of the world.

23. The State of Idaho has by far the largest known deposits of high-grade material, totaling over 5,000,000,000 tons. Tunisia, Algeria, and Morocco follow with 1,000,000,000 or more tons each. Montana and Utah deposits outrank Florida reserves, which are believed to contain less than 300,000,000 tons, and are being reduced at a current rate of 3,000,000 tons per year. Tennessee has reserves of 85,000,000 tons. There can be no question, therefore, that the Nation must eventually depend on Idaho for its chief source of phosphatic raw materials.

TABLE X.—*World reserves of phosphate* [1] *in metric tons*

Total		16, 866, 565, 000
High grade		10, 621, 565, 000
Low grade		6, 245, 000, 000
High-grade deposits:		
United States		6, 430, 565, 000
Western field:		
Idaho	5, 169, 257, 000	
Montana	397, 584, 000	
Utah	331, 973, 000	
Wyoming	117, 594, 000	
		6, 016, 408, 000
Eastern field:		
Florida	298, 704, 000	
Tennessee	85, 300, 000	
Arkansas	20, 320, 000	
South Carolina	8, 941, 000	
Kentucky	892, 000	
		414, 157, 000
Algeria		1, 452, 000, 000
Morocco		1, 400, 000, 000
Tunisia		1, 000, 000, 000
Egypt		179, 000, 000
Nauru and Ocean Island		140, 000, 000
Makatea Island		10, 000, 000
Angaur Island		3, 000, 000
Rasa Island		3, 000, 000
Palestine		4, 000, 000
Low-grade deposits:		
Russia		[2] 5, 568, 000, 000
Siberia		667, 000, 000
Spain		10, 000, 000
Total low grade		6, 245, 000, 000

[1] Committee on Ways and Means, H.R. 70th Cong., 2d sess., vol. XV., p. 9076.
[2] High-grade rock has recently been discovered in vicinity of Saratov, extent of deposits not known.

24. *World production of phosphate rock.*—The United States was the principal producer of phosphate rock for many years, but the development of Morocco deposits since 1917 and the extensive production of Tunisia have made the African phosphates sharp competitors. Table II shows the tonnage by country in the last 4 years.

25. *French control.*—The French Government, acting through its protectorate of Morocco, exercises complete control of the production and sales of all phosphate mined in that country. The department of the Morocco Government which operates the mines is known as the Office Cherifrien des Phosphates. Production is financed through a Government loan and the Government receives all profit from the operation. No prospecting or exploitation of phosphate rock can be done by any private group. The railroad which carries the rock to Casablanca, as well as port facilities, are all Government owned. The French Government also, through its colonial governments, exercises a paternalistic attitude toward the development of phosphate mining in Tunisia and Algeria. The largest Tunis producer, Compagnie de Gafsa, is controlled by French capital.

26. *English control.*—A nominee of the Government of Australia, New Zealand and Great Britain conducts the production and sale of the entire output of phosphate rock in the Ocean, Christmas, and Naura Islands. This Government bureau also buys rock required in Australia and New Zealand when the demand is in excess of England's island production.

27. *Japanese production.*—By the terms of the peace treaty, the island of Angaur, about 800 miles east of the southern end of the Philippines, passed from Germany to Japan. Japan has been actively at work producing phosphate rock for her own agricultural needs. Production exceeded 60,000 metric tons in 1928.

The table following indicates the total production during the last 4 years for all countries.

TABLE XI.—*World production of phosphate rock* [1]

[In metric tons]

Country	1925	1926	1927	1928	1929
Algeria	815,116	929,355	919,108	766,834	747,674
Angaur Island	60,963	62,818	[2] 61,000	[2] 63,000	
Australia	957	1,275	893		
Belgium	15,125	30,030	39,760		
Canada	[3] 15	[3] 36	[4] 137	[4] 396	
Christmas Island (Straits Settlements)	[5] 111,829	[5] 131,051	[5] 118,553		
Dutch West Indies, Aruba, and Curacao	[5] 81,771	[5] 106,807	[5] 108,881	200,563	
Egypt	106,808	232,008	279,389	6,859	215,311
Estonia	2,044	4,054	3,576		
France	225,565	253,350			
Germany: Bavaria and Prussia	323	542	443		
Gilbert and Ellice Islands	[6] 213,405	[6] 191,357			
India (British)	1,504	730	613		
Indo China	30,236	14,511	20,700		
Japan	87,375	108,569	75,386		
Madagascar	449	6,135	6,480	136,306	
Makatea Island	[5] 81,061	[5] 127,177	[5] 135,666		242,990
Morocco, French	692,181	882,821	1,400,000	[7] 1,337,100	1,608,249
New Caledonia	12,000	[5] 10,647	9,000		
New Zealand	Nil	Nil	Nil		
Norway [3]	467	343			
Ocean and Nauru Islands	[6] 478,278	[6] 398,059	604,372	[6] 509,971	512,265
Philippine Islands	7,528	7,512	705		
Russia	36,067	[8] 72,516	[8] 56,460		
Seychelles Islands	[5] 3,259	[5] 6,935	[5] 11,511	(9)	
Spain	5,315	5,656	4,202		
Tunis	2,691,000	2,564,000	3,074,950	2,789,000	2,511,000
United States	3,537,876	3,261,487	3,221,589	3,495,132	3,889,881
Total	9,298,517	9,409,781	10,153,374	[2] 10,600,000	[2] 10,500,000

[1] Compiled by K. D. Jacob, U.S. Bureau of Chemistry and Soils.
[2] Estimated.
[3] Apatite.
[4] Apatite and phosphate rock.
[5] Exports.
[6] Exports during fiscal year ended June 30 of year named.
[7] Marketed production.
[8] Year ended Sept. 30.
[9] Data not available.

28. *United States production*.—Details concerning United States production are given on table XII. As will be seen, the general production tendency is upward, Florida land pebble rock forming the bulk of the production. Western production declined, however, in 1928 and 1929. The distance from consuming markets limits the mining of this rock at this time. Tennessee production shows a healthy increase.

TABLE XII.—*Phosphate rock sold or used by producers in the United States* [1]

State	1925	1926	1927	1928	1929
Florida:					
Total:					
Long ton	2,929,964	2,708,207	2,637,420	2,883,446	3,088,607
Value	$8,789,070	$8,683,508	$8,646,162	$9,424,022	$9,901,074
Hard rock:					
Long ton	171,649	116,264	131,254	95,918	72,733
Value	$707,933	$465,308	$525,016	$383,672	$267,218
Land pebble:					
Long ton	2,758,315	2,591,943	2,506,166	2,787,528	3,015,874
Value	$8,081,137	$8,218,200	$8,121,146	$9,040,350	$9,633,856
Kentucky:					
Long ton	12,837	8,797	----------	----------	----------
Value	$94,064	$67,659	----------	----------	----------
South Carolina:					
Long ton	2,147	----------	----------	----------	----------
Value	$8,051	----------	----------	----------	----------
Tennessee: Brown and blue rock:					
Long ton	464,240	455,395	481,769	577,095	633,939
Value	$2,334,995	$1,980,613	$2,318,785	$2,856,850	$3,097,104
Idaho: Western rock:					
Long ton			45,260	37,477	35,899
Value			$259,405	$147,908	$141,931
Montana: Western rock:					
Long ton	[2] 72,631	[2] 37,577	----------	----------	40
Value	$319,498	$162,020	----------	----------	$400
Wyoming: Western rock:					
Long ton			6,250	3,388	2,679
Value			$29,000	$14,399	$12,750
Total:					
Long ton	3,481,819	3,209,976	3,170,699	3,501,406	3,761,164
Value	$11,545,678	$10,893,800	$11,253,352	$12,443,179	$13,153,259

[1] Table compiled from reports of U.S. Bureau of Mines.
[2] Total for Western States.

UNITED STATES IMPORTS AND EXPORTS OF PHOSPHATE ROCK

29. In spite of our extensive deposits, over 40,000 long tons of rock was imported into this country during 1928 and also during 1929. The larger importations came from Morocco. It was charged that Morocco was "dumping" phosphate rock in Baltimore because the purchase price at Baltimore was $6.50 and $7 per ton as compared with a foreign market value of $7.52 and $7.58 per ton f.o.b. Casablanca, Morocco. Consequently the Secretary of the Treasury on February 9, 1928, assessed this importation with a dumping duty. Efforts were made to secure a duty on phosphate rock, but the Tariff Act of 1930 leaves phosphate rock on the free list.

30. Whether importation will increase until it threatens our own production for domestic consumption is problematical. Since 1921 it appears that a material part of our export market had been lost to the French companies, as exports maintained a relatively low level. Consequently, a phosphate export association was organized under the Webb-Pomerene Act to handle phosphate exports. As a consequence, unquestionably in part, of this organized effort, our exports of phosphate rock in 1929 exceeded all records since 1903.

Germany, Japan, and the Netherlands are the largest importers of American phosphate rock, as will be seen on table XX, page 186. Mr. Morgan H. Grace, president of the Phosphate Export Association, believes that Japan, Australia, and New Zealand are good potential consumers. Japanese imports increased 60 percent from 1913 to 1928. Australia and New Zealand are finding the practice of top dressing pasture lands as well as wheat fields beneficial.[28]

31. Germany, the heaviest unit consumer of fertilizers, uses much more potash and nitrogen than phosphate, mainly because she has abundant supplies of potash and nitrogen but no phosphatic rock. The scientific soil needs, therefore, may force a purchase of more phosphates in future years.

TABLE XIII.—*Phosphate rock production and supply in the United States*[1]

Year	Marketed production	Imports	Exports	Available supply
	Long tons	*Long tons*	*Long tons*	
1920	4,103,982	63	1,069,712	3,034,333
1921	2,064,025	3,535	733,312	1,334,248
1922	2,417,883	5,890	719,294	1,704,479
1923	3,006,706	6,725	827,551	2,185,880
1924	2,867,789	16,098	818,773	2,065,114
1925	3,481,819	2,735	870,200	2,614,354
1926	3,209,976	17,378	748,963	2,478,391
1927	3,170,699	28,195	918,211	2,280,683
1928	3,501,406	45,812	898,764	2,648,454
1929	3,761,164	44,899	1,142,746	2,663,317

[1] U.S. Bureau of Mines, Phosphate Rock in 1928.

PHOSPHORIC ACID MANUFACTURE

32. The oldest and until recently the only commercial method of producing phosphoric acid is by treatment of high-grade phosphate rock with sulphuric acid. Because equipment in use was manufactured over a period of years, manufacturing details differ, but in modern plants the production essentials are the same.

SULPHURIC-ACID PROCESS

33. The first step in the process is the preparation of the rock. This goes from preliminary crushers into impact pulverizers which reduce it to a size that will pass through an 80-mesh screen. The pulverized rock is dumped into mechanical mixers with sulphuric acid which has been diluted with 16° B. phosphoric acid. The heat generated by the reaction, together with the dilution of the sulphuric acid, raises the temperature in the mixers almost to the boiling point. The mixed contents are fed into a series of agitator tanks, where plows break up the product and aerate it until the decomposition of the phosphate rock is complete. The acid solution and solids are pumped to a series of thickeners. The phosphoric-acid liquor which overflows the sides of each thickener is collected by a peripheral launder, which discharges it into the thickener ahead in order that it may extract soluble matter from the sludge received from the preceding thickener. By this counter-current system 95 percent of the phosphoric acid is obtained from the rock. The relatively clear phosphoric acid (27° to

[28] Proceedings National Fertilizer Association, June 1929, p. 47.

30° B.) is finally pumped into evaporators to be concentrated, while the saturated residue is used in diluting the sulphuric acid employed in decomposing another batch of phosphate rock. If the phosphoric acid is to be used for food or medicinal purposes, it must be filtered and purified, but for industrial and agricultural needs concentration to 50° B. may follow immediately. This is done in lead-lined vessels surrounded by steam coils.

34. The purification of phosphoric acid produced by the sulphuric acid process requires extensive manipulation. The solids held in solution, silica and calcium sulphate, may be taken out in a filter press or by the counter current decantation system. Arsenic is precipitated either by adding soluble sulphide or by directing a stream of hydrogen sulphide gas directly into the acid. Iron, aluminum, and fluorine are removed by adding finely ground limestone to the phosphoric acid and passing this mixture through a filter. The residue must be washed to free it of absorbed phosphoric acid. The monocalcium phosphate solution produced by the addition of this limestone must be mixed with sulphuric acid to reduce it again to phosphoric acid. This acid has a usual strength of 30° B. and must be concentrated to 50° B. for marketing.

Western ores contain vanadium which is precipitated by the use of sodium ferro cyanide.

ELECTROTHERMAL PROCESSES

35. There are two methods of producing phosphoric acid by electrothermal processes. One extracts phosphorus from the phosphate rock and then produces phosphoric acid by oxidation and hydration. The other is a continuous process. The fundamental principles involved in both methods are the same, their relative value depending upon the final product desired.

36. In the continuous process, phosphate rock, a siliceous flux and carbonaceous reducing agent, are fed continuously into a 3,000 kilowatt electric furnace. At a temperature of approximately 1,300°, phosphorus is freed from the rock. As the phosphorus vapor combine with carbon monoxide issues from the surface of the charge, a controlled stream of air is admitted to burn these gases with oxygen to phosphorus pentoxide (P_2O_5) (commercial phosphoric acid) and carbon dioxide. The gases pass from the combustion chamber to gradiently controlled cooling equipment. By means of a water spray the highly volatile heated phosphorus pentoxide is hydrated to the chemical phosphoric acid (H_3PO_4). This is collected by Cottrell electrical precipitators or in hydrated and cooling towers. The collected acid contains 85 percent H_3PO_4 with some silica, lead, and arsenic, which must be removed for food and medicinal purposes.

37. As the process is continuous, ferrophosphorus slag, formed from the iron in the raw material which has fixed some of the phosphoric acid, is tapped periodically. The cold stock, fed into the furnace continuously, is heated in part by coming in contact with the combustion heat caused by the burning of carbon monoxide, oxygen and phosphorus vapors. The entire operation is automatically controlled.

Theoretically 4,580 kilowatt-hours are required per ton of phosphoric acid (P_2O_5) produced. Actually, 5,400 kilowatt-hours is considered efficient consumption.

38. *Advantages of process.*—This process, as well as other furnace processes, has several marked advantages over the sulphuric acid process. In the first place, any phosphate ore may be used. This means that, in the Rocky Mountains, the low grade ore found embedded in the rich ores can be mined along with the rich ore. In the South, ores having relatively high iron and aluminum content, unsuitable for the sulphuric process, may be used to advantage in the electric furnace. So, too, the silica in phosphate rock, which may seriously dilute the acid made by the sulphuric acid process, is an advantage in the furnace process. Then, too, the washing and screening processes used to prepare Appalachian ores for the market which results in a loss of much phosphatic material, is no longer necessary.

39. Secondly, any concentration of phosphoric acid may be obtained directly by the furnace method so that the expense involved in the sulphuric acid process of evaporating weak solutions is avoided.

40. And the third advantage is that many impurities that must be removed from the phosphoric acid produced by the sulphuric acid process before the acid can be used in foods, medicinals, or in some chemical industries are not found in carefully controlled electric furnace phosphoric acid. The costly steps required in the sulphuric process of removing iron, aluminum, and vanadium are eliminated by the volatization process.

41. *Phosphorus manufacturing.*—When phosphorus is the main product desired, and phosphoric acid production is secondary, the phosphorus is collected by a condensing system from the furnace after it has been separated from the rock. The energy required per ton of phosphoric acid in acid and metal is about 9,000 kilowatt-hours. To produce the acid it must then be oxidized with steam in the presence of a catalyst at about 800° C. Carbon catalysts or catalysts made of oxides of nickel and copper deposited in pumice have given satisfaction. An excess of steam is necessary to bring about the necessary reaction. Consequently, the resulting steam phosphoric acid mixture is subjected to fractional condensation to produce 70 percent chemical phosphoric acid (H_3PO_4) giving hydrogen as a byproduct.

THE FUEL-FIRED FURNACE PROCESS

42. Experimental work has been and is being carried out on the blast-furnace production of phosphoric acid at the fixed-nitrogen laboratory of the Department of Agriculture. These experiments, together with 4 years' experimentation at Chicago Heights by the Victor Chemical Co., indicate the feasibility of this process and have resulted in its commercial application at Nashville in 1929.

43. By this method the necessary temperature to effect the reduction of phosphorus from the rock is produced by burning coke instead of with electric current. Tests indicate that a temperature close to 1,450° C. must be reached in the blast furnace before the charge is reduced and that the present thermal efficiency of the furnace is about 70 percent.[29] Unlike the electric furnace, heated air must be introduced into the blast furnace for combustion and there is more heat loss through radiation. In practice, however,

[29] Cottrell, F. G. Report of the Chief of the Bureau of Chemistry and Soils, U.S. Department of Agriculture, 1929, p. 39

all the carbon monoxide from the furnace is burned to carbon dioxide and part of the heat units so obtained are recovered in regenerators and returned to the furnace in the form of hot blast while the remainder are used in the production of steam or for power.[30]

Cost of Manufacture

44. The production of phosphoric acid by the sulphuric-acid process has been carried on so many years and the improvements in manufacture are so well known, that quantities of material consumed under modern operating conditions are fairly standard. Actual costs vary with locality, with type of equipment, and with general manufacturing efficiency.

45. In the table following costs are shown for modern plants in three phosphoric acid producing regions. Phosphoric acid plants on New York Harbor purchased Florida phosphate rock and Texas sulphur, paying ocean shipment freight charges. The price quoted for sulphuric acid is a fairly low manufacturing cost, some plants reporting a manufacturing cost as high as $9 to the National Fertilizer Association in 1927.[31] Tennessee plants given buy their sulphuric acid from copper companies who produce it as a byproduct. The Montana plant manufactures its own sulphuric acid from sulphur fumes obtained from copper smelting. In Montana the freight rate per ton of rock is $2.50 for a 300–400-mile haul. In Tennessee, it is assumed the manufacturing plant is in the heart of the mining region and that the rock bears no freight charge.

46. The amount of labor used will vary with the type of equipment. Plants in which all materials are handled by automatic conveyors may need but 6½ man-hours. The 13.4 man-hours of service charged in table XIV is based on that given by the Montana plant. Variations will be found in charges for supervision, miscellaneous supplies, and power, for all phosphoric acid manufacturers consume a part of the acid in the production of other products so that varying amounts of such items may be allocated to each product by different cost accounting systems. The same condition exists with regard to administrative expenses, although $2.50 to $3 is regarded as an equitable sum.

47. Waggaman and Easterwood, formerly of the Bureau of Soils, Department of Agriculture, in their book on Phosphoric Acid, Phosphates, and Phosphatic Fertilizers, figure 6 percent interest and 10 percent depreciation on a $100,000 plant producing 50,000 tons of superphosphate. This is equivalent to $0.32 per ton of material handled, or to a total cost of $2.12 per 1 ton of phosphoric acid produced. These experts allow $4.30 for taxes, insurance, and overhead and $2.50 for miscellaneous items. Or, according to Waggaman and Easterwood, approximately $8.90 added to manufacturing costs would give the total cost of producing phosphoric acid by the sulphuric acid process.

[30] Kochs, Ernest. President, Victor Chemical Works. Comment in Chemical and Metallurgical Engineering. December 1929.

[31] McCloskey, W. B., cost accountant, National Fertilizer Association. Comparison of Cost Figures in proceedings of the third annual convention, June 1927.

TABLE XIV.—*Estimated manufacturing cost of producing 1 ton available phosphoric acid (P_2O_5) by the sulphuric acid process in the several producing regions*

Item	New Jersey seaboard			Tennessee mining region			Montana [1]		
	Quantity (short tons)	Price, including freight	Total cost	Quantity (short tons)	Price at mine	Total cost	Quantity (short tons)	Price, including freight	Total cost
High grade phosphate rock (32 percent P_2O_5)	3.18	$4.64	$14.76	3.18	$4.35	$13.83	3.7	$6.00	$22.20
Sulphuric acid (50° B.)	3.44	[2] 6.50	22.36	3.44	[3] 4.50	15.48	3.7	[4] 3.50	12.95
Labor	[6] 13.4	[7] 4.00	6.70	[6] 13.4	[7] $2.40	4.02	[6] 13.4	[7] 4.75	8.00
Miscellaneous supplies, power, and repairs			7.00			4.59			8.00
Total manufacturing cost [5]			50.72			37.92			51.15

[1] Figures based on plant operating at 60 to 75 percent capacity.
[2] Produced from sulphur shipped from Texas.
[3] Byproduct sulphuric acid purchased from copper companies.
[4] Byproduct sulphuric acid produced in own plant.
[5] Estimates by Waggaman and Easterwood for interest, depreciation, overhead, taxes and, insurance would add $8.92 to complete cost.
[6] Man-hours.
[7] Per 8-hour day.

48. Although the mining, crushing, and drying of high-grade phosphate rock now costs $3.25 per ton in Montana, such high-grade rock could be produced for $2 per ton if the market would permit operations to be carried on a larger scale. Run of mine rock could be produced at a still cheaper rate. Table XV gives estimated costs of the electrothermal process on the basis of full-capacity operation. Freight rates are assumed as the exact location of phosphoric factories near hydroelectric plants is not yet determined. (The western freight rate for 300 to 400 miles is $2.75 per ton rock.) The dams at Muscle Shoals, Ala., are less than 50 miles by rail from Tennessee phosphate fields, and Dam No. 3 was to back up water of the Elk River so that rock could be barged from the mines to the contemplated Muscle Shoals fertilizer plant, where abundant power is available.

49. While electricity is the major cost item in electrothermal production, coke, if expensive, may become a cost item of importance. Coke from Provo, Utah, at Montana costs $12 a ton, coke breeze $8. The fixed-nitrogen laboratory is experimenting with certain noncoking coals from the Green River region of Wyoming in its experimental blast furnace. If these experiments prove successful, in place of coke, 2 tons of noncoking coal at about $0.90 per ton would reduce the cost of the electrothermal process in the Rocky Mountain region by about $4.35 per ton phosphoric acid produced. The value of cracking-still coke available in Wyoming, Colorado, and Montana in phosphoric furnace production has not been ascertained.

50. Cost estimates given on tables XIV and XV indicate that manufacturing costs of producing phosphoric acid by the continuous-electric furnace process compare very favorably with manufacturing costs of the sulphuric-acid process.

TABLE XV.—*Estimated manufacturing cost of producing 1 ton of available phosphoric acid (P_2O_5) by the continuous electrothermal process*

Item	Tennessee-Alabama region			Idaho-Wyoming region [1]		
	Quantity (short tons)	Price per unit	Total cost	Quantity (short tons)	Price per unit	Total cost
Run of mine rock	4.84	$2.50	$12.10	3.32	[3] $1.50	$8.30
Silica	None			1.0	.50	.50
Coke	.75	3.00	2.25	.75	8.00	6.00
Power	[4] 5,400	.003	16.20	[4] 5,400	.002	10.80
Electrodes			2.13			2.40
Labor	[5] 7½	[6] 4.00	3.75	[5] 7½	[6] 4.75	4.45
Miscellaneous operating expense			6.30			6.40
Total manufacturing cost [2]			42.73			38.85

[1] Full-capacity operation.
[2] Estimates of Waggaman and Easterwood on interest, depreciation, overhead, taxes, and insurance would add $17.12 to complete costs.
[3] Plus $1 freight.
[4] Kilowatt-hours.
[5] Man-hours.
[6] Per 8-hour day.

51. While such manufacturing costs range from $38 to $51 a ton by the latter process, the electric furnace can produce the acid for from $39 to $43. Because only one firm is actually operating an electric-furnace plant, capital costs and miscellaneous costs which must be carried by the electrothermal phosphoric acid cannot be definitely ascertained. Waggaman and Easterwood figure them at almost double those given for the sulphuric acid process. While it is probable that experience will lessen such items as laboratory cost, at Waggaman's estimates the electric furnace phosphoric acid total costs would be $56 to $60 as compared with total sulphuric acid process costs of $46 to $60. That is, if these figures are approximate, the electric furnace cannot yet equal the lowest production costs quoted for the sulphuric acid process.

52. This low figure for Tennessee sulphuric acid process is achieved because the rather high-priced rock carries no freight charge, because a very cheap sulphuric acid is purchasable so that the costly acid chambers need not be installed, and because labor is generally lower here than in the West or in the Northeast. A higher cost of sulphuric acid, freight haulage on the rock, and an increasing labor cost would bring this figure close to those in other areas. This south central area is favored for phosphoric acid production, however, for if sulphuric acid cannot be cheaply obtained, coke or relatively cheap electric power are close at hand. Markets are also within short freight haul.

53. While one factory has begun operation on fuel-fired furnace phosphoric acid in 1929, it is too early to predict operating costs. The original blast furnace has been superseded by a second blast furnace embodying numerous improvements. It is believed by observers that commercial production costs have not yet gone below $85 per ton P_2O_5. A second company has started building a phosphoric-acid blast furnace at Pembroke, Fla.[31] The fixed nitrogen laboratory is experimenting with this process. Their laboratory estimates indicate that small-scale manufacturing costs, exclusive of miscellaneous operating expenses, total only $24.63, with a probable

[31] McBride, R. S., assistant editor of Chemical and Metallurgical Engineering.

actual large-scale operating cost of $20.50. The general opinion of scientists is that these figures represent a cost which may be attained eventually, but which is not within immediate reach.

54. *Double superphosphate manufacturing costs.*—When phosphoric acid is produced for use in agriculture it must be combined with a base, preferably phosphate rock or ammonia. The following table indicates the cost per ton of available phosphoric acid when high-grade phosphate rock is treated with electric-furnace phosphoric acid produced in the Tennessee and Idaho regions, respectively. The cost of soluble phosphoric acid is reduced by $7 to $9 through this treatment, which would obviously be advantageous whenever this type of fertilizer could be profitably marketed, regardless of method of producing the phosphoric acid.

TABLE XVI.—*Estimated cost of producing 1 ton of available phosphoric acid (P_2O_5) in the form of double superphosphate by treating high-grade phosphate rock with phosphoric acid produced in electric furnace*

Item	Quantity (short tons)	Tennessee-Alabama region		Idaho-Wyoming region	
		Price per unit	Total cost	Price per unit	Total cost
Phosphate rock	0.98	$4.35	$4.26	$3.00	$2.94
P_2O_5 in form of 58° Baumé acid	.66⅔	59.00	39.33	56.00	37.33
Labor and repairs			2.68		3.65
Interest and depreciation [1]			.65		.65
Overhead, taxes, and insurance [1]			1.30		1.30
Miscellaneous [1]			2.50		2.50
Total cost			50.72		48.37

[1] Overhead, depreciation, and miscellaneous expenses given by Wm. H. Waggaman and Henry W. Easterwood in Phosphoric Acid, Phosphates, and Phosphatic Fertilizers, p. 226.

BYPRODUCTS OF PHOSPHORIC ACID PRODUCTION

In considering costs, possible byproducts must also be given weight.

55. *Ferrophosphorus.*—The one company using the electric furnace for continuous production of phosphoric acid sells ferrophosphorus as a byproduct. As all commercial grades of phosphate rock and coke contain varying quantities of iron oxide, which is converted into ferrophosphorus, and as the presence of iron aids the furnace operation (it is objectionable in the sulphuric acid process) this is a very convenient byproduct even if additional scrap iron, iron ore, or bauxite have to be added to the charge.[32] Over 200 pounds of 18 percent ferrophosphorus is obtained per ton of phosphoric acid in average grades phosphate rock and coke. However, the market for ferrophosphorus is limited. It is used in the manufacture of thin-rolled iron sheets and in the castings for stoves and certain automotive equipment to give such metals from 0.4 to 0.8 percent phosphorus content. And in such markets it comes in competition with high phosphorus iron ore found in the Alabama district.

56. *Concrete aggregate.*—The slag produced by the electric furnace is well suited for use as a concrete aggregate in localities where other aggregate materials are scarce. Prices will depend upon local conditions.

[32] Simultaneous production of phosphoric acid and ferrophosphorus is patented: United States patent 1168495 and United States patent 1410550.

57. *Gypsum.*—At sulphuric-phosphoric-acid plants the gypsum waste is so bulky and cheap that it has only a local market. Some is sold as agricultural gypsum and some goes to coal mines for dusting to prevent explosion. One producer manufactures building blocks and tile from acid-free gypsum.

58. *Fluorine.*—Fluorine is present in commercial phosphate rock in quantities varying from 3 to 4 percent, about 25 percent of which is volatilized. When phosphoric acid is manufactured by the sulphuric-acid process, the silicon tetrafluoride gas formed is passed through spray towers to decompose the compound and produce hydrofluosilicic acid. This is combined with sodium chloride to produce silicofluoride sodium used in acid rinses in laundries and in the manufacture of opalescent glass and iron enamel ware and is also valuable in insecticides. The annual consumption is over 2,500 tons. Eight plants were producting the sodium silicofluoride in 1929. Dr. F. G. Cottrell, chief of the fixed-nitrogen laboratories, states that—"A general recovery of fluorine in the manufacture of superphosphate would result in the production of compounds having a direct value of $3,000,000 annually." As far as is known, the volatilization process users have not collected the fluorine released in the manufacture of furnace phosphoric acid. Mr. K. D. Jacobs, of the Bureau of Chemistry and Soils, Department of Agriculture, states that there is a possible recovery of approximately 43 pounds of fluorine, equivalent to 71 pounds of sodium silicofluoride per ton of 100 percent phosphoric acid produced.

59. *Hydrogen.*—When the Liljenroth process is used for the production of phosphoric acid, hydrogen is a byproduct. This hydrogen contains some phosphorus which must be completely removed by passing the gas over silica gel, charcoal, or other absorbents, if the hydrogen is to be used for ammonia production. Oxidation of 1 ton of phosphorus by the Liljenroth process yields 57,809 cubic feet of hydrogen, or a little less than the amount required to produce a ton of ammonia. If ammonia were produced from this byproduct hydrogen, it would be directly available for treatment of the phosphoric acid producing either monoammonium phosphate or diammonium phosphate for fertilizer purposes. While this is not being done in this country, it is stated that the German I. G. Farbenindustrie A. G. at its Piesteritz plant is producing 30,000 metric tons of phosphorus annually by this process, and that the larger part of this phosphorus is converted by the oxidation process into a complete fertilizer marketed as "Nitrophoska." [33]

60. *Carbon monoxide.*—As has been stated on page 168, heated air is admitted to the electric furnace to oxidize furnace gases. Patents have been taken out proposing to use only a limited supply so that only the phosphorus will be oxidized, leaving the carbon monoxide as a byproduct to be used for power generation or for the manufacture of synthetic methanol, when hydrogen is also a byproduct.

[33] United States patents 1594372 and 1605960.

Consumption of Phosphate Rock, Phosphoric Acid, and Phosphorus

PHOSPHATE ROCK CONSUMPTION

61. More than 91 percent of the phosphate rock sold enters the fertilizer trade. While a small amount is applied directly to the soil, the mass is sold to manufacture superphosphate by treating the rock with sulphuric acid. In 1928, according to Department of Commerce reports, 172 superphosphate plants operated by 80 companies produced 4,489,392 tons of superphosphate or over 94 percent of the domestic phosphoric-acid fertilizer material. In this tonnage figure are included the double or triple superphosphates which required the use of phosphoric acid, but not mixed fertilizers containing phosphoric acid.

Only 7½ percent of the rock was sold to producers of phosphorus and phosphoric acid for use in food and medicines, in chemical and miscellaneous industries.

PHOSPHORIC ACID CONSUMPTION

62. *Fertilizers.*—Some phosphoric acid entered the fertilizer industry through its use in producing 55,000 short tons of double superphosphate in 1928 and 80,000 short tons in 1929. This multiple phosphate is obtained by treating phosphate rock with phosphoric acid, both rock and reagent furnishing phosphoric acid to the finished product. Whereas sulphuric acid produced superphosphate contains 14 to 18 percent phosphoric acid, the double superphosphate contains 45 to 50 percent of this plant food.

63. Phosphoric acid was also used to produce 30,000 tons of ammonium phosphate fertilizer produced by making phosphoric acid the carrier of the nitrate-ammonia fertilizer. This fertilizer may contain 52 percent phosphoric acid and 13 percent ammonia or 20 percent phosphoric acid and 20 percent ammonia, or may be made in other proportions.

64. While phosphoric acid made by the sulphuric-acid process is used almost entirely for this fertilizer production, the furnace processes produce almost three fourths of the acid used for technical and industrial purposes.

65. *Baking powders.*—The purest phosphoric acid is used in phosphatic compounds for baking powders and self-rising flours. Phosphoric acid is added to hydrated lime in such quantities that all the lime is converted to monocalcium phosphate, or it may be added to sodium carbonate to produce monosodium phosphate. As the latter compound is hygroscopic, it is usually heated to a temperature of about 225° to produce sodium-acid pyrophosphate. Either one of these phosphatic compounds may be used in baking powders by combining it with granular or powdered sodium bicarbonate and starch or flour. The various brands of baking powders use different ingredients but the United States Pure Food and Drug Act standards specify that a minimum of 12 percent carbon dioxide must be released when the baking powder is mixed with batter in baking. Such reaction usually requires about 33 percent of one of the phosphates and approximately 26 percent sodium bicarbonate. While definite pro-

duction figures are lacking, it is believed that more than 30,000 short tons of monocalcium phosphates and about 2,500 tons of sodium acid pyrophosphate are consumed annually in the manufacture of baking powder.

66. *Phosphatic cleansers and water softeners.*—More than 63,000 short tons of trisodium phosphate, a compound made by treating soda ash with phosphoric acid and the resultant product with caustic soda, is produced annually. It contains 19 percent phosphoric acid. It is an emulsifier of grease and a water softener. Trisodium phosphate is sold by the barrel to laundries and boiler-compound manufacturers, and to hardware manufacturers, railroad companies, garages, dairies, packing houses, and other industrial establishments requiring large amounts of cleanser. It is put up in small packages for the household trade. In these markets trisodium phosphate competes with sal soda and other forms of soda and borax.

67. Because of the character of its market, trisodium phosphate is widely distributed. About half is sold in carload lots by manufacturers to brokers who, in turn, distribute it to consuming manufacturers, wholesale grocers, or wholesale chemical establishments. Both manufacturers and wholesalers put up trisodium phosphate in small packages for the retail trade. The imported material coming chiefly from Belgium is sold directly to consuming industries. The largest consuming centers for wholesale trade are in the New York City-New Jersey vicinity, in and near Cleveland, Ohio, and in the Chicago area. Detroit, Philadelphia, and other industrial centers furnish excellent markets. Some trisodium phosphate is exported to Canada.

68. *Silk industry.*—Disodium phosphate, made by mixing phosphoric acid and soda ash with a little caustic soda, is used in silk weighting. It contains 20 percent phosphoric acid. The tin, which actually weights the silk, is fixed on the fiber by the disodium phosphate which also enables a larger amount of tin to be used as well as adding to the luster of the silk. While this field consumes 90 percent of the domestic production, disodium is used in small quantities in a number of industries. It prevents dye and wax losses in textile and tanning industry; it enters into cheese and vinegar production, into a number of medicines, into fireproofing materials and into optical glass, ceramic enamels, and into photography. But because 90 percent of the 118,250 tons manufactured in 1928 was sold to the silk industry, Paterson, N.J., is the center of consumption, and material amounts enter Pennsylvania and New York silk-production areas.

69. *Miscellaneous uses.*—Tricalcium phosphate, made from phosphoric acid and an emulsion of milk of lime, is mixed with salt to prevent salt lumping, enters into tooth pastes and into medicinal preparations. Over 500 short tons is believed to be sold for these purposes. Monosodium phosphate is used only in small quantities in the pharmaceutical trade. Normal sodium pyrophosphate is used in tin plating and in bleaching baths.

70. Pure phosphoric acid is added to soft drinks and to jellies and jams to impart acid flavors. It also finds use in small quantities in photography for the reproduction of line subjects, and in the production of optical glass, translucent ware, bone china, and in enamel glaze, and as a sugar clarifier.

71. The electric furnace process of manufacturing phosphoric acid gives ferrophosphorus as a byproduct. This is used in open-hearth furnaces and in foundries to control the phosphorus content of steel. A rust-proofing solution is made of phosphoric acid containing ferrous phosphate and manganese dioxide.

72. *Phosphorus consumption.*—Phosphorus finds its largest industrial outlet in the manufacture of phosphor copper. This is used as a vehicle to introduce phosphorus into certain bronzes. It acts as a deoxidizer and adds strength and durability to molten metal. Phosphorus oxychloride and phosphorus trichloride enter into production of organic chemicals, the largest outlet being in triphenyl and tricresyl phosphate entering as plasticisers into the plastic and lacquer industry. The consumption of these phosphorus chlorides is estimated to be about 500 tons annually. Other phosphorus compounds are used in the manufacture of matches, in the pharmaceutical trades and in chemical production.

73. *Prices.*—Phosphoric acid for food, pharmaceutical, or technical purposes brings a price of \$0.08½ to \$0.09 a pound or a ton will net the manufacturer of this pure product from \$170 to \$180. Calcium phosphate is sold at only a slightly smaller price, that is from \$160 to \$170 a ton. Disodium phosphate, containing 20 percent acid sold on a hundredweight basis, for \$60 a ton and trisodium phosphate, containing 19 percent phosphoric acid at \$75 a ton.

74. The fertilizer material, superphosphate, which is made without producing the phosphoric acid but is the most popular phosphate fertilizer sells at \$8.50 and \$9 a ton containing 17½ percent soluble phosphoric acid or at \$50 a theoretical ton of phosphoric acid. It is obvious why the producers of phosphoric acid have sold to other industries before attempting to enter the fertilizer field in competition with superphosphate.

Organization of the Phosphorus and Phosphoric Acid Industry

PHOSPHORUS AND PHOSPHORUS COMPOUND PRODUCERS

75. There is only one producer of elemental phosphorus in the United States, the Oldbury Electro-Chemical Co., of Niagara Falls. Prior to 1927 this company produced electric furnace phosphorus for sale, selling to the Warner Chemical Co., of Newark, and the Phosphorus Compounds Co., of Niagara Falls, as well as to phosphor-bronze manufacturers. But when the two chemical companies abandoned the manufacture of phosphorus chlorides, the Oldbury Co., purchased the Phosphorus Compound Co.'s plant, extended the facilities and entered into the manufacture of phosphoric acid, phosphorus chloride, and phosphorus oxychloride as well as phosphorus. Phosphor-bronze, containing 15 percent phosphorus, is manufactured by the following companies: National Bearings Metal Co., St. Louis, Mo.; the Crown Smelting Co., Chester, Pa.; Richards Co., Boston, Mass.

PHOSPHORIC ACID PRODUCERS

76. There were 14 producers of phosphoric acid in 1930. A fifteenth company, the Coronet Phosphate Co., was erecting a blast-furnace plant at Pembroke, Fla. As each producer usually makes

some phosphatic compounds, all phosphatic manufacture will be considered under each firm name.

(1) The American Cyanamid Co., Warners, N.J. This company produces its own phosphate rock in Florida and ships it to Warners, N.J., where it is converted into phosphoric acid by the sulphuric-acid process. Ammonia, which has been autoclaved from cyanamide produced at its Niagara Falls plant, is united with the phosphoric acid to produce ammonium phosphate. The Warners plant has a capacity of 250,000 tons of ammonium phosphate. The company has begun the production of a complete fertilizer by adding 10, 12, or 15 percent potash to the different types of ammonium phosphate. The company is building a large double superphosphate plant at Tampa, Fla.

(2) The Anaconda Copper Co., Anaconda, Mont. The Anaconda Copper Co. entered into the production of phosphoric acid in order to utilize the sulphur fumes that were issuing from its copper smelters in such volume as to be considered a danger to national park vegetation in Montana. Although owning large deposits of phosphate rock in the Deer Lodge section of Montana, it acquired two of the most promising deposits in Idaho and built a town at Conda, 400 miles south of Anaconda. A 9-mile railroad connects this phosphate mine with the Oregon Short Line of the Union Pacific Railroad just east of Soda Springs. The Utah Power & Light Co. furnishes power to the mine. Five thousand tons of rock averaging 32 percent P_2O_5 and containing 4 to 6 percent moisture are mined per month.

The phosphate rock is shipped to a phosphate plant at Anaconda. This plant has a capacity for handling over 150 tons of rock a day. The sulphuric acid is produced at the plant from byproduct sulphur, the acid plant having a capacity of 225 tons daily although only 125 tons is produced for the phosphate plant.

Some of the phosphoric acid produced by treatment of rock with sulphuric acid is sold to the manufacturers of sodium phosphates and other chemicals. It has a 53 to 54 percent P_2O_5 content and is shipped in carload lots. The remainder is used to treat phosphate rock making concentrated fertilizer containing 45 to 48 percent P_2O_5, or is combined with ammonia bought in the Chicago district to produce ammonium phosphate containing 15 percent ammonia and 52 percent phosphoric acid. A substantial quantity of superphosphate is sold in California, while small amounts reach Oregon, Washington, Montana, Wyoming, Idaho, Colorado, Utah, Iowa, Kansas, Nebraska, South Dakota, and North Dakota. The ammonium phosphate is shipped to Indiana fertilizer manufacturers and to the Chicago district to be mixed with other fertilizers. Some reaches the Hawaiian Islands.

(3) The Bowker Chemical Co., of Carteret, N.J., produces phosphoric acid, disodium and trisodium phosphate. The disodium is marketed in the Paterson silk-mill district while the trisodium is consumed in Hoboken, Newark, and Jersey City districts.

(4) The Federal Phosphorus Co., Anniston, Ala. This company produces 15,000 tons phosphoric acid annually by the electric-furnace process, with ferrophosphorus as a byproduct. It has licensed its electric-furnace process to the Societe des Phosphates Tunisiens at Pierrefitte, France.

Until recently a large part of the pure phosphoric acid was sold to the Victor Chemical Co. This company, however, erected its own

phosphoric-acid manufacturing plant in 1929. The Federal Phosphorus Co. converts some of the phosphoric acid into ammonium phosphate which is mixed and sold as concentrated fertilizer in small quantities by the Jax Plant Food Co. of St. Louis and by the Federal Fertilizer Co. in Maine. To the Provident Chemical Works at St. Louis some phosphoric acid is shipped to be converted into calcium and sodium phosphates for baking powder and into other phosphates for use in the chemical, textile, and pharmaceutical trades. Other shipments are made to the Iliff-Bruff Chemical Co., of Hooperston, Ill., where monocalcium phosphate and calcium sulphate are made for the food, pharmaceutical, chemical, and pulp and paper industries. The Anniston plant also manufactures some sodium compounds.

The Southern Manganese Corporation at Anniston handles the ferrophosphates and crushed slag. The plants mentioned (other than the Victor Chemical Co.) are a part of the Swann Corporation. This corporation also controls several other electric-furnace producing plants. It has filed two applications for the development of power in Tennessee. The first, filed in the name of the Hiwassee Power Co. is for the development of a 40,000 primary horsepower plant on the Hiwassee River, the power to be used for electrochemical and electrometallurgical industries. The second is filed in the name of the Federal Power Co. of Tennessee and asks permits to build 2 diversion dams and 5 storage dams on the Nolichucky and Toe Rivers of Tennessee. The plant is to have a 27,800 primary horsepower capacity. The latter application conflicts with an application of the Tennessee Eastern Electric Co. In the meantime the Anniston plants are purchasing power from the Alabama Power Co.

(5) The General Chemical Co. manufactures some phosphoric acid but also purchases additional acid. At Marcus Hook, Pa., and at its Baltimore plant, this acid is converted into disodium for the silk and trisodium for the cleanser trade.

(6) The Grasselli Chemical Co. both manufactures and buys phosphoric acid. Disodium and trisodium phosphates are produced at Grasselli, N.J., and at Grasselli, Ind. Superphosphate fertilizer is also made at Grasselli, Ala.

(7) The International Agricultural Corporation produces phosphoric acid at its plant at Wales, Tenn., from rock mined at its own mines at this point. The acid is used in the production of double superphosphate and ammonium phosphate for the fertilizer market. Some disodium and trisodium phosphate is also produced. This company manufactures sulphuric acid and superphosphates at other plants; tankage and other fertilizer material are also handled.

(8) The Oldbury Electro-Chemical Co. has been considered under phosphorus.

(9) The Rumford Chemical Works at Rumford, R.I., manufactures phosphoric acid for use in monocalcium, dicalcium, and tricalcium phosphates for baking powders.

(10) The Tennessee Products Co. erected a phosphoric acid and multiple superphosphate plant at Columbia, Tenn., in 1928. This plant is located near the company's Tennessee phosphate mines.

(11) The Victor Chemical Co. This company has a plant at Chicago Heights, Ill., where it is manufacturing monocalcium, dicalcium, and tricalcium phosphates, monosodium, disodium, and trisodium phosphates, and acid pyrosodium phosphates. For 4 years

a semicommercial experimental plant was in operation, producing phosphoric acid in a blast furnace. As a result of these experiments, a $1,500,000 blast-furnace plant has been erected at Nashville, Tenn., where high-grade phosphoric acid for use in the food, pharmaceutical, and other industries will be produced for the present.

(12) The Virginia-Carolina Chemical Corporation, one of the largest fertilizer manufacturers, is manufacturing phosphoric acid for use in the production of multiple superphosphates or in complete fertilizers at Charleston, S.C. It operates its own phosphate mine in Tennessee and Florida, and produces sulphuric acid and ordinary superphosphates at other plants.

(13) The Warner Chemical Co., of Carteret, N.J., produces the phosphoric acid for use in the manufacture of sodium acid pyrophosphates and normal sodium pyrophosphate as well as other sodium compounds.

(14) Wilckes-Martin-Wilckes Co., of Camden, N.J., produces the acid and also makes ammonium, calcium, and potassium phosphates, as well as solvents.

77. *Other phosphoric-acid-compound producers.*—Companies other than those listed above who manufacture phosphoric acid compounds for industrial uses are: The Blockson Chemical Co., the Calumet Chemical Co., both of Joliet, Ill., and the Phosphate Products Co., of Virginia.

78. In all, 5 double superphosphate plants were in operation, the 3 named making their own phosphoric acid while the United States Phosphoric Products Co., of Tampa, Fla., and the Mountain Copper Co., of Martinez, Calif., purchased their acid for the manufacture of double superphosphates.

FUTURE MARKET FOR PHOSPHORIC ACID

79. Phosphoric acid is a reagent quite similar in its chemical activity to sulphuric acid, one of the most economical reagents. When applied to phosphate rock, phosphoric acid produces a fertilizer containing 40 to 50 percent plant food. Sulphuric acid applied to phosphate rock produces a fertilizer containing 16 to 20 percent plant food and 80 to 84 percent gypsum and other impurities. When ammonia gas is absorbed in phosphoric acid, a fertilizer containing 61.7 percent phosphoric acid and 14.7 percent nitrogen may be produced. When ammonia gas is fixed with sulphuric acid in the form of ammonium sulphate, only one plant food containing 20.5 percent nitrogen is obtained.

80. Or, while sulphuric acid has value in fertilizer production only as a reagent to convert plant food into usable form, phosphoric acid acts as a reagent and also adds fertilizer value to the treated material. As the superphosphate sold as fertilizer in 1928 contained 808,000 tons of phosphoric acid and as the sulphate of ammonia sold as fertilizer in 1928 contained 128,450 tons of nitrogen, a large future market is available for pyrolytic phosphoric acid in the production of double superphosphate, ammonium phosphate, and even potassium phosphate, if the marketed fertilizer can be sold delivered at a price per unit of available phosphoric acid that will encourage its substitution for sulphuric acid in fertilizers.

81. Pyrolytic phosphoric acid already has attained a conspicuous place in the European fertilizer industry. The Societe des Phosphates Tunisiens at Pierrefittee, France, operating under the patents of the Federal Phosphorus Co., is producing phosphoric acid from the electric furnace and feeding ammonia gas into it to produce ammonium phosphate. The Piesteritz plant of the I. G. Farbenindustrie A. G., as has been stated on page 174 combines phosphoric acid, ammonia, and potash into a complete fertilizer, "Nitrophoska."

82. It is believed that eventually phosphoric acid will play an important part in fertilizers in our own country. In order to appreciate the possibilities of such expansion, a detailed statement of the organization of the domestic fertilizer industry and the present outlook for development of a concentrated fertilizer industry is given.

83. *The fertilizer industry in the United States.*—The American farmer is accustomed to mixed fertilizers. Approximately 70 percent of the total purchased in 1927 contained all 3 plant foods—that is, phosphates, nitrogen, and potash; 3 percent contained phosphoric acid and potash only, 24 percent contained only phosphoric acid, and only 1 percent were ammoniated fertilizers. He is using about 808,000 tons of phosphoric acid, 345,000 tons of nitrogen and 343,000 tons of potash in these marketed fertilizers to replenish his soils.

84. As about 90 percent of the fertilizer potash is imported, and as the larger amount of the nitrogen fertilizer was imported until the recent increased domestic production of sulphate of ammonia, domestic fertilizer manufacture has grown up about the production of phosphatic materials.

85. *Location of industry.*—The most used source of phosphatic fertilizer, superphosphate, is made by mixing 1 part of phosphate rock with 1 part of 50° sulphuric acid producing a product containing 16 to 18 percent phosphoric acid as monocalcium phosphate and a large quantity of gypsum. The phosphate rock from which this fertilizer was produced contained 30 to 34 percent phosphoric acid. As fertilizer market value is based on phosphoric acid content rather than on bulk, it was cheaper to ship the rock containing over 30 percent phosphoric acid to the fertilizer consuming districts than to manufacture the fertilizer at the mine and ship the finished product containing only 16 to 18 percent phosphoric acid. Consequently, the manufacture of superphosphate has been centered in fertilizer consuming areas. Interior plants serve a rather limited territory. Seaport plants have, however, because of low transportation costs, reached a larger fertilizer market.

86. The larger plants, numbering approximately 100, produce their own sulphuric acid. Almost all fertilizer manufacturers who sell over 10,000 tons of fertilizer a year make their own superphosphate.[34] Potash and nitrogen are purchased from merchandising firms selling imported products, from chemical engineering manufacturers of ammonia, synthetic nitrogen products, cyanamide and potash, or from packing houses or other firms selling natural fertilizer materials. These materials are combined with the phosphatic fertilizer according to numerous formulas supposedly designed to meet the requirements of varying soils and crops. Commercial fertilizer grades indicate the units of available nitrogen, phosphorus, and potash in the order

[34] Van Derlinden, Lee (United States Metals Selling Co.), A New Selling Policy Needed. The American Fertilizer, Jan. 5, 1929, p. 30.

named, 1 unit being 1 percent of a ton. For example, a 2-10-2 grade indicates a fertilizer containing 40 pounds of nitrogen, 200 pounds of phosphoric acid, and 40 pounds of potash, or a total of 280 pounds of plant food per ton of fertilizer.

87. A larger number of local fertilizer plants are merely mixers of the fertilizer ingredients and do no manufacturing. There were, in 1929, according to the American Fertilizer Handbook, almost 900 fertilizer plants operated by 667 fertilizer companies.

88. Twelve companies sold 60 percent of the total amount marketed. The largest fertilizer firms, all of which own mines in Florida or in Tennessee, or in both States, are:

89. The American Agricultural Chemical Co. which operates 28 fertilizer plants, 2 phosphate mining plants, 1 limestone quarry, and 7 chemical reducing and byproduct plants; the fertilizer plants being located in North Carolina, South Carolina, Alabama, Georgia, Virginia, Maryland, Florida, Maine, Massachusetts, New Hampshire, Connecticut, New York, Ohio, Illinois, and Michigan;

90. The Virginia-Carolina Chemical Corporation with fertilizer plants in North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, Tennessee, Virginia, Maryland, Ohio, Indiana, and New Jersey;

91. The International Agricultural Corporation with mines in Florida and Tennessee, and fertilizer plants in North Carolina, South Carolina, Georgia, Florida, Alabama, Virginia, Tennessee, Maine, Massachusetts, New York, and Ohio;

92. The Davison Chemical Co. with a 400,000-ton superphosphate plant at Curtis Bay, Baltimore, 11 plants in Maryland, 9 in Virginia, 11 in North Carolina, 2 in Tampa, 10 in Pennsylvania, 2 in Ohio, and 1 in Connecticut, New Jersey, Indiana, West Virginia, Texas, Louisiana, Mississippi, South Carolina, and Tennessee;

93. The F. S. Royster Guano Co. with plants in southeastern States and in Ohio;

94. The Armour Fertilizer Works with southeastern plants and plants in Illinois, Indiana, Ohio, Kansas, Nebraska, Iowa, Maine, New Jersey, Texas, and Louisiana as well as Cuba and Puerto Rico; and the

95. Swift & Co. with southeastern plants and fertilizer factories in Illinois, Indiana, Kansas, Missouri, Minnesota, Nebraska, Ohio, Oregon, New Jersey, New York, as well as in Louisiana and Texas.

The largest amount of fertilizer is produced, in the order given, in Maryland, Georgia, North Carolina, Virginia, and South Carolina.

96. The fertilizer is sold through local merchants who handle the product on a consignment basis or who purchase outright for resale to the farmer. Recently, much has been sold to farmers' cooperative buying associations. Or the fertilizer may be sold directly to the farmer by local dry-mixing plants.

97. *Fertilizer consumption.*—The following table shows fertilizer sales in the last 10 years. While there has been no steady increase in tonnage, there is an obvious tendency to increase the percentage of usable plant food. In 1921, domestic fertilizers contained but 13 percent plant food, whereas in 1929 they averaged 17.5 percent plant food.

TABLE XVII.—*Fertilizer sold in the last 10 years* [1]

[In short tons]

Year	Fertilizer sales	Percentage (approximate) of plant food contained	Tonnage of plant food	Year	Fertilizer sales	Percentage (approximate) of plant food contained	Tonnage of plant food
1920	7,270,000	14.0	1,020,000	1925	7,330,000	15.5	1,140,000
1921	4,860,000	13.0	630,000	1926	7,330,000	16.0	1,170,000
1922	5,670,000	13.5	770,000	1927	6,840,000	16.0	1,090,000
1923	6,440,000	14.5	930,000	1928	7,930,000	17.0	1,360,000
1924	6,820,000	15.0	1,020,000	1929	7,800,000	17.5	1,360,000

[1] Data compiled by Chemical and Metallurgical Engineering from material supplied by National Fertilizer Association.

98. The United States uses 5.26 pounds of plant food per acre of crops and improved pasture and hay land. Holland consumes 99 pounds per acre, Germany 50 pounds, France 20 pounds, and Great Britain 16 pounds.[35] It is obvious, therefore, that the longer our soils are used, the greater will our fertilizer needs become. Table XVIII shows the sales of fertilizer by States in 1929. Such farming States as Nebraska, North and South Dakota, have hardly begun to practice of applying commercial fertilizer to their soils. Almost three fourths of all fertilizer sold was consumed in the Southeastern and South Central States. North Atlantic States used 13 percent. California was the only far Western State that applied more than 1 percent of the total fertilizer produced to its soils.

99. The extensive use of fertilizer in the South is due to the raising of cotton, for almost a third of all fertilizer sold is fed to cotton producing fields. Tobacco and peanuts add to the total consumption in the South. In New England, the potato crop of Maine and the tobacco crop of Connecticut are accustomed to soil replenishment. The country's corn crop consumes 1,509,000 tons or 22.5 percent of the total produced. The Ohio corn grower used 140 pounds per acre, while the Missouri corn grower applies but 75 pounds. Wheat lands were fed only 10.2 percent of the total fertilizer consumed. The following table gives the amounts of fertilizer used in 1927 (the latest figures available) on various crops.

[35] Smalley, H. R.: (National Fertilizer Association), Observations on Recent European Fertilizer Developments. Paper given before the division of fertilizer chemistry, American Chemical Society, September 1928.

TABLE XVIII.—*Fertilizer consumption in 1929* [1]

State	Year ending	Quantity consumed	
		Short tons	Per-cent
United States		7,914,687	100.0
Connecticut	Dec. 31	69,000	.9
Maine	do	171,500	2.2
Massachusetts	June 30	62,491	.8
New Hampshire	do	16,900	.2
New Jersey	Oct. 31	141,981	1.8
New York	Dec. 31	250,000	3.2
Pennsylvania	Oct. 31	325,000	4.1
Rhode Island	Mar. 31	10,100	.1
Vermont	June 30	14,904	.2
North Atlantic		1,061,876	13.4
Illinois	Dec. 31	38,864	.5
Indiana	do	250,303	3.2
Iowa	do	17,000	.2
Kansas	do	9,943	.1
Michigan	do	124,000	1.6
Minnesota	do	13,024	.2
Missouri	do	58,891	.7
Nebraska	do	700	.009
North Dakota	do	550	.007
Ohio	do	338,662	4.3
South Dakota	do	250	.003
Wisconsin	do	40,671	.5
North Central		892,858	11.3
Delaware	Dec. 31	41,256	.5
Florida	May 31	416,885	5.3
Georgia	June 30	868,911	11.0
Maryland	Dec. 31	165,443	2.1
North Carolina	June 30	1,293,573	16.3
South Carolina	do	760,053	9.6
Virginia	Dec. 31	429,886	5.4
West Virginia	do	44,900	.6
South Atlantic		4,020,907	50.8
Alabama	Sept. 30	675,150	8.5
Arkansas	do	156,582	2.0
Kentucky	Dec. 31	93,000	1.2
Louisiana	Aug. 31	174,278	2.2
Mississippi	Sept. 30	327,806	4.1
Oklahoma	June 30	14,045	.2
Tennessee	May 31	142,745	1.8
Texas	Aug. 31	192,133	2.4
South Central		1,775,739	22.4
Arizona	Dec. 31	1,200	.02
California	do	130,477	1.7
Colorado	do	800	.01
Idaho	June 30	550	.007
Montana	Dec. 31	100	.001
Nevada	do	30	------
New Mexico	do	1,500	.02
Oregon	do	10,000	.1
Utah	do	550	.007
Washington	do	17,500	.2
Wyoming	do	600	.008
Far western		163,307	2.1

[1] Compiled by National Fertilizer Association from fertilizer tag sales for Southern States and on sales records, except in New York, Kentucky, Illinois, North Dakota, Connecticut, Colorado, Arizona, and Oregon, where estimates are made by State authorities.

TABLE XIX.—*Amount of fertilizer used on various crops in the United States in 1927* [1]

Crop	Amount used	
	Short tons	Per-cent
Cotton	2,108,000	31.4
Corn	1,509,000	22.5
Potatoes	688,000	10.3
Wheat	682,000	10.2
Tobacco	470,000	7.0
Oats	326,000	4.9
Citrus	241,000	3.6
Hay	184,000	2.7
Sweetpotatoes	112,000	1.7
Tomatoes	78,000	1.2
Vegetables (miscellaneous)	60,000	.9
Peanuts	49,000	.7
Buckwheat	26,000	.4
Watermelons	22,000	.3
Barley	20,000	.3
Rye	18,000	0.3
Peaches	15,000	.2
Sweet corn	14,000	.2
Rice	13,000	.2
Strawberries	13,000	.2
Beans (dry)	12,000	.2
Cucumbers	8,000	.1
Soybeans	7,500	.1
Cabbage	6,000	.1
Cantaloupes	4,500	.1
Sugar beets	4,500	.1
Onions	4,500	.1
Cow peas	3,000	------
Sugarcane	2,000	------

[1] Compiled by Chemical and Metallurgical Engineering, January 1930, p. 44.

100. *Imports and exports.*—The following table indicates the extent to which we are still dependent upon other countries for specific fertilizer materials. If cyanamide from Canada is excepted, the larger proportion of imported fertilizers is natural fertilizers. Sodium nitrate from Chile, guano from Peru, slaughterhouse products from the Argentine and Germany form the bulk of our fertilizer importations.

101. Exports of superphosphate are made chiefly to Canada and Cuba. Ammonium sulphate and other nitrogenous fertilizers are shipped to Japan, Java and Madura, the Philippine Islands, and Cuba. Mixed- and potash-fertilizer exports are principally to Japan.

TABLE XX.—*Exports of phosphate rock and phosphatic and nitrogenous fertilizers from the United States in 1929 by country of destination* [1]

Country	Phosphate rock		Superphosphates		Sulphate of ammonia		Other nitrogenous materials		Potash fertilizer materials		Prepared fertilizer mixtures		Other fertilizers	
	Tons	Value	Tons	Value	Tons	Value	Tons	Value	Tons	Value	Tons	Value	Tons	Value
Total	1,142,746	$5,386,919	85,118	$1,489,476	144,761	$6,295,519	24,358	$1,229,995	13,868	$582,690	33,508	$1,795,918	89,936	$3,660,160
British India			200	10,282	700	34,293	126	6,032			2,095	128,793	3,834	233,572
British Malaya			30	1,549	100	4,402	142	8,373			50	2,995	193	11,083
Canada	28,384	217,739	58,205	805,737	689	40,997	6,508	272,806	380	17,620	7,887	314,672	43,046	1,107,546
China	3,599	12,597			1,288	56,981	9	516					21	1,168
Cuba	17,196	77,702	18,761	290,177	9,773	383,930	1,019	37,819	264	11,092	1,093	59,521	3,763	132,314
Germany	268,684	1,264,014					4,992	329,925					195	12,297
Hong Kong			100	6,942	2,259	107,111			1,171	46,000			7	371
Italy	122,224	589,656					11	473					48	1,942
Japan	230,548	827,316	6,734	313,498	60,025	2,523,349	3,189	185,832	10,039	383,290	11,485	659,387	22,233	1,132,412
Java and Madura			224	15,459	25,265	1,174,516	1,312	70,779			4,548	289,385	4,227	254,773
Netherlands	172,689	859,989					978	59,259					964	54,679
Philippine Islands			4	263	30,376	1,350,811	4,302	174,536	1,673	99,342	1,497	91,934	4,469	304,217
Spain	76,818	374,946												
Sweden	45,455	252,066	20	1,900										
United Kingdom	9,677	38,744	78	2,107			1	99			14	626	242	18,135
All others	167,472	872,150	762	41,562	14,286	619,129	1,769	83,546	341	25,346	4,839	248,605	6,694	395,651

[1] Compiled from unpublished data, Bureau of Foreign and Domestic Commerce, Department of Commerce.

TABLE XXI.—*Imports of phosphate and nitrogenous materials into the United States, by country of origin* [1]

Country	Bone phosphates	Guano	Other phosphates	Sulphate of ammonia	Cyanamide	Calcium nitrate	Sodium nitrate	Dried blood, tankage, and other nitrogenous	Prepared salts	All others
Total:										
Long tons	55,877	45,905	48,937	35,096	184,260	31,684	930,458	99,591	5,066	94,992
Value	$1,624,483	$2,202,709	$524,848	$1,646,303	$6,220,996	$1,256,589	$34,913,254	$4,165,920	$380,876	$1,764,948
Argentina:										
Long tons	4,888	3,022						17,061		1,298
Value	$151,025	$126,848						$869,526		$15,664
Belgium:										
Long tons	4,386		4,038			22		1,496		321
Value	$119,400		$55,677			$846		$48,724		$10,671
British India:										
Long tons	11,814									
Value	$398,223									
Canada:										
Long tons	1,147	582	741	6,175	184,260		158	9,280	242	19,544
Value	$28,360	$31,042	$14,144	$220,922	$6,220,996		$9,387	$398,019	$18,410	$318,535
Chile:										
Long tons							921,813			
Value							$34,466,391			
French Oceania:										
Long tons			19,348							
Value			$261,411							
Germany:										
Long tons	20,006	1,695		28,917		31,388	6,476	40,916	4,824	13,371
Value	$545,432	$59,662		$1,424,108		$1,246,051	$351,688	1,760,111	$362,466	$245,148
Morocco:										
Long tons			16,400							
Value			$96,102							
Netherlands:										
Long tons	1,623	3,924	160	2				1,311		20,900
Value	$52,053	$198,087	$2,060	$193				$51,957		$652,106
Norway:										
Long tons		18,661				274	2,011	23		55
Value		$1,092,399				$9,692	$85,788	$1,341		$1,793
Peru:										
Long tons	15	11,967						236		4
Value	$624	$415,522						$11,251		$60
United Kingdom:										
Long tons	986	1,369						21,114		4,485
Value	$42,119	$54,988						$665,536		$141,737
Venezuela:										
Long tons										25,681
Value										$244,559
All others:										
Long tons	11,012	4,685	8,250	2				8,154		9,333
Value	$287,247	$224,161	$95,454	$1,080				$369,455		$134,685

[1] Compiled from unpublished data, Bureau of Foreign and Domestic Commerce, Department of Commerce.

CONCENTRATED-FERTILIZER DEVELOPMENT

102. The importance of maintaining soil fertility is so great that both National and State Governments are engaged in active research on soil and crop needs and in the problem of securing better and more economical fertilizers. Data concerning the former are available to farmers in many sections of the country, while manufacturers have and are availing themselves of results leading toward the most advantageous production of phosphoric acid, nitrogen, and potash.

103. One of the activities of the Department of Agriculture has been to educate manufacturer and farmer alike to the waste involved in shipping large quantities of fertilizer that contain but a little plant food.

HAULING AND HANDLING SUPERPHOSPHATE AND CONCENTRATED FERTILIZER

104. The freight saving in high-grade fertilizer production has been graphically set forth by William H. Waggaman at one time with the Bureau of Soils, United States Department of Agriculture in Department Bulletin No. 1179.

105. Starting with 100,000 tons of run of mine rock containing 20,000 tons of phosphoric acid—by present methods, after this rock is washed, 30,000 tons are available containing 10,000 tons of phosphoric acid. This, together with 7,000 tons of sulphur from Texas, is shipped to the fertilizer manufacturer. He converts the sulphur to sulphuric acid and treats the 30,000 tons of phosphate rock with almost equal amounts of sulphuric acid thereby making 90 to 95 percent of the 10,000 tons of contained phosphoric acid available as plant food, but increasing the bulk to 62,000 tons. This is shipped to the consuming centers. According to these rough figures, there is a 50-percent phosphoric-acid (P_2O_5) loss in material handled at the mine. Thirty-seven thousand tons of material containing 27 percent useful plant food is shipped from Florida or Tennessee and from Texas to fertilizer plants. Here finished product is diluted by one half, so almost five times more material is handled, bagged, and shipped than has any market value, all sales being made on phosphoric-acid content. A car loaded to capacity contains 60,000 pounds. When 17.5 percent superphosphate is shipped, there will be sales value on 10,500 pounds of actual phosphoric acid contained, although transportation charges will be paid on 60,000 pounds.

106. In the pyrolytic process, phosphoric acid can be produced economically at the mine, as almost all the phosphoric content of run of mine rock is extracted. The 100,000 tons mined will pass through the furnace producing roughly, 33,000 tons of bulk containing 18,000 tons of phosphoric acid. The liquid phosphoric acid will also be shipped in 60,000-pound carload lots. This would contain 32,700 pounds of available phosphoric acid, or, if phosphoric acid were shipped freight rates would be paid on less than 50 percent bulk.

107. A 60,000-pound carload of double superphosphate would contain 28,800 pounds of plant food, while a 60,000-pound carload of monoammonium phosphate may contain 37,000 pounds of plant food. The decrease in freight charges that each pound of available plant food would carry is obvious. Add to this a decreased cost in bagging

and handling and there is a marginal difference that pyrolytic phosphoric-acid manufacture may cost before the concentrated marketed fertilizer will equal the ordinary superphosphates' unit price.

108. The present annual freight expenditure for finished fertilizers from factory to consumer is estimated to be $20,000,000 and the costs of bags and bagging, $15,000,000. An annual saving of over $8,000,000 is estimated will result in freight charges from the shipping of concentrated fertilizers and probably bagging cost could be decreased by $6,000,000.

GRADUAL GROWTH

109. As this saving would be reflected in the fertilizer price and as the farmer himself would have less bulk to haul and handle, the question arises as to why there has been such a gradual increase in fertilizer content. The reasons are very real.

110. In the first place, technical developments which may lead to the production of high-analysis fertilizers are of recent date. As has been shown elsewhere, there are, today, only three producers of pyrolytic phosphoric acid, production having begun in one factory in 1920, in another in 1927, and in the third plant in 1929. The synthetic-ammonia industry also belongs to this last decade. And even in 1930 only a little of the ammonia and pyrolytic phosphoric acid produced by chemical engineering methods is entering the fertilizer industry, because such production had not yet exceeded materially the demands of higher-priced commodities. But increasing production of both materials is unquestionably requiring extended markets.

111. Then, too, the machinery for applying fertilizer in the field has been designed to apply about 150 pounds fertilizer per acre. These distributors will not handle half this amount effectively as would be necessary were concentrated fertilizer used. Agricultural machine manufacturers had first to be convinced that there was a market for such machine adjustments before machines were designed to apply less than 100 pounds per acre satisfactorily.

112. And lastly, the farmer must also be impressed with the material value of concentrated fertilizers to himself before he will be ready to replace his old machines with new ones. Even though agricultural experts advocate the concentrated fertilizer, as long as the number of salesmen urging the farmer to buy low analysis fertilizer far exceed the few selling concentrated fertilizer, old machines will probably continue in use.

The present growth of the concentrated fertilizer industry in the United States has come about chiefly through recognized economies on the part of manufacturers.

THE BEGINNING OF THE INDUSTRY

113. The pioneer concentrated fertilizer producer in this country, the American Cyanamid Co., required additional markets for the cyanamide produced at the Canadian plant. By manufacturing phosphoric acid and making it the carrier of ammonia produced from the cyanamide, a high-grade fertilizer was obtained. The company developed a foreign market for this fertilizer because, by quoting delivered prices, the further the shipment in competition with ordinary fertilizer, the more profitable was the "AmmoPhos." It

is only recently that this company is attempting to develop a home market for its product and, to satisfy the American farmer's demand for mixed fertilizer, potash is being added to the original 2-plant food fertilizer.

114. The production of double superphosphate by the Anaconda Copper Co. of Montana was brought about primarily by its distance from consuming markets. According to Mr. H. C. Gardner, in charge of its fertilizer operation, fertilizer had to be hauled 1,525 miles before reaching fertilizer-consuming territory and be shipped in 40-ton lots before obtaining advantageous freight rates. Consequently, the ordinary superphosphate produced in Montana could not compete in central markets with eastern and southern superphosphates.

115. The five firms manufacturing double superphosphate today produce phosphoric acid through the sulphuric acid process so that high-grade rock, the costly sulphuric-acid chambers, and the additional steps required to produce the concentrated fertilizer are still a part of the cost of the fertilizer. Several of these firms are located near mines, however, and as the phosphoric acid produced from high-grade rock is used to treat low-grade ore, mine waste and haulage of raw material is greatly lessened. Then, too, the concentrated phosphate fertilizer gains all advantages of lessened handling and hauling costs.

116. *Ammoniated superphosphate.*—Many superphosphate producers have added equipment to their plants during the last year to use the acid properties of superphosphate for the fixation of ammonia. Superphosphate, as ordinarily made, had to remain in an aging pile for a considerable time to permit the maximum conversion of phosphoric acid. Even then, about one sixth of the acid was in a free state. If this was not absorbed in lime or other base, it caused mixed goods to cake, bag rotting, and other troubles. By adding controlled amounts of 25 percent ammonia liquor into the fertilizer mixer, all free acid is neutralized and the fertilizer can be bagged and shipped without aging. The quantity of ammonia used depends upon the free acid in the superphosphate and the type of mixture produced. An average amount is 40 to 60 pounds per ton of superphosphate.

117. From the viewpoint of the producer of ammonia, instead of shipping ammonium sulphate with its useless sulphate radical to fertilizer plants to be mixed with superphosphates, ammonia liquor from coke works or anhydrous ammonia from synthetic plants can be utilized. The freight rate on the liquor is the same as for the sulphate, but one process in manufacture is eliminated. The freight rate on anhydrous ammonia is greater than on the sulphate but as it carries almost four times as much nitrogen, its freight rate per ton of useful plant food is actually cheaper than on the sulphate.

118. Consequently, the development of the ammoniated superphosphate fertilizer means a saving for the superphosphate producer and a saving for the ammonia manufacturer.

119. An interesting Pacific coast development in 1930 was the manufacture of a potash-phosphate fertilizer at San Pedro, Calif., by the Agricultural Potassium Phosphate Co. of California, Ltd. Plant capacity is 40,000 tons. Phosphate rock is secured from Paris, Idaho, and potash is sent from Trona, Calif., Las Vegas, Nev., and from Italy. The company expects to ship to Pacific coast points, to Louisiana sugar fields, to China, and the Philippines.

Potash

120. As has been stated, the American farmer applies approximately 343,000 tons of pure potash to farm lands each year. In addition, potash enters into the manufacture of a number of chemicals. In 1929, 107,800 tons of crude potash containing 61,590 tons of pure potash were produced in the United States. This was mined and manufactured by the American Potash & Chemical Co., securing potash and borax at Searles Lake, Calif., and by the United States Industrial Chemical Co., of Baltimore, which distills the waste from alcohol manufacture. Only 57,540 tons of pure potash were sold. In 1930 the application of alunite from Sulphur, Nev., was tried out on California soils. Alunite is a potassium alum which has been produced at Marysvale, Utah, for a number of years.

121. Domestic production formed but 16 percent of the total pure potash available in the United States in 1929, and but 15.2 percent of that offered for sale in 1930.

122. The country has been, and still is, dependent upon Germany and France for its potash. In 1929, 782,975 short tons of potash fertilizer salts and 57,780 short tons of potassium salts for the chemical industry were imported, bringing total potash salt importations to 835,689 short tons containing 325,000 tons pure potash.

123. *The German and French potash industry.*—The potash industry is well established in both France and Germany, where cartels enjoy governmental protection and where deposits of potash salts are enormous. In Germany a large byproduct output is a part of potash refining. From carnalite salts, bromine and magnesium chloride are also secured. Sodium sulphate and magnesium sulphate (epsom salts) are gained from kiesnite salts, and sylvinite contains not only potassium chloride but also magnesium sulphate. The principal potash companies have entered into the production of concentrated fertilizer containing potash and one or two of the other plant foods. The Wintershall Co. in Germany not only produces potash and allied chemicals but also manufactures synthetic ammonia, nitric acid, and a concentrated potash-ammonium nitrate. Tests are underway in the treatment of potassium chloride with nitric acid for a potassium-nitrate recovery; the byproduct, hydrochloric acid, is treated with ammonium to produce ammonium chloride.

Domestic potash resources

124. Domestic potash resources were assessed carefully during and after the war. Congress has recently appropriated funds for further geological work on our resources and for investigations which will render our potash commercially available. Numerous sources of potash exist in the United States. In many deposits, such as those in Wyoming, the potash is not water soluble, as is German and French potash, and, therefore, must be chemically treated before it is available as plant food. This potash is combined with other products so that its successful commercial development depends upon the recovery of byproducts and upon the markets for these byproducts.

125. The United States Bureau of Mines and the United States Geological Survey are drilling wells in a potash area extending from western Texas into New Mexico. In 1931 one company, the United

States Potash Co., had developed promising potash deposits 22 miles east of Carlsbad, N.Mex. These are reported to contain 30 percent potash in the form of potassium chloride. Much of the potash fertilizer salts now imported contain less than 20 percent potash, although in both France and Germany refineries are increasing to produce more concentrated material.

126. This discovery of sylvinite by private engineers has led to the belief that much of this type potassium salt from which potassium chloride is easily extracted will be found in the Texas-New Mexico field. The wells drilled by Government experts contain polyhalite, a salt from which potassium sulphate has been extracted at an experimental station of the Bureau of Mines.

127. At the same time Pike and West of Emeryville, Calif., are working the leucite deposits of Wyoming. These are potash-aluminum-silicate-silica rock deposits believed to be the most extensive potash deposits in the United States. This development is taking place at Superior, Wyo. The mineral is reported to contain 11.5 percent potash, 13 percent anhydrous alumina, and 51 percent silica with small amounts of other minerals. This California company leaches the ground ore with soda brine, obtained from brine wells at Green River, securing a mixture of potassium and sodium carbonate. The latter is evaporated while the potassium carbonate is removed by crystallization. Phosphate rock from Georgetown, Idaho, and sulphuric acid from Garfield, Utah, are then used to treat the potassium carbonate, the resulting product being potassium phosphate (KH_2PO_4) used in compounding baking powder and in medicines.

128. At present the known resources of potash in the United States would be summarized as follows:

I. Feldspar and other potash silicates:
   (*a*) The Leucite Hills in Wyoming are a potential source of almost 200,000,000 tons of potash. Alumina would be separated from the ore.
   (*b*) Mill tailings in Colorado and Utah.
   (*c*) Georgia shale contains 3 to 4 percent K_2O.
   (*d*) Glauconite is located in New Jersey and Delaware.

II. Alunite:
   The best-known deposit of alunite, a potassium alum, is near Marysville, Utah; some production has begun in Nevada. The Utah deposits run about 9 percent K_2O. Mining has been carried on, potash being used as fertilizer while the alumina byproduct is shipped to California and New Jersey makers of refractories.

III. Polyhalite and Sylvinite:
   Wells recently drilled at various parts in New Mexico and Texas disclose deposits of a complex sulphate of potash, lime, and magnesia. The territory believed to contain potash is extensive. A recent development in New Mexico indicates potash deposits in the form of sylvinite, from which potassium chloride is easily extracted.

IV. Saline Lakes:
   (*a*) Searles Lake in California has produced potash and borax for a number of years. The dependence of one product upon the market for the other determines the rate at which expansion will be made.
   (*b*) *Utah Salt Lakes.*—Some potash may be secured as a primary and as a byproduct from the waste liquors of salt works.
   (*c*) *Nebraska Lakes.*—While these lakes furnished much needed potash during the war, the potash is limited and considered of value only in low-grade fertilizers.

V. Organic Sources:
(*a*) Waste molasses, beet sugar, and wood ashes offer regular, if small, sources of potash.
(*b*) *Kelp.*—Estimates place the potash in kelp along the Pacific coast at from 250,000 to 400,000 tons per year.
VI. Byproduct:
Cement dusts contain potash and lime, but it is believed that the lime can be removed if a market exists for the postash.
Much domestic pig iron contains potash in small quantities.

129. *Agricultural research.*—While work is being done in developing potash deposits, Dr. William H. Ross, of the Bureau of Soils of the Department of Agriculture, is studying ways of producing potash fertilizer. Mixtures of phosphate rock, potash silicates, and carbon have been efficiently volatilized in the laboratory furnace. While further experiments will be carried on with new enlarged equipment, indications favor the commercial feasibility of this procedure as a means of producing a cheap combined fertilizer.[36]

130. Experiments elsewhere deal with the treatment of potash materials with nitric oxide, the combining of sodium nitrate and potassium chloride or calcium nitrate and potassium sulphate to produce potassium nitrates.

131. *Electrolytic potassium compounds.*—Potassium enters into a number of chemicals. While many potassium compounds are prepared by purely chemical reactions, a few compounds are manufactured by electrolysis.

132. *Potassium hydroxide.*—Potassium chloride (KCl) serves as the base for electrolytic compounds manufactured in the United States. This is made by the fractional crystallization of potash brines in this country or is imported. Potassium hydroxide, also called caustic potash, is the principal compound electrolyzed from it in the United States. It is produced in diaphragm cells similar to those employed in caustic soda production, the chlorine gas being given off at the anode while the potassium is deposited on the cathode where it reacts with water to form potassium hydroxide. Current consumption approximates 2,200 kilowatt-hours per ton potassium hydroxide produced, including the chlorine produced. (For manufacturing details see pp. 289 and 290 of Power in the Manufacture of Chemicals and Metals from Brine.)

133. Seven thousand one hundred and ninety-six tons of potassium hydroxide were manufactured in 1929 in the United States, while imports totaled 7,821 tons. Potassium hydroxide is used in the manufacture of soft soaps, of dyes, and of potassium permanganate. The latter product is used in lithopone, as a sanitary reagent, and in nickel refining as well as in tanning and bleaching. The electrolyte is composed of potassium hydroxide, manganese ore, and chlorine. Production figures are not reported for the United States, although it is known that importations were but 16.8 tons.

POTASSIUM CHLORATE

134. Potassium chlorate is made by the electrolysis of an aqueous solution of potassium chloride in the same manner as potassium hydroxide. However, instead of separating the chlorine and potassium hydroxide formed by use of a diaphragm cell, these are permitted

[36] United States patents 1492712, 1492757, and 1598259.

to mix at a temperature of 70° C. in a simple cell, thus producing the chlorate. This is evaporated from the solution and sold as crystals or powder. Approximately 1,350 kilowatt-hours are required per ton of chlorate.

135. Potassium persulphate is obtained by the electrolysis of a strong solution of potassium-hydrogen sulphate in a diaphragm cell. It is used in the manufacture of hydrogen peroxide and as an oxidizing agent in photography.

136. Metallic potassium is also an electrolytic product but is not manufactured commercially in the United States.

POTASSIUM COMPOUND MANUFACTURERS

137. Potassium Compounds are manufactured by the following companies in the United States:

American Cyanamid Co. (fertilizer salts), Warners, N.J.
American Potash & Chemical Co. (fertilizer salts), Trona, Calif.
J. T. Baker Chemical Co., Phillipsburg, N.J.
Carus Chemical Co., La Salle, Ill.
Grasselli Chemical Co., Inc., Grasselli, N.J.
Harshaw Chemical Co., Philadelphia, Pa., Cleveland and Elgin, Ohio.
International Agricultural Corporation (fertilizer salts), Montgomery, Ala., Cincinnati, Ohio.
Mallinckrodt Chemical Works, St. Louis, Mo.
Merck & Co., Rahway, N.J.
Mutual Chemical Co. (fertilizer salts,) Jersey City, N.J., Baltimore, Md.
Niagara Alkali Co., Niagara Falls, N.Y.
Charles Pfizer & Co., Brooklyn, N.Y.
Roessler & Hasslacher Chemical Co., Niagara Falls, N.Y.
Rohm & Haas Co., Inc., Bristol, Pa.
Sterling Products Co., Easton, Pa.

BIBLIOGRAPHY

NITROGEN AND ITS COMPOUNDS

Year — Name and title

1920. Barnitz, H. L. Electrolytic Production of Hydrogen, Chemical and Metallurgical Engineering, 22, pp. 201–206.
1906. Birkeland, K. On the Oxidation of Atmospheric Nitrogen in Electric Arcs. Trans. Forady Soc. 2, 98–116.
1924. Braham, J. M. The Air Nitrogen Processes. U.S. Department of Commerce Bulletin No. 240.
1929. British Sulphate of Ammonia Federation, Ltd. Ninth Annual Report.
1930. Chemical and Metallurgical Engineering, January 1930. pp. 31–32.
1922. Claude, G. The Manufacture of Hydrogen by the Partial Liquefaction of Water-Gas and Coke-oven Gas. J. Ind. Eng. Chem. 14.
1929. Cottrell, F. G. Fertilizer and Fixed Nitrogen Investigation in Report of Chief of the Bureau of Chemistry and Soils.
1929. Dobson, W. P., and Barnes, A. S. Oxygen and Hydrogen in Industry Paper before American Electrochemical Society.
1927. Ernst, Frank A. Fixation of Atmospheric Nitrogen.
1922. Fixed Nitrogen Research Laboratory and Nitrate Division, Ordnance Office, War Department. Report on the Fixation and Utilization of Nitrogen. No. 2041.
——. Haber, F. Synthetic Production of Ammonia.
1929. House Committee on Ways and Means. Brief of By-product Coke Producers. H.R. 17th Cong., 2d sess., Vol. 1, p. 309.
1927. House Committee on Military Affairs. Hearings on Muscle Shoals. H.R. 16396, 16614.
1916. Landis, W. S. The Production of Ammonia from Cyanamide. The American Cyanamide Industry. Paper before American Electrochemical Society.

Year Name and title

1923. Lheure, M. Synthetic Ammonia by the Claude Process. Chemical and Metallurgical Engineering. 28.
1930. McMichael, Paul. Cheap Ammonia with Off-peak Electric Power. Chemical and Metallurgical Engineering. August.
1928. Noeggerath, J. E. Article in Chemical and Metallurgical Engineering. July.
1912. Norton, T. H. Utilization of Atmospheric Nitrogen. Department of Commerce and Labor Bulletin No. 52.
1922. Parkington, J. R., and Parker, L. H. The Nitrogen Industry.
1930. Pollitt, G. P. The Synthetic Ammonia Industry. Paper given at World Power Conference, June.
1922. Tour, R. S. The German and American Synthetic Ammonia Plants. I to IV. Chemical and Metallurgical Engineering. 26.
1928. Tryon, F. G., and Bennit, H. L. Coke and By-products in 1928. U.S. Bureau of Mines.

PHOSPHORIC ACID AND PHOSPHATIC COMPOUNDS

1930. The American Fertilizer. Vol. 72. Vol. 73.
1929. British Sulphate of Ammonia Federation, Ltd. Ninth Annual Report.
1929. Bureau of Railway Economics: Commodity Prices in Their Relation to Transportation Costs. Bulletin No. 36.
1930. Chemical and Metallurgical Engineering: Nitrogen Situation in the United States. January, p. 31. Fertilizer, p. 43. Phosphate, p. 43.
1930. DuPont Ammonia Corporation: Anhydrous Ammoniation with Anhydrous and Aqua Ammonia.
1929. Federal Power Commission: Hearings before Executive Secretary on Conflicting Applications of the Rocky Mountain Power Company and Walter H. Wheeler to Develop Power on Flathead Lake and Flathead River, Montana. Washington, D.C.
1923. Federal Trade Commission: Report on the Fertilizer Industry.
1929. Grace, Morgan H. International Aspects of the Phosphate Rock Industry in National Fertilizer Association Proceedings, June 1929, p. 47.
1930. Huttol, J. B. Phosphate Mining and Milling at Conda, Idaho, in Engineering and Mining Journal, February. 24.
1929. Jacobs, K. D. Chemistry and Economics of Superphosphate. Paper before the National Fertilizer Association, June 1929.
1929. Klugh, Bethune G. Electrothermal Production of Phosphoric Acid in Chemical and Metallurgical Engineering. November.
1929. Kochs, Ernest. Comment in Chemical and Metallurgical Engineering. December.
1929. McBride, R. S. Ammoniated Phosphate. New Factor in Fertilizer Manufacture.
1930. McKee, Barclay. Character of Superphosphates.
1929. Mineral Industry During 1928. Vol. XXXVII.
1930. The National Fertilizer Association. American Fertilizer Handbook.
1929. Proceedings of the Fifth Annual Convention.
1927. Proceedings of the Third Annual Convention.
1925. Ross, W. H. Use and Preparation of Concentrated Fertilizer. Paper before American Electrochemical Society, September 24.
1929. Ross, Wm. H., and Mehring, A. L. Preparation of Potassium Nitrate in Industrial and Engineering Chemistry. April.
1928. Smalley, H. R. Observations on Recent European Fertilizer Developments. Paper given before American Chemical Society. September.
1930. Turrentine, J. W. Potash, in Chemical and Metallurgical Engineering. January 30, p. 46.
1929. United States Department of Agriculture: Report of the Chief of the Bureau of Chemistry and Soils.
1923. United States Department of Agriculture: Bulletin No. 1179. Investigations of the Manufacture of Phosphoric Acid by the Volatilization Process.
1924. United States Department of Agriculture: Bulletin No. 1180. Field Experiments with Atmospheric Nitrogen Fertilizers.
1930. United States Department of Commerce: Bureau of Mines: Commercial Possibilities of the Texas-New Mexico Potash Deposits. Bulletin 316.
1928. United States Department of Commerce: Bureau of Mines: Phosphate Rock.

Year	Name and title
1929.	United States Department of Commerce: Bureau of Mines: Phosphate Rock.
1923.	Bureau of Foreign and Domestic Commerce: Chemical Trade Bulletin No. 3A. November 23.
1929.	Bureau of Foreign and Domestic Commerce: The American Chemical Industry.
1923.	United States Department of the Interior: Geological Survey: Mineral Resources. Vol. II. pp. 109–132, 186–187.
1924.	United States Department of the Interior: Geological Survey: Mineral Resources. Vol. II. p. 266.
1930.	United States Department of the Interior: Geological Survey: News Release August 25.
1922.	United States Department of the Interior: Geological Survey: Phosphate Rock.
1929.	United States House of Representatives: Tariff Readjustments: Vol. 1. pp. 172–175; 311; 872; 877.
1929.	United States House of Representatives: Tariff Readjustments: Muscle Shoals Hearings: Part 2.
1928.	United States Tariff Commission: Sodium Phosphate.
1929.	Van Derlinden, Lee. A New Selling Policy Needed, in The American Fertilizer. January 5, p. 30.
1927.	Waggaman, W. H., and Easterrod, Henry. Phosphoric Acid, Phosphates and Phosphatic Fertilizers.

POWER IN COPPER AND COPPER-ALLOY PRODUCTION

TABLE OF CONTENTS

	Page
Power consumption	197
Development of the copper industry in the United States	198
Growth of copper-ore reduction in the several States	199
Establishment of copper refineries	200
Changes in copper-reduction methods	200
Flotation introduced	200
Leaching and electrolytic precipitation	201
Position of United States in world copper market	202
Nineteenth Century conditions	202
Period prior to World War	202
Post-war period	202
Price pegging, copper production, and imports	204
Increased production in Belgian Congo, Rhodesia, and Canada	205
World consumption compared with production	206
World copper reserves	210
Reserves in the United States	210
Canadian developments	212
South American reserves	213
European dependence	214
Belgian Congo and Rhodesian developments	214
Copper-ore reduction processes	215
Ore leaching	215
Precipitation by electrolysis	216
Power equipment	217
Iron and other precipitation processes	218
Flotation	218
Power and material consumption	219
Direct smelting	220
Sulphide-ore smelting	220
Electric-furnace smelting	221
Flotation, leaching, and electrolysis	221
Process chart	not printed
Crude-copper refining	222
Furnace refining	222
Electrolytic copper refining	222
Multiple system	222
Series system	223
Power requirements	224
Melting and casting	224
Recovery of precious metals	224

Page
Cost of ore reduction 225
Cost of leaching and electrolysis 225
Distribution of flotation costs 227
Smelting costs 228
Total reduction and refining costs 230
Organization and location of copper-producing units 235
Markets for refined copper 236
Copper and copper-alloy fabrication 238
Electric-furnace brass melting 238
Copper and brass electric annealing 240
Markets for copper and copper-alloy fabrications 241
Bibliography 241

Although electrolytic copper refining is regarded as a pioneer in electrochemical industries, new applications of electrolysis and electrothermal processes in copper production and fabrication have occurred in the last 15 years in the United States. Today, leached-oxide and mixed-copper ores are precipitated by electrolysis; 93 percent of all primary copper is electrolytically refined; more than 90 percent of brass, bronze, and nickel brass is melted electrically in rolling mills; about a third of the foundry production of copper alloys is melted electrically; accurate annealing of copper and copper alloys is done in electric annealing furnaces; and a beginning has been made in copper electric melting.

Electrolytic precipitation of oxide and mixed ores required 1,700 to 2,625 kilowatt-hours energy at the tank per ton copper deposited, variations in power consumption depending largely on ore characteristics and resultant tank efficiencies. The two Arizona plants employing this process had a gross current consumption, at electrolytic tanks, of 62,848,806 kilowatt-hours.

The power required in electrolytic copper refining is dependent primarily upon the system of electrolysis used and upon current density. At 18 amperes per square foot of cathode, from 141 to 233 kilowatt-hours electricity were consumed per ton copper refined. When operating at capacity, United States copper refineries would consume annually approximately 310,000,000 kilowatt-hours of electricity in electrolytic refining.

Electrical energy required to melt copper alloys varies with the respective melting points of the several component metals and with the type of furnace used. Consumption falls between 200 to 300 kilowatt-hours per ton alloy melted. Approximately 220,000,000 kilowatt-hours were consumed in rolling mills and in foundries in such alloy melting in 1927.

Copper and brass electric annealing requires from 50 to 100 kilowatt-hours per ton metal, depending upon the product annealed and the type of furnace used. Although electric annealing is done only for operations requiring accuracy, it is adding a number of million kilowatt-hours to the electrical load of fabricating plants. Pure copper-ingot melting requires about 310 kilowatt-hours energy per ton. The tonnage melted is still small because present furnace-lining life is low with metal containing more than 90 percent copper.

Copper reduction and major fabrication units, with one exception, have not been located at sites where cheap electric power was obtainable. The reduction plants have located at mines because our

copper ore rarely contains more than 2 percent copper and cannot, therefore, be shipped economically any distance. Fabricating plants were established on the Atlantic seacoast in the early days of copper and copper-alloy manufacture. As alloy production was dependent upon the knowledge and skill of workmen until the introduction of electricity in 1915, the industry remained where trained craftsmen were found. The refinery branch, securing blister copper from South and Central America, as well as from the United States, Canada, and Alaska, serving eastern fabrication markets and exporting refined copper to Europe, was established on the Atlantic seaboard, with one plant on the Pacific. The only major unit located at a source of cheap power was the electrolytic refinery at Great Falls, Mont., not far from the Butte Copper Mining District. Electrolytic or electrothermal processes, therefore, have been adopted at many localities where current costs are higher than fuel costs.

The United States achieved its highest position in the world copper market in 1909, when it contributed almost 60 percent to world copper production. In 1928 it smelted 53.5 percent of the world's copper. The total copper refined was greater than ever before in 1929, but our exports of refined copper dropped 7 percent from the average of 5 preceding years. The successful development of copper mining and refining in the Belgian Congo decreased demand for American copper in Europe. Belgian Congo and Northern Rhodesia are believed to have the largest bodies of rich copper ore in the world. The copper is won from the ore and refined at a low-cost figure. The lowest production costs in the United States occur at a Utah plant having disseminating ore containing less than 1 percent copper. A second large United States producer controls low-cost producing mines in South America. But, unquestionably, the growing competition from Africa and Canada will necessitate lower operating costs in other United States plants if they are to continue regular production. Improvements in mining methods, in ore reduction, and refining processes may be looked for in the next 10 years. The trend is toward a greater application of electrical power.

Development of the Copper Industry in the United States

1. Although copper was used by man in remote antiquity, the present chapter in copper history may be said to have begun with the growth of the electrical industry. Between 1881 and 1890, world production of copper exceeded the production of the first 50 years of the nineteenth century by almost 66 percent. From 1890 until 1920, the average annual world increase in copper production was about 30 percent.

2. Demand has been the governing factor in copper development during this late nineteenth century and twentieth century period. Although the real beginning of the copper mining and reduction industry in the United States was brought about by the rediscovery of native copper ores (the metal copper uncombined) in the Keweenaw peninsula of Michigan, the establishment of the industry in the Rocky Mountains was due to a demand which made it feasible to work lower grade copper sulphide ores. The price obtainable for copper has determined the ores from which copper was recoverable commercially and has led to a continuous improvement in copper mining and reduction methods.

GROWTH OF COPPER ORE REDUCTION IN THE SEVERAL STATES

3. Copper mining and smelting began in this country in 1842.[37] Great lumps of native ore were crushed in stamping mills, roasted, and smelted in blast furnaces in Michigan. In 1866 metallic copper occurring as cementing material, or conglomerate ores, in the same Lake Superior peninsula was judged of value and about 20 years later the possibilities of deep vein mining for native ore were realized. By 1880, the United States was producing 14.66 percent of the world's copper, most of which was coming from Michigan although small amounts were produced in Arizona, California, Colorado, Montana, Nevada, New Mexico, Tennessee, and Utah.

4. Copper ores had been found in the Rocky Mountain region while prospectors were seeking gold and silver. Small amounts of this had been shipped East, but it was not until 1882 that the sudden increased demand for copper, due to the invention of the dynamo and the resultant growth of the electrical industry, caused the development of the copper industry on a large scale at Butte, Mont. Gradually, the old methods of ore reduction borrowed from Michigan and England were adjusted to meet the requirements of copper sulphide ores of Montana. Crushers and rolls were substituted for stamp mills; jigs, tables and screens were arranged between crushers, until a gravity concentration was effected that greatly increased the recovery of copper from sulphide ores. At the same time the fire reduction operations were increased in number and roasters, reverberatory and blast furnaces, and converters increased in size and effectiveness.

5. Large developments began in Arizona soon after Butte became a copper center. But it was 1903 before quantitative production on low grade disseminated ore began in Utah. By 1887 Montana had surpassed Michigan in quantity of copper smelted. By 1907 Arizona was the leading copper producing State, a position which she held in 1929.

TABLE I.—*Copper-smelter output in the United States from domestic ores*

[Includes copper produced from ore by leaching and electrolysis][1]

State	1925	1926	1927	1928	1929
	Short tons	*Short tons*	*Short tons*	*Short tons*	*Short tons*
Total	837,435	869,811	842,020	912,950	1,001,432
Alaska	36,102	33,816	28,245	20,271	19,934
Arizona	361,327	364,662	340,584	367,816	414,603
California	23,472	15,221	12,901	12,354	16,542
Colorado	1,582	2,329	4,003	5,131	5,260
Idaho	1,572	586	906	1,168	3,134
Michigan	69,015	87,389	97,567	89,552	92,650
Missouri	6	27	3	(2)	1
Montana	135,302	128,636	112,604	125,523	149,947
Nevada	38,569	54,521	59,149	79,666	69,495
New Mexico	38,234	41,424	39,881	46,389	50,083
North Carolina		734	2,681	4,104	(3)
Oregon	63	140	242	188	370
Pennsylvania	281	248	1,075	2,507	1,791
Tennessee	9,895	9,301	7,249	8,187	(3)
Texas	(2)	9	13	216	197
Utah	121,365	129,825	133,853	149,188	162,983
Vermont	(2)	223	119		376
Washington	592	668	883	599	785
Wyoming	(2)			1	2
Undistributed	58	52	62	89	13,279

[1] U.S. Bureau of Mines: Copper in 1928 and Preliminary Reports for 1929.
[2] Less than 1 ton.
[3] Included under undistributed. Bureau not at liberty to publish.

[37] Some copper had been obtained in New England States and New Jersey since 1632 but the amounts were small.

ESTABLISHMENT OF COPPER REFINERIES

6. Although the village craftsman had smelted some copper for use in kettle manufacture in early colonial times, the copper and copper-alloy industry began with the manufacture of brass buttons in the Naugatuck Valley of Connecticut. At first brass was secured from England but in 1802 brass was manufactured here by the direct fusion of copper and zinc, the copper being smelted from old kettles and the zinc being imported. Following upon this advance, brass was rolled into sheets. As the Waterbury rolled-brass industry grew, copper was shipped from Chile, refined in regular smelters at Baltimore and near New York harbor, and sent to the brass centers for alloying, rolling, and casting. The objects into which copper and brass were fabricated at this time were of such a nature that smelting produced sufficiently pure copper and, therefore, smelting was refining.

7. But as western copper came to smelters, it was not possible to smelt as pure a copper from this low-grade ore as was done from Lake ores, nor could the silver and gold western ores contained be recovered. It was with a view to the better recovery of these precious metals that the Balbach Works at Newark, N.J., and the St. Louis Smelting and Refining Co. began the electrolytic refining of copper in 1885. The copper produced at these early electrolytic plants was free of objectionable metals such as arsenic, tellurium, bismuth, and antimony, that had not been reduced by smelting. These eliminations increased the copper's electric conductivity and gradually the demand from the electrical industry shifted from Lake to electrolytic copper. At this time only a part of Lake copper and other high-grade ore is refined by smelting.

8. In 1892 the first electrolytic copper refinery in the West was erected at Great Falls, Mont. But because copper from South America, Cuba, and Mexico came to United States refineries to be electrolytically refined, because the major fabricating industries were on the East coast, and because refined copper was exported, refineries were established on the Atlantic coast in reach of ocean shipping. One plant was erected at Tacoma, Wash., to smelt Alaskan and Canadian ores. Only in 1929 was a third refinery built in the West, this time at El Paso. This refinery will secure blister copper from Arizona, refine it and ship refined copper via Gulf ports to East and West coasts and to foreign countries.

9. *Changes in copper reduction methods.*—Relatively little of the copper ore still found in the United States contains over 2 percent copper. In fact, the dumps of the earlier Michigan reduction plants contain more copper than is found in the remaining known ores of this region. Consequently, competitive prices forced the adoption of methods that would increase the copper obtained per ton of ore.

FLOTATION INTRODUCED

10. Flotation, or the use of chemicals and air to float desirable minerals while allowing the gangue to sink, began to be adopted on sulphide ores about 1914 and 1915. At first it was used in connection with gravity concentration equipment, but gradually new types of classifiers were introduced and now all but high-grade ore goes from classifiers to flotation machines before entering the furnaces. The

high recovery brought about by flotation methods, together with the use of coal-dust, oil, or gas for reverberatory furnace firing, led to the abandonment of the blast furnace. The original oils used for mineral flotation have been replaced with xanthate which has made differential flotation possible and thereby increased still further the amount of copper in the concentrate.

11. In the last few years Michigan companies have adopted flotation in order to treat the native disseminated ore, known as amygdaloidal diabase. By this method copper recovery has been increased and smelter cost decreased because of cleaner concentrate.

LEACHING AND ELECTROLYTIC PRECIPITATION

12. In the meantime, the world-old process of leaching or dissolving the copper from its ore by alternate wetting with a sulphuric-acid solution and air drying was begun in worked-over mines and on dump heaps in the Rocky Mountains. Increased attention was also given to leaching for the recovery of copper from low-grade disseminated ore containing both oxidized and sulphide minerals. While the copper in solution from waste ore leaching was precipitated by iron, in 1917, the New Cornelia Copper Co. at Ajo, Ariz., completed an electrolytic plant to precipitate copper from tank leaching solutions. While these ores were primarily oxide, they contained a small quantity of copper as sulphide. In 1926 a second Arizona leaching and electrolytic plant was put in operation at Inspiration to leach mixed oxidized and sulphide ores.

13. Experiments conducted by the Southwest experiment station of the United States Bureau of Mines in cooperation with the Department of Mining and Metallurgy, University of Arizona, have shown that the prevailing oxidized minerals of copper, namely, azurite, malachite, chrysocolla, and tenorite, are soluble in sulphuric acid and ferric-sulphate solutions.[38] At the same time the actual experiment of the Chile Copper Co. at Chuquicamata, Chile, has proved leaching and electrolysis a successful process for brochantite, a more unusual copper oxide ore. The building of leaching and electrolytic plants at Panda in the Belgian Congo and by the Andes Copper Co. in Chile leave no doubt that today leaching and electrolysis are regarded, commercially, as the best method of winning copper from oxide copper ores.

14. Experiments of the Bureau of Mines [39] indicate that chalcocite, one of the sulphide copper ores, can be leached with ferric sulphate and the sulphide converted into dissoluble sulphate. The ferrous iron produced can be reoxidized to the ferric condition for reuse as the reagent for further chalcocite dissolution by the electrolysis which precipitates the copper. Ferric salts, however, reduce current efficiency and necessitate higher current densities in the electrolytic tanks. The commercial success of these experiments has been assured when chalcocite is mixed with oxide ores by actual practice at the Inspiration plant.

15. Chalcopyrite, another prevalent sulphate copper ore, and certain silicates are not dissolved, however, by ferric sulphate or sulphuric acid. A company mining primary chalcopyrite in a slightly basic

[38] U.S. Bureau of Mines: Dissolution of Various Oxidized Copper Minerals. Serial 2934. 1930.
[39] U.S. Bureau of Mines: Chemistry of Leaching Chalcocite. Technical paper 473. 1930.

porphyry, with chalcocite as a secondary ore, is combining the flotation process with sulphuric acid agitation and electrolysis to reduce these ores. Production is just beginning so the commercial success of this process must still be ascertained. If the combination proves successful, it will greatly lessen equipment costs and production costs in plants producing both oxide and sulphide ores, for the two plants employing leaching and electrolysis in the United States on oxide and mixed ores treat sulphide ores by flotation and smelting.

Position of United States in World Copper Market

NINETEENTH CENTURY CONDITIONS

16. At the opening of the nineteenth century England was the largest copper-producing country, copper smelting having become concentrated at Swansea in Wales. Russia and Japan produced about half as much copper while Chile and Venezuela held important places in copper production. The copper ore smelted at Swansea was obtained principally from Spain and South America. So dominant was the position of the Associated Copper Smelters at Swansea that it dictated terms to miner and consumer of copper. The effect of this policy led to the establishment of smelting furnaces in Spain and in Chile just at the time copper mining was beginning in the Lake Superior region of the United States. By 1860 Chile had wrested the dominant position in the copper industry from England and continued to hold first place until 1883 when the United States produced more copper than any other country.

THE PERIOD PRIOR TO THE WORLD WAR

17. From that time until 1915, the United States set a new all-time copper-production record in 22 of the 30 years. During this period the United States production increased 9½ times, while world production increased 3½ times. The United States reached its highest peace-time position in world production in 1909 when it produced almost 60 percent of the world's copper.

18. In the first 15 years of the twentieth century, or the period prior to the World War, the century-old copper-mining countries continued regular production. Japan's contribution to world production was about 6 percent; Mexico's contribution, 4 percent to 7 percent; Canada's production, 3.6 percent; Chilean production, about 5 percent; Peruvian, about 3 percent. Spain produced between 5 percent and 7 percent of the world's copper; Russia about 3 percent; Germany refined 3 percent; Australasia produced about 5 percent, and South Africa, 1 percent.

In 1906 copper production had started in Rhodesia and, in 1911, in the Belgian Congo.

POST-WAR PERIOD

19. During the World War, production in this country and in other producing countries reached unprecedented heights. Production exceeded war-time demands. As a result, the end of the war found such large accumulations of copper stocks that 1921 saw the price of copper at New York fall to $0.125 and a lower production than

had occurred in the previous 23 years. All the larger producing countries were similarly affected.

20. The Copper and Brass Research Association was formed by American copper miners and manufacturers to find new markets for copper and advertise old ones. The Copper Institute was formed in 1927 to "further the interests of the copper industry", while "Copper Exporters, Inc.", had power to allocate copper to the export field and to fix the selling price abroad.

21. By 1923, the average price of electrolytic copper per pound in New York was $0.1442 and production had reached 717,500 tons in the United States. Chile produced 201,044 tons and the Belgian Congo achieved a 63,808-ton copper production.

22. The price deviated slightly in the following years and copper production increased in the United States and Mexico, Canada, Chile, and the Belgian Congo. The following table shows world production and consumption in 1928. Although our production was the highest as yet achieved in peace periods, we were producing a little over half of the world's copper or relatively less of the world's copper than in 1909. This position was due to the increase in production in the Belgian Congo and in Chile since 1909.

TABLE II.—*World copper production and consumption in 1928*

Country [1]	Mine production [2]		Smelter production [2] (including copper from leaching and precipitation)		Consumption [3]	
	Metric tons	Per-cent	Metric tons	Per-cent	Metric tons	Per-cent
Total	1,703,076	100.0	1,704,000	100.0	1,836,300	100.0
North America	984,784	57.8	1,007,063	59.1	909,600	49.5
Canada	91,941	5.4	56,619	3.3	17,400	.9
Cuba	6,431	.4				
Mexico	65,506	3.8	[4] 39,000	2.3		
United States	820,906	48.2	[5] 911,444	53.5	892,200	48.6
South America	354,015	20.8	330,205	19.4		
Argentina [4]	800	(6)				
Bolivia	8,486	.5				
Chile	289,428	17.0	277,913	16.3		
Peru	55,301	3.2	52,292	3.1		
Europe	132,602	7.8	156,157	9.1	820,500	44.7
Austria	3,035	.2	3,424	.2	18,900	1.0
Belgium			[4] 9,000	.5	25,000	1.4
Bulgaria [4]	1,000	(6)				
Czechoslovakia	1,627	.1	1,010	(6)	19,300	1.1
Finland	2,665	.2	375	(6)		
France	(7)		[4] 2,000	.1	125,700	6.8
Germany	25,500	1.5	48,500	2.9	253,700	13.8
Great Britain	69	(6)	[4] 23,000	1.4	161,000	8.8
Italy	802	(6)	900	(6)	76,400	4.2
Norway	14,000	.8	(7)			
Portugal	[4] 2,000	.1				

[1] In addition to the countries listed, copper is produced and smelted in Asiatic Turkey, but data of output are not available.

[2] U.S. Bureau of Mines: "Copper in 1928." (Figures represent fine copper in blister production per smelter production of ingot and anode copper.)

[3] American Bureau of Metal Statistics.

[4] Approximate production.

[5] Smelter output from domestic and foreign material, exclusive of scrap. The production from domestic material only, exclusive of scrap, was 828,210 tons.

[6] Less than 0.1 percent.

[7] Data not available.

TABLE II.—*World copper production and consumption in 1928*—Continued

Country [1]	Mine production [2]		Smelter production [2] (including copper from leaching and precipitation)		Consumption [3]	
	Metric tons	Percent	Metric tons	Percent	Metric tons	Percent
Europe—Continued.						
Rumania	104	(6)	104	(6)		
Russia	[4] [8] 15,000	0.9	[4] [8] 20,000	1.2	50,400	2.7
Spain	53,000	3.1	27,758	1.6	14,900	.8
Sweden	800	(6)	[4] 5,000	.3	21,600	1.2
Yugoslavia	[4] 13,000	.8	15,086	.9		
Other Europe					53,600	2.9
Asia	81,612	4.8	71,041	4.2	88,400	4.8
China	[9] 4,395	.3	[9] 4,395	.3		
Cyprus	4,878	.3				
India, British	[4] 5,000	.3				
Japan			66,039	3.9	79,900	4.3
Japan proper	66,039	3.9				
Chosen	(10)		607	(6)		
Taiwan	1,300	(6)				
Other Asia					8,500	.5
Africa	140,444	8.2	127,441	7.5	11,000	.6
Algeria	303	(6)			(11)	
Belgian Congo	112,456	6.6	112,456	6.6		
French Congo	[4] 1,000	(6)				
Rhodesia:						
Northern	6,026	.4	6,026	.4		
Southern	110	(6)	110	(6)		
Southwest African Protectorate	11,700	.7				
Union of South Africa	8,849	.5	8,849	.5		
Oceania	9,619	.6	12,048	.7	6,800	.4
Australia	9,618	.6	12,048	.7	6,800	.4
Papua	1	(6)				

[4] Approximate production.
[6] Less than 0.1 percent.
[8] Year ended Sept. 30.
[9] Exports of ingots and slabs.
[10] Copper ore produced in Chosen, content not stated, was 3,977 tons in 1928.
[11] Consumption not reported by country.

23. *Price pegging.*—From September 1928, prices climbed until they reached $0.23775 on March 23, 1929. By May the price had dropped to $0.1775 New York refineries and $0.18 delivered, Connecticut. The organized group of American copper producers pegged the price at this point, the Copper Exporters, Inc., maintaining the price of $0.183 c.i.f. in the foreign market. With these prices, United States smelter production reached a height exceeding even war years, or 1,001,432 tons.

24. Our smelters received 62,310 tons of foreign ores chiefly from Canada and Chile, and 26,864 of concentrate mainly from Mexico, Cuba, and Canada. This brought the imports of unmanufactured copper to this country to a record figure. (See table IV.) Copper refineries produced 1,537,135 short tons at the same time, while 67,000 tons of refined copper came into the country chiefly from Chile.

In the refinery production are included 378,691 tons of black or blister or other coarse coppers principally from Canada, Belgian Congo, Chile, and Peru.

25. As our exports of refined copper dropped 7 percent from the average of 1924–28, the close of 1929 found an accumulation of refined copper on hand in this country.

TABLE III.—*Production of refined copper by regular refining plants in the United States* [1]

Type	1925	1926	1927	1928	1929
	Short tons	*Short tons*	*Short tons*	*Short tons*	*Short tons*
Total	1,251,354	1,359,085	1,319,455	1,402,492	1,604,142
Primary:					
Domestic: [2]					
Electrolytic	766,998	776,521	760,038	803,560	892,877
Lake	69,015	86,186	97,568	89,552	92,650
Casting	5,435	2,942	1,870	2,787	5,838
	841,448	865,649	859,476	895,899	991,365
Foreign: [2]					
Electrolytic	258,316	294,466	302,874	316,894	378,278
Casting and best select	2,523	1,128	532	1,011	413
Refinery production, new copper	1,102,287	1,161,243	1,162,882	1,243,804	1,370,056
Imports refined copper	49,887	85,283	51,639	42,365	67,007
Total new refined copper made available	1,152,174	1,246,526	1,214,521	1,286,169	1,437,063
Secondary:					
Electrolytic	70,175	81,531	84,383	95,662	165,929
Casting	29,005	31,028	20,551	20,661	1,150
	99,180	112,559	104,934	[3] 116,323	167,079

[1] U.S. Bureau of Mines: "Copper in 1929."
[2] The separation of refined copper into metal of domestic and foreign origin is only approximate, as an accurate separation of the amounts at this stage of manufacture is not possible.
[3] Plants treating secondary copper only produced an additional 377,708 tons.

26. Generally poor business conditions in the latter half of 1929 and in 1930, decreased markedly the demand for copper.

27. The larger United States producers curtailed production while holding the price of copper at $0.18 here and abroad. Only the smaller producers continued usual production, and developments in the Belgian Congo and Canada proceeded rapidly. This price regulation in the face of a falling market caused bitter resentment in foreign countries purchasing our copper. But the $0.18 price was maintained until April 15, 1930, when it dropped to $0.14. Since that date its tendency has been downward. In October of 1930 it reached the low level of $0.095.

28. *Increased production in British and Belgian possessions in 1929.*—In 1929, the Belgian Congo mine of the Union Miniere du Haut Katanga, known as "Katanga", became the largest copper producer in the world. This is operated by English and Belgian capitalists. While Katanga's 1929 production was 151,000 short tons of copper, the Chile Copper Co. produced 149,788 short tons, the Utah Copper Co. 148,313 short tons, and the Anaconda Copper Co. 141,000 short tons. Or, together these four companies produced at least 30 percent of the world's output.

29. Katanga ore contains over 6 percent copper, Chilean ore 2.1 percent, while the copper content of the Utah copper ores is less than 1 percent. While Belgian Congo is distant from consuming markets, its production costs are said to be lower than in any other producing region. Production at these plants for the first 6 months of 1930 continued at 1929 levels.

30. Development of Rhodesian copper also increased during 1929, American capital having aided in such development. These ores contain from 3 to 6 percent copper. It is estimated by A. B. Parsons

for Metal & Mining Shares, Inc., New York, that by 1939 the production of this district can reach 500,000 tons of copper.

31. Canadian production increased 19.5 percent from 1928 to 1929 and in the first 6 months of 1930 it was 36.3 percent greater than in the first half of 1929. In these 6 months 78,763 tons were produced in the four Provinces of British Columbia, Ontario, Quebec, and Manitoba. The opening up of new mines, the establishment of concentration plants and refineries presages the entrance of Canada into the world market as an important producer of copper.

32. *Production curtailment for 1931.*—As has been stated, while the large American producers were attempting to maintain the $0.18 price by curtailing their own production, small American producers and the new Canadian, English, and Belgian companies were increasing their production. The tumbling of copper prices immediately upon the withdrawal of price restrictions, however, brought world copper interests to New York in November 1930. At these meetings 90 percent of the world copper production facilities were represented. It was agreed to reduce the world copper production during 1931 by 15 percent or about 20,000 tons a month in the hope that a balance between demand and production would be achieved thereby.

33. *World consumption.*—Table II shows the relationship of consumption and smelter production in the several countries. While the United States produced 53.5 percent of the copper, it consumed 48.5 percent in 1928. Europe used 44.7 percent while smelting but 9 percent. Japan's consumption and production were approximate. South America produced 19.4 percent of the world's copper, all of which was exported. The Belgian Congo and Rhodesia produced 7.5 percent, almost all of which reached foreign markets. And at least two thirds of the Canadian production was exported.

34. The exports of the United States, as shown in table V, are chiefly of refined and fabricated copper. The largest markets for United States refined copper in the form of ingots and bars has been in Germany, France, Great Britain, Italy, Belgium, the Netherlands, and Canada. The manufactured products found good markets in Great Britain and Canada. The increased production of refined copper in Canada and in British- and Belgian-controlled plants in Africa will unquestionably claim the larger part of present United States copper export markets. The extent to which the United States market can be held by United States copper producers will depend in part on our copper reserves as compared with those in other countries and on the price at which our copper can profitably be marketed.

TABLE IV.—*Imports of copper into the United States in 1929, by country of origin* [1]

Country	Ores	Concentrates	Composition metal; copper chief value	Regulus; coarse metal and cement copper	Unrefined, black, blister, and converter	Refined copper	Old, and clippings	Copper manufactures
Total:								
Short tons	62,310	26,864	40	1,052	323,084	67,007	6,799	
Value	$15,358,271	$7,907,180	$12,064	$292,316	$104,306,141	$23,757,421	$1,823,464	$253,323
Belgium:								
Short tons	536				12		(2)	
Value	$94,584				$3,279		$60	$456
Belgian Congo:								
Short tons	132				27,546			
Value	$34,000				$9,032,538			
Canada:								
Short tons	27,422	2,917	3	109	66,260	340	5,697	
Value	$6,473,728	$588,408	$550	$27,350	$23,300,230	$120,748	$1,542,562	$7,486
Chile:								
Short tons	20,267	536			82,132	66,541	7	
Value	$4,968,972	$128,568			$28,220,576	$23,592,298	$1,558	
Cuba:								
Short tons	170	4,905					546	
Value	$51,422	$1,372,703					$146,805	$15
Finland:								
Short tons		556						
Value		$145,441						$202
France:								
Short tons	593				1,859	10	25	
Value	$153,586				$627,137	$2,347	$3,350	$29,235
Germany:								
Short tons	827	709	37	53	3,557	116	76	
Value	$243,917	$158,874	$11,386	$14,452	$1,092,756	$42,028	$21,913	$54,268
Italy:								
Short tons	119		(2)					
Value	$32,196		$12					$7,311
Japan:								
Short tons	(2)				1,408		(2)	
Value	$11				$342,302		$138	$3,507
Mexico:								
Short tons	724	14,955		445	69,087		74	
Value	$226,550	$4,843,306		$109,016	$20,612,066		$17,747	
Mozambique:								
Short tons	(2)	1		26	3,902			
Value	$225	$435		$6,353	$1,357,926			
Norway:								
Short tons		2,165		382				
Value		$638,145		$122,160				$778
Peru:								
Short tons	3,503	25		37	58,886		14	
Value	$960,819	$5,356		$12,985	$16,954,503		$3,466	
Spain:								
Short tons	7,317				1,123			
Value	$1,909,510				$332,839			$481
United Kingdom:								
Short tons	510	5	(2)		7,218		5	
Value	$153,172	$990	$116		$2,399,328		$1,671	$111,744
All others:								
Short tons	190	90			94		355	
Value	$55,579	$24,954			$30,661		$84,194	$37,810

[1] Compiled from unpublished reports, Bureau of Foreign and Domestic Commerce, Department of Commerce.

[2] Less than 1 ton.

TABLE V.—*Exports of copper from the United States in 1929 by country of destination* [1]

Country	Ores, concentrates, composition metal, and unrefined copper	Refined copper (ingots, bars, and other forms)	Old and scrap copper	Pipes and tubes	Plates and sheets	Rods	Wire	Insulated wire and cable	Other manufactures
Total:									
Short tons	2,790	411,227	18,818	1,723	3,161	40,544	8,434	12,540	
Value	$935,604	$148,435,789	$5,675,750	$967,462	$1,576,383	$14,584,737	$3,332,229	$6,176,455	$1,720,363
Argentina:									
Short tons	14	355	28	24	23	(2)	1,552	960	
Value	$3,291	$141,972	$9,184	$14,315	$13,909	$216	$605,747	$406,602	$67,482
Belgium:									
Short tons		22,875	308			1,267	(2)	18	
Value		$8,372,776	$75,917			$462,766	$550	$17,922	$81,094
Brazil:									
Short tons		1,122		49	60	4,908	133	722	
Value		$429,532		$26,878	$33,422	$1,779,444	$61,362	$307,564	$51,042
British India:									
Short tons		2,022	79	16	7	45	177	225	
Value		$624,679	$27,906	$10,116	$5,108	$15,491	$73,046	$77,015	$28,775
Canada:									
Short tons	299	19,346	2,231	1,285	1,554	11,086	870	1,521	
Value	$54,109	$6,798,371	$748,312	$705,719	$826,142	$4,033,817	$355,988	$1,032,226	$657,402
Chili:									
Short tons		49		4	43	3	634	1,115	
Value		$23,406		$2,693	$22,559	$1,396	$208,184	$445,208	$25,950
China:									
Short tons		2,802	27	3	9		298	192	
Value		$973,986	$8,900	$4,337	$6,586		$115,285	$94,950	$33,830
Colombia:									
Short tons		18		2	12	6	383	598	
Value		$8,168		$1,162	$6,707	$2,933	$154,619	$262,699	$28,354
Cuba:									
Short tons		1,936	4	145	67	9	764	1,270	
Value		$649,674	$1,135	$82,316	$40,286	$4,398	$313,407	$534,752	$68,610
France:									
Short tons		87,632	1,327	(2)		1,250	24	66	
Value		$32,053,395	$369,914	$436		$448,174	$11,231	$65,285	$56,628
Germany:									
Short tons	188	89,439	9,595	(2)	336	37	305	6	
Value	$50,082	$31,651,754	$2,915,496	$140	$117,098	$12,472	$107,882	$4,575	$63,197
Italy:									
Short tons		42,246	139		326	157	341	616	
Value		$15,145,361	$38,678		$118,910	$66,591	$137,981	$252,896	$4,692

Japan:									
Short tons		3,977	2,065	2	2	23	93	89	
Value		$1,596,178	$633,929	$904	$1,890	$7,583	$34,478	$69,789	$13,101
Mexico:									
Short tons	(2)	745		54	47	5	662	1,204	
Value	$35	$278,551		$33,197	$28,490	$2,912	$270,923	$528,381	$66,775
Netherlands:									
Short tons	17	16,267	1,480	3	56	2,718	31	52	
Value	$6,119	$5,787,069	$436,445	$2,066	$19,600	$1,004,433	$8,419	$45,515	$1,825
Norway:									
Short tons		683	13	3		1,287	8	11	
Value		$248,039	$3,020	$3,383		$485,426	$4,568	$7,440	$13,093
United Kingdom:									
Short tons	2,268	87,725	979	6	435	15,857	525	749	
Value	$821,102	$31,772,608	$274,034	$4,345	$234,805	$5,527,541	$202,998	$558,541	$232,440
Venezuela:									
Short tons		(2)		5	17	5	132	341	
Value		$75		$2,650	$9,336	$2,824	$53,670	$145,628	$23,120
All others:									
Short tons	4	31,988	543	122	167	1,881	1,502	2,785	
Value	$866	$11,879,995	$132,880	$72,805	$91,535	$726,320	$611,891	$1,319,467	$282,953

[1] Compiled from unpublished reports, Bureau of Foreign and Domestic Commerce, Department of Commerce.
[2] Less than 1 ton.

World Copper Reserves

35. Definite figures are not available concerning the world's copper reserves. Copper is widely scattered and material that one generation regards as commercially valueless becomes very useful at a later time when demands for copper develop new methods of securing the once discarded ore. Large producing mining companies explore their territory from time to time and give out statements concerning ore reserves. In spite of the large amounts that have been mined, ore reserves are constantly increasing.

36. *Reserves in the United States.*—The extent and relative value of the reserves in the United States are better known than in other copper countries, largely because development has been greater in this country. The figures given on table VI must be considered tentative, however, even for the districts listed as further exploration or new methods of copper recovery may cause adjustments in these figures. With few exceptions, the large mass of copper ore remaining contains less than 2 percent of the metal. Sulphide copper ore prevails. This is often found mixed with iron pyrite. Quantities of oxide and mixed oxide and sulphide ores are found chiefly in the Globe, Ajo, and Ray districts of Arizona and in the Santa Rita district of New Mexico.

37. *Arizona.*—The largest known copper reserves in the United States are in Arizona. The Bisbee district, located near the Mexican border, has some reserves with copper content as high as 4 percent, although by far the larger amount is believed to have a copper content of 1.6 percent. The copper ores in this district vary. The primary ores consist of chalcopyrite and bornite ores, containing both sulphur and iron as well as copper, in faults and fissures in limestone porphyry. There are also large bodies of disseminated ore in which chalcocite ore (copper and sulphur), are found in siliceous gangue.

38. The Globe-Miami district has about 200,000,000 tons of known reserve containing from less than 1 to 1.4 percent copper. These ores are varied in the Globe area. They are largely oxide although much sulphide ore is found. In the Miami area the disseminated ores are usually chalcocite and chalcopyrite.

39. The Morenci-Metcalf district is known to have about 233,000,000 tons of copper reserves containing 1.2 percent copper. The main ore body is chalcocite. In the Jerome district there is a small body of rich chalcocite ore. Other ores are chiefly chalcopyrite. The Ajo district has 113,000,000 tons of ore containing 1.25 percent copper. These are carbonate and sulphide ores, the carbonate ores being azurite ($2CuCO_3,Cu(HO)_2$). The Ray district has both oxidized and sulphide ores.

40. *California.*—In Plumas County there are reported to be about 550,000 tons of copper ore containing 2 percent copper. The principal minerals are bornite (Cu_3FeS_3) and chalcopyrite (CuS, Fe_2S_3). The minerals occur in interlacing networks of small veins, as lumps of ore, and as disseminations. In Shasta County about 12,000,000 tons of chalcopyrite and other sulphide ores are reported. These ores vary in copper content from 0.7 to 3.5 percent. In the Foothill district ores are of pyrite and chalcopyrite.

41. *Colorado.*—Colorado has copper but it is usually combined with other minerals and recovered as a byproduct of lead-zinc reduction.

TABLE VI.—*Copper reserves reported by some producers in the United States*[1]

State	District	Mine owner	Copper reserves	Copper content	Year of report
			Short tons	*Percent*	
Arizona	Bisbee	Calumet and Arizona Mining Co	1,829,546	4.15	1925
	do	Phelps Dodge Corp.: Copper Queen Mine.	23,500,000	1.63	1930
	Morenci-Metcalf	Phelps Dodge Corp.: Morenci Mine	233,000,000	1.20	1930
	Globe-Miami	Inspiration Consolidated Copper Co	96,010,935	1.40	1926
		Miami Copper Co	97,391,980	.95	1929
	Jerome	United Verde Extension	625,000	7.50	1929
	Ajo	New Cornelia Copper Co	113,262,128	1.25	1929
California	Plumas County	Engels Copper Co	556,837	2.00	1928
	Shasta County	Island Mountain Copper Co	275,000	3.50	1926
		Mountain Copper Co	5,000,000	.70	1926
		California Zinc Corp	3,000,000	3.00	1926
		Mason Valley Mines Co. (lessee):			
		Balaklala Mine	3,000,000	2.70	1926
		Rising Star Mine	300,000	2.00	1926
		Greenhorn	250,000	3.00	1926
		Mammoth Copper Co	125,000	3.00	1926
Michigan	Lake Superior	Calumet and Hecla, Consolidated	168,143,000	1.20	1925
Nevada	Ely	Nevada Consolidated Copper Co.[2]	273,500,000	1.47	1929
		Consolidated Coppermines	30,000,000	1.10	1929
New Mexico	Burro Mountain	Phelps Dodge Corp	11,725,000	1.95	1930
Tennessee	Ducktown	Tennessee Copper Co	5,779,559	(3)	1929
Utah	Bingham	Utah Copper Co	640,000,000	1.07	1929
		Ohio Copper Co	36,000,000	.3	1923
		Ohio Copper Co. (tailing dump)	4,995,459	.475	1928

[1] Compiled from U.S. Bureau of Mines, Copper in 1928; Mineral Industry, vols. XXXVII and XXXVIII; and reports of State mineralogists.
[2] Includes reserves at Ray, Ariz., and Chino, N.Mex.
[3] Not reported.

42. *Idaho.*—The Couer d'Alene District has disseminated bornite, chalcocite, and chalcopyrite. The Mackay District has primary pyrite ore in siliceous gangue. It is believed that a number of undeveloped mines exist.[40]

43. *Michigan.*—The largest company in Michigan estimates its copper ore reserves to be about 168,000,000 tons containing 1.2 percent copper. This ore is almost entirely native copper found in enormous masses in vein deposits, as cement material, or disseminated through other rock. Because such ore is not combined with other materials it requires far less treatment than any other copper ore. Original mining in Michigan recovered only the ore of high copper content. For some years the accumulated waste piles have been worked over and yield as much, if not more copper, than the existing deposits.

44. *Montana.*—No figures are available concerning the copper reserves in the Butte District. The ores are chiefly chalcopyrite and chalcocite, bornite, and other compounds of copper, iron, and sulphur. These occur in granitic rock and all mining is underground. Silver and zinc occur in some of these deposits.

45. *Nevada.*—The Ely District of Nevada is reported to have over 300,000,000 tons of copper reserves yielding 1.1 to 1.5 percent copper. The deposits are chiefly sulphide porphyry ores.

46. *New Mexico.*—One company in the Burro Mountain District claims reserves of 12,000,000 tons, having 2 percent copper content. They are principally chalcocite found in porphyry and in granite. In the Santa Rita District some native ore is found and much oxide ore, although chalcocite ores are also abundant.

[40] U.S. Geological Survey. Copper in 1915, p. 693.

47. *Oregon.*—Copper lodes are among the more promising of the mineral deposits in western Oregon although they are small compared with the large copper deposits in other States. The copper belt extends from Riddle southward to the California line and it includes the Galice, Kerby, and Takilma districts. The ores contain some native copper but are chiefly chalcopyrite, bornite, and other sulphide copper ores, usually containing some gold and precious metals. Mines near Baker will be operated by the Oregon Copper Co.

48. *North Carolina.*—Small amounts of low grade sulphide ores are found in one locality.

49. *Tennessee.*—At Ducktown, Tenn., there is still believed to be about 6,000,000 tons of pyritic ore. Because of its large sulphur content, sulphuric acid recovery has become one of the major products of the copper smelter.

50. *Utah.*—The Utah Copper Co. estimates its reserves at 640,000,000 tons containing a little more than 1 percent copper. These ores are pyrite and chalcopyrite disseminated through altered porphyry and quartzite. Some copper is also recovered in the Tintic district as a byproduct of lead mining.

51. *Vermont.*—Copper mines worked in colonial times were reopened in 1929.

52. *Washington.*—Snohomish and Stevens Counties produce small amounts of copper and some is recovered in the course of gold and silver extraction. An electrolytic plant will be established near Twisp to leach and precipitate gold and copper.

53. *Wyoming.*—Largest deposits are in the Encampment district. They are chalcocite and chalcopyrite.

54. *Alaska.*—Copper is found in three districts, the Copper River district being the largest. Although exploration work has been carried on extensively, new ore bodies have not been discovered.

CENTRAL AMERICA

55. *Mexico and Lower California.*—The most important copper producing area in Mexico lies near the Arizona border in the Sonora district. The Boleo mines in Lower California have been worked since 1887. It is believed that other copper ore bodies exist but thorough prospecting has not taken place. The Green Cananea mine in the Sonora district is owned by the Anaconda Copper Co., while the Moctezuma mine belongs to the Phelps Dodge Corporation. This mine was reported to have a reserve of 3,500,000 tons containing 2.7 percent copper.

56. *Cuba.*—Cuba has produced some copper for more than a century. At Pinar del Rio there is an estimated reserve of 1,000,000 tons copper ore averaging 5 percent copper content.[41]

CANADA

57. Although copper was mined in Ontario, Canada, as early as 1867, it is only since 1914 that extensive prospecting has taken place throughout Canada and only in the last few years that the extensive developments are being brought into operation.

58. In the Anyox district of British Columbia, the Hidden Creek mine is believed to have almost 9,000,000 tons of copper ore carrying

[41] Engineering and Mining Journal. Feb. 8, 1930.

1.8 percent copper. Ore having the same content is available in large tonnage in the Copper Mountain, Bonanza, and Outsider mines.[42]

59. The Britannia mine (Howe Sound) is believed to have over 5,000,000 tons of copper ore containing 2 percent copper. The concentrate from this mine is smelted at Tacoma, Wash. The mines of the Granby Consolidated Ltd., contain over 14,000,000 tons of 1.8 percent copper.[43]

60. The mining deposits in the Pas mining district in western Manitoba and eastern Saskatchewan were discovered in 1915. This deposit ranks rather high in copper content ranging from 3 to 5 percent.[44]

61. The Flin Flon Mine in western Manitoba, operated by the Hudson Bay Mining and Smelting Company, Ltd., by hydroelectric power from the power site of Iron Falls, claims a deposit of 18,000,000 tons having 1.4 percent copper content and 3 or 4 percent zinc content together with some gold and silver.[45]

62. The Sherritt Gordon Mine Co., prospecting in the neighborhood of the Flin Flon Mine, revealed deposits of over 5,000,000 tons having copper content reaching 2.9 percent.

63. The International Nickel Co. and the Mond Nickel Co. have always secured some copper in the mining of nickel ore. The copper of the Sudbury district of Ontario has been shipped to Carteret, N.J., for refining. A new refinery is being built by the American Metals Co., Ltd., at Copper Cliff, Ontario, having an initial capacity of 120,000 tons of copper per year. The operating company will be known as the Ontario Refining Co.[46]

64. In western Quebec in the Rouyn district shafts were sunk in 1924 and rich copper and gold ore beds are being located. The Noranda mine reports an ore reserve of 3,426,000 tons of 7.5 percent, and 3,000,000 tons of 2 percent copper. The entire district is being developed.[47]

SOUTH AMERICA

65. South America has been a copper producing country for many years, the largest production coming from Chile at this time. There are three large producing mines in Chile: The Chuquicamata mines of the Chile Copper Co., owned by the Anaconda Copper Co. whose reserves were estimated, in December 1922, to be 600,000,000 tons carrying a 2.1 percent copper content; the Andes Copper Co., also owned by the Anaconda Copper Co., estimated, in December 1924, to have over 100,000,000 tons with 1.5 percent copper content; and the Braden Copper Co. owned by the Kennecott Corporation having over 200,000,000 tons of 2.2 percent copper.[48]

66. Copper has been mined in Peru, Bolivia, Argentina, and Venezuela but the prospecting has not been sufficient to indicate how extensive the copper deposits are.

---

[42] Canada. Geology, Mines and Metallurgical Industries, p. 209. (1927).
[43] Mineral Industry. 1929, pp. 123, 148.
[44] Canada. Geology, Mines and Metallurgical Industries, p. 137 (1927).
[45] Mineral Industry, 1929, pp. 150, 158.
[46] Mineral Industry. 1929, pp. 150-151; 152.
[47] Annual Report for 1929. Noranda Mine, Ltd.
[48] Mineral Industry. 1929, p. 123.

EUROPE

67. In southwestern Spain and eastern Portugal copper has been worked for several centuries. An English company took over the principal producing mines in 1922 at which time it was stated that the reserves were sufficient to maintain normal production for 50 years. Normal production seems to range between 40,000 and 60,000 tons of copper.

68. Only small amounts of copper are found in Germany, Bohemia, Rumania, northern Italy, and Sardinia.

69. The Soviet Government of Russia is inviting capital to aid in the development of Russia's copper deposits. Some copper has been mined in different sections for many years. Just how extensive the deposits are is not known, although there is reason to believe that ore of high copper content will be found in a number of regions.[49]

ASIA

70. Japan has been a steady producer for a number of years. Copper is distributed generally throughout the Empire and is worked in sufficient quantity to meet the demands of this country.

71. It is generally believed that low-grade deposits of copper will be found in China, but almost no work has been done in this country.

72. The Indian Copper Corporation has begun developing copper in India. The extent of the deposits are not known.

AFRICA

73. *Belgian Congo.*—The Katanga district in Belgian Congo is believed to be one of the richest areas for base metals in the world. It is only since transportation facilities have been perfected so that labor can be brought into these sections and minerals transported from them that copper production has made extensive headway. At the end of 1928 it was stated that there were 78,000,000 tons containing between 6 and 8 percent copper available. By 1930 the production of the mines of the Union Miniere du Haut Katanga had exceeded all other mines in the world. Lump ore containing 15 percent copper is smelted. Mixed fine and lump ore containing 6 to 14 percent copper is concentrated. Ore containing less than 6 percent copper is leached.

74. *Northern Rhodesia.*—Drilling and development work in northern Rhodesia has definitely established this section as one of the greatest copper belts in the world. While estimates are partly conjectural, it is believed that there are at least 600,000,000 tons of copper ore averaging 3.5 percent copper. The belief prevails that the total reserves far exceed this figure. The control of the development is in the hands of British capital, although some American capital has aided in the establishment of railroads, hydroelectric plants, and other facilities essential to bring the copper to market.[50]

75. *Australasia.*—It is believed that Australia has much copper and that the ore would be found in New South Wales, Queensland, and Tasmania. Production is occurring at several places, but prospecting has not been extensive. The Mount Lyell Mining & Railway Co.

[49] Economic Review of the Soviet Union. Nov. 15, 1929.
[50] Mineral Industry. 1929. pp. 163; 167.

completed an 8,000-ton electrolytic copper refinery in 1928. The company believes it has 500,000 tons of copper ore in its Comstock mine, ore containing 3.75 percent copper.

COPPER ORE REDUCTION PROCESSES

76. Just as conditions within the ore body determine mining methods, so physical characteristics of copper ores dictate ore-reduction processes. Three major reduction processes have been developed—flotation, leaching and electrolysis, and direct smelting. Differences in chemicals used or in mechanical equipment occur with each process. The process details described in the following pages are those in more frequent use in this country.

ORE LEACHING

77. Leaching or dissolving ores from impurities is a process which may be carried on by several methods.

78. *Leaching in place.*—At the Ohio Copper Co.'s mines in Utah from 1,200 to 1,500 gallons of water and launder tailings per minute are passed through mined-over sections estimated to contain 0.3 percent copper. These waters percolate through the caved ores, decomposing the sulphide ore and forming soluble copper sulphates. This solution is collected at the bottom of the shaft, from which it goes to precipitation launders.

79. *Heap leaching.*—At the famous Rio Tinto mines in Spain, ores low in copper are removed from the mine and heaped up on prepared ground having a slight slope. Fresh water and waste liquor from which copper has been precipitated are directed over the pile. After saturation the ore is permitted to dry in the sun, thus causing gradual natural oxidation. At the next saturation the oxidized copper is carried off in the drainage which collects at a controlled point. As this process results in a 60 percent extraction of copper in the first 3 years and an 80 to 85 percent extraction in 7 to 9 years, it is very slow unless very large quantities of low-grade ore are available. The Utah Copper Co. is using heap leaching on its vast accumulated ore dumps.

CONFINED LEACHING

80. Confined leaching, or leaching in tanks, is practiced on oxide and mixed ores by the New Cornelia Co. of Ajo, Ariz., the Inspiration Consolidated Copper Co., of Inspiration, Ariz., and by other companies for the extraction of copper from mill tailings.

81. Copper ore is crushed first in gyratory and later in intermediate and in fine disk crushers. The size to which the ore is crushed depends upon the character of the mineral grain. When copper occurs along fissures or natural cleavage lines, as it does at the New Cornelia mine, it is reduced to 3-mesh size. Richer material requires finer crushing. At the Inspiration plant, rollers are used to reduce the ore to three eighths inch after disk crushing and screening.

82. Oxide ores are ready for the leaching process immediately after crushing, but sulphide or mixed ores must be converted to copper oxides. This oxidation takes place when ores are subjected to a roasting, which also makes some impurities less soluble.

83. Leaching tanks are usually of concrete lined with lead The filter floor over the tank bottom is sometimes a plank bored with ⅜-inch holes for upward percolation. The tanks are arranged in series. While one tank is being filled, others are under acid contact, others are being washed, and one is being excavated.

84. The reagent most frequently used to dissolve copper from its ores is sulphuric acid. In very dilute solutions it reacts with copper in preference to other minerals in the ore. As it is frequently a by-product of copper smelting, it is also cheap. At the inspiration plant and at the New Cornelia plant, ferric sulphate produced in the electrolyte is combined with sulphuric acid. Some ores, however, contain materials that require other reagents. Ammonia and ammonium carbonate are used to leach tailings at the Calumet and Hecla mines in Michigan and at the Kennecott Copper Corporation of Alaska. Ferric chloride and nitric acid may also be used.

85. The ore is charged into the tanks by a spreader bridge. The leaching solution is percolated upward or downward and circulated through the tanks by motor-driven pumps. The strongest solution from the tank house enters the oldest ore under acid contact, and a fourth of the solution is advanced from tank to tank each minute. Leaching requires 8 to 16 hours, dependent upon the strength of the acid solution. The oldest tank under contact is drained first. The treated ore is then washed with a number of wash waters from preceding washing cycles to remove entrained copper solution. The solutions are clarified by settling and decantation, and prepared for the type of precipitation they are to undergo. The remaining tailings are lifted from the tank by an excavator bridge.

PRECIPITATION BY ELECTROLYSIS

86. The purest copper is produced through precipitation by electrolysis. After excessive ferric iron, if present, has been reduced from the copper solution by passing through roasters, dust and spray chambers, and reduction towers, and the copper solution emerges clean from a second set of settling tanks, it is mixed with sulphuric acid to form the electrolyte to be pumped into electrolytic tanks. Starting sheets are built up on blanks of antimonial lead or of rolled copper.[51] They weigh about 18 pounds and form the cathodes in the electrolytic tank. Anodes of antimonial lead or an alloy of copper, lead, and silicon, with porcelain insulation, are suspended in the tank by copper bars secured to them. They usually weigh about 215 pounds when new and are used for 13 years. The cathodes are suspended upon copper bars by loops. The tank itself is of pine lined with soft lead or may be of reinforced concrete lined with asphalt. Outlet and inlet pipes are usually of porcelain.

87. Electrolytic tanks are arranged in banks, each tank having about 84 cathodes and 85 anodes placed perpendicular to the direction of the solution flow. By passing electric current through the electrolyte, the copper in solution is removed and deposited on the cathodes. The electrolyte is circulated from tank to tank by a centrifugal pump. Cathodes when finished weigh from 100 pounds to 140 pounds and contain from 99.15 percent to 99.85 percent copper. They are removed from the electrolytic tanks and submerged in hot water in wash

[51] For further description see p. 223.

tanks to remove soluble copper or salts. Without further treatment these copper cathodes are ready to be melted and cast into marketable shapes.

88. *Power equipment at Ajo.*—At the New Cornelia plant at Ajo, Ariz., oil fuel is transported and used in 10 Stirling boilers which supply steam at 250 pounds pressure for three 7,500-kilowatt alternating-current turbine units. Two of these operate at 1,800 revolutions per minute and one at 3,600 revolutions per minute. The direct current for electrolytic precipitation is supplied by four double-end motor-generator sets. Each set consists of a 2,400-horsepower synchronous motor connected to two 170-volt, 5,000-ampere, direct-current generators. This gives two circuits of 20,000 amperes maximum.[52] The average kilowatt-hour of power obtained during 1929 per barrel of fuel oil was 290.4.[53]

89. The electrolytic tanks are arranged in 12 banks of 10 tanks each and 4 banks of 8 tanks each. The maximum anode capacity of the tank house is 12,768 anodes, and the maximum cathode capacity is 9,779 cathodes, exclusive of starting sheet blanks. The highest current density used amounts to 8 amperes per square foot with 84 anodes per tank, while the average current density is 5.35 amperes per square foot.

90. The ampere efficiency with this current density is approximately 75 percent and the cathodes are built up at a rate of about 10 pounds per day. The direct current consumed per ton of copper produced in 1928 was 2,588 kilowatt-hours. The gross consumption of power at this tank house during 1928 was 22,115,300 kilowatt-hours. The percent of copper extracted from the ore by electrolysis was 67 percent, by iron precipitation 8 percent, or a total extraction of 75 percent.

91. *Power equipment at Inspiration.*—At the Inspiration electrolytic reduction plant the generating equipment consists of 3 units, each having 2 generators with a capacity of 6,000 amperes at 320 volts, making a total generating capacity of 36,000 amperes at 320 volts. In the tank house there are 8 banks of 15 tanks, each tank having 84 cathodes and 85 anodes, or a capacity of 10,080 commercial cathodes and 10,200 lead anodes. As the amount of copper dissolved from the ore varies considerably, current density is varied to meet this condition. During 3 months in the spring of 1928 it averaged 11.4 amperes. The voltage varied from 2.22 to 2.32 per bank, and the ampere efficiency ranged from 71.84 to 54.74 percent from first to eighth bank. The average kilowatt-hour alternating current consumed per ton of copper produced during this period was 3,000 kilowatt-hours. The gross direct current consumption at the tank house has amounted to 40,733,506 kilowatt-hours, the gross alternating current to the substation, 45,731,074 kilowatt-hours per year for the previous 3 years.

92. *South American plants.*—At the Chile Copper Co. at Chuquicamata where a steam-power plant was built 140 miles from the plants and where almost all operations are electrical, 83 percent of all power generated is used for the electrolytic process. One short ton of copper requires 2,350 kilowatt-hours of energy at this modern plant.

[52] U.S. Bureau of Mines: Information Circular 6303.
[53] Young, George J. Engineering and Mining Journal. July 10, 1930.

The Andes Copper Co. at Potrerillos, Chile, receives the current for its electrolytic plant from four motor-generator sets consisting of a motor between two generators. Each of the eight generators has a capacity of 3,750 amperes at 425 volts. There are three circuits, each containing 576 commercial cells divided into three divisions connected in series. The current density averaged 13 amperes per square foot. The plant had an ampere efficiency of slightly over 90 percent and used about 1,700 kilowatt-hours of energy per ton of copper produced.

93. At the Chuquicamata plant 90,000 horsepower is required and at the Potrerillos plant, 15,000 horsepower.[54]

94. *Iron precipitation.*—Leached copper ores too high in impurities for electrodeposition may be precipitated by metallic iron. Ferric salts in the ore must first be reduced. One and a half to two pounds of scrap or, more preferably, sponge iron, are used per pound of copper produced. A sulphate or chloride copper solution is usually cascaded over the scrap iron in a series of launders, or if sponge iron is used, the solution may be kept in active agitation through the iron. The iron is dissolved and the metallic copper is precipitated. After standin a settling tank, the solution is again passed over the iron. Cement copper, as the copper precipitated by this method is called, after washing and drying, contains 75 to 80 percent copper, and must pass through pyrometallurgical processes before it is ready for refining. Both electrolytic ore-reduction plants in this country precipitate some cement copper from wash washers.

95. *Other precipitation processes.*—Sulphur dioxide is used to saturate a copper and ferrous sulphate solution. When this is heated under pressure, about 60 percent of the copper is precipitated and sulphuric acid is freed. Hydrogen sulphide, produced by the reaction of sulphuric acid on low-grade copper matte, precipitates copper as cupric sulphide when applied to a copper chloride or sulphate solution. The process is not being applied at the present date.

96. *Concentration by flotation.*—Flotation is the principal method of sulphide copper-ore reduction today. It is based on the tendency of certain chemicals to adhere to mineral surfaces while refusing to adhere to other substances, making it possible, by the introduction of air bubbles, to float off valuable minerals. A few years ago flotation developed only one concentrate, but today differential flotation causes some of the normally floating minerals to drop with the gangue, while selective flotation recovers each mineral in the order of its floatability.

97. Before copper ore reaches the flotation cells it is crushed and ground by a series of crushers, rolls, and ball mills. Dorr bowl classifiers are usually employed after rolling to remove primary slime, leaving the heavy sulphides for additional grinding. Drag classifiers are in closed circuit with cylindrical ball mills. The fineness to which the ore is ground varies with the character of the ore. When pyrite is mixed with chalcopyrite or chalcocite, grinding is carried to a point where the major portion of pyrite is freed from the sulphide.

98. The pulp from the classifier overflow is usually piped to the flotation machine. The type of machine used varies with the character of the ore. In one type each machine has a number of cells,

[54] Billinger, H. C. (vice president Chile Copper Co.). Mining the World's Largest Copper Ore Deposit. Engineering and Mining Journal. Vol. 128. Aug. 21, 1920.

12 for roughing, 3 for cleaning, and 2 for recleaning. Air is supplied through a shiplap bottom at a pressure of 5½ pounds from motor-driven blowers. These blowers require 2 kilowatt-hours of power per ton of ore treated.

99. Another type of flotation machine in use admits air to the cells through a number of small pipes led down into the pulp from an air main extending along the top of the cell.

100. When pyrite is found with copper sulphide ores, it is customary to add dry lime to the ball-mill feed at the rate of 5 pounds per ton of ore. Potassium xanthate or other chemicals are added to the solutions before they enter the roughing cells. Pine oil is added at various points in the flotation circuit, as the frothing agent. The lime conditioning renders the copper sulphide ores more floatable than pyrite, because the lime acts as a pyrite depressant when in the presence of xanthate. This not only increases the copper recovery through flotation but lessens the demands on roasters, as the amount of sulphur sent to the roasters has been materially decreased.

101. Usually the concentrates from the first three cells of the rougher are finished product and go directly to thickeners. The concentrates from the other roughers are cleaned and recleaned before going to thickeners. After about 70 percent solids are obtained in the thickener, the concentrate enters drum filters, where compressed air agitates it. When completely dewatered the concentrate is ready for roasting.

102. *Power consumption.*—Power consumption in concentrator plants varies from 11 kilowatt-hours to 16.33 kilowatt-hours per ton of dry ore concentrated. The larger proportion of this is consumed in the fine grinding. Power-consumption details for the plants giving lowest and highest consumption, both treating about 8,000 tons ore per day and recovering 90 percent of the copper, are as follows:

Operation	Kilowatt-hours' consumption per ton dry ore concentrated	
	Plant A	Plant B
Conveying and feeding	0.486	
Coarse crushing	9.801	0.45
Fine crushing, roll circuit		3.25
Fine grinding, ball-mill circuit		4.03
Flotation	3.310	1.87
32-ounce air	.946	
Dewatering and filtering	.865	.25
Primary and recovered water	.155	1.17
Lighting and other incidental equipment	.771	.11
Total	16.334	11.13

103. As concentrators are usually located close to smelters, a part of the power used at some concentrators is developed from waste gas recovered from reverberatory furnaces. The remaining power was either purchased or obtained from oil-operating diesel engines. One plant reports the oil-engine power cost at about $0.009 per kilowatt-hour.

104. Labor required for operation and repairs ranged from 25 dry tons to 39 dry tons of ore per man shift.

105. *Materials consumed.*—Reagent consumption varied widely. Lime ranged from 1 pound to 9½ pounds per ton of dry ore; sodium and potassium xanthate from 0.06 pound to 0.16 pound; pine oil from 0.13 pound to 0.09 pound. Some firms also used a little calcium cyanide or sodium aerofloat. The principal supplies consisted of grinding balls, averaging approximately 2 pounds per ton of dry ore ground, steel lining, pump parts, and flotation impellers.

106. *Direct smelting.*—Lumps of native copper found in Michigan mines, or rich, coarse ores of high copper content are crushed in steam stamps. Jigs and Wilfley tables are used where concentration is desired. The "mass" copper and concentrates, together with black oxide obtained from leaching dumps, are fed to reverberatory furnaces fired with powdered coal. Differences in specific gravity cause the metallic copper to separate from the gangue. The gangue is skimmed off and the resulting "black copper" is ready for refining. Refining may be done in the same reverberatory furnace or by remelting in a second furnace.

107. *Sulphide ore smelting.*—The smelting of copper sulphide concentrates is not as simple as the smelting of native copper ores. The flotation concentrate is fed automatically to the top hearth of roasting furnaces having seven or more hearths and water-cooled arms. These plowlike arms move the concentrate from center to circumference of the top hearth of the cylindrical roaster from which it drops through openings to the hearth below where the plows carry it to the center and the process is repeated. Hot gases pass through the concentrate from these lower hearths where, due to the amount of iron pyrite in the ore, the concentrates are roasting in their own heat. Sometimes a small quantity of fuel oil will be used to maintain the temperature. The ore passing out of these roasting furnaces today has but 18 percent sulphur content as compared with the 29 percent or 32 percent in the concentrate, a reduction made possible by differential flotation.[55]

108. From the roasting furnaces the ore goes to reverberatory smelters where it is heated by powdered coal sprayed upon the hearth. The slag flows out of the furnace continuously into a stream of cold water; the waste gases are utilized in boilers which produce steam to furnish part of power for plant operation; while the matte, made up of copper sulphide with some iron sulphide, is tapped from the furnace, runs through launders lined with siliceous material, and is taken to the converters by mechanical cranes.

109. Blast furnaces were once operated for smelting but now either have been dismantled in this country or are used only in peak loads. Because of the lowered sulphur content of concentrates due to differential flotation, some smelters are dispensing with concentrate roasting and are sending the concentrate directly to reverberatory furnaces.

110. Both matte and some raw ore are admitted to the converter. Compressed air, passed through the matte, releases sulphur dioxide and causes the iron oxide to join the raw ore to form iron slag. The blowing is continued until all suphur is burned out and the metallic copper, with a few other valuable metals, sinks to the bottom of the furnace. No external heat is required as the heat of oxidation keeps the ore in molten condition. This copper is called "blister copper." After casting into suitable shapes it is ready for shipment to refineries.

[55] Bender, Louis V. Engineering and Mining Journal, 128, 301. (1929).

111. In the last few years several smelters are carrying the smelting one step further, that is, instead of shipping the copper as blister copper to the refinery where it had to pass through a preliminary fire refining before entering the electrolytic bath, this fire refining work is done at the smelter and the copper is shipped as anode copper. This final fire refining consists of an oxidizing fusion to volatilize and oxidize remaining impurities. Producer gas, oil, or pulverized coal is used as fuel. As the copper becomes saturated with oxygen, this must be eliminated before the copper is cast into anodes.

112. The power generated at a smelting plant produces air for converters and heat for the buildings and power for mechanical operations.

113. *Electric furnace smelting.*—Prior to 1915, the United States Bureau of Mines conducted experiments on the electric smelting of native copper concentrates and sulphide copper ores. The conclusions reached are stated as follows: "The electric smelting of copper ores is nothing more than the substitution of electric heat for heat derived from the combustion of carbon. Inasmuch as carbon which is used in the reverberating furnace or in the blast furnace plays no important part in the reactions that take place in these furnaces, there is no reason, metallurgically, why electric heat may not be substituted for the heat derived from the combustion of carbon."

114. The power consumed in these experiments varied greatly. The scientists determined, however, that on the basis of 70-percent efficiency, a 750-kilowatt furnace smelting native copper concentrates containing 25 to 40 percent copper would require 564 kilowatt-hours energy per ton of charge smelted while a much larger furnace working on sulphide copper ores would consume 480 kilowatt-hours per ton of charge smelted.[56]

115. As far as is known, electric smelting has not been adopted in this country although the Consolidated Copper Co., at Trail, British Columbia, is experimenting with it and the Evergreen Mines Co. at Apex, Colo., has carried on successful tests with the idea of applying it to small mines where cheap power was attainable and ore transportation inexpensive.

FLOTATION, LEACHING, ELECTROLYSIS

116. One copper company in Arizona is employing flotation, leaching, and electrolysis on its ores. The ore is primary chalcopyrite in a slightly basic porphyry with chalcocite as a secondary enrichment, the copper content averaging 1.25 percent. Jaw crushers, ball mills, and Dorr classifiers are employed before the pulp reaches the rougher and cleaner flotation cells. The resulting concentrate has about 33.5 percent copper. This is roasted in a multiple-hearth roaster to reduce the sulphur content and to completely oxidize the charge so as to render the copper soluble and the iron insoluble. The roasted concentrate is agitated with hot sulphuric acid in agitator tanks. As the resulting electrolyte enters the electroylytic unit it contains about 55 grams copper per liter and 20 grams acid. In the pilot plant, power is supplied by a 180-horsepower diesel engine connected to a direct-current generator of 2,000 amperes capacity at 50 volts. The major electrolytic unit consists of 16 cells per section, each cell con-

[56] U.S. Bureau of Mines. Bulletin 81. "The Smelting of Copper Ores in the Electric Furnace," 1915.

taining 9 cathodes and 10 lead anodes. Twenty amperes per square foot were used when this high-copper electrolyte was pure. This resulted in a power consumption of 2,334 kilowatt-hours per ton. Where a current density of 13 amperes per square foot was used, the power consumption was 2,112 kilowatt-hours per ton.

117. This pilot plant was put in operation in April 1929. The superintendent believes that roasting is the key to the success of the process from a metallurgical viewpoint and that cheap power costs and large quantities of oxide ore that could be leached with the excess sulphuric acid produced will make it successful commercially.[57]

118. In Michigan, lake copper tailings of early operations are being recleaned by both leaching and flotation. At the largest plant, 80 percent of the material dredged is leached and 20 percent is treated by flotation.

Crude Copper Refining

119. Almost 93 percent of all primary copper refined in the United States in 1929 was refined electrolytically. "Lake" copper—or the output of Michigan furnace refineries—forms less than 7 percent of the total new refined copper, while casting copper—or blister copper furnace-refined and suitable for copper castings—forms less than 1 percent of the total primary copper. In refineries, 99 percent of the secondary copper—or material recovered from old copper, from copper scrap, and from copper alloys—is treated electrolytically. The remainder is marketed as copper casting.

120. *Furnace refining.*—The crude copper shipped from smelters to electrolytic refineries must first undergo the same type of furnace refining that lake copper is submited to after leaving the smelting furnace. If not already in molten condition, this blister or black copper is melted in reverberatory furnaces. A part of the impurities are volatilized and oxidized by compressed air. The cuprous oxide thus formed is reduced by the dry distillation of green poles forced under the surface of the molten charge. The molten copper is cast into anode molds by a casting machine if it is to be given electrolytic treatment or is cast into marketable shapes if it is to be marketed as "Lake" copper.

ELECTROLYTIC COPPER REFINING

121. In the electrolytic tank, direct current fed to these impure anodes dissolves the copper in the anode into an electrolyte of copper sulphate and sulphuric acid and deposits the dissolved copper on the cathodes. Precious metals in the anode are electronegative and so drop to the bottom of the tank, forming "anode slime." Other impurities are dissolved but remain in solution in the electrolyte or enter the anode slime.

122. There are two systems of electrolytic refining in use, the "multiple" and the "series" system, varying chiefly in the arrangement of the electrodes.

THE MULTIPLE SYSTEM

123. In the multiple system, the electrodes in each tank are connected in multiple and the tanks in series. The current is led to the

[57] Baroch, Charles T. "Hydrometallurgy of Copper at the Bagdad Property". Paper before the American Electrochemical Society, June 1, 1930.

first tank by a heavy busbar and after passing through the one row of tanks is carried by a heavy busbar to the second row of tanks. Each anode has its individual current supply, the amount being dependent upon the depositing surface and the current density per square foot. The cathodes consist of pure copper starting sheets suspended between the anodes.

124. *Starting-sheet production.*—Each refinery employing the multiple system has a section producing electrolytic starting sheets. Anodes of the purest copper are used as a copper source for starting sheets. Plates of rolled copper, coated with a mixture of graphite and oil or other lubricant, are suspended between anodes in the starting-sheet tank. Edges of the blank are protected so that copper will not be deposited on them. After the electric current has deposited the copper from the anode to the starting sheet for 24 hours, such blanks are removed from the tank by an electric crane to racks where the pure copper sheets are stripped from the blanks. Supporting loops of copper are riveted to these sheets and they are ready to form the cathodes of the electrolytic tanks. The blank is regreased to aid in stripping and goes back to the starting-sheet tank.

125. *The tank house.*—Electrolytic tanks employed in the multiple system were formerly of wood lined with 6 percent antimonial lead sheeting. Now reinforced lead-lined concrete tanks are coming into use.

126. The anodes and cathodes are accurately spaced upon a triangle bar running the length of the tank partition. Their number per tank varies from 27 anodes to 41 anodes. The electrolyte, composed of sulphuric acid with some copper and small amounts of impurities, is circulated through the tanks by centrifugal pumps. It is heated before entering the tank, to reduce the electrical resistance, by lead pipes through which steam passes. The electrolyte is purified continuously in order that the free acid content may be as high as possible and the sulphate content low.

127. Anodes weigh about 525 pounds and the starting sheets 8 pounds. After 10 days' deposition with an ampere efficiency of 93 percent and a current density of 18 amperes per square foot, cathodes will weigh 158 pounds. They are lifted from the tank by overhead cranes and taken to a wash box. After a hot wash the cathodes are melted and cast into commercial shapes. One anode of 525 pounds is used to produce three 158-pound cathodes. The remaining 75 pounds of anode is scrapped.

THE SERIES SYSTEM

128. In the series system starting sheets are not used. The current dissolves impure copper from one side of the anode and deposits pure copper on the back of the preceding anode. When cast anodes are used, the cathode side is sprayed with resinous soap emulsion to facilitate stripping and the cathode is considered built when about 8 percent of the anode remains. One hundred twenty-one bars are hung in a tank. When rolled anodes are used, two plates are put in wooden frames which are placed in the tank, 135 electrodes being hung in each tank. The rolled anode is almost completely dissolved as cathode and there is very little anode scrap. The current enters the first electrodes and passes through all electrodes in series.

129. The electrolyte and other factors are the same as in the multiple system. The tank, however, must have an insulating lining, such as asphalt, because of the high voltage used.

POWER CONSUMPTION

130. The amount of power required in the tank house is dependent chiefly upon the current density, on the resistivity of the electrolyte, and on the spacing between the electrodes. In the series system a current density of 16 amperes per square foot deposited 377 pounds of copper per 24 hours. With current density of 18 amperes, 340 pounds were deposited, or 141 kilowatt-hours of power were required to deposit 1 ton of copper. With the same current density, 233 kilowatt-hours were required in a plant employing the multiple system to deposit 1 ton of copper. When a density of 24.4 amperes was employed in the series system, only 271 pounds of copper was deposited, whereas a multiple-system plant using 26.4 amperes per square foot produced but 144 pounds of copper per kilowatt-day. Or at the higher current densities, about 180 kilowatt-hours were required per ton of copper deposited in the series system, and 533 kilowatt-hours power in the multiple system.[58]

131. All refineries equip their reverberatory furnaces with waste-heat boilers which supply a part of the heat and energy required for plant operation. The remaining power required is obtained from steam-driven generators or purchased from utility companies.

FINAL MELTING AND CASTING

132. The cathodes, after washing, are charged into reverberating furnaces where a process of oxidizing and poling similar to that done in the original anode fire refinery is repeated. Great care must be exercised, however, in this final process. In this, as in the anode furnace, pulverized coal, lump coal, natural gas, or fuel oil may furnish the necessary heat, the fuel used being entirely dependent upon its relative cost at the refinery.

133. The refined copper is cast into commercial shapes; that is into wire bars for copper-wire drawing, into slabs and square cakes for rolling into sheet copper, into billets for seamless tubing, into circular cakes for seamless cylindrical products, and into ingots and ingot bars when copper is to be remelted for alloying or casting.

134. The copper produced is of three commercial grades: Exceptionally pure (99.93 percent) and correct pitch copper for electrical purposes; tough-pitch copper (99.25 percent) in which tensile strength and heat conductivity are of greater importance than electrical conductivity as it is used for pipes and tubes and other engineering purposes; and best select copper (99.75 percent) for use in copper alloys.

RECOVERY OF ANODE SLIME

135. Almost all copper refined electrolytically contains precious metals. These settle to the bottom of the electrolytic tank from which they are emptied into launders. After slime has settled, it is

[58] Corwin, Frank R., and Harloff, Carleton S. (Nichols Copper Co.) "The Series System of Electrolitic Copper Refining at Nichols Copper Co." Paper presented before American Electrochemical Society, May 30, 1930.

clarified, filtered, and roasted and is then leached in hot dilute sulphuric acid to remove copper. After filtering, it is ready for the doré furnaces. These remove the remaining impurities, producing silver and gold, platinum, or other precious metals, which are cast into anodes for electrolytic separation.

136. Not all copper refineries refine precious metals. Some recover the copper in the anode slime and send the remaining metals, filtered and dried, to refining plants.

TABLE VII.—*Copper refineries in the United States, 1929*

Location	Company	Approximate capacity [1] (tons copper per year)	Process
Electrolytic refineries:			
Maryland: Baltimore	Baltimore Copper Smelting & Refining Co.	100,000	Series and multiple.
Montana: Great Falls	Anaconda Copper Co	165,000	Multiple.
Michigan: Hubbell	Calumet & Hecla Consolidated Co	[2]	Do.
New Jersey:			
Maurer	American Smelting & Refining Co	120,000	Do.
Perth Amboy	Raritan Copper Works	138,000	Do.
Chrome	United States Metal Refining Co	240,000	Do.
New York: Laurel Hill	Nichols Copper Co	250,000	Series.
Texas: El Paso	do	100,000	Multiple.
Washington: Tacoma	American Smelting & Refining Co	114,000	Do.
Arizona [3]		35,000	
Total electrolytic copper capacity.		1,562,000	
Furnace refineries:			
Arizona: Hayden	American Smelting & Refining Co	[4] 10,000	
Michigan:			
Hubbell	Calumet & Hecla Consolidated Co	108,000	
Houghton	Michigan Smelting Co	28,000	
Hancock	Quincy Mining Co	15,000	
Total furnace refining capacity.		161,000	
Total		1,723,000	

[1] Estimated by Engineering & Mining Journal.
[2] Used only on ores high in precious metals. Reported to have been dismantled.
[3] The 2 Arizona electrolytic ore refineries having capacities of 35,000 tons copper are included under ore reduction plants.
[4] Conjectural.

COSTS OF ORE REDUCTION AND REFINING

137. As the several processes of ore reduction are applied to different types of copper ores, the costs of such reduction are not directly comparable. They indicate only the economic possibilities of employing given processes under favorable ore conditions.

138. The following cost data is compiled from Information Circular 6303 of the United States Bureau of Mines and deals with operating costs, in 1928, at a leaching and electrolytic plant in Arizona. This plant has varied oxide and sulphide ores associated with iron and small amounts of pyrite.

COST OF LEACHING AND ELECTROLYSIS

139. The cost of crushing and leaching the ore was about $0.505 per ton ore handled, equivalent to $0.0278 per pound of copper obtained. The necessary reduction of ferric oxide added somewhat to the cost

of electrolytic precipitation which totaled $0.0273 per pound of copper. This made a total cost of $0.0551 per pound of electrolytic copper, of which about 26 percent was power cost.

140. In addition to these operating costs the mining and transporting of ore cost $0.01472 per pound of copper produced. This, together with local and State taxes and general expenses brought the operating costs per pound of electrolytic copper produced to $0.08303.

TABLE VIII.—*Cost of leaching and electrolysis*

Item	Cost per ton of ore	Cost per pound copper produced
Crushing and conveying		
Power:		
Course crushers	$0.002	
Fine crushers	.011	
Operating conveyors	.001	
Lighting	.001	
Total	.015	
Supplies	.058	
Labor:		
Operating	.047	
Repairs	.028	
Total	.075	
Total crushing and conveying	.148	
Leaching		
Power:		
Pumping	.029	
Excavating tailings	.003	
Lighting	.001	
Total	.033	
Supplies	.221	
Labor:		
Operating	.099	
Repairs	.004	
Total	.103	
Total leaching	.357	
Total cost per ton ore treated	.505	
Total cost per pound copper		$0.0278
Electrolytic precipitation		
Power:		
Crushing sulphide ore		.0003
Tower operation		.0008
Tank house pumping		.0006
Electrolysis		.0106
Crane		.0001
Dissolving cement copper		.0001
Lighting		.0001
Total		.0126
Supplies		.0075
Labor:		
Operating		.0069
Repair		.0003
Total		.0072
		.0273
Total operating cost per pound electrolytic copper		.0551

COST OF IRON PRECIPITATION

141. If acid necessary for iron precipitation is available at the plant, iron precipitation of copper is not a costly process. One plant in which this process is used on tailings only reports the cost to be $0.04, including the smelting and all incidental expense. The statement of costs is as follows:

	Per pound copper produced		*Per pound copper produced*
Iron expense	$0. 0234	Superintendence	$. 0009
Water supply	. 0009	Lighting	. 0003
Handling and loading	. 0014		
Transportation	. 0038	Total cost per pound copper produced	[59]. 0396
Smelting	. 0089		

142. In one plant where waste dumps are leached and leachings precipitated by iron the entire operating cost is given as approximately $0.065 per pound.

FLOTATION COSTS

143. Flotation costs vary considerably from plant to plant due, in part, to differences in ores and details of treatment and, in part, to differences in the allotment of handling and other miscellaneous expenses. Cost reports obtained range from $0.3658 per ton of ore [60] to $0.7365 per ton, ore concentrated. The company having low concentrate costs reported mining and ore delivery costs of $0.5017, making a total cost of $0.8675 per ton of ore concentrated.

144. The following statement of detail is given to indicate the distribution of costs in flotation rather than as an example of flotation under the best conditions. The plant treated iron-sulphide copper ores and recovered gold, silver, and zinc as well as copper. In these operations power formed about 15 percent of the total crushing and flotation costs.

TABLE IX.—*Example of distribution of costs in concentrating copper ores by flotation* [61]

Item	*Cost per ton ore*	
Crushing and conveying		$0. 2260
Grinding:		
Supplies	$0. 0735	
	. 0642	
Labor:		
Operating	. 0178	
Repairs	. 0084	
	. 0262	
		. 1639
Flotation:		
Power	. 0248	
Supplies	. 1250	
Labor:		
Operating	. 0216	
Repairs	. 0043	
	. 0259	
		. 1757

[59] U.S. Bureau of Mines. Information Circular No. 6303.
[60] Utah Copper Co. Twenty-Fifth Annual Report for Year Ending Dec. 31, 1929.
[61] Compiled from U.S. Bureau of Mines Information Circular 6343.

TABLE IX.—*Example of distribution of costs in concentrating copper ores by flotation*—Continued

Item	Cost per ton ore	
Thickening of concentrates:		
Power	$0. 0037	
Supplies	. 0010	
Labor:		
Operating	. 0118	
Repairs	. 0012	
	. 0130	
		$0. 0177
Filtering:		
Power	. 0028	
Supplies	. 0037	
Labor:		
Operating	. 0082	
Repairs	. 0012	
	. 0094	
		. 0159
Miscellaneous, including:		
Mill water, tailings disposal, and power	. 0070	
Sampling, testing, and handling of supplies	. 0330	
Labor	. 0873	
Concentrates: Flotation royalty	. 0100	
		. 1373
Total per ton ore		. 7365

145. Concentration costs in a second plant were as follows:

	Per ton ore		Per ton ore
Coarse crushing and conveying	$0. 094	Water	$0. 024
Fine grinding	. 133	General mill	. 038
Flotation	. 085		
Concentrate retreatment	. 017	Total (or $0.032 per pound copper produced)	. 413
Concentrate disposal	. 008		
Tailing disposal	. 014		

To this must be added the mining cost of $0.032 per pound and general milling expense of $0.013, bringing the total cost of copper concentrate produced to $0.077 per pound copper contained. Before this figure can be compared with costs of leaching and electrolytic precipitation, the costs of smelting and refining must be added. This plant sent its concentrate to a nearby smelter to be converted into blister copper after which it was shipped to an Eastern seaboard refinery at a cost of $12.50 per ton copper via the Gulf or $14.50 via rail. Consequently, freight must also be added to the cost which brings the cost of smelting, refining, and marketing to $0.035, making a total cost of refined copper $0.112 per pound.[63]

146. *Smelting costs.*—Roasting, smelting, and converting costs where ore treated was 80 percent direct smelting ore, 10 percent concentrates, and 10 percent siliceous flux is reported to be as follows by an Arizona plant: [64]

[63] Engineering and Mining Journal, vol. 126, no. 3, July 21, 1928, pp. 96–97, 117.
[64] The Mining Congress Journal, April 1930, pp. 369–383.

TABLE X.—*Roasting, smelting, and converting costs* [1]

Item	Cost per ton ore charged	Cost per ton of copper
Roasting:		
Operating belt conveyors:		
Wages and bonus	$0.0301	
Power, repairs, and supplies	.0135	
	.0436	
Operating roasters:		
Wages and bonus	.0490	
Fuel	.0181	
Power, supplies, repairs	.0630	
	.1301	
Miscellaneous	.0133	
Total roasting cost	.187	
Smelting:		
Tramming and weighing charge	.06	
Tramming slag	.05	
Operating wages and bonus	.125	
Fuel:		
Gross $0.78		
Credit for waste heat .38		
	.40	
Sundry supplies	.04	
16-ounce air	.015	
Power	.003	
Switching, crushing cleanings	.002	
High-pressure air	.002	
Light	.002	
Repairs	.14	
Flux-limerick	.025	
Mud mill	.012	
Total direct smelting charges	.876	$4.04
Converter:		
Crane operation		.8388
Converter operation		5.5655
Lining converters		1.7499
Handling product		.8949
Miscellaneous		.5952
Total concentration cost		9.6443

[1] The Mining Congress Journal, April 1930, pp. 369-383.

Total, $13.6843 or $.00684 per pound copper.

147. In Michigan one of the large producers employing direct smelting methods had the following costs in 1928:

Cost per ton of rock hoisted	$1.832
Cost per ton of rock stamped	1.887
Total per ton of rock	3.719
Mining and stamping per pound of copper	.05835
Smelting, freight and marketing product	.01519
Taxes	.00269
Total cost per pound of refined copper	.07623

148. Leaching and flotation applied to tailings at another Michigan plant cost but $0.0294 per pound copper recovered. The smelting and other expenses of marketing these copper tailings brought the total cost to $0.0595 per pound of copper.

TOTAL OPERATING COSTS

149. Table XI shows the type of reduction process used in each of the larger plants in the United States and the differences between reduction costs, total operating costs, and final costs of refined copper. The value of precious metals recovered at the refinery is deducted from the total costs of copper reduction and refining and sometimes reduces total costs below operating costs of copper production.

150. Dump leaching of native ore and leaching in place are done at lowest operating costs. However, the Utah Copper Co., concentrating low grade disseminated ores chiefly by flotation, has the lowest operating and lowest total cost for a large copper output. Production costs of electrolytic precipitation, while higher than flotation and smelting costs in low cost production plants, compare very favorably with concentration and smelting costs in the larger number of reduction plants.

TABLE XI.—*Copper ore reduction plants in the United States and cost of ore reduction and refining* [1]

Location	Company	Reduction process	Tons ore or concentrate treated in 1929	Percent mill recovery	Percent copper in concentrate	Reduction costs per ton ore treated	All operating costs per pound copper produced	Total cost per pound refined copper produced [2]
ARIZONA								
Ajo	Calumet & Arizona Mining Co.: New Cornelia Copper Co. (subsidiary).	Leaching Iron precipitation Electrolysis	1,122,031	8.33 66.69 } 75.0	60.0	$0.505 [3] .041 [3] .027	$0.083	
		Flotation	2,456,304				.0989	$0.0984
Douglas	Calumet and Arizona Smelter	Smelting	[4] 150,000					
Christmas	Christmas Copper Co	Flotation						
Inspiration	Inspiration Consolidated Copper Co.	Leaching Iron precipitation Electrolysis	3,239,440	80.37				
		Flotation		83.14	38.86		.1037	.1113
		Tabling	2,560,147					
		Direct smelting			4.25			
Superior	Magma Copper Co	Direct smelting and concentrates smelting.	291,218	92.0			.1008	.09997
Miami	Miami Copper Co	Flotation	4,260,599	68.4	38.36	.381	[5] .0953	.1194
	International Smelting Co	Smelting of Miami, Inspiration, and Old Dominion concentrates (starting sheets for Inspiration).	200,000					
Hayden	Nevada Consolidated Copper Co.: Ray Branch.	Flotation	3,609,100	89.4	20.1	.394		
	American Smelting & Refining Co	Custom smelting for Ray and Christmas concentrates.						.0953
Bisbee	Shattuck Denn Mining Corporation		[3] 44,404					.158
Walker	Sheldon Mining Co	Concentrates	[4] 18,250					
Humboldt [6]		Smelting own concentrates and custom concentration.	[4] 45,625					
Hillside	Bagdad Copper Co	Flotation	[4] 18,250		33.5			
		Leaching						
		Electrolysis						

[1] Data compiled from companies' annual reports, from accounts of operations in Mining Congress Journal and Engineering and Mining Journal. Also from The Mineral Industry During 1929 and Copper in 1928, U.S. Bureau of Mines.
[2] Total cost before depletion but after deducting credits for sundry metal.
[3] Cost per pound copper produced.
[4] Plant capacity.
[5] Figures quoted are for 1928.
[6] Not operating in 1929.

TABLE XI.—*Copper ore reduction plants in the United States and cost of ore reduction and refining* [1]—Continued

Location	Company	Reduction process	Tons ore or concentrate treated in 1929	Percent mill recovery	Percent copper in concentrate	Reduction costs per ton ore treated	All operating costs per pound copper produced	Total cost per pound refined copper produced [2]
ARIZONA—Continued								
	Phelps Dodge Corporation:							
Warren	Copper Queen Branch	Flotation	1,445,425	91.3				
Douglas	Copper Queen Smelter	Smelting Copper Queen concentrates	[5] 816,926					
		Anode production						
Morenci	Morenci Branch	Tabling and flotation	1,711,449	81.8	24.6			
Clifton	Clifton Smelter	Smelting Morenci concentrators						
		Anode production						$0.124
Globe	Old Dominion Co	Flotation	[5] 353,392		21.48		$0.1475	
Holbrook Shaft	Holbrook Plant	Underground leaching and precipitation		97.2				
Sacramento Hill	Don Luis Plant	Dump leaching and precipitation		94.7				
Clarkdale	United Verde Copper Co	Flotation	473,295	92.5	16.03	$0.7395		
		Smelting ores and concentrates	726,600			[7] 1.063		
Clemenceau	United Verde Extension	Smelter	343,115			.027	.075	.0708
Jerome District	Verde Central Mines, Inc	Flotation	73,000	91.5				
CALIFORNIA								
Superior	Engles Copper Mining Co	Flotation	[5] 357,564	91.6	27.8	[8] .074		.12
Iron Mountain	Mountain Copper Co., Ltd	Flotation						
Spring Garden	Walker Mining Co	Flotation	[5] 391,275	91.3	22.8			
IDAHO								
Custer County	Mackay Metals	Flotation	273,750					
MICHIGAN								
Hubbell	Calumet and Hecla Consolidated Mining Co.	Leaching dumps		81.9		.233	.0562	
Lake Linden	Calumet Mill	Flotation	[5] 1,075,960	81.8	29.23	.0891		.1146
	Ahmeek Mills	Flotation	1,939,462					
		Smelting and refining	[5] 102,939				.0871	
Portage Lake	Isle Royale	Stamping and flotation	[5] 404,731					[9] .1263
Redridge	Copper Range: Champion Mill (stamping for Baltic and Trimountain Mill in 1929).	Stamping	[5] 427,240		22.9		.1648	.1446
		Flotation						
		Smelting	45,719					

Gay	Mohawk Mining Co	Stamping	[5] 656,739		32.3	1.887	.0704	.0709
		Flotation						
Houghton	Michigan Smelting Co	Smelting and refining concentrates of Copper Range, Mohawk.						
Mason	Quincy Mining Co	Flotation	60,834		20.1			
Hancock		Smelting and refining						
MONTANA								
Anaconda	Anaconda Copper Co	Flotation	[5] 2,975,206		23.0			
		Leaching and iron						
		Iron precipitation			25.0			
		Smelting	[5] 648,940					
		Anode casting						
NEVADA								
McGill	Nevada Consolidated Copper Co	Flotation	6,254,029			[10] .421		[11] .0953
		Smelting						
Thompson	Eastern Iron & Metal Co	Flotation [6]	[5] 475,848	91.3	12.9	.59		
		Smelting	[6] 132,518			.448		
NEW MEXICO								
Hurley	Nevada Consolidated Copper Co.: Chino Mines.	Flotation	3,973,300			[10] .59		[11] .0953
Tyrone	Phelps Dodge Corporation, Burro Mountain Branch.	Experimental leaching	([6])					
OREGON								
Drew	Oregon Copper Co	Flotation	[4] 18,250					
Riddle	Silver Peak Mining & Milling Co							
TENNESSEE								
Copperhill	Tennessee Copper & Chemicals Co	Flotation	[4] 328,500					
		Smelting						
Isabella	Ducktown Chemical & Iron Co	Flotation	[4] Over 3,000					
		Smelting						
TEXAS								
El Paso	American Smelting & Refining Co	Smelting Chino and other concentrate						
UTAH								
Bingham	Ohio Copper Co	Leaching in place and precipitation	[12] 54,000		90.0			0.06
Bingham	Utah Copper Co.:							
	Mine dumps	Heap leaching and precipitation	[12] 2,210			[8] 0.065		
	Arthur Mill	Flotation	17,724,000	85.7	32.0	.366	0.0638	.0665
	Magma Mill	Flotation					.0127	
Garfield	American Smelting and Refining Co	Smelting for Utah Copper and other mills in Utah, Nevada, Idaho, Colorado and California.	840,000					
Tooele	International Smelting Co	Smelting crude and concentrate	[5] 193,450					

[4] Plant capacity.
[5] Figures quoted are for 1928.
[6] Not operating in 1929.
[7] Roasting and smelting only.
[8] Includes mining cost.
[9] Before depreciation.
[10] Includes overhead.
[11] Average for three plants in three States.
[12] Copper produced.

TABLE XI.—*Copper ore reduction plants in the United States and cost of ore reduction and refining*—Continued

Location	Company	Reduction process	Tons ore or concentrate treated in 1929	Percent mill recovery	Percent copper in concentrate	Reduction costs per ton ore treated	All operating costs per pound copper produced	Total cost per pound refined copper produced
VERMONT								
Stratford	National Copper Corporation		[4] 146,000	90.0–95.0				
WASHINGTON								
Index	Sunset Copper Co	Table and flotation	[4] 36,000	95.0	30.0–35.0	[13] $0.90		
Turk mine	Snowdrift Mining Co	Flotation						
Tacoma	American Smelting & Refining Co	Customs smelting for Kennecott concentrates and others.	[4] 900,000					
ALASKA								
Kennecott	Kennecott Copper Co	Flotation	76,272	95.2	40.87			$0.0778
		Gravity concentration and ammonia leaching.		66.2	75.0			
Latouche		Flotation	452,962	82.64	14.47			

[4] Plant capacity.

[13] Only figures available are for 1925.

Organization and Location of Copper Producing Units

151. Early experience indicated the need of placing concentration and smelting plants near mines. As a consequence, all mining companies do their own concentration or leaching near their mines. Smelting plants, either owned by the mining company or operating independently as custom smelters, are located in the heart of each large copper district. (See table XI.) Small, scattered mines must incur the cost of shipping low-content concentrates to the nearest smelter. Freight rates are based on value of product. For example, a concentrate worth $10 would pay a $1 freight rate when carried from Lordsburg, N.Mex., to the El Paso smelter, and $1.80 if worth $20.

152. Table VII shows the location of refineries as well as their respective capacities. As furnace refining naturally follows immediately upon matte conversion, furnace refineries are a part of smelting plants in the Michigan peninsula and at one Arizona plant. With two exceptions, the electrolytic copper refineries, having a total capacity of 1,500,000 tons of copper annually, are located at the seacoast. Four are on New York Harbor, one on Chesapeake Bay, and one on Puget Sound. The Anaconda Copper Mining Co. placed its refinery inland at Great Falls, Mont., near its smelter. Only in 1929 did the Phelps Dodge Corporation, the Calumet & Arizona Mining Co., and the Nichols Copper Co. erect an inland refinery at El Paso, Tex. This refinery will operate on Arizona and New Mexico blister copper, much of which had been sent previously to Perth Amboy, N.J., for refining. The location of electrolytic precipitation plants near mines, both in this country and in other countries, has lessened the refining demands on seaboard refineries, although the copper cathodes produced are shipped to such refineries for casting into commercial shapes and for marketing.

153. The companies engaged in copper-ore mining, reduction, and refining may be divided into four groups: The Michigan peninsula group, the Anaconda Copper Mining Co., the Kennecott Copper Corporation, and scattered companies located chiefly in Arizona. Michigan has four principal mining and concentrating companies. The Calumet & Hecla Consolidated Mining Co. has plants of largest capacity; it not only smelts its own concentrate but also refines that which enters the market as lake copper. The Copper Range Co. and Quincy Mining Co. smelt their own ores. A custom smelting and refining company is located on the peninsula which smelts and refines ores and concentrates.

154. The Anaconda Copper Mining Co. owns its mines in the Butte district, its concentration and smelting plant at Anaconda, and its electrolytic-copper refinery at Great Falls, Mont. It owns the International Smelting Co. at Miami, Ariz., and has an important stock interest in the Inspiration Consolidated Copper Co. of Arizona, the Walker Mining Co. of California, and the Greene Cananea Copper Co. of Mexico. In addition to its Montana refinery, it controls the Raritan Copper Works, Perth Amboy, N.J. The two largest producers of electrolytic copper in South America, the Chile Copper Co. and the Andes Copper Mining Co., are controlled by Anaconda.

155. In addition to this control of American copper mining and refining, the Anaconda Copper Mining Co. controls about 40 percent of copper and copper alloy fabrication.[65] It erected a copper wire and cable mill at Great Falls in 1918 and a new wire mill at Kenosha, Wis., in 1923. These two plants formed the subsidiary, known as "Anaconda Wire and Cable Co." To this was added, in 1929, the Inland Wire & Cable Co. of Sycamore, Ill., one of the largest consumers of copper rods in the country and a large producer of weatherproof wire. Later, in 1929, the Tubular Woven Fabric Co. of Pawtucket, R.I., manufacturers of rubber insulated wire, was taken over and, in the same year, the Maring Wire Co. with plants at Muskegon, Mich., and Anderson, Ind., was made part of the Anaconda Wire & Cable Co. By adding the Hastings-on-Hudson plant of the Hastings Wire & Cable Co., the Anaconda Wire & Cable Co. secured control of complete facilities for the manufature of all bare- and insulated-wire products.

156. In 1922 the Anaconda Copper Mining Co. absorbed the American Brass Co. with plants at Ansonia, Torrington, and Waterbury, Conn., Detroit, Mich., and Buffalo, N.Y.

157. The Kennecott Copper Corporation, in addition to its copper mines and concentration plants in Alaska, controls the Utah Copper Co.'s mines and concentration plants in Utah and the Braden Copper Co. of South America. It has indirect control of the Nevada Consolidated Copper Co. with mines and concentration plants in three States, and mines, concentration, and smelting plants in Arizona and Nevada.

158. The Kennecott Corporation is affiliated with the American Smelting & Refining Co., which, in addition to its smelting plants, does electrolytic refining at Tacoma, Wash.; Maurer, N.J.; and at Baltimore, Md.

159. The consolidation in 1929 between the Chase Brass & Copper Co., of Waterbury, Conn., and the Kennecott Copper Corporation, brought Kennecott directly into the fabricating field. Through its interest in the American Smelting & Refining Co. it may also exercise some influence over production of the General Cable Corporation, with wire plants at Emeryville, Calif.; Fort Wayne, Ind.; Baltimore, Md.; St. Louis, Mo.; Bayonne and Perth Amboy, N.J.; Rome, N.Y.; and other points.

160. The Phelps Dodge Corporation and the Calumet & Arizona Co., both operating mines, concentration, and smelting plants in Arizona, have an interest in the Nichols Copper Co., with refinery at Laurel, N.Y., and the new refinery at El Paso, Tex. It is rumored that other independent copper mining and concentrating companies in Arizona would join this group and that several Connecticut brass fabricating plants and a copper wire Pennsylvania plant would add strength to the merger.

MARKETS FOR REFINED COPPER

161. Approximately 80 percent of copper-refinery production is used for the manufacture of unalloyed copper products. The largest amount is drawn into wire and rods, while about a fifth is worked into sheets and strips, and about a twentieth into tubing. Of the 20

[65] Wall Street Journal, Sept. 6, 1930.

percent that is alloyed with other metals, less than half is rolled into sheets, a fourth is drawn into brass wire and rods and a fifth becomes tubing. Alloyed castings form less than 10 percent of the total alloyed copper manufacture.[66]

162. The larger rolling mills manufacture both copper and copper alloy products into a number of products. For example, the American Brass Co. alloys copper with zinc, tin, nickel, lead, silicon, and manganese, and works the copper or the alloy into the following forms: Sheets, rolls, and strips; wire as spring wire, trolley wire, conductors, cables, magnet wire, resistance wire, weaving wire; round, square, rectangular, hexagonal, and special shaped rods and bars; seamless and brazed tubes in many shapes for piping, condenser tubes, bus tubes; die-pressed parts, turbine blades, cable connectors, and other special products. The Bridgeport Brass Co. produces trolley wire, brass wire, seamless and brazed brass, and copper tubes, brass rods in all kinds of special shapes chiefly for building construction, and strip and sheet brass. Other firms specialize on several types of wire and cables, plumbers' supplies, and other lines.

The leading fabricators of copper and copper alloys in the country are listed by location.

Location of mill	Company
California:	Emeryville, General Cable Co.
Connecticut:	Ansonia, American Brass Co.
	Bridgeport, Bridgeport Brass Co.
	Bristol, Bristol Brass Co.
	Seymour, New Haven Copper Co., Seymour Manufacturing Co.
	Torrington, American Brass Co.
	Waterbury, American Brass Co., Chase Brass & Copper Co., Scoville Manufacturing Co.
Illinois:	Chicago, American Insulated Wire & Cable Co. (General Cable subsidiary), Brenner-Mervis Co. (General Cable subsidiary), American Sheet & Wire Co., Revere Copper & Brass, Inc.
	Decatur, Mueller Co.
	Hawthorne, Western Electric Co.
	Sycamore, Anaconda Wire & Cable Co (formerly Inland Wire & Cable Co.).
Indiana:	Anderson, Anaconda Wire & Cable Co. (formerly Maring Wire Co.).
Maryland:	Baltimore, Baltimore Tube Co., General Cable Co., Revere Copper & Brass, Inc., Western Electric Co.
Michigan:	Detroit, American Brass Co., Detroit Brass & Malleable Works, General Cable Co., Revere Copper & Brass Co. (formerly Michigan Copper & Brass Co.), Wolverine Tube Co.
	Dollar Bay, John A. Roebling's Sons.
	Grand Rapids, Wolverine Brass Works.
	Muskegon, Anaconda Wire & Cable Co., (formerly Maring Wire Co.), Enterprise Brass Works.
	Port Henry, Mueller Brass Co.
	Sturgis, Morevcy-VanBuren Manufacturing Co. (subsidiary of Scoville Manufacturing Co. of Connecticut).
Massachusetts:	New Bedford, Taunton-New Bedford Copper Co.
	Taunton, Taunton-New Bedford Copper Co., New England Brass Co.
	Springfield, Cheney-Bigelow Wire Works, Keating Valve Co. (subsidiary of Bridgeport Brass Co.).
Missouri:	St. Louis, General Cable Co.
Montana:	Great Falls, Anaconda Wire & Cable Co.

[66] Estimates, The Mineral Industry, 1929.

Location of mill	Company
New Jersey:	Bayonne, General Cable Corporation.
	Carteret, Foster Wheeler Corporation.
	Harrison, General Cable Co.
	Roebling, John A. Roeblings' Sons.
	Trenton, John A. Roeblings' Sons.
	Perth Amboy, General Cable Co.
New York:	Buffalo, American Brass Co., General Cable Co.
	Hastings-on-Hudson, Anaconda Wire & Cable Co. (formerly Hastings Wire & Cable Co.).
	New York, Hendricks Brothers.
	Rome, Revere Brass & Copper Co. (formerly Rome Brass & Copper Co.), Rome Wire Co. (division of General Cable Corporation).
	Schenectady, General Electric Co.
Ohio:	Bellefontaine, Fisher Brass Co.
	Delaware, Fisher Brass Co.
	Maryville, Fisher Brass Co.
	Lisbon, National Brass & Copper Co.
Pennsylvania:	Economy, National Electric Products Corporation.
	Pittsburgh, National Electric Products Corporation, C. G. Hussey & Co.
Rhode Island:	Pawtucket, American Brass Co. (formerly Tubular Woven Fabric Co.), General Cable Co.
	Phillipdale, American Electrical Works.
Wisconsin:	Kenosha, Anaconda Wire & Cable Co.
	Racine, Hamiston Beach Manufacturing Co. (subsidiary of Scoville Manufacturing Co.).

The large copper and copper alloy fabricating States are shown on the map.[67]

Copper and Copper Alloy Fabrication

163. When copper reaches the rolling mills from the refineries it is either softened by heat and drawn, rolled, or pierced into desired products, or it is mixed with other metals and then drawn, rolled, pierced, or cast. As the fundamental processes are the same for copper as for its alloys, the melting of copper with other metals will be described first, following which the rolling mill processes may apply equally to copper, brass, bronze, or other alloys.

Electric Melting of Brass, Bronze, and Other Copper Alloys

164. Prior to 1917 the melting and casting of copper, combined with zinc, tin, lead, nickel, and other metals, was done in crucibles in coal-fired pit furnaces. The operation was entirely dependent upon the experience and skill of master casters and much work had to be carried on in the midst of zinc-oxide fumes. Scientific control of melting was impossible with such methods. Consequently, the perfection of the brass electric furnace for melting brass and other copper alloys has been seized upon by copper alloy manufacturers. Commercialization began about 1917, and today it is believed that almost all the brass and bronze melting in rolling mills is done in electric furnaces. The connected load for 321 such furnaces in active operation in 1927 was 27,100 kilowatts.

165. Copper, zinc, or other metals necessary for the desired alloy are weighed and sent in charging cars to the electric furnace. Several types of furnaces are in use. In one type the heating medium is an electric arc with carbons inserted at each end, the carbons being kept

[67] Not printed.

the correct distance apart, automatically, to develop the maximum amount of heat. The charge is brought to the melting point, at which time the furnace commences to rock. This rocking motion thoroughly mixes the several metals in the charge and by washing the furnace walls, utilizes wall heat. A furnace control indicates when rocking is to be started and when the metal is ready to be poured. Metal is poured into molds or pots swung under the furnace which is tipped gradually.

166. The vertical-ring induction furnace is used largely in rolling mills operating on a 24-hour basis. In this type the metal itself is used as the resistor. The flow of electricity through the metal is established by induction from a primary winding. The repellant action results in metal motion. At the same time a "pinch effect", or center depression caused by passing large currents through a liquid-metal conductor, results in a pumping action that materially aids circulation of metals. Because molten metal is necessary to start this type of furnace, it is not used extensively in foundries that operate only during daylight hours as some heat would be necessary, when the furnace was not operating, to hold the metal in a molten condition.

167. The energy required for the same size furnace will vary with the differing melting points of metals. One ton red brass (85Cu 5Zn 5Sn 5Pb) required 252 kilowatt-hours electricity to be melted in a 75-kilowatt vertical-ring inductive furnace. The same furnace melted a ton of yellow brass (66Cu 33Zn) with 195 kilowatt-hours of heat. Nickel brass (50Cu 25Zn 25Ni) required 290 kilowatt-hours per ton; bronze (95½Cu 4½Sn) 285 kilowatt-hours of electricity per ton melted. If operations are not continuous from 8 to 12 kilowatts are required to hold the furnace overnight.[68]

168. Rocking furnaces consume a minimum of 275 kilowatt-hours electricity per ton of red brass, 240 kilowatt-hours on leaded bronzes, and 300 kilowatt-hours per ton composition metal. Actual practice in foundries results in a little higher power consumption. The electrode consumption is about 4½ pounds per ton of alloy melted.

WIRE PRODUCTION

169. Wire bars from copper refineries or brass or other alloy billets from the electric casting shop of rolling mills, are softened by being heated gradually in furnaces to a temperature proper for rolling. The heated bars are drawn through a series of rollers, the grooves of which decrease in dimension with each draw. Consequently, each bar is reduced in cross section and increased in length, with each pass. The resulting product is known as a "rod." This is, in turn, sent to the wire mill, where it is cold-drawn through a number of dies until wire of the desired diameter is obtained, if "hard-drawn" wire is desired. If "soft-drawn" or "half-hard" wire is to be produced, the wire passes through annealing furnaces during the process.

170. Because the original annealing in the rolling mill demands a general softening of the wire bar, careful heating is not necessary and fuel-fired furnaces are used. But annealing of hard-drawn wire to produce half-hard material or very thin gage wire requires careful

[68] Adams, William. (Ajax Metal Co.) The Ajax-Wyatt or Vertical-Ring Induction Furnace. Paper presented before the American Electrochemical Society, May 31, 1930.

temperature control. Consequently, electric furnaces are displacing wood-fired muffles for this type of annealing.

171. In some rolling mills brass rods are made by the extrusion process. That is, instead of passing through rollers, the heated billet is inserted into the cylinder of an extrusion machine and an hydraulic plunger presses upon it. The metal is forced through holes in a die at the end of the cylinder and emerges from the machine as rods. The rods then undergo the same drawing and annealing treatment as do rods formed by rolling.

TUBE MANUFACTURE

172. Copper billets from the refineries, or brass billets from the electric casting shop of rolling mills, may be formed into tubes at rolling mills by several methods, depending upon the type of tubing desired. In the "piercing" process the billet is first turned to remove any surface imperfection and impurities. It is then annealed to the proper temperature and rides into the piercing machine on rollers. The cross rolling action within the machine gives the billet a powerful forward motion against a steel point carried on a long rod. It is forced over this rod gradually. After leaving the piercing machine, rods are removed and the tubes go to draw benches where they are pointed and drawn by action of an hydraulic plunger.

173. After each draw tubes must be annealed and pickled. Annealing of tubing is of great importance; temperatures, heating and cooling rate must be controlled. Consequently, copper tube is often, and condenser tubing quite generally, annealed in an electric furnace. After drawing to desired diameter, tubes are straightened by passing through rollers and sawed to desired lengths.

174. When the "cupping" process is used, a blunt-nosed plunger is forced into the heated billet by hydraulic pressure. In the cast-shell process the molten metal is cast about a core. The steps following the formation of these tubes are similar to those carried on for pierced tubes.

SHEET METAL

175. In the manufacture of sheet metal, copper cakes from refineries or brass bars from the electric casting shop are inserted into breaking-down rolls and then into straightening rolls. After the surfaces of the sheets are removed in a milling machine, the bars pass through the breaking-down rolls again. At various stages of this process the bars are annealed, preferably in electric furnaces, so that temperature may be accurately controlled.

ELECTRIC-FURNACE ANNEALING.

176. The furnaces used for annealing wire and tubes must necessarily be long. They are frequently box type, having inside dimensions such as the following: 17 feet long, 4½ feet wide, and 1½ feet high. Such a furnace required 100 kilowatt-hours power to anneal 1 ton of brass tubing. A newer furnace cut down this power consumption to about 85 kilowatt-hours per ton of tubing annealed. A counter-flow recuperative furnace is reported to have annealed a ton of brass using only 50 kilowatt-hours of electricity.[69]

[69] Electrical World. Apr. 20, 1929. Progress in Electric Brass and Copper Annealing.

177. The number of annealing installations is not definitely known, but Jewett F. Schrumm, of Waterbury, Conn., declared in April 1929 that rapid progress was being made in their adoption. Mention in various reports is made of at least 34 electric brass and copper annealing furnaces having a capacity of 6,770 kilowatts in Connecticut, alone.

CASTING OF COPPER ALLOYS

178. Recent experience in brass, bronze, and other alloying foundries indicates that if tonnage is sufficient to warrant the purchase of an electric furnace, lower melting costs are obtained than in oil-fired or other fuel furnaces, metal losses are reduced, the castings are more uniform, and working conditions are necessarily improved. When figures were last compiled (February 1927) 151 foundries had installed 303 furnaces with a connected load of 39,200 kilowatts.[70] Unquestionably, installations have increased since this date.

179. Foundries usually operate on an 8-hour, 9-hour, or 10-hour day. Consequently, the connected load signifies a much smaller consumption of power than is found in rolling mills which operate on a 24-hour schedule. In rolling mills, the load factor is between 85 and 95 percent, whereas in foundries it will average 40 percent. The rocking furnace has gained greater hold in foundries than in rolling mills, for as each batch must be heated to melting point anew, there is no power loss by having the furnace idle during the night. Then, too, foundries may melt radically different alloys from heat to heat, a condition made possible by the rocking furnace to a greater degree than by the induction furnace. The alloys are poured directly from the furnace spout into foundry molds, thus making it possible to pour the metal under conditions in which very little oxide can form.

POWER LOAD FOR COPPER-ALLOY MELTING AND ANNEALING

180. Manufacturers reporting active connected furnace loads for copper-alloy melting and annealing to the Bureau of Standards in 1927 were 32 in number. One had a load of nearly 10,000 kilowatts; 3 between 3,500 and 4,500; 11 from 1,000 to 2,000 kilowatts, and 17 from 400 to 900 kilowatts. For brass, bronze, and nickel-brass melting alone, at 90 percent load factor in rolling mills and 40 percent in foundries, it is estimated 220,000,000 kilowatt-hours of energy were consumed in 1927.

MARKETS FOR COPPER AND COPPER-ALLOY FABRICATIONS

181. A large proportion of the fabrications of these rolling mills and foundries are sent to other industries. The distribution of industrial consumption, as estimated by American Bureau of Metal Statistics, is given in table XII.

182. As is well known, the electrical industry consumes the largest amount of copper. In generators, motors, switchboards, telephone and telegraph apparatus, light and power lines, and other electrical manufacture, over 48 percent of all copper refined is used. The electrical industry is located chiefly in Illinois, Pennsylvania, New York,

[70] Gillett, H. W. (Chief, Division of Metallurgy, Bureau of Standards). Twenty-five Years of Non-Ferrous Electrothermics; 15 Years of Electric Brass Heating.

Ohio, New Jersey, Massachusetts, and Indiana, although six other States produce over $10,000,000 worth of electrical products.

183. The automobile industry consumes about 12 percent of all copper and copper alloy produced. As this industry is located chiefly in Michigan, Ohio, Wisconsin, New York, and Indiana, it is close to the copper and copper-alloy fabricating centers. At least 5 percent of copper and copper alloys is used in building construction, exclusive of plumbers' supplies, which consume an additional 2 percent. Many other scattered industries consume copper, brass, or bronze and other alloys in small amounts.

TABLE XII.—*Industrial consumption of copper in the United States in 1929* [1]

Industry	Short tons copper consumed	Percent
Total	1,137,000	100.00
Electrical manufactures: Generators, motors, switchboards, lamps, etc	261,000	22.95
Telephone and telegraph	164,000	14.42
Automobile	135,000	11.87
Light and power lines: Transmission and distribution wire and bus bars	127,000	11.17
Wire and rods, n.e.s.[2]	95,000	8.36
Buildings	59,000	5.19
Bearings and bushings	48,000	4.22
Valves and pipe fittings	22,000	1.93
Refrigerators, electric	17,200	1.51
Radio receiving sets	7,000	.62
Ammunition	6,900	.61
Plated ware	6,900	.61
Trolley wire	6,700	.59
Wire cloth	6,700	.59
Railway cars	5,600	.49
Washing machines	4,500	.40
Clocks and watches	4,300	.38
Water meters	3,900	.34
Lubricators, etc	3,500	.31
Automobile brake lining	2,600	.23
Copper-bearing steel	2,600	.23
Locomotives	2,500	.22
Fire-fighting apparatus	2,400	.21
Water heaters, household	2,300	.20
Ships, commercial	2,000	.18
Condensers	1,900	.17
Agricultural machinery	1,500	.13
Air brakes	1,500	.13
Coinage	1,200	.11
Radiators	1,300	.11
Safety razors	1,100	.09
Steam railways electrified	500	.04
Ships, naval	400	.04
Cash registers	400	.04
Other uses [2]	55,000	4.84
Manufactures for export [3]	73,600	6.47

[1] Estimates made by American Bureau of Metal Statistics.
[2] Conjectural.
[3] Includes all primary fabrications of copper and its alloys.

BIBLIOGRAPHY

Year	Author	Title
1930	Adams, William, Jr	The Ajax-Wyatt or Vertical Ring Induction Furnace. Paper presented before American Electrochemical Society. June 1.
1921	Addicks, Lawrence	Copper Refining.
1929	Aldrich, H. W., and Scott, Walton.	Leaching Mixed Oxide and Sulphide Copper at Inspiration. Engineering and Mining Journal, Oct. 19. Oct. 26.
1929	American Bureau of Metal Statistics.	Metal Statistics.
1930		Barron's. Aug. 4.
1930	Baroch, Charles T	Hydrometallurgy of Copper at the Bagdad Property. Paper presented before the American Electrochemical Society. June 1.
1929	Bender, Louis V	Development of Copper Smelting at Anaconda. Engineering and Mining Journal, vol. 128. Aug. 24.
1929	Billinger, H. C. (Vice president, Chile Copper Co.).	Mining the World's Largest Copper Deposit. Engineering and Mining Journal, vol. 128. Aug. 24.
1920	Bridgeport Brass Co	Seven Centuries of Brass Making.

BIBLIOGRAPHY—Continued

Year	Author	Title
1929	Burns, W. T. (Manager, Raritan Copper Works).	Refining Anaconda Copper at Raritan and Great Falls. Engineering and Mining Journal, vol. 128. August.
1927	Canada	Geology, Mines and Metallurgical Industries.
1928	Chamber of Commerce, Salt Lake City, Utah.	Utah, America's Greatest Non-Ferrous Mining and Smelting Center.
1930	Corwin, Frank R., and Harloff, Carleton S. (Nichols Copper Co.).	The Series System of Electrolytic Copper Refining at Nichols Copper Co. Paper presented before American Electrochemical Society. May 30.
1925	Crump, Norman E	Copper.
1924	Davis, Watson	The Story of Copper.
1928	Douglas, Walter	Historical Sketch of The Phelps Dodge Corporation. Engineering and Mining Journal, vol. 126. Oct. 27.
1929	Russia	Economic Review of the Soviet Union. Nov. 15.
1925 1929	Electrical World	Progress in Brass and Copper Annealing. Apr. 4, 1925. Apr. 20, 1929.
1928 1929 1930	Engineering and Mining Journal	News notes.
1927	Gillett, H. W. (Chief, Division of Metallurgy, Bureau of Standards).	Twenty-Five Years of Non-Ferrous Electrothermics; Fifteen Years of Brass Melting. Presented before American Electrochemical Society. Feb. 15.
1928	Johnson, Homar L	A Glimpse of the Michigan Copper Country With Copper at Fifteen Cents. Engineering and Mining Journal. Oct. 20.
1928	do	Copper. Mineral Industry.
1929	Banbour, Percy E	Copper. In Mineral Industry.
1929	Laist, Frederick	Modern Metallurgical Miracles. Engineering and Mining Journal. Aug. 24.
1926	Liddell, Donald M	Handbook of Non-Ferrous Metallurgy.
1930		Mining Congress Journal. April.
1930		Moody's Industrials.
1930	Noranda Mines, Ltd	Annual Report for 1929.
1930	Pulp and Paper Magazine	Bronze Castings Produced Under Scientific Methods of Modern Control. June 19.
1928	Robie, E. H	Revisiting Arizona's Mining Camps. Engineering and Mining Journal, vol. 126. Aug. 4, Aug. 18, Sept. 29, Oct. 20, Nov. 17, Nov. 24.
1927	Skowrowski, S	Twenty-Five Years in the Electrolytic Refining of Copper. Paper presented before the American Electrochemical Society. Mar. 4.
1929	Thuerk, H. C. (Commercial engineer, Erie Pennsylvania Lighting Co.).	Electric Brass Melting Reduces Costs.
1927	U.S. Bureau of the Census	Biennial Census of Manufactures.
1929	U.S. Bureau of Foreign and Domestic Commerce.	Unpublished reports.
	U.S. Bureau of Mines:	
1928	Economic Paper No. 1	Summarized Data of Copper Production.
	Mineral Resources of the United States.	Copper in 1928, and Preliminary Metal Statistics for 1929.
1915	Bulletin 81	The Smelting of Copper Ores in the Electric Furnace.
1922	Bulletin 202	Electric Brass Furnace Practice.
1921	Bulletin 205	Flotation Tests of Idaho Ores.
1930	Bulletin 321	Innovations in Copper Leaching Employing Ferric Sulphate-Sulphuric Acid.
	Information Circular:	
1930	No. 6260	Mining Methods and Costs at the Engels Mine, Plumas County, Calif.
1930	No. 6261	Milling Methods and Costs at the Concentrator of the Cananea Copper Company, Cananea, Sonora, Mexico.
1930	No. 6289	Mining Methods at the Campbell Mine of the Calumet and Arizona Mining Company, Warren, Ariz.
1930	No. 6303	Leaching Practice and Costs at the New Cornelia Mines of the Calumet and Arizona Mining Company, Ajo, Ariz.
1930	No. 6343	Milling Methods and Costs at the Concentrator of the United Verde Copper Company, Clarkdale, Ariz.
1930	No. 6357	Methods and Costs of Treatment at the Calumet and Hecla Reclamation Plant.
1929	Serial 2934	Dissolution of Various Oxidized Copper Minerals.
1928	Serial 2871	Flue Dusts from Copper Smelters of the Southwest: Composition and Methods of Treatment.
	Technical Paper:	
1918	No. 198	Sulphur Dioxide Method for Determining Copper Minerals in Partly Oxidized Ores.
1924	No. 359	The Purification of Copper Sulphate Solutions.
1930	No. 472	Acceleration of Extraction of Soluble Copper from Leached Ores.
1930	No. 473	Chemistry of Leaching Chalcocite.
	U.S. Geological Survey	Copper in 1915.
1930	do	Copper Deposits Near Keating, Oreg.
1930	U.S. Senate	Document 145: The Copper Industry and the Tariff.
1930	Utah Copper Co	Twenty-Fifth Annual Report for Year Ending Dec. 31, 1929.
1929	do	In Mining Congress Journal. June.
1881	Vivian, Henry Hussey	Copper Smelting: Its History and Processes.
1930		Wall Street Journal. Sept. 6.
1929	Woodward, C.D	How Anaconda Applies Electricity in Mining and Metallurgy.

POWER IN ZINC AND LEAD PRODUCTION

TABLE OF CONTENTS

	Page
Power in zinc and lead production	245
Development of the zinc industry in the United States	245
Zinc-oxide deposits developed	246
Zinc-lead sulphide mining	246
Complex zinc ores made available	246
Reorganization of the industry	247
Present-day conditions	247
Production of zinc and lead ores in the several States	248
Washington	248
Idaho	248
Montana	249
Colorado and Utah	249
Other Rocky Mountain States	250
Other Pacific Coast States	250
The Tri-State District	251
Eastern States	252
Production of metallic zinc and zinc oxide from ore	252
Location of reduction plants	252
Slab zinc production	254
Zinc oxide production and location of plants	254
Zinc dust production	255
Byproduct sulphuric acid	255
Zinc reduction processes	255
Reduction by electrolysis	256
Selective flotation	256
Electrolytic zinc processes	257
Roasting and leaching	257
Cadmium production	258
Tainton process of electrolytic precipitation	258
Comparison with Anaconda process	259
Reduction by distillation	259
Concentration	259
Distillation	259
Zinc oxide manufacture	261
Coley process	261
Electrothermal process	261
Byproducts	262
Production costs	263
Concentration costs	263
Costs of electrolysis and distillation	264
Zinc consumption	265
Electric galvanizing by hot process	265
Electrozincing	266
Sheet zinc	266
Pigments and salts	267
Exports and imports	268
World zinc production and consumption	269
European zinc cartel	269
European zinc mining and metallic zinc production	271
Zinc mining and metallic zinc production in Asia, Australasia, and Africa	272
Zinc mining and metallic zinc production in South America, Mexico, and Canada	272
Treatment of lead ores and concentrates	273
Refining of lead bullion	274
Electrolytic process	274
Pyrometallurgical processes	276
Comparison of processes	277
Electrolytic production of white lead	277
Lead producing and consuming units	277
Location of mines, smelters, and refineries	277
Imports and secondary lead	278
Consumption of lead	279
Bibliography	279

Power in Zinc and Lead Production

The electrolytic treatment of zinc has made available zinc found in abundance in the complex ores of Idaho, Montana, northwestern Washington, Utah, and Colorado. Zinc and lead occur in the same deposits in these States. Lead smelters were erected in districts in which lead was the dominant mineral; electrolytic zinc plants are being erected in districts in which zinc is the principal mineral. The companies operating zinc- and lead-reduction plants are usually identical, each company shipping all zinc recovered from its lead concentration and smelting plants to its electrolytic zinc units, and all lead recoveries from zinc concentration and refining plants to its lead smelters.

A steady current is essential for the electrolysis of zinc which requires from 2,500 to 3,350 kilowatt-hours of energy per ton of zinc produced. The capacity of plants in the United States totals 645 tons electrolytic zinc daily. British Columbia has a 380-ton electrolytic plant, while the world's total electrolytic zinc plant daily capacity is approximately 2,000 tons.

Electrolytic zinc competes with zinc distilled in retorts. Not only is the cost of electrolysis less, but electrolysis produces a zinc of higher quality, secures a higher extraction of zinc, and recovers other elements lost in distillation operations. The gold and silver recovered during electrolytic processes are shipped in lead concentrates to lead smelters and refineries; residue copper is sent to copper refineries, while cadmium is produced electrolytically at some zinc electrolytic plants. Other elements such as cobalt, arsenic, thallium, indium, gallium, and germanium are recoverable wherever a market is found for these byproducts. Sulphur dioxide can be recovered from electrolytic plants as well as from retort plants.

The productive capacity of electrolytic and retort plants already built exceeds present zinc consumption in the United States. The same situation prevails throughout the world. The major problem of the industry is, therefore, to increase the outlets for zinc so that the abundant resources in the United States, Canada, Australia, Africa, Mexico, and Poland may be adequately developed.

A minor market for electricity in zinc application is being developed in the galvanizing of iron and steel. From 100 to 230 kilowatt-hours of energy is consumed per ton of metal galvanized, dependent upon the quantity galvanized at one heat and upon the period of plant operation.

Lead is smelted and refined so easily and cheaply by pyrometallurgical methods that electrolytic refinement is employed only to produce the highest quality lead, free of bismuth, an outlet for which is found in the white lead pigment industries. In the pigment industry electrolytic lead competes with the electrolytic production of pigment for impure furnace-refined lead. Approximately 95 to 110 kilowatt-hours of energy are required for the electrolytic refinement of lead. Byproduct bismuth is also refined electrolytically. Gold and silver in the residue may be parted chemically or electrolytically.

DEVELOPMENT OF THE ZINC INDUSTRY IN THE UNITED STATES

1. The expansion of the zinc industry in the United States parallels the adoption of ore treatment and reduction methods that have made

metallic zinc available from ores containing differing minerals. Zinc does not occur as a metal in nature but is found as a sulphide, an oxide, or as a carbonate. Some zinc ores are almost free of other metallic elements, others are associated with iron, lead, or copper, and others are combined with a number of metals.

2. *Zinc oxide deposits developed.*—In New Jersey only are located large deposits of zinc oxide ores free of other metals or combined with some iron or with silica. Small deposits of carbonate ores were found in Pennsylvania and Wisconsin. As calcining was sufficient treatment for zinc oxide and carbonate ores, these deposits were the first to be developed. They supplied the brass industry of Connecticut with zinc in the early nineteenth century. The zinc oxide mines of New Jersey have been continuous producers, New Jersey ranking third in zinc mining in 1929.

3. *Zinc-lead sulphide mining.*—Lead miners in Missouri discovered zinc sulphide in lead mines. At the close of the Civil War zinc mining was successfully developed in this State, thus causing zinc-lead mines located in neighboring States to become zinc producers. For a time Missouri was the largest zinc-producing State in the Union, but as lead proved to be the more abundant mineral, Missouri's position as a zinc producer of importance was lost. But the two adjoining States of Oklahoma and Kansas continued to increase zinc production until Oklahoma held first place in zinc mining and Kansas, second position.

4. Desultory mining of zinc sulphide ore without lead was carried on from time to time in Tennessee and Virginia. Rocky Mountain lead smelters penalized miners who delivered lead ores containing more than a specified percent of zinc because zinc was detrimental in lead blast furnace operation. Middle western retort plants would not purchase concentrates containing less than 40 percent zinc. Consequently only a few zinc mines could be developed in the Rocky Mountains, although much zinc was found in combination with other metals.

5. In 1871 there were 7 zinc smelters producing 6,900 tons of zinc; in 1880 there were 13 smelters producing 25,100 tons.[71] Or, in this 10-year period, 152,700 tons of metallic zinc was produced in United States smelters. In the next 10 years zinc production almost trebled. Production increased to meet national demands until a maximum of 346,676 tons were smelted in 1913.

6. *Complex zinc ores made available.*—The zinc industry had become well established in Germany, Belgium, France, and Great Britain long before it began in this country; consequently, European markets were supplied by European zinc smelters. With the beginning of the World War, the German and Belgium zinc industry was demoralized. Zinc was essential for the manufacture of brass cartridge metal. United States zinc mines increased their output in all zinc-producing States, and smelter capacities doubled. In 1917, 669,573 tons of metallic zinc were produced.

7. This sharp demand gave impetus to the commercialization of the electrolytic treatment of complex zinc ores of Montana, Idaho, and Colorado. The development of the electrolytic zinc process brought about the application of selective flotation to complex zinc ores. Not only was a greater recovery of zinc made possible, but lead, silver,

[71] Siebenthal, C. E. Zinc Production in the United States Before 1882.

gold, cadmium, and other metals were recovered, thereby lessening the cost of zinc production. The zinc produced was also of great purity. The low cost of production in the Rocky Mountains forced tri-State miners to adopt flotation where ores had valuable byproducts and forced smelters to consider new methods of concentrate reduction.

8. *Lead ores a source of zinc.*—In 1925 the big lead smelters of Utah constructed lead-zinc flotation plants where lead-zinc ores of their own and other mines were concentrated. These ores usually contain less than 10 percent zinc. Instead of being penalized for this zinc, the miner is now paid for it.

9. More recently any zinc that is not segregated from lead by selective flotation is removed from lead furnace slags and recovered as a fume containing 70 percent metallic zinc.

10. *Reorganization of the industry.*—The tri-State mining district had been built up by many small miners selling their ores to smelters located outside the mining fields. But with the growth of the zinc industry, firms originally operating as smelters only acquired zinc mines. Firms consuming zinc in galvanizing, in paints, or in chemicals have built zinc smelters and purchased or leased zinc mining properties. The New Jersey ores have been mined and reduced by one company. The electrolytic treatment of ores has been developed in large units by firms mining their own ores but also purchasing some concentrate. But even today, in the tri-State region and in Colorado and other Rocky Mountain States, there are still a number of small mines in operation.

11. Not only, therefore, are there zinc producers only interested in the zinc industry, but lead, copper, steel, and chemical firms are also zinc manufacturers and miners. The Mining Congress Journal of November 1930 states that there are 92 zinc mines, representing an investment of $200,000,000. There are 4 electrolytic zinc plants and 21 operating retort smelters.

12. *Present-day conditions.*—The expansion in zinc production in the United States, stimulated by war's demands and made possible by electrolysis and flotation, has outstripped the market demands for zinc. Before the war had closed, the American Zinc Institute was organized to bring about better relationships between miner, smelter, and galvanizer and to stimulate the use of zinc. In 1929, 624,520 tons of primary zinc were produced in this country and 47,348 tons of secondary zinc were redistilled, making a total of 671,868 tons. This production was attained with smelters operating at less than 60 percent capacity. The apparent consumption given by the Bureau of Mines was but 564,049 short tons.[72] Output of primary zinc fell to 498,045 tons in 1930, while production of redistilled secondary zinc was 34,849 tons, giving an available supply of but 532,894 short tons in the last year.

13. Zinc slab prices at St. Louis were $0.04266 in November of 1930, as compared with $0.06242 in November 1929 and $0.08568 in November of 1925. In the Rocky Mountain regions where complex ores are mined, zinc has been regarded as somewhat of a byproduct, adding value to the silver, lead, and copper marketed. The low prices prevailing in 1930 on all four ores caused small mines in the West as well as in the Middle West and East to close down.

[72] U.S. Bureau of Mines. Production of Slab Zinc and Rolled Zinc in 1929. U.S. Bureau of Mines Production of Slab Zinc and Rolled Zinc in 1930.

TABLE I.—*Types of zinc and lead ore mined in each State in 1928* [1]

[In short tons]

State	Zinc-lead, lead-zinc, and complex ores				Zinc-oxide or sulphide ores		Lead-sulphide ore	
	Zinc content	Value	Lead content	Value	Zinc content	Value	Lead content	Value
Total	551,125	$67,237,300	607,052	$70,302,227	144,045	$19,516,228	20,082	$2,329,246
Arizona	639	77,997	1,640	190,347			5,550	643,749
Arkansas	86	10,492	38	4,408				
California							946	109,680
Colorado	35,731	4,359,182	21,861	2,419,914			5,890	683,186
Idaho	31,263	3,814,126	142,354	16,513,042			2,969	344,420
Illinois	17	2,074	385	44,660				
Kansas	107,251	13,084,622	25,276	2,932,016				
Kentucky	92	11,224	39	4,524				
Missouri	12,974	1,582,828	195,393	22,665,588				
Montana	82,830	10,105,270	16,221	1,881,631			659	76,428
Nevada	3,398	414,599	4,278	496,174			3,596	417,178
New Jersey					99,871	$14,127,000		
New Mexico	31,203	3,806,766	7,795	904,270			10	1,139
New York					11,257	1,373,354		
Oklahoma	180,252	21,990,744	43,687	5,067,692				
Oregon							7	768
South Dakota							37	4,292
Tennessee	(2)	(2)			[2] 32,917	4,015,874		
Texas							348	40,343
Utah	46,929	5,725,298	145,845	16,918,078			70	8,063
Virginia	(2)	(2)	(3)	(3)				
Washington	43	5,204	542	62,915				
Wisconsin	18,417	2,246,874	1,698	196,968				

[1] Compiled from reports of U.S. Bureau of Mines.
[2] Includes zinc content of ores mined in Virginia.
[3] Lead content of Virginia ores not available.

PRODUCTION OF ZINC AND LEAD ORES IN THE SEVERAL STATES

14. *Washington.*—In the northeast corner of Washington, in Pend Oreille and Stevens Counties, are located zinc carbonate, lead-zinc ores, lead ores, and copper-lead ores. One thousand tons of zinc and 508 tons of lead were produced in 1929. The only year in which a greater amount of zinc was produced was in 1923, when a total of 1,512 tons was reached. The lead-zinc ores contain some silver and a little gold. The zinc ore averages about 8.6 percent recoverable zinc and the lead-zinc ore about 7 percent. Recently a "zinc rush" to the Metaline district led to the establishment of a number of claims by individual miners in this district. It has been reported that the Pend Oreille Lead & Zinc Co., with mines and flotation plant near Metaline Falls, and the Reeves McDonald properties in British Columbia have been taken over by the Pend Oreille Mines & Metals Co. It is believed this company is contemplating the establishment of an electrolytic plant for reduction of both Canadian and American ores in Washington State.[73] In 1929 zinc concentrate from the Grandview Mill was shipped to the new electrolytic zinc plant near Kellogg, Idaho. Lead-zinc ore from the Great Western project was shipped to Mineral Point, Wis.

15. *Idaho.*—Zinc is found in largest quantity in the lead-zinc ores in Idaho. While 60 percent of the lead mined in the State and 51 percent of the silver is gotten from lead ores, 98 percent of the zinc is concentrated from lead-zinc ores containing silver, a little gold, and

[73] Senate hearings. Tariff Act of 1929. Vol. III.

some copper. The Coeur d'Alene district in Shoshone County is by far the largest producing district, but Blaine County mined about 2,500 tons in 1929, and small amounts were mined in Valley and Bonner Counties. Custer County produced zinc in 1928.

16. The State mined 5.5 percent of the total zinc in the United States in 1929, 22.9 percent of the lead, and 15.4 percent of the total silver mined. The erection of the electrolytic zinc plant near Kellogg by the Bunker Hill & Sullivan Mining & Concentrating Co. and the Hecla Mining Co. to treat zinc ores of the Couer d'Alene district will serve to stimulate the mining of complex ores in northern Idaho when market conditions warrant. Much Idaho ore is still sent to Great Falls and Anaconda electrolytic plants.

17. *Montana.*—Until the adoption of selective flotation, zinc was largely a waste product of silver mines in Montana. Although some lead occurs with the zinc, lead is distinctly a by-product of zinc concentration, rather than zinc a by-product of lead concentration, as in Idaho.

18. Almost four fifths of the zinc produced in 1929 came from the Butte region in Silver Bow County. Some was recovered from the fuming plant at the East Helena lead smelter of the American Smelting & Refining Co. Zinc ore in relatively small amounts was produced in Lewis and Clark, Judith Basin, Granite, Jefferson, Cascade, Broadwater, Lincoln, Madison, Mineral, and Sanders Counties. The total State production of zinc in 1929 was 54,900 tons, forming 8 percent of the total national production. In addition, 19,607 tons of lead and 12,716,977 fine ounces of silver were produced. In 1928 zinc production totaled 82,830 tons, the highest achieved to date.

19. The electrolytic plants at Great Falls and Anaconda treat all ores mined by the Anaconda Copper Co. and custom ores from Montana, Colorado, Utah, and Idaho. A rough estimate states that about half the concentrate treated originates in Montana, about a third in Colorado and Utah, and about 17 percent in Idaho. This mixed concentrate contains approximately 53 percent zinc and 3.6 percent lead.

20. *Colorado.*—Colorado has a large number of relatively small complex ore bodies containing lead, zinc, or copper, gold, and silver. The principal zinc-producing counties are Lake, San Juan, and Dolores Counties, although some zinc is produced in Summit, Pitkin, Hinsdale, Gunnison, Eagle, and Clear Creek Counties. Total production in 1929 was 23,600 tons or 3.4 percent of the United States total. In 1928 it was 35,731 tons. This is less than the average annual production from 1911 to 1920. With the increased zinc production in other mountain States, Colorado miners have found competition keen. The smallness of the mines, their individual ownership, and the relatively low-grade ore do not permit the establishment of smelters or electrolytic plants. Consequently, concentrate is shipped to Illinois, Texas, or Montana for smelting or electrolytic treatment, and must bear transportation costs. Colorado produced 24,445 tons of lead, 4,397,377 fine ounces of silver, and $4,417,358 in gold.

21. *Utah.*—Until 1925 Utah produced but little zinc. Most of its lead-zinc ores contain less than 10 percent zinc. They were smelted for their lead and silver content, and zinc was not recovered. Ores containing more than this amount of zinc incurred a zinc penalty

at the lead smelters and yet had not sufficient zinc content to warrant shipment to zinc smelters. The adoption of selective flotation by the Tooele lead concentrator of the International Refining & Smelting Co. in November 1924 and by the United States Smelting & Refining Co. caused the production of zinc in Utah to jump from 9,281 to 26,306 tons in 1 year. Other companies later installed selective flotation units, so that Utah's zinc production reached 49,593 tons in 1928 and 46,929 tons in 1929, in which year it formed 9 percent of the total United States zinc production. The lead production of Utah in 1929 was 149,377 tons, the silver, including placer production, 17,592,396 fine ounces, and the gold, 240,419 fine ounces. The principal zinc-mining counties are Salt Lake and Wasatch. Summit, Tooele, Beaver, Juab, Sevier, and Utah Counties also produced zinc in 1929.

22. *Other Rocky Mountain States.*—Nevada produced 3,398 tons of zinc in 1928 and 1,200 tons in 1929, chiefly as a byproduct of lead concentration. Lincoln County was the chief zinc and lead mining center, while some zinc was produced in Nye, Clark, Elko, Eureka, and Mineral Counties. Nye County was the principal silver-producing county.

23. Arizona produced its maximum amount of zinc in 1926 when, from ores mined, 6,473 tons of zinc were obtained. In 1929 production was but 1,000 tons. The production is chiefly from lead-zinc ores in Santa Cruz County. Concentrate is shipped to the Amarillo and El Paso, Tex., smelters.

24. New Mexico produced 35,100 tons of zinc in 1929, or 5 percent of the United States total. Zinc is found in complex sulphide ore containing lead, iron, and sometimes copper and gold and silver. The largest producing mine is the Pecos Mine of the American Metal Co., in San Miguel County. Grant and Socorro Counties also produced some zinc. Lead production totaled 11,130 tons, and silver 1,121,546 fine ounces.

25. *Other Pacific Coast States.*—California mined ore having 10,217 tons zinc content in 1926, but has not produced any zinc in 1928 or in 1929. In the copper region of Shasta County some ores have higher zinc than copper content. Lead-zinc sulphide ore was reported from Plumas County in 1915. Zinc sulphide has also been found in the foothill copper belt, extending from Nevada County to Madera County. Ingo County produced 670 tons of lead in 1929, while small amounts were produced in seven other counties.

26. Oregon produces some lead in the eastern part. It is not marketing any zinc, although the zinc occurs in complex lead-zinc deposits in western Oregon.

TABLE II.—*Mine production of recoverable zinc in the United States* [1]

State	1925 (short tons)	1926 (short tons)	1927 (short tons)	1928 (short tons)	1929	
					Short tons	Percent
Total	710,847	774,563	718,541	695,170	695,000	100.0
Arizona	3,666	6,473	1,134	639	1,000	.1
Arkansas	43	87	128	86		
California	5,745	10,217	4,031			
Colorado	30,811	32,500	35,865	35,731	23,600	3.4
Idaho	15,619	26,307	26,778	31,263	38,300	5.5
Illinois	2,724	2,577	521	17		
Kansas	118,778	126,307	109,427	107,251	106,000	15.3
Kentucky	429	1,838	860	92		
Missouri	14,794	26,018	18,737	12,974	9,300	1.3
Montana	57,658	73,701	80,231	82,830	54,900	7.9
Nevada	7,411	5,409	3,172	3,398	1,200	.2
New Jersey	89,261	80,629	95,695	99,871	102,000	14.7
New Mexico	9,246	12,052	29,802	31,203	35,100	5.1
New York	5,158	5,041	3,750	11,257	(2)	
Oklahoma	283,371	272,567	206,611	180,252	197,000	28.3
Tennessee	16,256	12,098	10,400	[3]32,917	47,000	6.8
Utah	26,306	47,590	49,593	46,929	61,600	8.9
Virginia	2,732	5,830	8,325	(3)	(3)	
Washington	609	522	640	43	1,000	.1
Wisconsin	20,230	26,800	32,841	18,417	17,000	2.4

[1] Compiled from U.S. Bureau of Mines: Zinc in 1928, p. 376, and Mineral Industry, 1929, p. 665.
[2] Included with Tennessee total.
[3] Figures for Virginia not available; included with total for Tennessee.

27. *The Tri-State District.*—At the junction of Oklahoma, Kansas, and Missouri lies the largest zinc producing district in the United States. Oklahoma produced 197,000 tons of zinc in 1929, or 28.3 percent of the United States production; Kansas produced 15 percent, and Missouri 1.3 percent. Highest production was achieved by Oklahoma in 1925, when the zinc content of ores mined was 283,371 tons. Prior to 1915 Missouri was the principal zinc-producing State in the district, but since that date Oklahoma and Kansas have been by far the more important producers of zinc, and Missouri the leading lead-producing State in the Union. Oklahoma zinc is mined in Ottawa County, Kansas zinc in Cherokee County, Missouri zinc in Jasper, Newton, and Lawrence Counties, and also in St. Francois County, in the southeastern part of the State, where lead forms the principal mineral mined and zinc is a byproduct.

28. Surface deposits were found rich in zinc. Deeper mines contain disseminated ores. Both sulphide and carbonate zinc ores occur, the zinc ore being usually associated with lead ore. In Oklahoma the metal content of crude ore is 2.42 percent zinc and 0.42 percent lead. In Kansas it averages 2.4 percent zinc and 0.5 percent lead. In southwestern Missouri the ores contain 2.26 percent zinc and 0.25 percent lead, whereas in southeastern Missouri they contain 0.06 percent zinc and 3.13 percent lead. In addition to new ore mined, a quantity of old tailings and slimes are treated in Kansas and Oklahoma. Less than a third of the lead and zinc concentrates were produced by flotation in 1929. Thirty-two companies produced more than 5,000 tons of zinc concentrate in 1929, the largest operating company being the Commerce Mining & Royalty Co.

29. *Wisconsin.*—Wisconsin ore is similar in character to the zinc-lead ores of the Tri-State district but it contains 3.53 percent zinc and but 0.26 percent lead. Zinc has been mined in Wisconsin for many years and production played a greater part in the national markets

prior to 1920 than it does today. In 1929, 17,000 tons of zinc were produced, forming 2.4 percent of United States mined ore zinc content. Between 1916 and 1920, Wisconsin mined about 7 percent of the country's total production. Mining is done in Iowa, Granite, and Lafayette Counties. Lead production is small.

EASTERN STATES

30. New Jersey is the third largest zinc producing State in the Union. Sussex County contains zinc oxide ores known as franklinite, zincite, and willemite, ores found nowhere else in any quantity. In 1929 ore having 102,000 tons zinc content was mined by the one producing company, the New Jersey Zinc Co., which owns both mines and smelters. The franklinite concentrate is used to produce zinc oxide and the willemite concentrates for metallic zinc.

31. Pennsylvania has small deposits of zinc and lead ores in Lehigh County and in Blain County which are operated occasionally. The principal zinc producing area in New York is operated by the St. Joseph Lead Co., near Edwards in St. Lawrence County. The ore is chiefly sulphide and iron sulphide and is fine grained.

32. Some mining has taken place in Tennessee for many years. Recently, developments have proceeded on a large scale. Sulphide zinc ores are produced at Mascot in Knox County by the American Zinc Co. Carbonate ores are produced by the Mineral Exploration Co. (a United States Steel subsidiary) and two other companies operating near Jefferson City, Jefferson County, and in Embreeville, Washington County. In addition, the Tennessee Copper Co. separates zinc from its copper ores through selective flotation.

33. The Universal Exploration Co. has developed not only a large reserve of carbonate ores now shipped to zinc oxide manufacturers, but also has large high-grade sulphide ore reserves. Mill equipment to treat 25,000 tons zinc concentrate per year is now installed and provision made to triple this capacity when market conditions are favorable.

34. Tennessee and Virginia produced 6.8 percent of the Nation's zinc in 1929, or 47,000 tons. This is more than twice as much as the State's 1927 production. The New Jersey Zinc Co. was the sole producer of zinc in Virginia in 1929. It operated zinc-lead-sulphide mines near Austinville in Wythe County. Tri-State companies are developing tracts near Wytheville and prospecting in other sections of the State is taking place.

35. Several other States have small zinc deposits that might be developed were the demand for zinc very great. However, the country's resources are so large that small deposits will have value only when very cheaply mined or when located close to consuming markets.

PRODUCTION OF METALLIC ZINC AND ZINC OXIDE FROM ORE

36. *Location of reduction plants.*—As fuel is essential to zinc distillation, zinc smelters were established in coal-mining regions or in natural-gas regions. The natural gas found in Oklahoma and Kansas was responsible for the erection of zinc smelters in these States to smelt zinc ores from the Tri-State district. The gradual depletion of the gas supply caused a number of companies to move to, or erect new plants in, Illinois coal fields or in Arkansas gas fields. New Jersey

ships its ore for distillation to Palmerton, Pa., while mines in the Southern States ship to Middle Western or Pennsylvania smelters. New construction is taking place in West Virginia coal fields. Texas smelters care for Arizona and New Mexico zinc.

Electrolytic plants are located near abundant power sources, whether such power is generated from water or from coal.

TABLE III.—*Zinc distillation and electrolytic plants operating in 1929* [1]

Location	Operating company	Zinc capacity (short tons)	Products other than slab zinc manufactured at plant
Arkansas:			
Fort Smith	Athletic Mining & Smelting Co	40,000	
Van Buren	Van Buren Zinc Co.[2]	40,000	
Idaho: Kellogg	Sullivan Mining Co	[3] 23,725	Manganese dioxide.
Illinois:			
Danville	Hegeler Zinc Co	64,000	Rolled zinc, sulphuric acid.
Depue	Mineral Point Zinc Co	100,000	Lithopone, sulphuric acid.
East St. Louis	American Zinc Co. of Illinois	46,000	Sulphuric acid.
Do	Evans-Wallower Zinc Co	[3] 20,075	Cadmium. Sulphur dioxide made into acid at neighboring plant.
La Salle	Matthiessen & Hegler Zinc Co	31,000	Rolled zinc, sulphuric acid.
Peru	Illinois Zinc Co	42,000	Do.
Indiana: Terre Haute	Grasselli Chemical Co	48,300	Sulphur dioxide shipped to Grasselli, Ind., plant.
Kansas:			
Caney	Weir Smelting Co	18,000	
Cherryvale	Edgar Zinc Co	51,000	
Montana:			
Great Falls	Anaconda Copper Mining Co	[3] 127,750	Cadmium.
Anaconda	....do	[3] 63,875	Do.
Oklahoma:			
Bartlesville	National Zinc Co	60,000	Sulphuric acid.
Blackwell	American Metal Co., Ltd	74,000	
Henryetta	Eagle-Picher Lead Co	64,000	
Kusa	Kusa Spelter Co	35,000	
Quinton	Quinton Spelter Co	40,800	
Pennsylvania:			
Donora	Donora Zinc Co	100,000	Sulphuric acid.
Langeloth	American Metal Co., Ltd	64,000	Sulphuric acid, zinc salts.
Palmerton	New Jersey Zinc Co	110,000	Rolled zinc, zinc oxide, sulphuric acid, lithopone, zinc dust, die casting alloy.
Texas: Amarillo	U.S. Zinc Co	96,000	
West Virginia:			
Meadowbrook	Grasselli Chemical Co	79,900	Zinc dust, sulphur dioxide shipped to other plants.
Moundsville	United Zinc Smelting Corporation.	31,000	Sulphuric acid.

[1] Compiled from The Mineral Industry During 1929, p. 665, and Zinc in 1928, U.S. Bureau of Mines.
[2] Idle part of year.
[3] Electrolytic zinc.

37. In 1929, the largest amount of primary zinc, or zinc manufactured from zinc concentrates and ores, was produced by the two electrolytic plants in Montana. Almost equal proportions were distilled in Oklahoma, Illinois, and Pennsylvania. Distilled zinc was also produced in Kansas, Arkansas, West Virginia, Indiana, and Texas, while electrolytic zinc production had gotten underway in Idaho and, in September 1929, in Illinois.

TABLE IV.—*Primary zinc produced in each State* [1]

State	1925	1926	1927	1928	1929	
	Short tons	Short tons	Short tons	Short tons	Short tons	Percent
Total	572,946	618,422	592,516	602,581	624,520	100.0
Arkansas	27,145	32,712	26,317	20,505	17,923	2.9
Idaho				1,939	16,582	2.7
Illinois	109,672	110,381	102,768	103,765	110,007	17.6
Kansas	25,765	33,671	33,144	33,923	37,795	6.0
Montana	79,004	111,596	112,629	158,221	[2] 139,510	22.3
Oklahoma	138,906	136,560	120,801	106,557	111,683	17.9
Pennsylvania	99,899	100,538	106,099	108,802	108,167	17.3
Other States	92,555	92,964	90,758	68,869	82,853	13.3

[1] Compiled from U.S. Bureau of Mines: Zinc in 1928, p. 366, and Preliminary Report of May 28, 1930, p. 2.
[2] Electrolytic includes a small quantity from Illinois.

38. *Slab zinc production.*—The primary zinc production totaled 624,520 short tons. Of this 13,311 tons was from Mexican ore, all other production being from domestic ore. In addition, 47,348 tons was smeltered from secondary metal secured from galvanizers' dross, ashes, and scrap metal. The total amount of slab zinc available at zinc reduction plants in 1929 was, therefore, 671,868 short, tons. This is the largest amount of metallic zinc produced to date in the United States.

39. In spite of this fact, the 21 zinc smelters in operation were using less than 60 percent of their capacity at the end of the year. The total number of retorts reported was 107,500, whereas but 62,200 were in active operation. Table III lists the electrolytic and distillation plants and their capacities in 1929. Distillation capacity totaled 1,235,000 short tons. Electrolytic capacity, based on 365-day operating year, totaled 235,425 short tons.

40. *Zinc oxide production.*—Zinc oxide is produced chiefly from zinc ores although it may be manufactured from metallic zinc and secondary zinc. One hundred twenty-four thousand and ninety (124,090) short tons of ore is used in the production of zinc pigments. Of this 70 percent enters into the production of zinc oxide by the American process, 21 percent into lithopone, and only 9 percent into leaded zinc oxide. Metallic zinc, to the extent of 37,588 tons, entered into the manufacture of French process zinc oxide, whereas 25,353 tons of secondary material produced lithopone, leaded zinc oxide, and zinc salts.

41. Firms manufacturing zinc oxide and leaded zinc oxide from zinc ores are as follows:

Colorado:	Canon City, Empire Zinc Co.
	Florence, River Smelting & Refining Co.
	Leadville, Western Zinc Oxide Co.
Illinois:	Hillsboro, American Zinc Co. of Illinois (also produces sulphuric acid); Eagle Picher Lead Co. (also produces sulphuric acid).
Indiana:	Grasselli, Grasselli Chemical Co. (also produces sulphuric acid and lithopone).
Kansas:	Coffeyville, Ozark Smelting & Mining Co.
Ohio:	Columbus, American Zinc Oxide Co. (disposes of sulphur dioxide gas to Farmer's Fertilizer Co.).
Pennsylvania:	Palmerton, New Jersey Zinc Co.
Wisconsin:	Mineral Point, Mineral Point Zinc Co. (also produces sulphuric acid).

42. Plants producing zinc oxide from metallic zinc are the International Lead Refining Co. of East Chicago, Ind., and Akron, Ohio, which receives electrolytic zinc from the Anaconda Copper Co., and the New Jersey Zinc Co. at its Freemansburg (Pa.) plant.

43. *Zinc-dust production.*—Zinc dust or "blue powder" results during the course of zinc distillation and is marketed by six companies for sherardizing small articles. The total sold was 9,172 tons in 1928. One company, the Alloys Co., of San Francisco, produces "atomized zinc dust" by ejecting molten metal from a nozzle under pressure. The electrolytic plants use their own atomized zinc dust in the process of purifying the zinc solution, whereas the larger number of distilleries distill their blue powder.

44. Smelters marketing zinc dust are the Grasselli Chemical Co., of Meadowbrook, W.Va., and the New Jersey Zinc Co., at Palmerton, Pa. Other firms specializing in zinc-dust production are the Alloys Co. and the John Finn Metal Works, of San Francisco; the Federated Metals Works, of Trenton; and the United States Zinc Co., of Sand Springs, Okla.

45. *Byproduct sulphuric acid.*—Wherever zinc sulphide ores are roasted sulphur dioxide is given off. This is manufactured into sulphuric acid by some zinc distillation plants and some zinc oxide plants, or it may be shipped to nearby acid plants or acid plants near acid markets. The gases, when converted to acid in zinc factories, are usually supplemented with sulphur to utilize acid-plant capacities to the fullest. Twenty-one zinc roasting plants manufactured sulphuric acid in 1928, producing 1,056,725 short tons of acid. While some of this was consumed at the plant, acid sold had a value of over $11,000,000. This byproduct manufacture formed about 19 percent of the country's total output of sulphuric acid, although only 10 percent was produced from byproduct gases, the remaining amount being derived from sulphur purchased. The zinc smelters that produced sulphuric acid or shipped it to other plants are indicated on table III. The Evans-Wallower Zinc Co. was the only electrolytic plant marketing its sulphur fumes. These were transferred directly to the neighboring plant of the Monsanto Chemical Co.

Zinc-Reduction Processes

46. The larger amount of zinc carbonate ores are calcined and zinc sulphide ores roasted before being distilled in retort furnaces, while complex ores are leached by sulphuric acid and precipitated electrolytically. At the present date, only one firm treating zinc-lead sulphide ore is employing the electrolytic process, although the process as now developed is applicable to all sulphide ores. Table V indicates the growth in the application of the electrolytic method in the last 5 years. Almost a fourth of all metallic zinc manufactured today is produced by electrolysis.

47. The zinc produced by electrolytic precipitation has different characteristics from high-grade retort zinc. It is easily drawn, stamped and extruded and may be rolled and beaten into thin sheets, whereas retort zinc is a harder metal.

TABLE V.—*Methods of primary and secondary zinc reduction in the United States*[1]

Reduction method	1925		1926		1927		1928		1929	
	Short tons	*Per-cent*	*Short tons*	*Per-cent*	*Short tons*	*Per-cent*	*Short tons*	*Per-cent*	*Short tons*	*Per-cent*
Total	612, 127	100. 0	659, 221	100. 0	635, 300	100. 0	651, 247	100. 0	671, 868	100. 0
Electrolytic	79, 004	12. 9	111, 596	16. 9	112, 629	17. 7	160, 160	24. 6	156, 092	23. 2
Distilled primary	493, 942	80. 7	506, 826	76. 9	479, 887	75. 6	442, 421	67. 9	468, 428	69. 7
Redistilled secondary	39, 181	6. 4	40, 799	6. 2	42, 784	6. 7	48, 666	7. 5	47, 348	7. 1

[1] Compiled from U.S. Bureau of Mines: Zinc in 1928 and Preliminary Report for 1929, p. 2.

48. *Reduction by electrolysis.*—Gravity concentration has given way almost entirely to selective flotation in the treatment of complex zinc ores. Only through such flotation is a concentrate produced suitable for the production of metallic zinc by electrolytic precipitation

49. *Selective flotation.*—Although the essentials of selective flotation are the same for complex zinc ores as for copper ores, the details of the process vary, due to the wide differences in the two ores. Galena (lead sulphide) and sphalerite (zinc sulphide) do not separate until crushing has been carried to minus 200 mesh. Consequently, fine grinding after crushing is essential. This is usually done in Hardinge ball mills in closed circuit with Dorr classifiers. The overflow from the classifiers passes to the rougher flotation machines of the mineral separations type. This machine consists of a number of cells arranged in series, the pulp flowing from one cell to the next cell, while the froth, carrying mineral, is floated off as it appears. Each cell has a vertical shaft stirrer to agitate the pulp and beat air into it. In the Fahrenwald machine, which is coming into use, rotation of the impeller draws air from the atmosphere, thus functioning as a stirrer and a blower. As the pulp falls upon the top of the rotating impeller it is forced vigorously into the body of the pulp in the cell. The flotation reagents used vary somewhat with the character of the ore treated. For an ore analyzing 13 percent zinc, 9 percent sulphur, 2 percent lead, iron, and lime each, 5 percent aluminum, gold, and silver, and 56 percent silica, sodium ethyl xanthate is used as a collector of the sphalerite and galena, copper sulphate for activation of the sphalerite, calcium cyanide as a depressant of pyrite; burnt lime is employed for alkalinity. These reagents, together with pine oil as a primary frother and coal-tar oil as a froth stabilizer, cause the sphalerite and galena to float while the pyrite and gangue fall to the cell bottom.

50. The bulk concentrate is often cleaned in a Callow or pneumatic type of flotation machine, in which air is introduced below a porous bottom to agitate the pulp and provide air for flotation. The cleaned concentrate is thickened to 50 percent solids and is then agitated with zinc sulphate and calcium cyanide which depress the sphalerite while floating off the galena. The tailing is a relatively high-grade zinc concentrate.

51. In other plants two circuits are operated—a lead circuit and a zinc circuit. Thiocarbanilid is used as the basic lead collector, sodium cyanide as the lead accelerator, and zinc iron as the depressant in the mineral separation subaeration machines. The lead concentrate floated passes through Callow pneumatic cells to Dorr thickeners and filters, while the middlings and Callow cleaner tailings pass through the rougher cells a second time. After lead is removed, the

lead rougher tailings are heated to 30° and pass through Dorr thickeners to the zinc circuit, where aerofloat or phosphocresylic acid is the basic collector and frother and copper sulphate the accelerator. The zinc concentrate passes to thickeners and filters, while the remaining pulp passes through an iron circuit in which the Callow cell is used as both rougher and cleaner flotation machines to float off iron.

52. *Electrolytic zinc processes.*—Two processes for producing electrolytic zinc have been developed in the United States. That used at the Great Falls and Anaconda plants of the Anaconda Copper Mining Co. is known as the Anaconda process and that employed at the Sullivan plant, Idaho, and at the Evans-Wallower plant, Ill., is the Tainton process. The principles underlying both processes are the same. Zinc concentrates are roasted to convert the zinc sulphide into soluble oxide or zinc sulphate. This calcine is leached with dilute sulpuhric acid to dissolve out the zinc content and is purified. The zinc is precipitated from the resulting solution by electrolysis. The chief differences in the two methods lie in the fact that in the Tainton process the plant is designed to make use of a high-acid process and high-current density, while Anaconda employs low-current density and low-acid content.

53. A description of the Tainton process, as carried on in Idaho, will be given and the major differences in other plant procedure will be noted later.

54. *Roasting and leaching.*—The concentrate, after being disintegrated by rolls, passes to modified wedge roasters having seven roasting hearths and a top hearth for drying the feed. Water or air cooled arms revolved from the center shaft carry the concentrate from circumference to center on the drying hearth, from which it dumps through holes to the next hearth, and so on down through the furnace. A Mahr oil burner is provided to maintain sufficiently high temperatures to insure a good roast. The calcine drops to a chain conveyor and is delivered to a leaching screen, while the gases rise upward and are cleaned by a Cottrell treater. The oversize from this screen is crushed in a ball mill and returned to the roaster. The calcine that passes through the screen goes to two magnetic separators which take out from 30 to 50 percent of the magnetic material present in the concentrate—that is, the zinc and copper ferrites and the zinc sulphide. This passes to ferrite bins, while the nonmagnetic calcine goes to oxide bins. These bins, together with a third manganese ore bin and weighers, are located above each leach agitator. Agitator tanks are made of wood lined with lead, the stirring mechanism being driven by a 15-horsepower motor equipped with reducing gears. Return electrolyte heated to 60° C. and containing 28 to 30 percent free acid is pumped into the primary agitators. A charge of ferrite is dumped in and agitated, decomposing most of the relatively insoluble zinc compounds. Crushed manganese dioxide ore is added to oxidize the dissolved iron. The zinc oxide is then added until all iron is precipitated. As the pulp reaches the boiling point, water is evaporated. The pulp is passed through Burt filters to mechanical purification agitators, where the solution which contains dissolved zinc, cadmium, copper, cobalt, and nickel is treated with zinc dust, which precipitates all the metals except zinc. When precipitation is complete, the solution goes through Shriver filter presses and is ready for the electrolytic cells.

55. *Byproducts.*—The residue from the leaching tanks contains lead, silver, gold, iron, and silica. It is thickened, filtered, and dried for shipment to lead smelters. The residue from the Shriver filter press passes to storage tanks in the cadmium plant. This copper-cadmium cake is treated in agitator tanks until the cadmium is in solution. It is filtered, separating out the high-grade undissolved copper, which is shipped to the smelter. The cadmium solution goes to an electrolytic cell, where it is precipitated. The cadmium cathode is melted down and cast into slabs. These are recast, frequently under molten caustic soda, into balls of 2-inch diameter for use in the plating industry, or into other marketable forms.

56. *Electrolytic precipitation according to Tainton process.*—At the Idaho plant the cell room contains 2 circuits of 150 cells, each cell containing 10 cathodes and 20 anodes. At the East St. Louis plant the cell room contains 190 cells in series, each containing 12 cathodes and 24 anodes. The cathodes are of aluminum sheet, with aluminum conductor bars welded at the upper end. The anodes are a silver-lead alloy perforated to permit free circulation of the electrolyte and to decrease terminal voltage. The cathodes slide into grooved wooden guides fixed in the cell with a wooden framework so that the framework also holds two anodes at definite spacing between each cathode. The solution, containing about 20 percent zinc and 22 percent sulphuric acid, is fed to the center of each cell through hard-rubber pipes and is circulated in parallel through the cells down to sumps. From the sumps it flows through a thickener that recovers manganese dioxide to storage tanks. Before returning to the cells it is cooled by passing through water-cooled coils to launders. A colloid, such as gum arabic, is added to the electrolyte for the smooth deposition of zinc.

57. The current is led into the conductor bars through spring chips at the side of the cell. It is supplied by motor generator sets having an efficiency of 91 percent.[74] At Kellogg 8,000 amperes at 500 volts can be delivered to each circuit, the motors each having a capacity of 4,000 kilowatts. At East St. Louis the motor has a 6,500-kilowatt capacity and can deliver 10,000 amperes at 600 volts.

58. Zinc is deposited at a current density of 100 amperes per square foot and is stripped from the cathodes at intervals of 12 to 16 hours. According to Mr. F. S. Elfred, of the Evans-Wallower Zinc Co., only 1,760 kilowatt-hours of energy are required, theoretically, to produce 1 ton of zinc.[75] The current efficiency in the tank averages 85 percent, according to E. R. Fosdick, which would only bring the tank consumption of energy per ton of zinc to 2,024 kilowatt-hours with this current density. With a 9 percent additional loss at transformers and other points, 2,206 kilowatt-hours energy would be essential for the deposition of 1 ton of zinc. Almost 10 percent additional power is necessary for compressed air, roasters, and other plant operations, bringing the total consumption to about 2,426 kilowatt-hours direct current.

59. A steady current is one of the essentials for the electrolytic deposition of zinc. For although zinc remains undissolved in sulphuric acid while electric current is passing through it, deposited zinc will be redissolved into the acid whenever current is off.

[74] Fosdick, E. R. Journal American Institute of Electrical Engineers. 1928. 77. P. 808.
[75] Elfred, F. S. Address Before American Die Casting Institute. January 1930.

60. The Kellogg plant secures its power from the Washington Water Power Co., whose generating station is 100 or more miles distant from the plant. The East St. Louis plant's power is supplied at 13,200 volts through an underground cable directly from the switchboard of the Cahokia power generating plant of the Union Light & Electric Co. This station is a large steam-power unit located within half a mile of the zinc reduction plant.

Zinc sheets are melted in either gas- or oil-fired furnaces, and the molten metal is cast into slabs. The zinc is 99.99 percent pure.

COMPARISON WITH THE ANACONDA PROCESS

61. At Great Falls the roasters are fired by natural gas having heat value of 930 B.t.u., 2,400 cubic feet being required per ton of new furnace feed as compared with 14 gallons of oil of 18,500 B.t.u. heat value and 0.92 specific gravity used per ton of feed at the Anaconda roaster.

62. In place of batch leaching of the calcine, continuous leaching is employed. To the spent electrolyte containing 10 to 15 percent free acid scrap iron is added. This is oxidized with manganese dioxide to ferric sulphate before calcine is added. The excess zinc oxide causes the oxidized iron to form insoluble salts with arsenic and antimony, which are precipitated. Because the recovery of zinc is low in this first or "neutral" leach, about half of the spent electrolyte is added to the second or "acid" leach to recover practically all acid-soluble zinc. The copper and cadmium in this solution are precipitated by agitating with finely divided particles of metallic zinc. This sludge is roasted and leached with sulphuric acid to recover the zinc and cadmium and precipitate the copper. The zinc cadmium solution is heated and circulated slowly through tanks in which zinc slabs are suspended to precipitate the cadmium as a spongy deposit on the zinc slabs.

63. The Great Falls electrolytic division is divided into 8 circuits each containing 144 cells arranged in cascades of 6 cells each, each cell containing 28 lead anodes and 27 aluminum cathodes. In addition there are 12 reserve cells. Rotary converters having a capacity of 10,000 amperes at 580 volts supply the current to each circuit. They have a conversion efficiency of about 93 percent. The Anaconda plant has four such units, but they are connected to motor-generator sets. Current density is approximately 30 amperes per square foot of cathode area in both plants, and the zinc deposited on both sides of the cathodes is recovered every 24 hours. The power required averages 3,200 kilowatt-hours per ton zinc produced. The other processes in the plant require an additional 5 percent power, so that the total number of kilowatt-hours used is about 3,350 per ton of zinc produced. The two zinc plants require approximately 75,000 kilowatts of electric energy daily.

64. The Great Falls zinc substation receives power at 110,000 volts which are stepped down to 406 volts through 9 water-cooled transformers. The Montana Power Co. furnishes power to the zinc plant at Anaconda over a 100,000-volt, 3-phase, 60-cycle transmission line to an outdoor high-tension bus.

REDUCTION BY DISTILLATION

65. *Concentration.*—Sulphide-zinc ores and much carbonate ore must undergo some concentration before shipment to smelters. For many years jigging following a coarse crushing was the usual form of concentration. In the jigs used water is forced through a screen by action of a piston causing particles to be sorted under the influence of the rising column of water. These fixed-sieve jigs have a number of cells per unit with a separate piston or plunger for each cell. The lessening of the amount of coarsely crystallized ore made up of zinc sulphide, lead sulphide, and waste, all having varying specific gravities, together with the sharp competition from complex ores, are gradually bringing about new methods of concentration. Electrostatic separation, causing the sulphides to be repelled from a charged table, has had much application. Flotation has been adopted for fine ores containing residue of some value. Mills continuing a mechanical concentration are grinding the ore after crushing for a more complete segregation of the minerals from the waste. Bendelaire diaphragm jigs are being introduced. Classifying before tabling has been found effective.

66. *Distillation.*—Distillation operations are also undergoing change in the effort to secure greater metal recovery at less cost. It is still standard practice to dry and crush the coarse milled zinc-lead sulphide concentrates and roast them in kilns until they contain but one half of 1 per cent sulphur. This calcine is a finished product ready for the regenerative furnaces. Carbonate ores are crushed and slightly calcined to drive off water and impurities. Zinc-sulphide flotation concentrates are roasted in hearth furnaces having water-cooled rabble arms until sulphur is reduced to approximately 3 or 4 percent. After screening and cooling, this calcine is carried in uniform thin layers through a wind box sintering machine from which it emerges as a porous cake with less than 1 percent sulphur. This is crushed and screened ready for the mixing room.

67. In the mixing room approximately 35 percent reduction fuel made up of coke, bituminous coal, and a little salt is added to the roasted concentrates. This is charged in retorts which are placed in rows in a regenerative furnace, usually about 400 per side. Gas and preheated air are introduced through ports under the retort rows. In burning, the flames rise and descend between the retorts. The direction of the gas current is reversed at intervals of 30 minutes. As the temperature is gradually increased the carbon first reduces the metallic oxides other than zinc. These, together with hydrocarbons, are driven off. At a higher temperature zinc vapors rise from the retorts and are cooled as they circle around the interior surface of a condenser. Vapors condense and are collected at the base of the furnace. Distillation requires about 19 hours and setting up the furnace, 5 hours.

68. In a plant using a Neurenther Siemens regenerative furnace 1 ton of coal is required as furnace fuel per ton of roasted Tri-State ore; and one half ton is required for power and steam. In a Hegeler furnace 1.6 tons of furnace fuel and one tenth ton of coal for power and steam are consumed. In the natural gas districts gas is used in place of coal, approximately 40,000 cubic feet being used to distill a ton roasted zinc sulphide. Waste gas from byproduct coke ovens is used

by one American zinc company in Mexico where there is no more immediate market for gas.[76]

69. Zinc distilleries manufacture their own retorts, as the average life of a retort is about 37 days. Clay, dug in Missouri, mixed with a little coke, is used chiefly in the Tri-State district.

After passing through a hammering machine and a hydraulic press the retorts are fired in gas kilns.

70. *Zinc oxide manufacture.*—When zinc oxide is desired, instead of condensing the zinc vapors they may be burned and the zinc oxide fume collected by filtration through bags or settlement in chambers.

71. But the larger amount of zinc oxide is produced by the Wetherill or American process. Zinc ore and coal, mixed in almost equal proportions, are spread thinly on grates in a furnace. The zinc is reduced and volatilized. This is immediately oxidized by the carbon dioxide and burned by excess air. The gas passes through settling chambers and then is drawn through long cooling flues and collected in a bag house where zinc oxide is filtered in woolen flues. By the French process, which is employed on metallic zinc, air only is used for oxidizing the distilled zinc, the air being blown through pipes in a central shaft of a Wedge roaster.

72. *New processes.*—Only 60 to 70 percent of the zinc in the concentrate is condensed as metallic zinc in the ordinary distillation furnace. While some of the remainder is secured by the redistribution of samplings, ladle skim, and other between products known as "blue powder", the old methods are not as successful in zinc recovery as is the electrolytic process. The amount of fuel consumed also adds greatly to the cost of these methods. Consequently, efforts are being made to secure greater metal recovery at less cost.

73. An English company is trying out the Coley process, in which liquid hydrocarbon is used as the reducer. The screened raw ore is fed to a preheater and passed through a vertical shaft to the main furnace rotating tube. Surrounding this tube is a regenerative system for burning producer gas to maintain the necessary high temperature. The ore, turned to zinc oxide, passes from the tube to the reduction section of the furnace, where heavy cold oil is sprayed over it. The zinc is liberated and volatilizes, passes to the condenser, and emerges as metallic zinc. It is claimed that 95 percent of the zinc is recovered by this process, that the cost of the plant is one fourth that of the ordinary distillation plant, and that the labor required is less than one third as much.

74. *Electrothermal process.*—The school of mines and metallurgy of the University of Missouri, at Rolla, has erected a modern experimental plant for electrothermic-dry distillation. A briquetted mixture of 100 parts roasted Tri-State zinc concentrate, 70 parts crushed coke, and 25 parts of hard coal is made. These small blocks are piled in a column upon the furnace hearth. A non-heat-conducting cylinder is dropped over the column so that it is gas-tight except for its connection with the condenser. The current is passed through the column of charge and volatilized zinc passes to the condenser and is turned into molten zinc. Any residue is easily removed from the column when distillation is complete. Dr. Charles H. Fulton, the inventor of this process, states that 2,500 kilowatt-hours of power are required

[76] Ingalls, W. R. I. Metallurgy of Zinc and Cadmium. Handbook of Non-Ferrous Metallurgy, pp. 1207–1208.

per ton of zinc. He believes that the electrothermal process for zinc connected with a coke plant will give economical results. This process had not been put into commercial operation in this country.

75. The St. Joseph Lead Co. has been experimenting with the Gaskill process, which is similar to the Fulton process, except that it is a continuous process, for the manufacture of zinc oxide. A small electrothermal plant is in operation in Scandinavia.

BYPRODUCTS

76. *Sulphuric acid.*—Wherever a market exists for sulphuric acid, the sulphur-dioxide fumes driven off from zinc-sulphide ores, whether zinc is produced by distillation or by the electrolytic process, are collected. The gases from roasting furnaces passes through lined steel flues in which part of dust settles. As they are cooled to 400° C. they enter Cottrell treaters for final cleaning. The precipitated dust is shaken out and the gas passes to chambers for sulphuric acid manufacture. When sintering machines are used, the Schmiedel process of collection and cleaning is employed. The gas passes through lead boxes containing a bath of nitrated acid. The sulphur dioxide is converted into trioxide and passed to a series of towers similar to the ordinary chamber process.

77. *Cadmium.*—Cadmium is being used to electroplate ferrous materials and to provide a primary wash for automobile parts that are later to be chromium or nickel plated. As it is only produced as a byproduct of zinc or lead, its extended use will unquestionably lead to greater recovery. As stated on page 258, cadmium is necessarily precipitated before the electro-deposition of zinc. The cadmium is recovered from this precipitation by electrolysis. Cadmium could also be recovered from the roaster flue dusts, zinc dust, or blue powder from zinc distillation. It has also become a byproduct of electrolytic-lead refining or of lead furnaces. In 1929, 1,241 tons were recovered by the Anaconda Copper Mining Co., the Grasselli Chemical Co., New Jersey Zinc Co., American Smelting & Refining Co. in Colorado, and the United States Smelting, Refining & Mining Co., of Midvale, Utah.

78. *Lead and other metals.*—The lead, copper, silver, and gold recovered in selective flotation and from leaching before electrolysis are usually shipped to lead or copper smelters for separation. Other metals could be recovered from zinc sulphide and complex ores if there was a market for them. Such metals are gallium, thallin, germanium, and indium.

ZINC REFINING

79. Ordinarily there is little need for zinc refining. The high-grade zinc produced electrolytically and high-grade distilled zinc more than meet the requirements of the brass-making, zinc oxide, die-casting, and other markets for 99.9 percent pure zinc. Prime Western, which may contain some lead, iron, and cadmium is a harder metal and is used to advantage in galvanizing iron and steel and for rolling into sheets.

80. During the World War, however, the demand for high-grade zinc for brass cartridges led to the refining of crude zinc. This was done at smelters by drawing off the product distilled at lowest tem-

perature and, consequently, low in lead, and shipping this to brass makers, while later draws were sent to galvanizers. Or crude smelter was redistilled or refined by electrolysis. Today these distilling furnaces which permit lead to be tapped from the lower end, while the zinc vapor passes out of the upper end into condensers, are used only for scrap and galvanizers' dross.

81. *Production costs.*—That an electrolytic zinc plant can operate in the Northwest zinc regions, pay freight on slab zinc, and compete with Middle Western retort zinc in the eastern market has been amply demonstrated in the last 10 years. That electrolytic zinc can press prime western zinc hard, is seen by the recent efforts of Tri-State producers to improve methods of concentration and distillation. How much of this commercial success has been due to real differences in cost of producing electrolytic zinc and retort zinc, and how much to the fact that manufacturing costs are partially distributed over recovered lead or copper, gold and silver, and cadmium, is difficult to state. There is no fixed apportionment of costs between the several products resulting from the electrolytic production of zinc. A high price for any byproduct, makes zinc production possible at a lower figure.

82. *Concentration costs.*—This difficulty in cost distribution begins with the production of flotation concentrates from complex ores. Take, for example, the concentrate produced at one western mine. The mill feed contained 5.15 percent lead, 4.5 percent zinc, 8.53 ounces of silver, and 0.024 ounce of gold, and other metals. A 2-circuit flotation system produced two concentrates: A zinc concentrate assaying 46.57 percent zinc, 2.71 percent lead, 11.8 percent iron, 28 percent sulphur, 13.65 ounces silver, and 0.03 ounce gold; and a lead concentrate containing 62.72 percent lead, 3.5 percent zinc, 7 percent iron, 0.2 ounce gold, 90.43 ounces silver, 15.3 percent sulphur, 1.4 percent arsenic, 1 percent antimony. The cost of concentration per ton of ore milled was $1.282, 26 kilowatt-hours of power costing $0.318; supplies, $0.554; labor, $0.244; and other manufacturing and general mill costs being $0.166. What was the cost of the zinc concentrate? The zinc-electrolytic plant and the lead smelter will pay for the various metals in each concentrate in accordance with their respective prevailing market prices and the miner will expect to make a profit on his entire operations.

83. The Tri-State Zinc and Lead Ores Producers Association reports costs of producing zinc-lead concentrates as follows:

Cost item	Cost per ton of ore hoisted	Cost per ton of concentrate
Power, all classes	$0.1993	$2.9458
Labor	.9081	13.4197
Explosives	.1456	2.1519
Other supplies and repairs	.2637	3.8967
Management	.1142	1.6873
Insurance	.0955	1.4104
Taxes	.0157	.2315
Miscellaneous	.1813	2.6785
Total operating costs	1.9234	28.4218
Depletion and depreciation		6.0601
Royalty		4.6800
Total		39.1619

84. It is obvious that a distillation plant not recovering any precious metals will be paying proportionately more for these zinc-lead concentrates than will the electrolytic plant in which large percentages of metals are recovered.

85. *Electrolysis and distillation.*—The same difficulty is found in comparing the electrolytic and the retort zinc process costs where comparisons are further complicated by the manufacture of sulphuric acid at retort plants. These difficulties are enhanced by the reticence of zinc producers concerning costs of production. Comparisons, therefore, can be based on rough estimates only, and will not take into consideration byproduct recovery.

86. *Plant costs.*—It is claimed by several engineers that the first cost of a 200-ton daily capacity retort and electrolytic zinc plant will be approximate; that with smaller capacities the retort plant will have the advantage. Frederick Laist and Russel B. Caples, of the Anaconda Copper Co., stated in 1926 that the first cost of a 200- to 250-ton electrolytic zinc plant using the Anaconda process would be from $25,000 to $40,000 per ton of daily zinc capacity, while a plant of half the capacity would cost from $30,000 to $35,000. Published cost figures of the two plants employing the Tainton process and having less than 100 tons daily capacity would indicate that plant costs were $20,000 per ton daily zinc capacity. The electrolytic plant has higher salvage value than the retort plant.

87. *Power costs.*—The Anaconda Copper Co. has an arrangement with the Montana Power Co. to purchase power for zinc production on a sliding scale. When zinc sells at $0.06 per pound or over the charge is $25 per horsepower-year; when zinc is priced at lower levels, the cost of power is reduced until it reaches $17.50 per horsepower-year with zinc at about $0.045 per pound.

TABLE VI.—*Estimated cost of producing 1 ton electrolytic zinc and 1 ton retort zinc in plant having capacity of 100 tons daily* [1]

[Byproduct values not considered]

Cost item	Electrolytic zinc	Retort zinc
Capital cost per ton-year	$60.00–$100.00	$50.00–$75.00
Amortization, interest, taxes charged:		
At 15 percent	9.00– 15.00	
At 16½ percent		8.25– 12.38
Power consumption, 2,500 kilowatt-hours to 3,350 kilowatt-hours, at $0.003	7.50– 10.05	
Fuel:		
20 gallons oil or 3,400 cubic feet gas	.52– .65	
1½ tons coal, at $2 or 40,000 cubic feet gas, at $0.13		3.00– 5.20
Labor:		
1.5 to 2 man-days, at $4.75	7.13– 9.50	
4 men, at $4.50		18.00
Supplies, repairs, and miscellaneous items	12.00	3.00
Cost of concentrates	47.00	56.78
	83.00– 94.00	89.00– 95.00
Freight rate to—		
New York from Black Eagle, Mont., Hillsboro, Ill	12.50	7.00
	95.50– 106.50	96.00–102.00
East St. Louis from Black Eagle, Mont., Henryetta, Okla	8.50	3.80
	91.50– 102.50	92.80– 98.80

[1] Estimated from data given by: Laist, Frederick, and Caples, Russel B., The Electrolytic Zinc Process; Ingalls, W. R. I., Pyrometallurgy of Zinc in Handbook of Non-ferrous Metallurgy; Ralston, Olive, Electrolytic Deposition and Hydrometallurgy of Zinc; and from individual plant data.

88. The estimates given on page 264 not only do not give credit for high recovery of metals other than zinc or for byproduct manufacture, but they do not take into consideration the percentage of zinc recovered by each process. As has been stated, the average retort recovers 5 or 6 percent less zinc in the concentrate than does electrolysis. There can be no question, therefore, but that, when all factors are taken into consideration, electrolytic zinc from complex ores can be produced for sufficiently less than retort zinc to be able to bear freight rates to central and eastern markets. Unfortunately, no data are available concerning the cost of production of the New Jersey Zinc Co. from zinc oxide ores; but as its plant contributes but 8 percent to the country's total metallic zinc capacity, its costs cannot affect market prices.

Zinc Consumption

89. Forty-six percent of the zinc consumed in the United States is used in galvanizing sheets, tubes, wire, wire cloth, and miscellaneous articles. Twenty-nine percent is mixed with copper to produce brass. Eleven percent is rolled into sheets or strips. A third of the remainder, or about 30,000 tons, is consumed in die casting. French zinc oxide, lithopone, and atomized zinc dust produced from slab zinc consumed less than 10 percent of zinc produced.

90. What is known as "Prime Western" zinc, or zinc containing 1.6 percent lead and 0.08 percent cadmium and iron, is consumed in the "hot process" galvanizing industry. While "Brass Special" is still a recognized grade of zinc, the increased production of high-grade electrolytic zinc has so decreased the premium formerly paid for high-grade zinc that much of it is being purchased by brass and other zinc-alloy manufacturers. High-grade metal is also used in die-casting alloy manufacture.

Table VII.—*Estimated consumption of zinc in the United States in 1929,*[1] *by principal uses*

Item	Short tons	Percent
Total consumption	628,300	100.0
Galvanizing		46.1
Sheets	142,800	22.7
Tubes	52,200	8.3
Wire	39,000	6.2
Wire cloth	10,800	1.7
Shapes	45,200	7.2
Brassmaking	180,000	28.7
Sheet zinc	68,300	10.9
Other uses [2]	90,000	14.3

[1] Estimate by American Bureau of Metal Statistics. These estimates exceed the consumption figures given by the Bureau of Mines by 64,000 tons.
[2] Includes slab zinc used in French oxide, lithopone, atomized zinc dust, die castings, slush castings, and for desilveration of lead.

91. *Galvanizing.*—Galvanizing is accomplished by three methods: the well-known hot process, electrozincking, and sherardizing.

92. *Hot process.*—Iron or steel that has been cleaned and pickled in a sulphuric acid bath is immersed in molten zinc, in the "hot" process. The heat for this process may be supplied by fuel or by electricity. The Southern California Edison Co. reports savings in the substitution of electrical heat for gas. A tank 3 by 5 by 3 feet was equipped with 70 kilowatts in 3-phase, 220-volt, heaters. The

material to be galvanized consisted of braces, angle irons, and small castings. During the working period 164 kilowatt-hours were consumed per ton of material galvanized. Radiation losses over night brought the total energy consumption to 230 kilowatt-hours per ton. At a rate of $0.0125 per kilowatt-hour, the electrothermal galvanizing cost $25.375 per ton whereas a gas-fired tank had cost $55 per ton. This saving resulted from a cut in the immersion period to 45 seconds in the electric tank as compared with a 2-minute immersion in the gas-fired tank. [77]

93. A much larger electric tank is used for galvanizing by a firm fabricating transmission-line towers. This tank is 30.5 feet long by 4 feet wide by 1 foot 10 inches deep, holding 45 tons of molten zinc. The heating element is continuous and is laid over the insulating supports which are a part of the brick lining. The capacity of the tank is 4 tons galvanized steel per hour consuming 405 kilowatt-hours of energy or 101 kilowatt-hours per ton. The tank temperature is maintained 24 hours per day.

94. *Electrozincking.*—Or iron and steel may be coated with zinc by the deposition of zinc from zinc anodes suspended in an electrolyte. The anodes are connected to the negative pole of the generator, the positive pole being the object to be zincked. It is claimed that electrozincking produces a superior product than does the "hot process." At the present time its use seems to be confined to objects that are difficult to make rustproof by other methods. Wire has been electroplated with zinc by use of an electrolyte containing zinc sulphate, ammonium, and sodium sulphates, and boric acid.

95. *Sherardizing.*—Small objects—such as screws, nuts, and bolts—are frequently galvanized in sealed containers. The objects to be coated and zinc dust are placed in the container which is heated to a given temperature.

96. Although there are a large number of firms that do contract galvanizing, the major consumption of zinc for galvanizing is in the large iron and steel sheet and tube mills located in Ohio, Pennsylvania, Illinois, and Indiana.

97. *Brass.*—The manufacture of brass and other copper alloys in which zinc plays an important part is discussed on pages 238 and 239 of "Power in Copper and Copper-Alloy Production." Such consumption of zinc occurs chiefly in Connecticut, New York, and Michigan, although Illinois, Pennsylvania, and Ohio are also large brass-producing States.

98. *Sheet zinc.*—The ductility of zinc permits it to be easily rolled into sheets, boiler plates, and strips, or to be drawn through disks. Approximately 68,300 tons of zinc was rolled in 1929 to be used later for roofing, valleys, flashings, boiler plates, electrotype, and in dry batteries. The adoption of socket-power radio receivers has caused a lessened local market for dry cells.

99. Four zinc-distillation plants roll zinc while five other firms purchase slab zinc for rolling. Zinc rolling mills at zinc distillation plants are:

Hegeler Zinc Co., Danville, Ill.
Illinois Zinc Co., Peru, Ill.
Matthiessen & Hegeler Zinc Co., La Salle, Ill.
New Jersey Zinc Co., Palmerton, Pa.

[77] Electrical World. Aug. 24, 1929.

The rolling mills purchasing slab zinc are:

The Platt Bros. & Co., Waterbury, Conn.
American Zinc Products Co., Greencastle, Ind.
Ball Bros. Co., Muncie, Ind.
Edes Manufacturing Co., Plymouth, Mass.
Hazel-Atlas Glass Co., Wheeling, W.Va.

100. *Die casting.*—The demands of the automobile industry for hardware that could be used in mass production led to the introduction of die castings made of zinc to which tin, aluminum, and copper or other metals are added. Only 6,000 tons of zinc were used for this purpose in 1921, whereas in 1929, consumption totaled 30,000 tons. The American Zinc Institute is endeavoring to increase the uses of die-cast zinc in building hardware.

101. *Zinc dust.*—As has been stated, zinc dust is sold for sherardizing. It is also used as a precipitating agent for gold in the cyanide process, as a reducing agent in the dye industry, and as a special paint pigment.

102. *Zinc oxide.*—As has been stated on page 254, while much more zinc oxide is made directly from zinc ores, 37,588 tons of metallic zinc is vaporized and oxidized by air to zinc oxide (french process). Zinc oxide is mixed with white lead to add a hard surface to the soft lead paint. It is used in lacquers to stabilize the nitrocellulose. French-process oxide adds brilliancy to enamels. In rubber, zinc oxide speeds up the curing and vulcanizing process and toughens the rubber. Zinc oxide is also used as a flux in vitreous enamel.

103. In addition to the plants manufacturing zinc oxide from the ore and, therefore, listed under zinc-reduction plants, the International Lead Refining Co. has plants at Akron, Ohio, and East Chicago, Ind., in which zinc oxide is made from electrolytic zinc. The New Jersey Zinc Co. also produces french zinc oxide at Freemansburg, Pa.

104. The location of rubber factories in Ohio and of paint and varnish factories in Ohio, Illinois, and New Jersey, is responsible for the location of zinc-oxide plants in or near these States.

105. *Lithopone.*—Lithopone is made up of 30 percent zinc sulphate and 70 percent barium sulphate. It is a dense white pigment used in the manufacture of paints and enamels. It is manufactured by the E. I. du Pont de Nemours Co.; by the Glidden Co. at Oakland, Calif., Collinsville, Ill., and St. Helena, Md.; by the Sherwin-Williams Co. at Chicago; by the Eagle-Picher Lead Co. at Argo, Ill.; the Mineral Point Zinc Co. at Depue, Ill.; at both plants of the New Jersey Zinc Co.; by the Grasselli Chemical Co. at Grasselli, N.J., and by a few other paint manufacturers.

106. *Zinc salts.*—Zinc chloride is produced by the action of hydrochloric acid upon zinc. It is a disinfectant and germicide and is used for medical purposes and in dentistry. Some is consumed in petroleum refining and in textiles. Zinc sulphate is used in lithopone manufacture, in cotton printing, in glue manufacture, and in medicine. Zinc salts are produced by several chemical companies in New Jersey, Indiana, Illinois, Ohio, Pennsylvania, West Virginia, California, and Massachusetts.

107. Although the American Bureau of Metal Statistics estimates the amount of zinc consumed by the several industries, neither the amount consumed by firms located in the several States nor the ton-

nage or value of finished products by States is available from Census figures except in scattered instances. While it is feasible to determine the States which are the heaviest consumers of zinc, the States which consume zinc for a number of purposes, and the States requiring it for one or two large industries, it is not possible to draw lines of demarcation as to actual amount of zinc consumed in each State or as to the total value of manufactured product containing zinc.

108. Ohio, Illinois, and Pennsylvania are heavy consumers of zinc for galvanizing. In them are also manufactured zinc oxide or zinc-ozide-consuming rubbers, paints, and lacquers, zinc salts, and brass. Illinois and Pennsylvania have zinc-rolling mills. Indiana has large galvanizing plants, two rolling mills, a zinc-oxide plant, and chemical plants consuming zinc. New Jersey is a large producer of zinc paints and zinc salts. New York manufacturers consume zinc in a number of industries. As the largest brass-producing State, Connecticut buys large amounts of zinc; it also has a zinc-rolling mill. Michigan is a heavy producer of brass and zinc paints. Massachusetts, Missouri, California, and West Virginia have galvanizing plants or zinc-rolling mills, or manufacture zinc pigments or zinc chemicals.

109. *Zinc exports.*—Only a little metallic zinc is imported into the United States. Some exporting is done of slab zinc, rolled products, and zinc dust. Of the 14,000 tons of slab or pig zinc exported, less than 5,000 tons reached English ports and about 2,000 tons went directly to France. Only 1,255 short tons of zinc dust was exported, of which half went to Mexico. Finished zinc products exports totaled less than 6,000 short tons. This reached Canadian or English ports, principally (see table IX, page 269).

TABLE VIII.—*Imports of zinc into the United States in 1929, by country of origin* [1]

Country	Ore, zinc content		Blocks, pigs, old zinc, etc.		Dust and other manufactures
	Short tons	Value	Short tons	Value	Value
Total	14,412	$1,127,432	226	$21,522	$152,758
Austria					13,518
Belgium			224	21,157	28,319
Canada	849	62,219			839
Cuba			(2)	13	25
Czechoslovakia					444
France			1	126	52,278
Germany			1	219	36,780
Italy					1,119
Jamaica			(2)	7	
Japan					2,655
Java and Madura					37
Mexico	13,563	1,065,213			40
Norway					20
Sweden					220
United Kingdom					16,464
All others					

[1] Compiled from unpublished data, Bureau of Foreign and Domestic Commerce, Department of Commerce.
[2] Less than 1 short ton.

TABLE IX.—*Exports of zinc from the United States in 1929, by country of destination* [1]

Country	Ores and concentrates		Dross		Cast; in slabs, blocks, or pigs		Rolled; in sheets, plates, etc.		Zinc dust		Other manufactures	
	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value
Total	71	$2,434	3,490	$217,019	14,344	$1,870,705	5,264	$1,075,000	1,255	$250,447	622	$233,789
Belgium			960	45,841	420	100,480					1	737
British India			36	3,640	1,681	220,114	340	47,320	2	497	(2)	208
Canada	61	1,950	20	4,000	974	128,892	2,124	384,602	148	30,924	222	92,180
Chile					565	80,285	26	8,458	4	1,093	1	559
France			56	3,809	2,299	289,021	13	2,338				
Germany	8	368	462	29,000	1,894	214,804	35	4,559			26	4,134
Japan			1,357	91,584	587	69,528	270	40,024	2	438	8	3,497
Mexico			(2)	91	22	3,965	149	31,919	689	140,861	74	29,200
Netherlands			36	2,150	554	64,491	58	8,435			3	1,793
New Zealand							18	5,712	11	2,070	100	25,921
Sweden					487	64,169	39	12,724			2	769
Union of South Africa									167	28,532	1	299
United Kingdom			562	36,855	4,716	613,235	1,592	367,664	52	8,013	49	24,476
All others	2	116	1	49	145	21,721	600	161,245	180	38,019	135	50,016

[1] Compiled from unpublished data, Bureau of Foreign and Domestic Commerce, Department of Commerce.
[2] Less than 1 short ton.

WORLD PRODUCTION AND CONSUMPTION

110. Metallic zinc was produced in Germany, Great Britain, Belgium, and Austria-Hungary many years before the industry gained a foothold in the United States. Production in Asia, Australasia, and Africa began only with the twentieth century. But in 1928 the United States mined by far the largest amount of zinc ore, it produced by far the largest amount of metallic zinc, and it was the largest zinc-consuming country. Mexico and Australia were the second largest zinc-ore-mining countries. While Australia reduced about one third of its ore, it consumed only a small proportion of the world's zinc. Other fairly large zinc-mining countries, in their order of importance, are Poland, Germany, and Canada.

111. The largest zinc-ore-reduction countries, following after the United States, are Belgium, Poland, Germany, France, Canada, and Great Britain. While the United States consumes 37 percent of the total metallic zinc produced, Germany consumes 14.3 percent, Great Britain 12.8 percent, France 8.8 percent, Belgium, 8.2 percent, and Japan 3.8 percent.

112. The importing countries for zinc ore are Belgium, France, Great Britain, and the Netherlands. The countries exporting zinc ore are Mexico, Australia, Italy, Spain, Austria, Algeria, British India, Indo China, Peru, and Canada. The countries which import finished zinc products are, principally, Germany and Great Britain, while the United States, Canada, Belgium, Poland, Australia, Northern Rhodesia, Sweden, and the Netherlands have finished zinc products to export.

113. *European zinc cartel.*—Attempts have been made since 1885 to maintain a good price for zinc by limiting production. Cartels have been formed by the principal metallic-zinc-producing countries and have been abandoned with changed conditions. The depression

of 1926 and 1927 brought about the formation of the present European zinc cartel with offices in Brussels. It aims to control production by reviewing the production and stocks on hand every 2 months. Agreements to curtail production have been entered into in an effort to stabilize the London market price at approximately £27. But new plants have developed near zinc mines and production has increased in spite of these agreements. The London price for zinc averaged £24 during 1929, having dropped as low as £19 during the year.

TABLE X.—*World zinc production and consumption in 1928*

Country	Mine production zinc content [1]		Primary zinc reduction [1]		Apparent consumption [2]	
	Metric tons	Percent	Metric tons	Percent	Metric tons	Percent
Total	[3] 1,498,022	100.0	1,410,728	100.0	1,433,300	100.0
North America	877,036	58.6	632,045	44.8	549,500	38.3
Canada	[4] 84,645	5.7	74,176	5.3	17,300	1.2
Mexico	161,747	10.8	11,220	.8		
United States	630,644	42.1	546,649	38.7	532,200	37.1
South America	30,400	2.1			10,800	.8
Argentina					10,800	.8
Bolivia (exports)	2,261	.2				
Peru	28,139	1.9				
Europe	353,978	23.5	695,804	49.3	789,600	55.2
Austria	1,818	.1			5,600	.4
Belgium	[5]		209,280	14.8	117,900	8.2
Czechoslovakia	291	[6]	8,039	.6	24,600	1.7
Finland	660	[5]				
France	[3]		96,873	6.9	125,700	8.8
Germany	116,979	7.8	98,256	7.0	204,300	14.3
Great Britain	720	[6]	56,284	4.0	184,100	12.8
Greece	4,476	.3				
Italy	84,840	5.7	10,564	.7	21,100	1.5
Netherlands			26,855	1.9	5,000	.4
Norway	22	[6]			[7] 6,000	.4
Poland	150,000	8.7	161,815	11.5		
Russia	[5]		4,300	.3	36,000	2.5
Spain	[3]		13,549	.9	9,500	.7
Sweden	14,172	.9	5,106	.4		
Yugoslavia	[3]		4,883	.3	4,300	.3
Other European countries	[5]				45,500	3.2
Asia	54,387	3.6	22,117	1.6	64,900	4.5
British India	32,901	2.2				
Indo China	21,486	1.4	3,000	.2		
Japan	[5]		19,117	1.4	54,900	3.8
Other Asia	[5]				10,000	.7
Africa	31,985	2.1	9,733	.7	3,500	.2
Algeria	15,098	1.0				
Northern Rhodesia	13,387	.9	9,733	.7		
Tunisia	3,500	.2				
Australia	150,236	10.0	51,029	3.6	15,000	1.0

[1] Compiled from U.S. Bureau of Mines: "Zinc in 1928", pp. 382 and 384.
[2] American Statistics Year Book. Compiled from reports of American Bureau of Metal Statistics and Metalgesellschaft.
[3] Total, incomplete; does not include content of ores mined in France—zinc ore, 8,729 tons; zinc-lead ore, 36,760 tons. Spain—ore, 122,141 tons; Yugoslavia—ore, 1,153 tons.
[4] Estimated smelter recoveries.
[5] Not available.
[6] Less than 0.1 percent.
[7] Includes Sweden.

EUROPEAN MINING AND METALLIC-ZINC PRODUCTION

114. *Germany and Poland.*—Germany was the leading zinc producer of the nineteenth century. In Upper Silesia the large smelters obtained ore from local mines while in the Rhine Provinces ore imported from Austria-Hungary and other countries was smelted. The Treaty of Versailles ceded the Upper Silesian smelting area to Poland although some zinc mines are located in German Upper Silesia. As a consequence, Germany's contribution to the world's metallic zinc dropped from 30 percent during the decade ending 1910 to 7 percent in 1928. Production took place in Poland first in 1919. By 1928 Poland mined 8.7 percent of the world's zinc ore and smelted 11.5 percent.

115. The largest Polish zinc-mining, -smelting, and -manufacturing company, Giesche Spolka Akcyjna, has been operated by the Anaconda Copper Co. since 1926. In 1928, this company sold approximately 67,000 tons of slab zinc, 7,000 tons of pig lead, 2,976,000 tons of coal mined in the company's mines, 5,347,000 zinc battery cups, 16,000 tons of zinc sheet, 405 tons lead pipe, 406 tons lead shot, 4,536 tons of litharge and red lead, 25,000,000 brick, 103,590 tons of sulphuric acid, and 67,360 tons of superphosphate and mixed fertilizer. The company also controls large timbering activities, a porcelain plant, and has holdings in paper and explosive factories. As much of the ore is zinc carbonate, after flotation, the zinc carbonate is converted into zinc oxide and then sent to an electrolytic plant at Bernhardc. Zinc-sulphide ore is treated in smelters. The power is supplied from generating plants located at the company's coal mines.[78]

116. Germany now secures her ores chiefly from Mexico, Italy, Russia, Algeria, and Bolivia. It is constructing an electrolytic plant at Magdeburg.

117. *Belgium.*—During Germany's supremacy as a zinc producer, Belgium ranked second in European metallic-zinc production. In 1928, she ranked first. All but a small proportion of zinc ores smelted are imported. The founding of the industry in Belgium before 1810 was due to a Belgian's discovery of a process for smelting zinc, together with the location of zinc ores, coal, and clay for retorts near Liege, at that time. Since 1856 zinc ore production has declined and Belgium has become the chief importer of zinc ores. Some ore comes from Italy, Spain, Australasia, and Mexico.

118. *France.*—France produces 7 percent of the world supply of metallic zinc. It has 6 smelters and 1 electrolytic plant. Only a small proportion is derived from ores mined in France but ore is secured from French colonies, Algeria and Tunisia.

119. *Austria, Czechoslovakia, Yugoslavia, and Italy.*—Prior to the World War, Austria-Hungary produced about 2 percent of the world's metallic zinc from zinc ores located within her boundaries. The northern zinc district in Galicia was ceded to Czechoslovakia and the southern zinc districts to Italy and Yugoslavia after the World War. Only a small amount of ore is still mined in Austria which is shipped to Czechoslovakia and Germany for smelting. Yugoslavia does some mining and smelting.

[78] Brooks, G. S., president, Giesche Spolka Akcyjna. The Polish Enterprise. Engineering and Mining Journal, Aug. 24, 1929.

120. In addition to the ores ceded to it in the north, Italy has produced much ore from Sardinian mines where deposits are extensive. These mines are controlled by American, Belgian, and French interests and all ore not smelted in Italy is shipped to Belgium and Great Britain for smelting. Electrolytic plants are located at Cotrone, Monteponi, and San Dalvazzo di Tenda.

121. *Spain.*—Spain has mined zinc ores for many years but the ore has low zinc content. It has produced as much as 18,000 tons metallic zinc but most of its ore has been shipped to Belgium and Germany.

122. *Great Britain.*—Great Britain has produced metallic zinc since 1740 but her own supply of zinc ore for smelting proved insufficient as early as 1860. Ores have been imported since that time but largely from British possessions. She produced 4 percent of the world's metallic zinc in 1828.

123. *Other European countries.*—While entirely dependent on foreign sources of ore, the Netherlands produces about 2 percent of the world's metallic zinc. Sweden mines zinc ore, treats some of it, and ships the remainder to Belgium. Norway produces a little ore but counts on foreign ores for its electrolytic reduction plants. A little mining and smelting is being carried on in Russia but little information as to zinc reserves is available.

124. *Asia.*—Japan mines and smelts zinc. Her ore is sufficient to meet local smelter demands, but Japan buys some ore from Indo-China and Korea, or from America and Mexico when prices are attractive. Chosen, a province of Japan on the mainland, produces some zinc ore.

125. China has exported zinc ores for many years and has also produced some metallic zinc. The industry is at a standstill at the present time. Indo-China produced a little over 1 percent of the world's ore, only a small amount being smelted, however. British India is a larger contributor to the zinc ore supply. The Burma Corporation, Ltd., is one of the world's important lead-zinc producers. Ore is high in both zinc, silver, and lead.

126. *Australasia.*—Australasia is the second largest zinc ore producing continent. Mining occurs at New South Wales where the Broken Hill Co. has vast reserves of lead-zinc ore, in Tasmania, and in Queensland. Prospecting is under way in New Zealand. In Queensland 20,000,000 tons of zinc-lead ore is blocked.

127. The completion of an electrolytic reduction plant at Risdon, Tasmania, increased the production of metallic zinc in Australasia until but two thirds of the ore concentrated is exported. A second electrolytic plant is being erected by the Electrolytic Zinc Co. of Australia.

128. *Africa.*—Both Algeria and Tunisia mine zinc ore which is shipped to France and other European markets.

129. Rhodesia became an important producer of zinc for the first time in 1928 when operations were begun at the electrolytic zinc plant of the Rhodesia Broken Hill Development Co., Ltd. Ore is reported to assay 30 percent zinc, 8 percent lead, and 0.9 percent vanadium oxide. The Base Metals Co. is shipping zinc ore averaging 47 percent to 48 percent zinc to Johannesburg.

130. *South America.*—Zinc ore has been produced in Bolivia and Peru. It is believed than zinc resources are abundant although lack of transportation facilities has retarded prospecting and development.

131. *North America.*—The complex ore belt which runs through the Rocky Mountain region in the United States extends into Canada and Mexico. Mexico mined approximately 11 percent of the world's zinc ores in 1928 and Canada 8 percent. Mexico has been an important but irregular source of the world's zinc ores for many years. Some of the smelting is done in the United States but more ore is shipped to Europe.

132. *Canada.*—The Consolidated Mining & Smelting Co. of British Columbia is one of the largest lead-zinc mining companies in the world. Reserves are extensive and ore is reported to contain 11 percent lead, 7.5 percent zinc, 40 percent iron, and 4.2 ounces of silver per ton.[79] This company has an electrolytic zinc plant at Trail with a capacity of 380 tons of zinc per day. The Reeves-McDonald property on the Pend Oreille River contains 2,000,000 tons of proved ore of 7 percent zinc content.

133. The Province of Quebec also produces zinc ore which is concentrated by flotation and shipped to Belgium. The Sudbury District of Ontario will also become an important producer of zinc in the near future. The Errington mine of the Treadwell Yukon Co. has developed 1,000,000 tons of ore above the 300 foot level and other companies are getting mines ready for operation. Manitoba is also the scene of much activity. The Flin Flon property has developed ore reserves of 18,000,000 tons above the 900-foot level. An electrolytic plant is planned to be located on the property. Nova Scotia mines report some reserves. The American Smelting & Refining Co. is operating a mine in Newfoundland having ore reserves of over 5,000,000 tons assaying 17.85 percent zinc, 7.65 percent lead, with some gold, silver, and copper.

Power in the Lead Industry

Treatment of lead ores and concentrates

134. All lead ores and lead concentrates are smelted in blast furnaces to produce metallic lead. Little power is required for their beneficiation. When ores comparatively free of silver and base metals are used, the smelted lead is sufficiently pure for many purposes and is marketed as "soft lead." While much of the lead ores from the Mississippi Valley and Southern States is of this character, some is refined further either because of silver content or because smelting does not remove objectionable metals. All complex lead ores and concentrates of the Rocky Mountain Region (see pp. 248 to 251 for location of ores) yield an impure pig lead called "base bullion" which must be refined before consumption. Foreign ore entering the United States is first smelted into base bullion and then refined.

135. In 1929, out of a total production of 774,633 short tons of refined primary lead, 30 percent was soft lead, 7 percent was desilverized soft lead, almost 50 percent was refined domestic bullion, and about 13 percent refined foreign bullion. In addition, 25,669 tons of antimonial lead were produced as a byproduct of base bullion refining.

136. Soft lead, produced from ores of the Southeastern Missouri District and the Tri-State District, is known in the trade as chemical

[79] Engineering and Mining Journal, vol. 124. Oct. 1, 1927.

lead and used principally in the manufacture of cable, pipe, and sheets. High-grade lead is essential for white lead, litharge, red lead, and other pigments. Antimonial lead, as well as lead oxide, is consumed in the manufacture of storage batteries, while antimonial lead enters into bearing metal and type metal.

REFINING OF LEAD BULLION

137. Lead bullion is refined electrolytically or desilverized by pyrometallurgical or by chemical processes. The electrolytic process may be used to convert the lead bullion into common lead containing as much as 2 percent impurities or it may be employed to produce the highest grades of refined lead. It removes bismuth from the crude metal which is not done by pyrometallurgical processes. It is in operation at East Chicago, Ind., at the plant of the United States Smelting Lead Refinery, Inc., and at the Omaha, Nebr., plant of the American Smelting and Refining Co. The Consolidated Smelting and Refining Co., Ltd., of Trail, British Columbia, has employed electrolysis in lead refining since 1904. The Evans-Wallower Lead Co. has announced its intention to erect an electrolytic lead plant at the location of its electrolytic zinc plant at East Chicago for the recovery of lead values from residues of the zinc plant. About 60,000 tons of crude metal is refined electrolytically.

138. Most of the plants refining lead by furnace and chemical processes have previously smelted led ores or concentrates. The exception is the International Lead Refining Co. at East Chicago which refines led bullion shipped to it from the International Smelting Co., at Tooele, Utah, and from the American Smelting & Refining Co. at East Helena, Mont. Plants refining lead by furnace processes are as follows:

California, Selby, American Smelting & Refining Co.
Idaho, Kellogg, Bunker Hill and Sullivan Mining & Concentrating Co.
Illinois, Collinsville, St. Louis Smelting & Refining Works of National Lead Co.
Indiana, East Chicago, International Lead Refining Co. (refinery only).
Missouri, Herculaneum, St. Joseph Lead Co.
New Jersey, Newark, U.S. Metals Refining Co.
New Jersey, Perth Amboy, American Smelting & Refining Co.
Pennsylvania, Carnegie, Pennsylvania Smelting Co.

139. *Electrolytic refining of lead bullion.*—The "Betts" process is the only process developed commercially for the refining of lead bullion While in principle it is similar to the multiple system of refining copper, the details of operation are different.

140. *Electrolyte manufacture.*—The electrolyte employed is lead fluosilicate. This is manufactured at the process plants. Ground high-grade fluorspar (2.5 pounds approximately) is mixed with 3 pounds of 66° B. sulphuric acid. This is heated gradually in a retort until hydrofluoric acid passes as a gas to condensers where it is absorbed by water. This hydrofluoric acid is fed slowly to tanks filled with pure silica sand. It percolates up through the bed of silica and the overflow passes through a cascade of tanks. The resulting product is hydrofluosilicic acid. This is converted into lead fluosilicate either by electrolysis of the acid with lead anodes and cathodes separated by a diaphragm or by adding white lead or basic lead carbonate to the hydrofluosilicic acid.

141. The electrolyte as used usually carries 6 percent lead and 8 percent hydrofluosilicic acid. After the electrolyte is in the cells, dissolved glue is added. Each ton of lead produced requires 1.5 pounds of glue.[80] The temperature of the electrolyte is kept at 38° to 40° C.

142. *Electrolytic cells.*—Concrete tanks with impervious asphalt linings are preferred although wooden tanks are still in use. The tanks are arranged either according to the Walker system of four tanks to a section or in cascades, or double rows of 5, 7, or 11 tanks. Hard rubber and soft rubber connections and feed lines are used between tanks and the centrifugal pumps are of copper. The electrolyte passes through the 4-tank sections at the rate of 2.5 to 4 gallons per minute to launders, from which it is pumped to cooling tanks and then returned to the cells. In the cascade system it flows through each tank by gravity to collecting launders and from there is pumped back to the gravity feed tank.

143. Smelters cast lead bullion to be used in the electrolytic process into anodes with a pair of lugs attached to support the anodes in tanks and to make the electrical contact. Anodes are about 24 inches by 36 inches in size and about 1.25 inches thick at the top, tapering toward the end. They weigh from 364 pounds to 460 pounds in different plants.

144. Cathodes are made by pouring molten lead over inclined cast-iron plates, thereby forming a thin sheet of lead about 0.025 inch thick and weighing 10 or 15 pounds. These sheets are folded over copper bars which act as supports and also conduct the current to the next cell. As these sheets have sufficient strength to hold the deposited lead, no starting sheet is necessary such as is essential in copper refining.

145. Cathodes are placed in the cells by hand and must be hand straightened. Anodes are lowered by cranes into position approximately 4⅜ inches center to center. One set of anode lugs rests on the positive bus bar or triangle of the cell and the other rests on the wooden heavy strip on the opposite side. Two sets of cathodes are usually drawn from each set of anodes. The cathodes are removed by cranes to wash tanks. They are then melted and cast as refined lead.

146. *Power consumed.*—The current density varies from 16 amperes per square foot of cathode surface to 18 amperes in the several plants. The initial cell potential of 0.35 volt gradually increases as sponge adheres to the anode surface until it reaches 0.44 volt. The lead deposited per kilowatt-hour will vary, with the current efficiency and the resistance, from 18 to 21 pounds. Or from 95 kilowatt-hours to 111 kilowatt-hours energy is required to refine 1 ton of lead.

147. *Slimes.*—About a fifth of the anode weight is left after two cathodes are produced from it. The larger amount of slime formed during electrolysis has adhered to the anode. The scrap anode is, therefore, removed and brushed mechanically. The washed scrap anodes, after melting and casting, are used again for anodes. The anode slime, together with tank slime, is filtered and washed free of any electrolyte or soluble lead. It is then dried by compressed air and in gas chambers. The dried slime is melted in a reverberatory furnace. After the lead-antimony slag is tapped off, silver, gold,

[80] Fingland, J. J. "The Betts Electrolytic Lead Refining Process in Practice." Paper before American Electrochemical Society, May 1930.

copper, tellurium, and bismuth are oxidized. The three last-named metals are oxidized as slag in a second reverberatory furnace, leaving a gold-silver alloy which is refined by air and niter to doré. The doré is cast into plates ready for parting at the lead refinery or special silver and gold refineries.

148. The bismuth, copper, and tellurium slags are retreated for the recovery of each metal. Bismuth is recovered electrolytically. The lead-antimony slag is reduced to antimonial lead in a blast furnace. Any metals that are volatilized during the furnace processes are collected in a bag house and by Cottrell treaters and are returned to the furnaces.

149. *Lead refining by furnace processes.*—Lead bullion for furnace refining is cast into slabs or bars at smelters for shipment to refineries. At refineries it goes to coal-fired drossing kettles in which it is melted. From there it is pumped to coal-fired reverberatory furnaces called "softeners." By alternative heating and cooling, metals held in solution in the bullion rise to the surface of the molten metal and are solidified. They are skimmed off every 6 or 8 hours. A charge of 250 tons requires a 48-hour softening.[81]

150. From the softening furnaces, the metal goes to desilvering, coal-fired kettles. Zinc is added here which causes nearly all the silver and gold to rise. The metal then passes to refining furnaces similar to the softeners. Steam is introduced for oxidation of the zinc. The dross formed is skimmed off until all traces of zinc, antimony, and other impurities are removed. The lead metal goes to a melting furnace from which it is poured into molds.

151. Zinc is recovered in retorts to be used again. Cupellation is employed for the separation of precious metals. This consists of melting the retort bullion in a reverberatory furnace and oxiding base metals with air blasts. The base metals are slagged off as litharge, while the silver and gold remain in metallic state. The doré is cast into bars and shipped to silver and gold refineries.

152. Skims from the softening furnaces, litharge from the cupels, and copper dross is charged to reverberatory furnaces with sufficient galena to form a matte. A lead antimoniate slag is produced which is remelted in the blast furnace to antimonial lead. Copper matte is shipped to copper smelters.

153. *Harris process.*—A chemical process to remove such impurities as arsenic, antimony, and tin from base bullion and zinc from desilverized lead is coming into use. Caustic alkali and alkali chloride are brought into contact with the bullion at a temperature beyond the melting point. They effect a clean separation of the lead from these base metals which are collected as oxide or oxysalts in the chemicals. By the wet process, these metals are recovered in marketable form.

154. Other chemical processes are also used to remove other base metal impurities and to simplify the kettle lead refining. At the Bunker Hill smelter in Idaho, a gold crust is obtained first in desilvering kettles which is retorted, cupelled, and parted with sulphuric acid. The silver crust is gotten after the gold crust has been removed. This is liquidated to remove lead and retorted to a bullion. The silver is cupelled and finally melted.

[81] Johnson, G. E., superintendent, International Lead Refining Co. Western Lead Refined at East Chicago by Parkes Process. August 1929.

155. The Bunker Hill process requires about 200 pounds of coal for each ton of metal produced, the coal consumption including that used for byproduct as well as lead production. The labor required is but 1-man-day per 4.2 ton refined lead.[82]

156. *Comparison of processes.*—The heaviest market demand is for common lead which can be produced so cheaply by pyrometallurgical processes as to preclude competition from electorlytic processes. In high-grade lead, the electrolytic process has the advantage of removing bismuth, which is objectionable in some industries. The bismuth, itself electrolytically refined, may be sold to the pharmaceutical manufacturer or for use in low melting-point alloys.

157. The demand for high-grade lead comes chiefly from manufacturers of white lead pigment. One eighth of the lead produced is manufactured into white lead or basic lead carbonate. As even small amounts of silver or other nitrates affect the whiteness of the pigment, a pure lead is essential. While white lead used in oil paints is manufactured more generally by the laborious old Dutch process or by the faster Carter process, one producer of such pigments uses furnace refined impure lead anodes for the electrolytic production of white lead. This process is as follows:

158. *Production of white lead by electrolysis.*—At the Anaconda Lead Products Co. at East Chicago, Ind., the Sperry electrolytic process is in use. The plant has a daily capacity of 28 tons of dry white lead.

159. Cells are arranged in series, each containing 18 lead anodes, 21 inches by 30.5 inches in size and 1 inch thick, and weighing 250 pounds. The anodes need not be pure lead as lead only is dissolved. The cathodes are thin sheets of steel. Each is enclosed in a heavy linen duck diaphragm.

160. The catholyte contains a relatively large amount of sodium carbonate in a sodium acetate solution. This is fed to each cathode frame by a separate feed tube and overflows through a spout at the top. In passing through the cell it gives the required carbonate to the anolyte and then passes out of the cell to an absorption tower for restoration. The anolyte solution contains the exact amount of carbonate necessary to precipitate the lead compound. It enters the cell, and circulates about the anode which dissolves. The lead is precipitated as basic carbonate in suspension in the anolyte. The discharge from the cell goes to thickeners, to filters, to washers, and to driers. When thoroughly dried, the lead carbonate is pulverized and packed in barrels.

LEAD PRODUCING AND CONSUMING UNITS

161. *Location of mines.*—Table XI shows the production of lead ore by States in 1929. Three States, Missouri, Utah, and Idaho produced more than three fourths of the lead in domestic ores in 1929. Missouri produced nearly 31 percent, Utah nearly 23 percent, and Idaho approximately 22 percent of the lead in domestic ores. The only other States of importance in lead ore mining were Oklahoma, Kansas, Montana, and Colorado.

162. *Location of smelters.*—Utah ranked first in lead smelting having the three largest lead smelters in the country, namely, the Murray plant of the American Smelting & Refining Co., the International

[82] Beasley, A. F., superintendent of the Bunker Hill & Sullivan Mining & Concentrating Co., in an address before American Institute of Mining Engineers at Spokane, Wash., June 1930.

Smelting Co. (subsidiary of Anaconda Copper Mining Co.), and the United States Smelting, Refining & Mining Co. The capacity of Utah smelters totals 1,714,000 tons. Idaho has a smelter capacity of 450,000 tons, Montana of 360,000 tons, Texas and Illinois each of 350,000 tons, Colorado of 300,000 tons, with 1 or 2 smelters of smaller capacities in Missouri, New Jersey, California, Arizona, Kansas, and Nebraska. It is obvious that western ores are smelted near lead mining regions, but that Missouri lead is smelted in Illinois as well as in Missouri and Kansas and other Central States.

163. *Location of refineries.*—As is shown in table XI, with the exception of Idaho and California, all lead bullion refining is carried on in Central or Eastern States. The freight rate on lead bullion from Utah smelters to St. Louis is $9, to New York $12.50; from East Chicago, the pig lead rate to St. Louis is $2.10. The freight rate on soft lead from Illinois and Missouri smelters to St. Louis varies from $0.25 to $3.50 and from $5 to $8.50 to New York.

TABLE XI.—*Sources of lead ore smelted and refined in United States in 1929* [1]

Source of lead ore, United States and Alaska	Amount smelted or refined		Source of lead ore, United States and Alaska	Amount smelted or refined	
	Short tons	Per-cent		Short tons	Per-cent
Total, domestic ores	685,992	100.0	Utah	157,085	22.9
			Washington	447	.1
Alaska	1,266	.2	Wisconsin	1,729	.3
Arizona	8,153	1.2	Undistributed	5,624	.8
California	1,459	.2	Zinc residues	1,903	.3
Colorado	23,675	3.5			
Idaho	147,595	21.5	Total, foreign ores	102,135	100.0
Illinois	777	.1			
Kentucky	303	(2)	Canada	9,499	9.3
Missouri	211,345	30.8	Europe	28	(2)
Montana	26,795	3.9	Mexico	16,807	16.5
Nevada	13,256	1.9	South America	3,285	3.2
New Mexico	12,249	1.8	Other foreign	56	.1
Oklahoma and Kansas	71,757	10.5	Foreign base bullion:		
Oregon	15	(2)	Mexico	51,295	50.2
Texas	559	.1	Peru	21,165	20.7

[1] Compiled from Bureau of Mines preliminary report, Lead in 1929.
[2] Less than 0.05 percent.

164. *Large producing units.*—The largest lead smelter and refiner in the United States is the American Smelting & Refining Co. producing more than 50 percent of the country's pig lead. It has 2 lead-silver smelters in Colorado, 1 at East Helena, Mont., its largest smelter at Murray, Utah, and a smelter at El Paso, and 1 at Federal, Ill.; it has smelters and furnace refineries in California and New Jersey; it has a smelter and electrolytic refinery at Omaha. The capacity of its plants in the United States totals 2,203,000 short tons of lead. In addition, this company operates 2 smelters and 1 smelter and refinery in Mexico. The company, through subsidiaries, operates mines in the Coeur d'Alene and tri-State districts and in other countries.

165. The St. Joseph Lead Co. is the largest lead producer in southeastern Missouri; only a part of the ores mined are smelted in its own furnaces. The Bunker Hill and Sullivan Mining & Concentrating Co.'s lead smelter in Idaho has a capacity of 450,000 tons.

166. *Ore and bullion imports.*—United States smelters and refineries treated 102,135 tons of foreign ore and bullion in 1929. Seventy-three percent of this was shipped in from Mexico and 20 percent came from Peru and other South American countries. Much of this is refined in bond and subsequently exported. Consequently, of the 72,261 short tons of pig lead exported, 53,003 tons or 73 percent was smelted from foreign ore.

167. *Secondary lead.*—Smelters also recovered about 70,000 tons of lead from secondary lead, while plants that treat only scrap and drosses recovered 244,400 short tons. Or, more than a third of all lead produced in the United States was manufactured from secondary metal.

168. *Consumption of lead.*—Industries demanding the largest amounts of lead are the storage battery and the lead-covered cable industries. Each requires from a fifth to a fourth of all lead produced. With continued growth of the automobile industry the demand for lead in storage batteries will increase. With continued use of underground cables for electrical transmission the demand for cable lead will increase. Common lead and antimonial leads are used by these markets.

169. Lead pigments are an outlet for 15 percent of lead refined. White lead is being hard pressed by the use of zinc-oxide pigments. This is offset somewhat by the use of red lead for protective coating of iron and steel framework. White lead produced in 1929 totaled 147,031 tons, litharge 87,916 tons, red lead 43,021 tons, and orange mineral 678 tons. A new pigment for spraying has been put on the market which is finely divided lead suboxide suspended in linseed oil.

170. The States manufacturing the largest amount of lead pigment are Illinois, Ohio, Missouri, New York, Pennsylvania, and New Jersey. California has several paint factories of size. The same States afford largest outlets for lead for other purposes.

BIBLIOGRAPHY

Year	Author	Title
1929	American Bureau of Metal Statistics	American Statistics Yearbook.
1930	Beasley, A. F., superintendent, Bunker Hill & Sullivan Mining & Concentrating Co.	Address Before American Institute of Mining Engineers at Spokane, Wash.
1929	Brooks, G. S., president, Giesche Spolka Akcyjna.	The Polish Enterprise, Engineering and Mining Journal. Aug. 24.
1929	Case, F. O.	French Process Modernized by Anaconda Production of Zinc Oxide at East Chicago, Engineering and Mining Journal. Aug. 24.
1930	Elfred, F. S., Evans-Wallower Zinc Co.	Address Before American Die-Casting Institute. January.
1929	----------	Electrical World. Aug. 24.
1927	----------	Engineering and Mining Journal. Vol. 124. Oct. 1.
	Fahrenwald, A. W.	Flotation Practice in the Coeur d'Alene District, Idaho. Technical Publication No. 1, American Institute of Mining and Metallurgical Engineers.
1930	Fingland, J. J.	The Betts Electrolytic Lead Refining Process in Practice. Paper presented before American Electrochemical Society, June 1.
	Fosdick, E. R.	Power in Zinc Production, Journal American Institute of Electrical Engineers. Vol. 77.
1918	Hansen, C. A.	Electrolytic Zinc, A.I.M.E.
	Hoffman, H. O.	Metallurgy of Zinc and Cadmium.
1926	Ingalls, W. R. I.	Metallurgy of Zinc and Cadmium, Handbook of Non-Ferrous Metallurgy.
1926	-----do	Pyrometallurgy of Zinc, Handbook of Non-Ferrous Metallurgy.

BIBLIOGRAPHY—Continued

Year	Author	Title
1929	Johnson, G. E., superintendent, International Lead Refining Co., East Chicago, Ind.	Western Lead Refined at East Chicago by Parkes Process, Engineering and Mining Journal. Aug. 24.
	Laist, Frederick, and Caples, Russell B.	The Electrolytic Zinc Process, Handbook of Non-Ferrous Metallurgy.
1930	Moody, John, Inc.	Moody's Industrials.
		Thomas Register.
1929	Pehrson, Elmer W., U.S. Bureau of Mines.	Flow of Lead into World Trade in 1928, Mining Congress Journal, November.
1920	Ralston, Oliver E.	Electrolytic Deposition and Hydrometallurgy of Zinc.
1926	Riddell, C. C.	Lead, in Handbook of Non-Ferrous Metallurgy.
1929	Roosevelt, Ralph M.	Use of Lead in Industry.
1930	Roush, G. E.	The Mineral Industry During 1929.
1929	U.S. Senate.	Hearings on Tariff Act of 1929. Vol. III.
1927	Sheet Steel Trade Extension Committee.	5,000 Sheet Steel Products and Who Make Them.
	Siebenthal, C. E.	Zinc Production Before 1882.
1926	Smith, Walter C.	Electrolytic Refining of Lead, in Handbook of Non-Ferrous Metallurgy.
1926	do	Treatment of Electrolytic Slimes and Zinc Crust, Handbook of Non-Ferrous Metallurgy.
1929	Tainton, U. G., and Bosqui, David.	The Electrolytic Zinc Plant of the Evans-Wallower Co. at East St. Louis, Ill. American Electrochemical Society.
1929	Tri-State Zinc & Lead Ores Producers Association.	Reports.
1927	U.S. Bureau of the Census.	Biennial Census of Manufactures.
1929	U.S. Bureau of Mines.	Lead in 1928. (General report.)
1929	do	Preliminary Reports for Lead.
1930	do	Preliminary Report on Zinc Production in 1929. May 28.
1930	do	Production of Slab and Rolled Zinc in 1929, and other reports.
1930	do	Reports of State Production of Metals.
1929	do	Zinc in 1928.
1915	U.S. Geological Survey.	Zinc and Cadmium in 1915.
1929	Wiggin, Albert E., and Caples, Russell B.	Electrolytic Zinc Practice at Great Falls and Anaconda, Engineering and Mining Journal. Aug. 24.

POWER IN THE MANUFACTURE OF CHEMICALS AND METALS FROM BRINE

CONTENTS

	Page
Electrolytic products of brine	281
Sources and chemical composition of raw materials	283
Caustic soda and chlorine industry	284
Historical development in England and France	285
Development in the United States	286
Present production in the United States	286
Caustic soda	287
Chlorine and bleaching powder	287
Producing plants and their locations	288
Electrolytic process	289
Diaphragm cells and power requirements	289
Mercury cells and power requirements	290
Caustic soda evaporation difficulties	290
Liquid chlorine, bleaching powder, and hydrochloric acid	291
Synthetic ammonia	291
Ammonia-soda process	292
Lime caustic soda	292
Causticized caustic soda	292
Other chemicals produced at electrolytic plants	293
Cost of production	293
Consumption	294
Caustic soda in wood pulp and rayon industries	294
Caustic soda in soap manufacturing and rubber reclaiming	294
Shifting markets	295
Well-established chlorine markets	295
New chlorine markets	296

Caustic soda and chlorine industry—Continued.
Consumption—Continued. Page
Chlorine in warfare 297
Location of consuming markets 297
Exports 297
Other electrolytic sodium products 298
Metallic sodium 298
Sodium chlorate 299
Magnesium 299
History and development of the industry 300
Present production in United States 301
European production and exports 302
Sources of raw material 302
Brine 302
Magnesite 303
Electrolytic processes 303
Chloride process 303
Brine as raw material with bromine production 304
Magnesite as raw material 305
Superseded oxide process 305
Fabrication 306
Consumption 306
Pure magnesium 306
Magnesium alloys 307
Bibliography 308

Electrolysis releases from brines valuable chemical constituents essential to industry. Chlorine, metallic magnesium, and metallic sodium are produced in the United States today solely from brine chemicals by electrolytic methods. Caustic soda, hydrogen, bromine, sodium chlorate, and other chemicals are secured from brine by electrochemical methods, but are also produced by pyrochemical processes.

The passage of from 2,328 to 2,984 kilowatt-hours of direct current from the positive terminal through purified brine solution to the negative terminal of specific electrolytic cells produces simultaneously 1 ton caustic soda, approximately nine tenths ton chlorine, and approximately 8,100 cubic feet hydrogen. One ton metallic sodium requires over 13,000 kilowatt-hours energy when electrolyzed from fused caustic soda. Metallic magnesium production from dehydrated magnesium chloride is effected with approximately 16,000 kilowatt-hours of energy.

The electrolytic caustic soda and chlorine industry is firmly established; it consumed approximately 660,000,000 kilowatt-hours of energy in 1929. If all caustic soda sold in that year had been produced electrolytically, approximately 1,900,000,000 kilowatt-hours of electric current would have been consumed. Metallic sodium and other electrolytic sodium products are marketed in such small quantities that their production is not separately recorded.

The magnesium industry is in the initial stages of development in this country. Its increased production is primarily dependent upon the development of aeronautics. In 1929 approximately 11,000,000 kilowatt-hours of energy were consumed in its manufacture.

Because caustic soda and chlorine have served well-established and expanding markets for many years while other brine electrolytic

chemicals and metals have had small markets, and also because some well brines contain from 96 to 98 percent sodium chloride and but small amounts of any one other chemical, the larger number of electrolytic plants have used only the sodium chloride content of brines. A beginning has been made, however, by one plant toward the complete utilization of the chemicals contained in complex brines. Natural brine containing 14 percent sodium chloride, 3 percent magnesium chloride, 0.15 percent bromine, and 9 percent calcium chloride is oxidized by electrolysis to separate out the bromine, which enters into dye, medicinal, and other chemical production. The sodium chloride crystallizes out of evaporated liquors and is separated into its component parts by electrolysis. The calcium chloride and magnesium chloride are separated, and the latter, after dehydration, is electrolyzed to metallic magnesium. A large number of valuable chemical products are manufactured from these basic brine constituents by combining them with such other basic chemicals as carbon, benzol, and sodium acetate. The total power generated at this chemical plant is 38,000 kilowatts.

Oceanic salts contain approximately 77.8 percent sodium chloride, 11 percent magnesium chloride, 5 percent magnesium sulphate, 2.5 percent potassium sulphate, and small amounts of magnesium bromide, calcium carbonate, and calcium sulphate. These salts have been evaporated for their sodium chloride content alone without recovery of other chemical constituents, along the California coast for many years. Only recently bromine and magnesium chloride are being produced from the accumulated bitterns on San Francisco Bay, and plans are under way to utilize the potash content of these bitterns. Unlike the recovery from the original brine, this reduction of bitterns is not an electrolytic process.

Handling of brine necessitates the evaporation of large quantities of water either before or after chemicals are produced electrolytically. While the market for dilute caustic soda is large, if the alkali is to be shipped any distance the cost of freight on dilute solutions must be balanced against the corresponding cost of more complete evaporation. Consequently the favored location of electrolytic alkali plants is near consuming markets, as well as near sources of raw materials. This condition has led to the erection of electrolytic caustic soda and chlorine units by consuming industries, such as pulp and paper mills, petroleum refineries, and detinning factories. It is seldom, however, that consuming industries can use to advantage in their own industry the three chemicals produced.

Chlorine and caustic soda find their principal consuming markets in the cellulose industries. These industries, as well as chemical industries, are affording expanding markets for both chemicals. Brine wells in New York State, abundant power, and a well-developed pulp and paper industry are responsible for the location of six electrolytic caustic soda and chloride plants in New York. Michigan electrolytic plants located above brine wells serve their own and Wisconsin pulp and paper industries. West Virginia electrolytic alkali plants serve principally organic chemical industries. Washington electrolytic plants have been established to serve the pulp and paper industry, while the California plant serves petroleum refineries and soap industries. The country's export market for alkalis lies in the Far East, a factor of importance in Pacific coast electrolytic alkali market development.

Sources and Chemical Composition of Raw Materials

1. Brine is the source of several chemical compounds which may be separated by electrolysis for use in industry. Obtained from sea water, from salt lakes, from salt desert and marsh lands, from salt springs, and from wells bored in rock-salt beds it contains varying amounts of sodium chloride in association with other chemicals.

2. *California.*—In oceanic salts, sodium chloride forms approximately 77.8 percent of the total salt content; magnesium chloride, 10.8 percent; magnesium sulphate, 4.7 percent; calcium sulphate, 3.6 percent; potassium sulphate, 2.5 percent; while less than 1 percent magnesium bromide and calcium carbonate are found. Solar evaporation is made possible by the long dry season of California along the shores of San Francisco Bay, Monterey Bay, San Pedro and San Diego Bays, and at other points along the coast where sea water is led into lagoons. Where salt has been evaporated for many years without the recovery of other chemicals, the bitterns contain accumulated amounts of magnesium chloride and magnesium sulphate as well as of bromine. Such bitterns are found in the San Francisco Bay region.

3. The brine of Owens Lake, Inyo County, Calif., in addition to sodium chloride, contains about 2 percent anhydrous boric acid and 2 percent potassium. Natural soda ash, sodium bicarbonate, and borax are produced. At Searles Lake, San Bernardino County, Calif., the brine averages 6 percent potash, 3 percent sodium tetraborate, 13 percent sulphate content, and contains iodine and bromine but little magnesium.[83] From this lake is produced much of the country's potash and borax.

4. *Utah.*—The Great Salt Lake of Utah contains 89 percent sodium chloride, 6.5 percent sulphate content, 2.5 percent magnesium, and 1.6 percent potash in its salts. Salt is produced at Saltair and at Garfield by solar evaporation.

5. What is claimed to be the most extensive rock-salt deposits in the world are located in the valley of the Sevier River near Salina, Utah. As the operating company has specialized in rock salt for livestock feeding, open-pit mining is employed. Salt springs occur in Juab County; and in Millard County and Tooele County crusts of salt appear in marsh and deserts where was once the ancient Lake Bonneville.

6. *Michigan.*—Michigan is the largest salt-producing State. Brine occurs in sandstone from 750 feet to 1,000 feet below the surface of the Saginaw Valley of Michigan. These brines are composed of approximately 83 percent sodium chloride, 3 to 7 percent magnesium, and from less than 1 percent to over 2 percent bromine. The calcine content is high in most beds, at times replacing the usual sodium content of 23 percent almost entirely. This brine is used largely for the manufacture of caustic soda, chlorine, soda ash, and other industrial chemicals.

7. The rock salt deposits which continue from the southeastern section of Ontario, Canada, under Lake Huron, under the St. Claire River, the Detroit River, and Lake St. Claire, yield a brine from bored wells 1,200 to 1,500 feet deep of approximately 94 percent sodium chloride and only small traces of other chemicals. Much the same composition is found in rock salt brines near Manistee.[84]

[83] U.S. Geological Survey Bulletin 669, Salt Resources of the United States.
[84] Michigan Geological and Biological Survey Publication 35, Geological Series 29, Production and Value of Mineral Products in Michigan for 1923 and Prior Years.

8. *New York and Ohio.*—New York ranks second in salt production, Ohio, third. The rock salt beds which extend from Lake Erie eastward across New York State and for a short distance south into Ohio, contain from 96 to 98 percent sodium chloride and but small amounts of any one other chemical.[85] These are frequently mined by blasting. However, at Syracuse, N.Y., and Pomeroy, Ohio, magnesium-bearing bitterns are found. Such bitterns are found also at Hartford, W.Va.

9. *Kansas.*—Kansas ranks fourth in salt production. Rock-salt deposits occur in Ellsworth, Harper, Reno, and Rice Counties. This is marketed as rock salt or as evaporated salt made by running fresh water into bore-holes in rock salt beds and pumping the brine to the surface for heat evaporation.

10. *Other States.*—Louisiana also produces rock salt and evaporated salt. In Oklahoma some brine is obtained as a byproduct of oil wells. Texas produces evaporated salt. Small deposits of rock salt or brine are found in Arizona, southeastern Idaho, Nevada, New Mexico, Wyoming, Virginia, and West Virginia. Washington State produces sodium carbonate at Warden, Grant County.

11. Just how much of the brine and rock salt produced at 58 salt mining and evaporating plants in the United States enters into table salt, into ice cream freezing and packing, into cattle feed, meat packing, or hide salting, and how much is used by the electrolytic-alkali and ammonia-soda plants in the production of sodium and magnesium compounds is not ascertainable from brine sources. Less than 80,000 short tons of natural soda was produced in 1928, this coming entirely from Searles and Owens Lakes in California. Most of this natural soda was converted into sodium silicate or into caustic soda by the lime-soda process and was consumed by local industries. But there can be no doubt that the country's brine resources in the East, the Central, the Southern, the Rocky Mountain, and the Pacific coast sections are ample to meet expansion in sodium production as well as expansion of other markets in each section of the country.

12. Brines containing magnesium are more limited in occurrence. However, mineral deposits are available in Washington and California whenever it is commercially feasible to develop them for the magnesium metal market.

Electrolytic Products From Brine

13. Among the more important products resulting from brine electrolysis are caustic soda and chlorine, metallic sodium, and metallic magnesium. While other chemicals can be made in this way, it is more usual to produce them by purely chemical processes from caustic soda, metallic sodium, or soda ash.

14. As market demands are greatest for caustic soda and chlorine, major attention will be given these electrolytic chemicals.

CAUSTIC SODA AND CHLORINE

15. Since the industrial development of the caustic soda industry, its manufacture has been intertwined with the manufacture of a chlorine bleach.

[85] U.S. Geological Survey, Bulletin 669, Salt Resources of the United States.

HISTORICAL DEVELOPMENT IN ENGLAND AND FRANCE

16. In the eighteenth century the alkali necessary in the soap and glass industries was obtained by the lixiviation of ashes of seashore plants. The bleaching of textiles was achieved by exposure of textiles to the sun's rays. With the expansion of the several industries, these methods of obtaining chemical reactions were too slow and too uncertain to meet the growing demands. At the close of the century a Frenchman prepared a bleaching agent by dissolving gaseous chlorine in water, the chlorine being obtained by heating salt, manganese, and sulphuric acid in lead stills. At about the same time, a Frenchman named Nicolas LeBlanc prepared soda from common salt. By his process, salt was heated and treated with sulphuric acid, producing sodium sulphate or salt cake. This, in turn, was heated with coal and mixed with lime to produce sodium carbonate. Treatment with additional lime resulted in caustic soda.

17. The manufacture of both products, the alkali and the chlorine, was first developed commercially in England. However, Charles Tennant produced the first commercial bleaching powder by chlorinating hydrate of lime, thereby establishing the bleaching powder industry in England. The first successful alkali works, using the LeBlanc process, was erected in England in 1823. This process evolved hydrochloric acid gas which was wasted until Gossage, in 1836, condensed it and, by its reaction on manganese dioxide, produced chlorine. Gradually, this method of producing the bleaching gas superseded the earlier process upon which Tennant had established the bleaching powder industry in England.

18. The hydrochloric-acid gas produced in the LeBlanc process, however, exceeded the market requirements for chlorine, and much was allowed to escape into the air destroying all crops with which it came in contact. Or, when condensed, the acid was sent into streams killing the fish. Consequently, the LeBlanc process was in popular disfavor and many litigations resulted from its use. In 1863 and 1864 alkali acts were passed in England rendering compulsory the condensation of 95 percent of the hydrochloric-acid gas produced.

19. This situation made welcome an ammonia-soda process of manufacturing sodium carbonate invented by a Belgian chemical Engineer, Ernest Solvay. The Brunner-Mond Co., of England, which was producing sodium carbonate and chlorine products for bleaching powder by the LeBlanc process, adopted the new process whereby sodium carbonate could be produced in one operation and calcium chloride was the only waste product. The alkali was manufactured at a cost substantially lower than the cost of the older process although no chlorine for bleaching was obtained. Consequently, the cost of caustic soda and other sodium compounds was likewise reduced. So great was the success of the new process, as far as sodium compounds were concerned, that the LeBlanc producers were forced to unite and in 1890 formed the United Alkali Co., which is still in operation. Emphasis was placed upon chlorine bleaching powder production and salt cake rather than upon sodium carbonate and caustic soda by this organization. Recently, it has adopted electrolytic caustic soda and chlorine production methods.

DEVELOPMENT IN THE UNITED STATES

20. During these years of English dominance in bleaching powder and sodium compound production the United States imported most of her bleaching powder. As the demands for sodium compounds increased, ammonia-soda process plants were established on top of salt beds in New York, Ohio, and Michigan. These plants produced sodium carbonate as their base product and manufactured caustic soda and other compounds from it to meet trade demands. About 1890 Hamilton Castner succeeded in separating common salt into its two component parts by the passage of electric current through brine at Niagara Falls. The chlorine was given off as a gas while the sodium was collected in a mercury floor of the cell.

21. At about the same time the Elektron Co. of Germany had succeeded in producing electrolytic caustic soda and chlorine. Both the United States and Germany established protective tariffs to permit the infant electrolytic chlorine and caustic industries to grow in face of competition from England's LeBlanc bleaching powders.

22. The first American electrolytic plant was established at Rumford Falls, Maine, in 1893. In 1898 this plant was transferred to Berlin, N.H., to operated in conjunction with a paper pulp mill. In the same year the Castner Electrolytic Alkali Co. began making bleaching powder at Niagara Falls. The Dow Chemical Co. had started a 400-kilowatt plant to manufacture bleaching powder in 1897 at Midland, Mich. The Pennsylvania Salt Manufacturing Co. started operations at Wyandotte, Mich., in 1903. The Hooker Electrochemical Co. built an electrolytic plant at Niagara Falls in 1906.

23. Since that time other electrolytic plants have been established and ammonia-soda process plants have added electrolytic units to produce chlorine and caustic soda until there are 19 electrolytic plants having a capacity of 320,000 short tons of caustic soda and approximately 280,000 short tons of chlorine, with hydrogen as a byproduct. In addition, 17 pulp and paper mills have their own electrolytic alkali plants with an estimated capacity of 50,000 tons of caustic soda.

24. Prior to 1916 most of the chlorine produced in these plants was converted into bleaching powder by passing the chlorine over lime. It has been definitely established, however, that lime adds nothing to the bleaching qualities of chlorine and that, when in properly constructed containers, liquid chlorine lasts indefinitely while bleaching powder deteriorates rapidly. As methods of shipping chlorine safely have been perfected, the tendency of industries using large quantities of bleach has been to buy liquid chlorine in place of bleaching powder. Bleaching powder will continue to be used, of course, for smaller, package markets.

25. *Present production.*—The electrolytic separation of salt has become the prevailing method of producing chlorine, having almost succeeded in pushing the LeBlanc process material from the market, even in England. Only about a third of the caustic soda manufactured, however, is made electrolytically. The demands for soda ash (sodium carbonate) so far exceed the market for caustic soda that five ammonia-soda companies have been able to control caustic soda prices. These plants produce the caustic soda from sodium carbonate by treatment with lime.

26. *Caustic soda.*—The increased demand for caustic soda shown on table I of approximately 128 percent since 1919, or from 333,000 tons to 758,800 short tons has been met by an increase in electrolytic production proportionate only to the increase in lime-caustic soda production.

27. Nor does the production of 758,800 short tons represent the total market demand for caustic soda. In soap and paper industries requiring large amounts of caustic soda in dilute solution large producers buy soda ash and causticize it themselves. As a consequence, part of the soda-ash market is really a caustic-soda market. Nor is the production of the 17 pulp and paper mills manufacturing electrolytic caustic soda and chlorine for their own requirements included, although it is estimated this would add from 30,000 tons to 50,000 tons to the electrolytic caustic-soda production.

TABLE I.—*Production of caustic soda (sodium hydroxide) in the United States* [1]

Year	Total production (short tons)	Percent increase or decrease over 1919	Electrolytic process [2]		Lime caustic soda	
			Short tons	Percent of total	Short tons	Percent of total
1919	333,361					
1921	238,591	−28.4	75,547	31.7	163,044	68.3
1923	436,619	+31.0	122,424	28.0	314,195	72.0
1925	497,261	+49.2	141,478	28.5	355,783	71.5
1927	573,417	+72.0	186,182	32.5	387,235	67.5
1929	758,800	+127.6	233,815	30.8	524,985	69.2

[1] U.S. Bureau of the Census: Chemicals.
[2] Does not include tonnage manufactured and consumed at pulp and paper mills estimated to be approximately 30,000 tons in 1927 and 1929.

28. *Chlorine.*—The failure of electrolytic caustic soda to secure a more important place in the alkali market has been due largely to its dependence on the market for chlorine. For every ton of caustic soda produced approximately nine tenths of a ton of chlorine is obtained that must find a profitable market. Fortunately, for the continued success of the electrolytic industry, the demand for chlorine is increasing. It is difficult, however, to determine the exact amounts of chlorine entering industry from census figures for firms producing chlorine convert some into bleaching powder, or into hydrochloric acid, and several manufacture a number of other chlorine compounds.

29. On the basis of electrolytic caustic soda produced, the production of chloride was probably approximately 210,000 short tons. The chlorine marketed as compressed and liquefied gas totaled 120,648 tons, an increase of 165 percent over 1919 production and a 45 percent increase over 1925. Bleaching powder manufacture, including sodium hypochlorite, decreased 0.2 percent since 1919, or a little over 119,886 tons were manufactured in 1929.

TABLE II.—*Production of chlorine and bleaching powder in the United States* [1]

Year	Chlorine		Bleaching powder and sodium hypochlorite	
	Total production (short tons)	Percent increase or decrease over 1919	Total production (short tons)	Percent increase or decrease over 1919
1919	45,571		126,425	
1921	37,985	−16.6	86,602	−31.5
1923	62,681	+37.5	157,914	+24.9
1925	83,163	+82.5	130,830	+3.5
1927	117,489	+157.8	133,642	+5.7
1929	120,648	+164.7	119,886	−5.2

[1] U.S. Bureau of the Census. Compressed Gases, and Chemicals.

30. *Producing plants and their locations.*—Plants at which electrolytic caustic soda and chlorine are produced are located in the following towns and cities:

California:	Pittsburg, Great Western Electrochemical Co.
Illinois:	East St. Louis, Monsanto Chemical Works.
Michigan:	Midland, Dow Chemical Co.
	Wyandotte, Pennsylvania Salt Manufacturing Co.
New Jersey:	Deepwater Point, E. I. duPont de Nemours & Co.
New York:	Niagara Falls, Hooker Electrochemical Co., Isco Chemical Co., Mathieson Alkali Works, Niagara Alkali Co., Niagara Smelting Corporation.
	Syracuse, Solvay Process Co.
Ohio:	Painesville, Diamond Alkali Co.
Pennsylvania:	Pittsburgh, Vulcan Detinning Co.
Texas:	Port Arthur, Gulf Refining Co.
Washington:	Tacoma, Hooker Electrochemical Co., Pennsylvania Salt Manufacturing Co.
West Virginia:	Belle, Belle Alkali Co.
	Nitro, Monsanto Chemical Works.
	South Charleston, Westvaco Chlorine Products Co.

31. Pulp and paper mills operating their own electrolytic alkali plants are:

Delaware:	Wilmington, Jessup and Moore Paper Co.
Maine:	Cumberland, S. D. Warren & Co.
	Great Works, Penobscot Chemical Fibre Co.
	Rumford, Oxford Paper Co.
	South Brewer, Eastern Manufacturing Co.
Maryland:	Elkton, Jessup & Moore Paper Co.
	Luke, West Virginia Pulp & Paper Co.
New Hampshire:	Berlin, The Brown Co.
New York:	Mechanicsville, West Virginia Pulp & Paper Co.
North Carolina:	Canton, Champion Fibre Co.
Ohio:	Carrollton, Miami Paper Co.
Pennsylvania:	Johnsonburg, New York & Pennsylvania Paper Co.
	Philadelphia, Dill & Collins.
	Roaring Springs, D. M. Bare Paper Co.
	Tyrone, West Virginia Pulp & Paper Co.
Virginia:	Covington, West Virginia Pulp & Paper Co.
Wisconsin:	Kimberly, Kimberly-Clark Co.

32. Ammonia-soda alkali plants producing lime-caustic soda are:

Kansas:	Hutchinson, Solvay Process Co. (not operating).
Michigan:	Detroit, Solvay Process Co.
	Wyandotte, Michigan Alkali Co.
New York:	Syracuse, Solvay Process Co.
Ohio:	Barberton, Columbia Chemical Co.
	Painesville, Diamond Alkali Co.
Virginia:	Saltville, Mathieson Alkali Co.

Electrolytic Caustic Soda and Chlorine Process

32. A pure solution of common salt (sodium chloride) forms the electrolyte for this process. Consequently, the first step is the purification of the raw material. Methods will vary with the type salt used. When magnesium and lime are present, the magnesium is removed by adding waste salt containing caustic soda; and lime is removed with soda ash. The purified brine is filtered and a little hydrochloric acid added. As the brine solution enters the electrolytic tank it has a salt content of approximately 26 percent.

33. The passage of a direct-electric current from a positive terminal or anode through a sodium-chloride solution to the negative terminal or cathode decomposes the salt into its component parts, sodium and chlorine. When chlorine and caustic soda (sodium hydroxide) are the desired products, electrolytic cells are used that prevent secondary reactions of these chemicals after their dissociation. Methods of effecting the separation of these chemicals vary in the different types of cells. The cells in most frequent use in this country are of the diaphragm and of the moving mercury cathode types.

34. *Diaphragm cells.*—In all diaphragm cells porous diaphragms separate the anode compartment from the cathode compartment. Liquor may be on both sides or on only one side of the diaphragms. The brine enters the anode compartment and percolates through diaphragms to the cathode sections. The liberated chlorine gas escapes at the anode into collection mains, while the sodium is deposited on the cathode, where it reacts with water in the submerged type of cell to form sodium hydroxide (or caustic soda) and hydrogen. The hydrogen is carried off and the caustic soda solution drops into troughs or pockets. In some tanks the cathode is not immersed but is only wetted by the percolations through the diaphragm and the alkali is washed away with steam.

35. In another type of cell, the cathode compartment is filled with high-boiling mineral oil. The brine percolates slowly through the diaphragm into the oil. The caustic soda is thrown off and sinks, while hydrogen bubbles rise to the oil surface and are carried off. In a third type of diaphragm cell a cylindrical form is used, and only one side of the diaphragm is submerged. The anode is made up of graphite strips fastened to the concrete asbestos anode cover. The cathode is a perforated iron cylinder around which the diaphragm of asbestos is wrapped.

36. Diaphragms in all types are usually of asbestos, although paper pulp has been used. Anodes are of electric-furnace graphite, and cathodes are made of perforated iron. Graphite anodes usually last a year.

37. The current density determines, to a large extent, the cell voltage required and, consequently, the production per unit of electricity. While a high current density will give greater output per cell, a low current density will require less energy per unit produced. The current density employed is determined by the particular cell in use and the cost of power. The cell having mineral oil in the cathode compartment takes highest current densities of the prevailing diaphragm cells. At 3,000 amperes and 4.05 volts it will produce 225 pounds caustic soda in 24 hours at a cost of 296 kilowatt-hours, while a 4,000-ampere cell at 4.65 volts would produce the same amount in

18 hours at a cost of 336 kilowatt-hours, or 1 ton of caustic soda would require 2,630 kilowatt-hours at the lower density and 2,984 kilowatt-hours at the higher density.

38. The cells having unsubmerged diaphragms usually require from 1,000 amperes to 1,500 amperes and a voltage of 3.6 to 3.9. Current efficiency in new cells is from 92 to 95 percent. The energy consumption per ton caustic soda would be from 2,340 to 2,500 kilowatt-hours. About nine tenths ton of chlorine and 8,100 cubic feet of hydrogen are produced at the same time.

39. A plant using the circular diaphragm cells having 95 percent current efficiency, with an average voltage of 3.5 and an average amperage of 948.1 per cell produced 0.859 pound of caustic soda and 0.793 pound of chlorine per kilowatt-hour, or the production of 1 ton of caustic soda and 1,846 pounds of chloride required 2,328 kilowatt-hours. Per ton of finished product, exclusive of hydrogen, 1,210 kilowatt-hours are consumed.

40. *Mercury cells.*—In the mercury cathode cell two slate partitions divide the cell into three sections which are sealed from each other by mercury covering the tank bottom. The central section contains an iron cathode, made up of strips, and is filled with water. The outer chambers have graphite anodes and are filled with brine. The chlorine is carried off as in other cells, but the sodium combines with the mercury. The mercury is circulated by an Archimedean screw or by tilting the tank slowly. As the sodium and amalgam pass to the center chamber, they act as the anode and water combines with the sodium to form caustic soda and hydrogen.

41. These cells require on an average 4,000 amperes at 4.4 volts. A 40-percent caustic solution is obtained which is a higher concentration than that gotten in diaphragm cells. The caustic soda is also very pure. But power requirements are 2,900 kilowatt-hours per ton of caustic soda and per 1,760 pounds of chlorine, or higher than in prevailing diaphragm cells. Mercury costs are also considerable items in this process.

42. The I. G. Farbenindustrie of Germany has patented a process whereby a 60-percent concentration of caustic soda is obtained through the agitation of the sodium amalgam with nitrobenzene and water.

43. *Evaporation of caustic soda solution.*—The solution from all diaphragm cells contains more salt than caustic soda. Consequently, evaporation must not only concentrate the caustic soda but free it of salt content. This is accomplished in double-effect, single, or triple-effect evaporators, operating under vacuum and heated by steam. In new plants the process is continuous and circulation is forced; in older plants it is a batch cycle requiring 5 or 6 hours to produce 12 tons of 50 percent caustic. The weak liquor is gradually concentrated to 50 percent caustic soda solution. This is pumped to crystallizers where cooling by a countercurrent flow of water in the jackets causes the salt to crystallize out. The salt is washed thoroughly and sent to settling tanks, ready to be used again in the purification of raw brine.

44. Much caustic soda is now marketed in tank cars as a 50 percent solution. The remainder is further evaporated in open fusion pots to solid and flake caustic.

45. During a 24-hour test run of a modern evaporating plant, 53 tons of 100 percent custic soda were evaporated from 1,026,000 pounds

of water using 746,000 pounds condensed steam at 10-pound gage pressure. The condensers required on an average of 2,200 gallons of cooling water per minute. Power consumption of the pumps which forced liquor circulation totaled 90 kilowatts per hour.[86] Or approximately 40 kilowatts hour of energy must be added to each ton of caustic soda produced for evaporator-pump operation. About 120 additional kilowatt-hours are consumed by the evaporating plant in lighting and in miscellaneous uses.

46. Although shipping 50 percent caustic soda to consumption plants lessens evaporation costs materially, efforts are being made to isolate caustic soda from the salt solution and to evaporate the weak caustic soda liquor by speedier and less expensive methods. The department of chemical engineering of the University of Michigan has dehydrated caustic soda in a forced circulation evaporation system by use of diphenyl vapor as a heating medium, thereby eliminating the pot-finishing process. A patent by D. A. Pritchard, of the United Alkali Co., of England, adds salts of sulphuric acid to precipitate the sodium chloride.

47. *Liquid chlorine.*—Chlorine gas withdrawn from the top of the electrolytic cells into stoneware collection mains is carried through cooling coils to drying towers. Here it passes against 66° Baumé sulphuric acid to remove moisture. The dry chlorine gas is delivered to liquefaction towers. It is entrained with a falling column of strong acid. Falling through a distance of approximately 90 feet into a compression chamber, gas pressure is increased and as gas rises through cooling coils it liquefies. The liquid chlorine is run into steel vessels and from there into tank cars for market, or into storage tanks.

48. *Bleaching powder.*—Some chlorine is still converted into bleaching powder. Hydrated lime is placed in coil-cooled concrete chambers to a depth of several inches. The chambers are sealed and chlorine gas and air are passed over the lime countercurrently. The chloride is absorbed by the lime to make chloride of lime or bleaching powder.

49. *Hydrochloric acid.*—An acid-proof refractory furnace is used as the reaction chamber when chlorine is made into hydrochloric acid. Chlorine and steam enter in the furnace bottom while coke is charged in at the top. The mixture passes through dust chambers, is cooled, and gases are absorbed in a tower system. The acid may be made directly from sodium chloride by the action of strong sulphuric acid in mechanical furnaces, producing sodium sulphate as a byproduct.

50. *Synthetic ammonia.*—Byproduct hydrogen (amounting to approximately 9,000 cubic feet per ton of chlorine produced is collected and metered. It is mixed with air in proportion of 75 to 25 and oxygen is burnt out. The residual gases are cooled and scrubbed to remove impurities. They are compressed at pressure of 4,000 pounds. At this pressure the nitrogen-hydrogen mixture passes over a soda-lime tower for further purification. The gases are then ready to be catalytically combined by a modified Haber process. (For details of Haber process see pp. 142 and 143, of Power in Fertilizer Material Production.) For this method of ammonia production from 85,000 to 100,000 cubic feet of hydrogen are required, 75,000 cubic feet to

[86] Lee, James A. Westvaco Sets New Record in Evaporating Electrolytic Caustic Soda. Chemical and Metallurgical Engineering, July 1930.

be used as hydrogen in the catalytic chambers and 10,000 to 25,000 cubic feet to secure nitrogen from air.[87]

Ammonia-Soda Process

51. The basic raw materials for the ammonia-soda process are salt, limestone, coke, and coal. Ammonia may be produced at the plant from water-gas hydrogen and producer gas nitrogen from the coke, or from coke-oven hydrogen and liquefied nitrogen (see pp. 144 and 145 of Power in Fertilizer Material Production), or it may be purchased. Carbon dioxide is obtained through the burning of limestone to produce lime and also from the recovery of ammonia from the mother liquors. One ton of sodium carbonate requires 253 pounds of coke, 2,645.5 pounds limestone, 1,102 pounds coal, and 5 pounds ammonia.[88] Large producers who own their own limestone quarries and are on waterways have been able to get limestone delivered for less than $0.70 per ton stone. Some plants also have their own coke ovens.[89]

52. Strong brine, after purification, is saturated with ammonia gas in saturator towers. This ammoniacal brine is cooled and then passes to carbonating towers. In these carbon dioxide is pumped in at the base and ascends the tower as ammoniacal brine descends. In the lower sections of the tower are cooling tubes. Usually the mixture passes to another tower, in which ammonium chloride (NH_4Cl) is formed and soda bicarbonate precipitated. The soda bicarbonate is filtered in vacuum filters and is calcined to sodium carbonate ($NaCO_3$). If bicarbonate of soda is desired, all ammonia is driven off the sodium is recarbonated, and is dried in a hot air current.

53. The ammonium chloride may be converted into calcium chloride with lime. Or, if ammonia is desired for continual use in the manufacture of sodium carbonate, it is recovered in distillery towers. Steam entering at the base dries off the carbon-dioxide gas. Milk of lime entering halfway up the tower frees the ammonia from the chlorine.

54. *Lime caustic soda.*—The tank liquor containing about 660 parts of sodium carbonate in 2,000 parts of water is heated to 90° C. Three hundred parts of quicklime are added gradually as the solution is stirred. This is boiled for about an hour, when the liquor filtered off from the calcium carbonate contains about 14.5 percent caustic soda and over 7 percent sodium carbonate. By a gradual cooling in a tank having cold brine circulating coils or other cooling systems, the sodium carbonate crystallizes out. At a temperature of minus 15° C. only about 0.8 percent sodium carbonate remains in the solution while the caustic soda forms 18 percent of the solution. The sodium carbonate crystals are recovered for reuse in caustic soda production. The caustic liquor is evaporated by waste heat and in soda pots or through a multiple-effect vacuum evaporating system as in electrolytic plants. One and thirty-five hundredths (1.35) tons of soda ash is required for 1 ton caustic soda.

55. *Causticized caustic soda.*—Crude sodium is calcined to a 40 percent sodium oxide (Na_2O). This is saturated in a rotary drum

[87] Manning, Paul D. Pacific Coast Industry Diversifies Products, Chemical and Metallurgical Engineering, June 1930, specified 100,000 cubic feet.
[88] Partington, J. R. The Alkali Industry, p. 127.
[89] Hughes, L. C. Modern Ammonia-Soda Plants. Chemical and Metallurgical Engineering, April 1930, p. 232.

and mixed with milk of lime. After passing through thickeners it goes to causticizing tanks where it is kept in agitation. In 1 hour a 90 to 91 percent caustic is secured. This passes through several thickeners and filters and finally goes to brine kilns. One ton of lime is used per ton caustic produced. Calcium carbonate is a byproduct.

56. *Other chemicals produced at electrolytic plants.*—As caustic soda or chlorine are raw materials for a number of other chemicals, as some brines contain chemicals other than sodium chloride, it is not surprising to find that electrolytic producers for the general market manufacture such sodium and chlorine compounds, or such other brine chemicals, as their market demands.

57. The Great Western Electro-Chemical Co. of California, in addition to 40 tons electrolytic caustic soda, 35 tons chlorine, 27 tons bleaching powder, 5 tons synthetic anhydrous ammonia, and 1.5 tons aqua ammonia, produces, as the market requires, hydrochloric acid, sodium hypochlorite, sodium xanthate, potassium xanthate and alkyl xanthate, ferric chloride, zinc chloride, and diammonium phosphate fertilizer.

58. While the new Tacoma plant of the Hooker Electrochemical Co. is at present confinding its manufacture to two basic chemicals, at the parent plant in Niagara Falls, the following additional chemicals are produced: Hydrochloric acid, monochlorbenzene, paradichlorbenzene, benzoate of soda, benzoic acid, benzoyl chloride, benzyl alcohol, benzyl chloride, antimony trichloride, ferric chloride, sulphur monochloride, sulphur dichloride, sulfuryl chloride, and table salt.

59. The Dow Chemical Co. produces from complex Michigan brines more than 45 chemicals. The bromine and the magnesium content of these brines is manufactured into bromides and ethylene bibromide, metal magnesium, and magnesium chloride, and arsenate, while the caustic soda and chlorine are treated with other basic materials to produce such chemicals as chlorbenzol, phenol, salicylic acid, and aspirin; carbon tetrachloride, chloroform, synthetic indigoes, and synthetic perfumes; ferric chloride, chloracetic acid, and acetic andydride used in cellulose acetates. Salt and metallic sodium are also among the many products.

60. The production of these three companies is illustrative of the interlocking chain of chemicals that may be manufactured in electrolytic caustic and chlorine plants in the several sections of the country.

61. *Cost of production.*—The multiplicity of chemicals manufactured at electrolytic caustic and chlorine plants permits a part of the cost of production of the basic chemicals to be borne by a number of materials having much greater market value than the base chemicals. The diversification of products in the several factories makes it impossible to determine the maximum cost of production of caustic and chloride that any individual plant may reach and yet compete successfully with other plants in its specific markets. The price of caustic soda is still determined by ammonia-soda plants in which caustic soda is almost a by-product.

62. Capital costs of electrolytic production are relatively high, especially when firms own chlorine tank cars. Engineers from firms operating such cars claim they represent an investment of almost $50 per ton per year. Where hauls are short and turnover of car capacity frequent, this unit cost would be materially reduced.[90]

[90] Transactions of American Electrochemical Society, 1926, p. 57.

63. Costs of raw materials are low unless salt carries heavy freight charges. Standard ocean freight rates run from $2.50 to $3 per ton, although coastwise steamers, wishing ballast cargo, accept a much lower rate.

64. With a total plant power consumption of from 1,350 to 1,704 kilowatt-hours per ton of caustic and per ton of chlorine produced, at a $0.003 rate, power costs would total but $4 to $5 per ton. Labor costs represent a larger item in total electrolytic plant costs than does power at this rate; however, this unit labor cost decreases with the size of the plant and varies with the character of additional chemicals manufactured. Renewals of equipment and plant maintenance costs are relatively high.

65. The location of any particular plant in relation to its sources of raw material and to its finished product markets are, therefore, more vitally important to its competitive success, at this time, than other items. Caustic soda, 76 percent solid, sold for from $58 to $60 a ton last year. In January 1931 the price had dropped to $45. Liquid chlorine brought from $12 to $14.75. Any hydrogen that could be marketed as such decreased the total cost by the price it brought.

66. *Caustic-soda consumption.*—The heavy increase in consumption of caustic soda between 1927 and 1929 was due primarily to the growth of the rayon industry. Increased demands came also from petroleum refineries, rubber reclaiming, pulp and paper, soap, and chemical industries. Table III, page 295, shows the estimated consumption by industries of caustic soda and soda ash in 1929 and 1930. The lessened consumption in 1930 is due to general industrial depression. Consequently, 1929 figures are regarded as better indices of alkali consumption markets.

67. The largest markets for caustic soda are offered, at present, by the rayon, the chemical, the petroleum, and the soap industries, each of which purchases 15 percent or more of the total amount marketed.

68. *Caustic soda in pulp production.*—While the pulp and paper industry bought from but 6 to 7 percent of the marketed caustic soda, a number of pulp mills produce caustic soda for their own needs either electrolytically or by causticizing soda ash. Caustic soda is essential to pulp manufactured by the soda process, as this process depends upon caustic soda to dissolve certain constituents of the wood as well as to hydrochlorize other constituents. Several of the newer methods of producing new types of paper also require caustic soda. It is probable, therefore, that the pulp and paper industry actually consumed about as much caustic soda as the other principal consuming industries.

69. *Caustic soda in rayon industry.*—Caustic soda is used in the Viscose process of manufacturing rayon to form cellulose xanthate which is decomposed. As the largest amount of rayon is now produced by this process and as it is believed this production will increase, unquestionably rayon will represent an increasing market for caustic soda.

70. *Caustic soda in soap manufacturing.*—All soaps require an alkali. This may be lye, made from caustic soda, sodium silicate made from soda ash, soda ash, or caustic soda, depending upon the fatty acid used and upon the kind of soap desired.

71. *Caustic soda in rubber reclaiming.*—Some 40,000 tons of caustic soda are used in rubber reclaiming. Production of reclaimed rubber

in the United States increased from 208,516 long tons in 1928 to 219,057 tons in 1929, while our exports increased from 9,577 to 12,721 tons. We export to 26 countries. Reclaimed rubber constitutes almost half of our total rubber consumption.[91] In this connection it is interesting to note that the Roessler & Hasslacher Chemical Co., which manufactures electrolytic caustic soda at a subsidiary at Niagara Falls reclaims rubber at El Morete, Calif.

72. *Shifting markets.* —Recently, a chemical market for caustic soda was successfully claimed by lime, a much cheaper alkali than caustic soda. This incident drew attention to the fact that perfection of processes in every industry, together with greater scientific data concerning the specific characteristics of each alkali in industrial application, may cause other adjustments in well established markets for specific alkalis. The increased production of ammonia as a result of the development, on a large scale, of direct synthetic ammonia plants in this country has led to a vigorous effort on the part of large ammonia manufacturers to find markets for ammonia as an alkali. Research is now underway to determine the possibility of substituting ammonia for other alkalis in the paper industry.

73. The electrolytic caustic soda manufacturer may be said to be protected from any such competition because hydrogen, the more costly constituent of ammonia, is a byproduct of electrolytic caustic soda production and is now being manufactured into synthetic ammonia at several electrolytic caustic soda plants.

TABLE III.—*Estimated consumption of caustic soda and soda ash in 1929 and in 1930* [1]

Industry	Caustic soda (sodium hydroxide)				Soda ash (sodium carbonate)			
	1929		1930		1929		1930	
	Short tons	Per-cent	Short tons	Per-cent	Short tons	Per-cent	Short tons	Per-cent
Total	750,000	100.0	640,000	100.0	1,668,000	100.0	1,475,000	100.0
Chemicals	135,000	18.0	100,000	15.6	335,000	20.0	290,000	19.7
Petroleum refining	121,000	16.1	105,000	16.4	26,000	1.6	22,000	1.5
Rayon	115,000	15.3	110,000	17.2				
Soap	108,000	14.4	100,000	15.6	213,000	12.8	200,000	13.6
Exports	60,000	8.0	63,000	9.8	40,000	2.4	36,000	2.4
Pulp and paper	[2] 45,000	6.0	[2] 42,000	6.6	110,000	6.6	100,000	6.8
Textiles	42,000	5.6	30,000	4.7	40,000	2.4	30,000	2.0
Rubber reclaiming	40,000	5.3	20,000	3.1				
Lye	25,000	3.3	22,000	3.4				
Vegetable oils	11,000	1.5	10,000	1.6				
Glass works					672,000	40.3	590,000	40.0
Cleansers and modified					125,000	7.5	112,000	7.6
Water softeners					60,000	3.6	55,000	3.7
Miscellaneous	48,000	6.4	38,000	5.9	47,000	2.8	40,000	2.7

[1] Compiled from estimates made by Chemical and Metallurgical Engineering, January 1931.
[2] Does not include caustic soda manufactured by pulp and paper mills.

CONSUMPTION OF CHLORINE

74. *Well-established chlorine markets.*—Although exact figures concerning chlorine consumption are not available, it is estimated that almost two thirds of all chlorine produced enters the pulp-and-paper

[91] U.S. Bureau of Foreign and Domestic Commerce, Rubber. June 1930.

industry. Whether in liquid or gaseous form, as a hypochlorite, or in bleaching powder, some form of chlorine is used commercially to remove undesirable impurities which are left by any method of isolating fibrous cellulose for paper.

75. Over 20 percent of chlorine produced is believed to be used in textile bleaching. In Europe, chlorine is used to degrease wool, but in the United States such grease is not recovered at all or recovered by solvent naphtha. In the bleaching of cotton, silk, and wool, chlorine may face competition with hydrogen peroxide.

76. With the increasing density of population, the requirements for chlorine or chlorine compounds in drinking water, as a purifier for bathing beaches and swimming pools, and to treat sewage and garbage odors are growing. The addition of ammonia to the chlorine used in drinking-water purification, to eliminate chlorine taste, may reduce the unit consumption of chlorine, but the increased need for adequate sanitation will unquestionably lead to an increased use of chloride compounds in populated areas. D. A. Pritchard of the Canadian Salt Co., Ltd., estimates 10 percent of all chlorine produced was required for sanitation measures in 1926.

77. *New chlorine markets.*—Chlorine, as sodium or calcium hypochlorites, has been used in the petroleum industry to remove objectionable odors from gasoline and kerosene. The Gulf Refining Co. at Port Arthur, Tex., has just perfected a method of producing a cheap supply of aluminum chloride for oil refining. This company has its own electrolytic chlorine plant. Bauxite is reduced by carbon and chlorinated simultaneously. Anhydrous aluminum chloride can be produced at the rate of 75,000 pounds per day at a cost of less than $0.05 per pound.

78. Another plant that has installed an electrolytic chlorine plant for its own use is the Vulcan Detinning Co. of Pittsburgh. Chlorine is used to detin tin-plate scrap, as chlorine gas will combine with tin under heat to form anhydrous tin tetrachloride. This is sent to the silk industry for weighting while steel scrap is available for steel furnaces.

79. The largest recent increased demand for chlorine has come from the organic chemical industry. Although employment of chlorine in organic chemicals—such as chloroform, carbon tetrachlorate, and chlorobenzene—has been carried on for many years, the more recent growth of the synthetic organic chemical industry in this country is responsible for the new demands.

80. Chlorine will react with many organic compounds. In the aliphatic series developed upon the segregation of component gases in natural gas, chlorine or its compounds may be used to form additional products, such as result from its combination with acetylene, to form substitution or oxidation products, or it may be used in combination with other elements. For example: Ethylene, a hydrocarbon gas, may be combined with hypochlorous acid to form ethylene chlorhydrin. Or it may be converted into ethylene chloride. Or, by the direct chlorination of methane, methlychloride, isopropyl, secondary butyl, secondary amyl, and secondary hexyl alcohol are obtainable. The greater demand for domestic electric refrigerators has led to a slow but increasing use of methyl chloride as the refrigerant in small-capacity refrigerators. In this field it has come in direct com-

petition with sulphur dioxide which was first used in household refrigerants.

81. Other organic chemicals in which chlorine is employed are monochloracetic, chloracetyl chloride, propylene chlorhydrin, ethylene dichloride, and dichlorodiethyl sulphite. Some chlorine organic chemicals have found ready markets; for others, markets must still be found.

82. *Chemical warfare.*—Consideration of chlorine markets would not be complete without recognition of the part chlorine plays in chemical warfare. According to Maj. Gen. Amos Fries, formerly head of our Chemical Warfare Service, chlorine is the basic ingredient of almost every one of modern chemical warfare agents. In phosgene, mustard gas, chloropicrin, tear gases, toxic smokes, and obscuring smokes, chlorine either appears in the product used or is essential to its manufacture.

83. The outlook for chlorine seems excellent, for with but minor competition in its well-established markets, its possibilities for increased use with the growth of the synthetic organic chemical industry are great.

84. *Location of consuming markets.*—The many products into which caustic soda and chlorine enter make it difficult to ascertain the amount of each chemical consumed in particular locations. By a process of weighting each State in accordance with its importance in the industries which are the heaviest consumers of each chemical, the relative size of the consuming markets have been ascertained.

85. Beyond a doubt, New York and Pennsylvania offer the largest existing markets for chlorine and caustic soda. Maine, because of its soda-pulp manufacture for which it requires caustic soda and because of its large consumption of chloride in all types of pulp production; New Jersey and Ohio, because of their chemical, soap, rubber, and miscellaneous industries; all three are heavy consumers of the heavy chemical and the gas.

86. The Pacific coast and such southern States as Virginia, West, Virginia, and Tennessee give promise of rapidly developing heavy markets for these chemicals. The South, because of its expansion as a rayon and chemical center must needs increase its requirements for caustic and chlorine. The diversification of wood-pulp production in the Pacific Northwest, which will not only increase the types of pulp made for paper but develop pulp for rayon and other cellulose-solution products, will bring with it an increased need of chlorine and caustic soda. The developments in gas cracking which have begun in California may lead to an organic chemical industry on this coast. The normal expansion of rubber reclaiming, of soap manufacture, of petroleum refining, in orchard spraying, and in the cyanide and flotation process for mining will call for chemicals of which one or the other of these electrolytic chemicals form the base.

87. *The export market.*—About 8 percent of the total caustic soda produced in this country is exported. Over a third of these exports is to Japan. Japan has a number of her own electrolytic caustic soda and chlorine plants but must import salt from Manchuria, Tsington, Spain, or Egypt at an average cost of $10 per ton.[92] While Japan

[92] Ochi, Shuichiro. Chlorine in Japan, in Transactions of the American Electrochemical Society, vol. XLIX, 1926.

has consumed caustic and bleach, chiefly in the pulp and textile industries in the past, the present development of viscose rayon manufacture will, unquestionably, increase her caustic requirements. Mexico, Cuba, Canada, the Philippines, and South American countries also buy caustic soda from the United States.

Chlorine and bleaching powder are shipped in small quantities to Canada and to South and Central America.

88. The United States has no European market for caustic or chlorine. Its export market lies principally in the Far East and in South and Central America. Here it comes in competition with Great Britain, which supplies about three fourths of the present market.

TABLE IV.—*Exports of sodium and chlorine products in 1929, by country of destination* [1]

Country	Caustic soda		Modified soda products		Chlorine		Bleaching powder	
	Short tons	Value	Short tons	Value	Short tons	Value	Short tons	Value
Total	60,538	$3,516,053	7,497	$424,541	3,584	$256,667	2,512	$127,767
Argentina	6,331	436,723	620	31,208	-------	40	650	17,780
Brazil	3,187	211,886	855	54,370	6	4,220	63	9,607
British India	852	52,942	36	3,423	-------	72	-------	-------
Canada	3,825	270,542	1,415	74,617	3,339	196,943	1,353	61,876
Chile	357	18,514	252	12,776	32	10,713	1	87
China	2,400	134,018	507	27,360	45	7,608	1	67
Colombia	677	40,525	198	11,921	36	9,452	65	1,971
Cuba	4,492	273,117	410	24,802	26	4,012	242	25,753
Japan	22,657	1,162,048	808	43,434	-------	40	-------	-------
Java and Madura	2,191	113,938	306	15,850	-------	-------	-------	-------
Mexico	7,450	446,005	944	51,136	26	7,349	32	1,736
Netherland West Indies	828	43,846	123	6,749	-------	71	1	299
Philippine Islands	2,730	143,076	507	25,044	39	6,077	41	2,401
Other countries	2,561	168,873	516	41,851	35	10,070	63	6,190

[1] Compiled from complete reports on exports and imports of the United States in 1929, which appear in Foreign Commerce and Navigation of the United States, U.S. Department of Commerce.

OTHER ELECTROLYTIC SODIUM PRODUCTS

89. *Metallic sodium.*—The world production of metallic sodium is estimated to be approximately 27,500 short tons by Dr. Hess, manager of the Dr. Alexander Walker Co., of Munich, Bavaria. Of this amount, Germany produces 11,000 short tons. American firms manufacturing it market but little, as it is used by them chiefly to produce sodium peroxide, sodium cyanide, or a synthetic indigo. Its ready oxidizability makes it essential to preserve it in kerosene or naphtha. No separate accounting is made of the metal or its sodium derivatives in United States statistics.

90. Metallic sodium is usually produced by the electrolysis of fused caustic soda (sodium hydroxide) with a nickel anode and iron cathode. Oxygen is liberated at the anode and passes out. Sodium and hydrogen are obtained in the cathode compartment. The sodium deposited on the cathode surface loosens, floats upward, and gathers in an iron cylinder. It is removed with a perforated iron ladle and may be cast into molds. This electrolysis requires over 13,000 kilowatt-hours of energy per short ton metallic sodium.

91. It is possible to manufacture the metal from fused salt with less energy but corrosion difficulties are encountered. A molten lead cathode is sometimes used, requiring a subsequent electrolysis of the sodium-lead alloy produced. Many other types of cells have been invented for this electrolysis but few are in commercial use.

92. When small pieces of metallic sodium are subjected to dry air heated to about 300° C., sodium peroxide (Na_2O_2) is formed. Sodium peroxide, when brought in contact with water or dilute acids, decomposes, yielding hydrogen peroxide. Consequently, sodium peroxide is used as a bleaching agent for textiles and straws and also in the refining of oils and fats. It competes with other hydrogen peroxides in the bleach market.

93. Sodium cyanide is made by passing ammonia through melted sodium mixed with charcoal. It competes in gold mining with cyanide made by fusing cyanamide and sodium chloride in an electric arc furnace and cooling the fused mixture quickly. From this calcium cyanide, hydrocyanic acid for fumigation purposes is produced. This acid competes with sodium cyanide fumigating liquors made by the sodium-ammonia process. Metallic sodium also forms an alloy with lead, which alloy is used for the preparation of hydrogen.

94. The Roessler & Hasslacher Chemical Co., then operating as the Niagara Electro-Chemical Co., began the manufacture of sodium by the electrolytic process. They have continued its manufacture for alloys, and also produce its derivatives—sodium peroxide, hydrogen peroxide, and sodium cyanide—at Niagara Falls. Liquid hydrocyanic acid is manufactured by them at El Morete, Calif. This firm reports sodium as having extensive use in organic industries.

95. *Sodium chlorate.*—Sodium chlorate is manufactured by electrolyzing a hot concentrated salt solution, the sodium hydroxide and chlorine generated being allowed to mix, thus producing the chlorate. This chlorate solution is evaporated and crystallized. The chlorate is used in the production of aniline black and other dyes.

95¼. *Sodium hypochlorite.*—Sodium hypochlorite (NaClO) is produced by the electrolysis of a cold solution of sodium chloride as well as by the chlorination of sodium carbonate. It is used as a deodorizer and disinfectant in dairies and ice-cream factories and also as a bleach in laundries and textile plants. In 1927, 23,118 tons of sodium hypochlorite were manufactured for sale by 11 establishments in the United States. While some electrolytic chlorine plants report the manufacture of this chemical, how much of the total production was by electrolysis is not known.

95½. Cells are of soapstone, concrete, or stoneware. They are divided into compartments by glass partitions so arranged that electrolyte enters and leaves each compartment above the electrodes or so that it is circulated over one and under the next electrode. Electrodes may be of graphite or platinum-iridium wire. The yield is 1 ton of active chlorine per 4,800 kilowatt-hours to 6,200 kilowatt-hours of energy in different types of cells.

MAGNESIUM

96. The magnesium industry has undergone rapid changes in the last few years. The successful manufacture of primary magnesium from the magnesium chloride in brine has ended all previous manu-

facture of the metal from the ore magnesite. With cheapened production and the growth of aeronautics which require metals having the specific properties of magnesium, the magnesium industry has advanced rapidly.

HISTORY AND DEVELOPMENT OF THE INDUSTRY

97. *Europe.*—Although pure magnesium metal was produced as early as 1830, it was the production of the metal by electrolysis of a fused bath of anhydrous magnesium chloride by Bunsen in 1852 that laid the foundations for the present magnesium industry. The first industrial trial production was undertaken in France in 1863 by DeVille and Caron. A mixture of anhydrous magnesium chloride and calcium fluoride was reduced to metallic magnesium in closed iron crucibles. Later, Sonstadt in Germany improved this method by a distillation of the impure metal resulting from the reduction of a mixture of magnesium chloride and sodium chloride with sodium.

98. However, the industry, as developed in Germany prior to the war, was based on the occurrence of the salts of magnesium with those of potassium in Germany's extensive potash deposits. A mixture of the magnesium chloride, potassium chloride, and sodium chloride was used as an anhydrous fused electrolyte. The iron cells formed the cathode while carbon anodes were used. The light magnesium floated on the top of the bath and was ladled off.

99. *United States.*—Although an American company produced small amounts of magnesium in the latter part of the nineteenth century, magnesium used in this country prior to the war was imported from Germany. Such metallic magnesium was used for photographic flashlights, fireworks, and for experimental purposes.

100. *World War production.*—The first recorded production in the United States was in 1914 and 1915, at which time 43.75 tons were produced. This was manufactured by the Rumford Metals Co. at Rumford Falls, Maine. The demand for magnesium in military pyrotechnics, tracer bullets, flares, and as a constituent of explosives was the incentive for the establishment of our domestic magnesium industry during the World War.

101. By 1917 five producers were operating and production had reached almost 58 tons. These producers were the American Magnesium Co., at Niagara Falls, N.Y.; the Dow Chemical Co., of Midland, Mich.; the General Electric Co., at Schenectady, N.Y.; the Norton Laboratories Co., at Lockport, N.Y.; and the Rumford Metals Co., at Rumford Falls, Maine. Production reached 142 tons in 1918. With the cessation of hostilities the industry slumped and production ceased at three factories.

102. *Post-war development.*—With the development of aeronautics came a demand for metals with a maximum strength in relation to weight. This demand was first met by the light aluminum alloys containing from 0.025 to 2 percent magnesium. The most striking property of magnesium is its extreme lightness. With a specific gravity of 1.74, it is only two thirds as heavy as aluminum, one fourth as heavy as iron, and one fifth as heavy as copper. By proper alloying and heat treatment, magnesium alloys were obtained with strength and toughness which permitted them to compete successfully with aluminum alloys in airplane construction.

103. By 1923 the demand for the metal in airplane construction led to an active resumption of activities. Production has increased steadily since that time until in 1929 almost 615 tons were produced. This represented a 155 percent increase in a year. From the close of the war until May 1927 this production came from two companies. The American Magnesium Corporation (a subsidiary of the Aluminum Co., of America) produced the metal at Niagara Falls from calcined magnesite from Washington State or Austria. The Dow Chemical Co. produced magnesium from magnesium chloride recovered as a byproduct of its salt wells at Midland. The cholride process, employing what had been waste material, proved to be so much less expensive than the oxide process used on calcined magnesite that the American Magnesium Corporation closed its factory in May 1927. All equipment for partial fabrication of the metal and for manufacturing the extruded bearings, alloys, castings, forgings, sheet, wire, and powder was moved from Niagara Falls to the plant of the United States Aluminum Co. (leased by the Aluminum Co. of America) at Cleveland, Ohio, where these magnesium shapes are now produced rom metal manufactured by the Dow Chemical Co.

PRESENT PRODUCTION

104. *United States.*—The Dow Chemical Co. of Michigan is, at present, the sole producer of magnesium in the United States, and importations of magnesium from Germany have decreased markedly.

105. A company was formed in 1929 for the purpose of producing magnesium, although no production was reported for this year. This was the United States Metallic Magnesium Co. which proposed to manufacture magnesium metal from dolomite deposits near Logan, Utah.

106. Prior to 1927 the fabrication of the magnesium into semi-finished and finished forms was done almost entirely by the two plants manufacturing the metal. Consequently, all statistics prior to 1927 include the ingot and its remanufacture. Since 1927 virgin ingot only is included in production figures and statistics for the manufactured magnesium are listed separately.

107. Table V indicates clearly the very real increase in the domestic production of magnesium. It also shows the decreasing cost of the metal that has accompanied this increased consumption; and in January 1931 ingot magnesium was quoted at $0.48 per pound.

TABLE V.—*Domestic metallic magnesium consumed in United States*[1]

[Virgin ingot only reported after 1927; prior to that year all forms sold were included]

Year	Consumption	Average ingot price per pound	Year	Consumption	Average ingot price per pound
	Pounds			*Pounds*	
1915	87,500	$5.00	1925	245,000	$0.86
1920	123,770	1.60	1926	322,650	.80
1921	48,000	1.30	1927	311,600	.90
1922	[2] 60,000	1.60	1928	521,075	.875
1923	[2] 125,000	1.25	1929	1,329,669	.862
1924	128,000	1.10			

[1] U.S. Bureau of Mines furnishes production figures and estimates. [2] Estimated.

108. *Europe.*—Magnesium production in Europe is also confined to a few companies. The I. G. Farbenindustrie A. G. controls German production, which is unofficially reported to total 2,000 tons annually. The metal is being used not only in German aircraft, but in automobile busses and trucks. The ingot is also sold to French and Italian fabricators. It is believed that the metal is still produced by the Magnesium Co. at Wolverhampton, England. A new factory in Switzerland was in course of erection in 1930.

109. *Imports.*—As a direct result of the Tariff Act of 1922 imports of magnesium decreased considerably and from 1924 to 1928 constituted only about 5 percent of the domestic consumption. In 1929 imports dropped to less than three tenths of 1 percent of total magnesium available in the United States. There were no changes in the duty on magnesium included in the Tariff Act of 1930, the duty being $0.40 per pound on metallic magnesium and scrap; $0.40 per pound on magnesium content plus 20 percent of the foreign market value on manufactured forms, including alloys.

TABLE VI.—*Magnesium imported to United States during last 10 years* [1]

Year	Pounds	Value		Year	Pounds	Value	
		Total	Average			Total	Average
1920	29,275	$25,055	$0.85	1925	8,326	$7,070	$0.85
1921	49,913	30,592	.77	1926	10,117	4,750	.47
1922	182,939	54,448	.30	1927	7,131	8,402	1.18
1923	13,974	11,576	.83	1928	12,039	11,890	.99
1924	8,738	6,561	.75	1929	3,490	6,539	1.87

[1] U.S. Bureau of Foreign and Domestic Commerce.

110. Table VII shows that none of the imported magnesium in 1929 was virgin ingot. Powdered magnesium was the only form in which imports were large enough to attract attention.

TABLE VII.—*Magnesium products imported to United States in 1928 and 1929* [1]

Class	1928			1929		
	Pounds	Value		Pounds	Value	
		Total	Average		Total	Average
Alloys (magnesium content)	20	$57	$2.85	52	$147	$2.83
Magnesium (metallic and scrap)	1,000	1,048	1.05			
Powder (magnesium content)	10,133	9,443	.93	2,951	5,351	1.81
Sheets, tubing, ribbons, wire, and all other	886	1,342	1.52	487	1,041	2.14
Total	12,039	11,890	.99	3,490	6,539	1.87

[1] U.S. Bureau of Foreign and Domestic Commerce.

SOURCES OF RAW MATERIAL

111. *Brine.*—As is indicated on page 283 of this report, oceanic salts contain about 11 percent magnesium chloride and 5 percent magnesium sulphate, while oceanic water contains about one eighth percent magnesium. The bittern from salt crystallization is made up

very largely of crystalline magnesium chloride ($MgCl_26H_2O$). The Great Salt Lake salt contains 2 percent magnesium or its waters hold 0.56 percent. The anhydrous brine in the Saginaw Valley of Michigan holds from 3 percent to 7.5 percent magnesium. At Syracuse, N.Y., Pomeroy, Ohio, and at Hartford, W.Va., some magnesium-bearing bitterns are also found. There is a dry-lake deposit of pure magnesium sulphate near Oroville, Wash.

112. Not all saline deposits have been analyzed for their magnesium content. It is likely, therefore, that salt beds in Utah and in other localities also contain magnesium chloride.

113. The only commercial producers of magnesium chloride in the United States in 1929 were the Dow Chemical Co., of Michigan, and the California Chemical Corporation with plants at Newark, San Mateo, and at Chule Vista on San Francisco Bay. Natural magnesium sulphate was produced only by the Dow Chemical Co.

114. The most famous salt-bed deposits are those in the Magdeburg-Halberstadt region of Germany, where the great Stassfurt salt beds contain the magnesium-bearing mineral, carnallite. Magnesium-bearing salt beds are found also in Alsace and in Spain. Imports to the United States totaled 1,646 tons of magnesium chloride and 6,770 tons of magnesium sulphate in 1929.

115. *Magnesite.*—In addition to magnesium contained in brine, large deposits of magnesium ore occur in different combinations. Magnesite, a carbonate of magnesium, is found in Washington State and in California. The Northwest Mangesite Co. operates a mine near Chewelah, Stevens County, Wash. It produces dead-burned or calcined magnesite and small amounts of caustic-calcined magnesite. In California largest operations were in Santa Clara County in 1929. Operations also took place in Stanislaus, Tulare, San Benito, and Monterey Counties. Magnesite has been produced, in other years, in Alameda, Fresno, Merced, Placer, San Bernardino, Sonora, and Tuolumne Counties.

116. War-time estimates placed the California reserves at 750,000 short tons and the Washington reserves at 7,000,000 short tons.

117. What was the old Austria-Hungary was estimated to have 120,000,000 short tons of magnesite. At present, producing countries are Austria, Hungary, Czechoslovakia, Greece, Italy, Spain, Australia, British India, South Africa, and Canada.

118. *Other magnesium ores.*—A large deposit of brucite, a magnesium hydrate, was discovered in 1927 in Nye County, Nev. Experiments are underway to determine its commercial value.

119. Dolomite, a high-content magnesium limestone, is widely distributed in the United States. As yet no metal magnesium has been made from this source of magnesium.

Magnesium Manufacturing Processes

120. As has been stated, only one method of manufacturing magnesium is practiced in the United States today. Although many processes have been patented, they are not actually used commercially.

121. *The chloride process.*—Magnesium chloride occurring in brine may serve as the raw material for this process. Or magnesium chloride may be produced from the mineral magnesite, first by calcining it to magnesium oxide and then by treatment with chlorine gas in the presence of a carbonaceous material.

122. As brine is the raw material source employed in this country its use will be described first.

123. *Brine separation.*—Natural brine, as it is pumped from Michigan wells in the Saginaw region, contains 3 percent magnesium chloride, 0.15 percent bromine, 14 percent sodium chloride, and 9 percent calcium chloride.

124. *Bromine production.*—Bromine is first removed. The brine is passed through electrolytic cells which oxidize the brine and thereby free its bromine content. These cells are placed above blowing-out towers so that the bromine-laden corrosive brine flows by gravity to these towers. In passing down the towers it comes in contact with air currents that remove the bromine by blowing out. This bromine-laden air passes over an alkali solution or iron, which serves to extract the bromine from the air. Bromine is used in the dye industry, in organic synthesis, for the production of medicinals, and for other chemical purposes.[93]

125. Brine impurities are precipitated and separated out in continuous thickeners and sedimentation tanks. The remaining liquor is then evaporated until the sodium chloride has crystallized. This is used for the electrolytic production of chlorine and caustic soda which are, in turn, combined with other basic chemicals to produce a number of compounds. The calcium chloride is then separated from the magnesium chloride by fractional crystallization.

126. *Dehydration of magnesium chloride.*—The remaining product contains 6 molecules of water. Four are removed by air-drying on the counter current principle. The last 2 molecules of water must be removed in an atmosphere of hydrochloric acid gas to prevent the formation of magnesium oxide.

127. *Electrolysis of dehydrated magnesium chloride.*—Rectangular cast-steel pots serve as the cells as well as the cathodes in the electrolysis of dehydrated-magnesium chloride. The anode is built up of graphite bars. The dehydrated-magnesium chloride is fed into the cells as finished metal is removed, the entire operation being continuous. At the Dow chemical plant power consumption is reduced by the use of exterior furnace heat to maintain proper cell temperature and by the addition of sodium chloride to reduce the melting point and increase the conductivity of the bath.

128. The magnesium metal formed by the electrolytic decomposition of magnesium chloride is lighter than the bath and floats while the chlorine is liberated at the anode. The metal is ladled out of the cell, while the chlorine is recovered. The magnesium metal is 99.9+ percent pure so that subsequent refining is unnecessary.[94]

129. Cells as now used can hold several tons of molten cell bath. The theoretical decomposition voltage is 3.25 volts although 5 or more volts are required in practice. The average current is 2,200 amperes or 16 amperes per square inch anode surface. A ton of metal requires approximately 16,000 kilowatt hours of current for its electrolysis.

The Chemical Co., which utilizes all constituents of its brine in the manufacture of metallic magnesium and an interlocking chain of valuable chemicals, has a power plant with a generating capacity of 38,000 kilowatts.

---

[93] Dow, Herbert H. Brine and Bromine Plant Development at Midland, Industrial and Engineering Chemistry, February 1930.

[94] Gann, John A. The Magnesium Industry. Industrial and Engineering Chemistry, vol. 22, July 1930.

130. *Magnesite as a raw material.*—In England, metallic magnesium is manufactured from calcined magnesite, the required chlorine being a byproduct of the process.

131. *Preparation of electrolyte.*—By suspending the calcined magnesite in water, milk of magnesium is formed. This is scrubbed with chlorine gas in a series of scrubbing towers. The chlorine is absorbed by the magnesium, the resulting solution containing magnesium chloride and magnesium chlorate in the proportion of 5 to 1. Upon evaporation and cooling, half the magnesium chloride content crystallizes.

132. These crystals of magnesium chloride are put through an extractor, are exposed to dry air currents and are lastly treated by dry hydrochloric acid gas to remove all water. The resulting product is 99 percent magnesium chloride.

133. As in the brine process, a little sodium or potassium chloride must be added to the magnesium chloride to produce the electrolyte, as the melting of anhydrous magnesium chloride, 750° C., is above the economical electrolysis temperature.

134. *Electrolysis.*—The English company uses two separate cells for the electrolysis. The first cell is charged with a few inches of molten lead which forms the cathode. A graphite anode is used. The electrolyte and the lead cathode are kept in constant circulation. An alloy of magnesium lead is formed which serves as the anode in the second cell. In this cell the cathode is made up of steel rods, and the electrolyte is magnesium chloride. The chlorine liberated from the cells is used in the milk of magnesia scrubbing towers. About 8.5 kilowatt-hours of electricity are required per pound of magnesium produced, or 17,000 kilowatt-hours per ton.

135. *Byproducts.*—By adding potassium chloride to the mother liquors after the magnesium chloride has crystallized out, potassium chloride is obtained. After washing and recrystallizing, this is available for the manufacture of explosives, matches, or pyrotechnics.

136. *The magnesium oxide process.*—Although this process has been superseded by the chlorine process on brines, it is of interest here because the magnesite deposits of the Pacific coast or Austria furnished the raw material.

137. The electrolyte consisted of equal parts of magnesium and barium fluorides to which some sodium fluoride was added. A steel box, having cast-iron cathodes extending longitudinally through its base and a graphite anode in the center of the top, served as the cell. The magnesium oxide, or calcined magnesite, was added to the bath near the anodes at frequent intervals. As the liquid magnesium separated out and ascended, it was caught in collecting hoods placed at the top of the cell. From these it was drawn off as desired. The metal was then refined by volatilization and condensation, or by remelting with a flux. One ton metal required 1.7 tons calcined magnesite.

138. These cells required from 9,000 to 16,000 amperes when operated at 9 to 16 volts. Current efficiency averaged but 50 percent, while power efficiency was but 10 percent. It is obvious that the efficiency of the oxide process was low, although it had low raw material and labor costs.[95]

[95] Harvey, W. G., vice president, American Magnesium Corporation. Production of Metallic Magnesium from Fused Salts. Transactions of the American Electrochemical Society, vol. XLVII ,1925.

FABRICATION OF METAL

139. *Melting and casting magnesium.*—Molten magnesium oxidizes rapidly near or above its melting point. Its extreme lightness is responsible for a tendency to trap air and gases. Consequently, pure magnesium melting operations must exclude air. This is usually done by a flux consisting of an anhydrous mixture of magnesium and sodium chlorides such as is used as the electrolytic bath; this flux also prevents nonmetallic contaminations.

140. The magnesium is melted in iron or steel pots. It is dipped from the pots by means of ladles equipped with skimming lips which part the protecting flux film. It is poured into permanent molds; all castings except green sand molds may be used.

141. The commercial magnesium-base alloys have lower melting points than the pure metal and, therefore, do not oxidize as readily. Aluminum and zinc alloys are made by adding fixed amounts of the solid metals to liquid magnesium, or all metals desired in the alloy may be melted and charged together.

142. *Commercial forms.*—Both magnesium and certain magnesium alloys can be readily rolled hot and, to some extent, cold. In general, the rolling, extrusion, drawing, and forging processes employed for other metals may be used for magnesium although the details of operation vary. It is easily machined with the usual carbon-steel tools.

143. Substantially pure magnesium is furnished the trade in the form of sticks, ingots, blocks, rods, bars, tubes, sheets, plates, wire, ribbon, powder, and foil. More than two thirds, however, is sold as ingot.

144. Table VIII indicates the form in which magnesium, other than ingot magnesium, is marketed. The increase in magnesium castings is outstanding.

TABLE VIII.—*Marketed production of manufactured magnesium (other than ingot)*[1]

Product	1926	1927	1928	1929
Total pounds sold	*Pounds* 85,895	*Pounds* 114,290	*Pounds* 137,232	*Pounds* 196,321
Alloys	6,862	11,835	16,210	13,145
Castings	36,936	31,992	55,861	116,350
Powder	31,551	31,658	27,294	35,943
Wire and ribbon	5,662	4,748	7,695	7,736
Rod and tubing	614	1,191	719	1,864
Sheet	4,198	10,883	8,425	8,512
Shavings	72	42	810	720
Other		21,941	20,218	12,051

[1] U.S. Bureau of Mines.

MAGNESIUM CONSUMPTION

145. *Pure magnesium.*—In powdered form, magnesium is used for flashlight work and in pyrotechnics, as it burns with a bright light when exposed to air in finely divided condition. Barium nitrate, potassium chlorate, or other oxidizers are added to it, however, to insure rapid and complete combustion. It was this demand for magnesium for military signals, flares, tracer bullets, and other pyrotechnics that led to the intitial establishment of the industry in the United States during the World War.

146. Its deoxidizing characteristics make it useful as a deoxidizer of other metals and of salts. It is employed in the nickel and monel metal industry particularly, where it is placed in an inverted cup underneath the molten metal in the furnaces. Some is used for scavenging scrap brass and zinc-base die-casting alloys, and to remove oxygen from chlorates and other salts.

147. Magnesium, alone or alloyed with copper, aids the synthesis of a number of organic chemicals. It is used principally for medicinal and perfumery preparations.

148. Magnesium wire and ribbon find a market in the radio lamp industry where they are used in the degassification of radio tubes. In sheet form it enters into radio rectifiers. As ribbon it can also be used as an insulator in heating appliances. And from sheet magnesium, moving parts of precision instruments, meter disks, chemical balance points, dry-battery elements, and of other delicate mechanisms are made.

149. *Magnesium alloys.*—But the recent growth of the industry is based upon its use in magnesium-base alloys, or alloys containing 90 to 95 percent magnesium. Magnesium alloys with most of the common metals other than iron and chromium. Manganese and zinc are regarded, however, as the best elements for alloying with magnesium to add high mechanical strength, toughness, and corrosion resistance to its extreme lightness. Castings made from such lightweight but strong magnesium alloys are of vital importance in airplane construction where savings in weight are essential. They have been used in such aircraft motor parts as crankcases, oil pans, fuel line fittings, and pistons, and in control levers, instrument housings, superchargers, and in seat frames. Magnesium alloys possess the same value of lightness combined with strength in portable machines and in machine tools that require continuous handling.

150. The principal marketed magnesium alloys are: A magnesium-aluminum-manganese alloy used for castings; a magnesium-manganese alloy having maximum corrosion resistance; an alloy of magnesium-aluminum-copper-manganese and carbon with high thermal properties.

151. An increase in magnesium consumption has been brought about by its use as a minor alloying ingredient of aluminum alloys such as duraluminum. These are manufactured into automobile pistons and other reciprocating engine parts, aircraft engine parts, and into structural parts. (See p. 127 of Power in Aluminum Production.) Unquestionably, every lowering of the price of magnesium nearer to the price of aluminum (about $0.23) increases the competition of the light aluminum alloys with the lighter magnesium alloys.

152. In zinc-base die-casting alloys small amounts of magnesium are used to prevent deterioration of the zinc when exposed to hot, humid atmospheres.

BIBLIOGRAPHY

CAUSTIC SODA AND CHLORINE

Year	Author	Title
1931		Price and Process Determine Choice of Alkalis. Chemical and Metallurgical Engineering. January.
1930		News Notes. Chemical Markets. March.
1926	Conroy, J. J	Use of Chlorine in the Organic Chemical Industry. Transactions of the American Electrochemical Society, vol. XLIX.
1924	Elliott, C	Electrolytic Caustic Soda, in The Chemical Trade Journal and Chemical Engineer (London). July 11, 1924, to Sept. 19, 1924.
1911	Engelhardt, Victor	Cost of Alkali Chloride Electrolysis. Chemiker Zeitung, vol. 35, nos. 64 and 65.
1926	Fries, Amos A	Use and Importance of Chlorine in Chemical Warfare. Transactions of the American Electrochemical Society, vol. XLIX.
1930	Hughes, L. C	Modern Ammonia-Soda Plants. Chemical and Metallurgical Engineering. April.
1924		Canadian Salt Co. Processes for Manufacturing Alkali-Chlorine Products. Industrial and Engineering Chemistry. October.
1930	Lee, James A	Westvaco Sets New Record in Evaporating Electrolytic Caustic Soda. Chemical and Metallurgical Engineering. July.
1930	Manning, Paul D	Pacific Coast Industry Diversifies Products. Chemical and Metallurgical Engineering. June.
1923	Michigan Bureau of Geological and Biological Surveys.	Production and Value of Mineral Products in Michigan for 1923 and Prior Years. Publication 35. Geological Series 29.
1926	Ochi, Shuichire	Chlorine in Japan. Transactions of the American Electrochemical Society, vol. XLIX.
1928 1929		News Notes. Oil, Paint, and Drug Reporter. January 28, 1929, October 25, 1928.
1929	Partington, J. R	The Alkali Industry.
1926	Pritchard, D. A	Economics of Chlorine. Transactions of the American Electrochemical Society, vol. XLIX.
1927 1929	U.S. Bureau of the Census	Chemicals and Compressed Gases.
1930	U.S. Bureau of Foreign and Domestic Commerce.	Rubber. June 1930.
1929	U.S. Department of Commerce	Foreign Commerce and Navigation of the United States.
1919	U.S. Geological Survey	Salt Resources of the United States. Bulletins 668 and 669.
1921	U.S. House of Representatives	Hearings on General Tariff Revision Before Committee on Ways and Means. Tariff Information. Part I.
1926	Wells, H. P., Mabey, H. M., and Rowland, J. M.	Transportation of Liquefied Chlorine Gas, in Transactions of the American Electrochemical Society, vol. XLIX.

MAGNESIUM

1922	Allen, S. T	The Production of Metallic Magnesium. The Electrician. Jan. 27, vol. 88.
1926	Anderson, R. J	Metallurgy of Magnesium and Magnesium Alloys. Handbook of Non-Ferrous Metallurgy, vol. II.
1922	Boyton, K. S., and Langford, V.	Electrolytic Recovery of Magnesium from Salt Works Residues. Industrial and Engineering Chemistry.
1930	Dow, Herbert H	Brine and Bromine Plant Development at Midland. Industrial and Engineering Chemistry. February.
1930	Gann, J. A	The Magnesium Industry. Industrial and Engineering Chemistry, vol. 22, July.
1925	Harvey, W. G	Production of Metallic Magnesium from Fused Salts. Paper before the American Electrochemical Society. April.
1929		Magnesium and Its Alloys in Aircraft. Paper before American Electrochemical Society. Sept. 19.
1927	Keyes, D. B	Review of Research Work of the Manufacture of Magnesium. Transactions of the American Electrochemical Society, vol. XLIX.
1925	Miyake, M., and Butts, A	Metallurgy of Magnesium. Engineering and Mining Journal. Press 119.
1928	U.S. Bureau of Mines	Magnesium and Its Compounds in 1928.
1929		Magnesium in 1929.
1925	Bulletin 236	Plastic Magnesia.
1927	U.S. Bureau of Standards	Light Metals and Alloys. Circular 346.
1918	Waldo, L	Development of the Magnesium Industry, Chemical and Metallurgical Engineering.
1922	Gann, J. A	Dow Metal and Its Applications, Transactions of the American Society of Steel Treating.

POWER IN THE CELLULOSE INDUSTRIES

CONTENTS

	Page
Summary	310
Pulp and paper industries	312
Development of the industry in the United States	312
Original sources of paper materials and adoption of power machinery	312
Location of industry	313
Changing status of United States as producer of paper and paper materials and as consumer of paper and paper materials	314
Newsprint importations, the tariff, and Canadian policies	315
Manufacture of book, board, and wrapping paper	317
Wood pulp production and consumption	319
Sources of woods available for paper manufacture	320
Wood species suitable for paper pulp	320
Quantities of pulpwood available	321
Location of pulpwood resources	324
Relation of pulpwood reserves to consumption markets	325
Kinds of pulpwood consumed	325
Pulpwood consumption and production on Pacific coast	327
Pulpwood consumption and production in Middle Atlantic States	327
Pulpwood consumption and production in New England and Lake States	329
Pulpwood consumption and production in Southern and Rocky Mountain States	331
Forest and lumber mill waste utilization	332
In Pacific Northwest	332
Other sources of paper materials	334
Cereal straws	334
Manufacturers of pulp and paper in United States and in Canada	335
Newsprint paper manufacturers	337
Book paper manufacturers	339
Board manufacturers	340
Other Pacific coast pulp and paper mills	340
Manufacturing processes	341
Pulp production	341
Power requirements for mechanical pulp	341
Sulphite pulp	342
Soda pulp	343
Sulphate pulp and other processes	344
Straw and corn pulp	346
Pulp bleaching	346
Alpha fiber	347
Paper making	347
Power requirements for newsprint	347
Book paper and chemicals required	348
Board manufacture	350
Power equipment of pulp and paper mills	350
Water and chemicals consumed in pulp and paper making	352
Costs of production	354
Costs of producing unbleached sulphite pulp	354
Costs of producing mechanical pulp and newsprint	355
Costs of producing sulphate pulp and kraft paper	356
Costs of producing bleached soda pulp and book paper	357
Pulp and paper markets and freight rates	358
Wood-pulp market	358
Newsprint paper market	359
Newsprint prices and freight rates	361
Manufacture of other cellulose derivatives	364
Sources of raw material	364
Pulpwood for rayon	364
Cotton linters	365

Manufacture of other cellulose derivatives—Continued. Page
Manufacturing processes 366
Viscose process 366
Transparent wrappings 366
Rayon 367
Quantities of raw materials used 368
Nitrocellulose or chardonnet process 368
Rayon 369
Plastics 369
Lacquers 369
Acetate process 370
Rayon 370
Plastics 371
Cupra-ammonium process 371
Zinc chloride process 371
Power requirements 372
In rayon manufacture 372
In manufacturing chemicals 372
Cost of rayon production 374
Development and control of industries 375
Cellulose plastic industry 376
Rayon industry 376
European control 376
Rayon manufacturers in United States 377
Production and consumption here and abroad 378
Markets 379
Cellulose lacquer industry 381
Bibliography 382

Industries of great commercial importance have been, and are being, built upon the fabrication of plant cellulose after subjection to varying pyrochemical treatment. The differences in plant celluloses, the methods used to remove combined substances, the structural changes wrought in the cellulose itself, as well as the chemical combinations made, all tend toward a wide variety of finished product. Outstanding among these products are paper, rayon, cellulose plastics, and cellulose lacquers.

Power plays an important part in these industries either in the production of the pulp material itself, in the production of chemicals entering into the processes, or in the mechanical operations essential to fabrication. The pulp and paper industry ranks second among all industries in the amount of installed horsepower capacity which totaled 2,700,000 horsepower. At present, only 62 percent of this horsepower capacity is electric, but there is a marked tendency toward greater electrification. The power is required for mechanical operations and for the production of steam. One ton of mechanical pulp requires approximately 1,280 kilowatt-hours of electrical energy. Other types of pulp require 200 kilowatt-hours or less of mechanical power. The total mechanical power necessary to produce 1 ton of newsprint is approximately 1,340 kilowatt-hours. The newsprint produced in this country in 1929 required, therefore, almost 2,000,000,000 kilowatt-hours of energy; if all newsprint consumed in this country had been produced here, the power consumption for newsprint alone would have been in excess of 5,000,000,000 kilowatt-hours of energy. Other kinds of paper require less energy because they do not use mechanical pulp.

The rayon, cellulose plastic, and cellulose lacquer industries are not large consumers of power in themselves although the rayon in-

dustry requires a 24-hour-a-day supply. Only when they are considered as markets for electrolytic chemicals do these other cellulose industries become of interest in power development. Each ton of viscose rayon requires 2 tons of high-quality caustic soda or, in 1929, approximately 287,500,000 kilowatt-hours of energy were expended in producing pure caustic soda for rayon. All pulp used is bleached with chlorine compounds, so that an outlet for a part of the chlorine manufactured in the process of caustic soda electrolysis is found in this industry. As two thirds of all chlorine produced is consumed in the pulp and paper industry, an electrolytic caustic soda and chlorine industry would find a market for its simultaneously produced chemicals in pulp and paper and rayon mills located near it.

The nitric acid necessary for cellulose nitrate plastics or lacquers is now made by the oxidation of ammonia, the hydrogen content of which may be obtained in the production of caustic soda and chlorine or by the electrolysis of water as well as by other methods. The cellulose acetate rayon and plastics require acetic acid which is now being manufactured from calcium carbide, an electric furnace product requiring over 3,000 kilowatt-hours of energy per ton to produce. Cellulose acetate products also require acetic anhydride, of which chlorine is an essential part.

While many different kinds of plant cellulose have been made into paper and rayon, wood cellulose has competed successfully with each type either because of its special suitability or because of its lower cost per unit weight. Cotton linters, however, are being used for plastics and lacquers and their use is growing in rayon production.

The wood most easily manufactured into newsprint paper and rayon is spruce. One half of the Nation's spruce reserves are in Washington and Oregon. One fourth of our pines, available for wrapping-paper pulp, are on the Pacific coast. These industries require an abundance of water which is available in these States. The principal chemicals necessary to convert the wood into pulp for paper or rayon are also being manufactured or could be manufactured on the Pacific coast. Yet Washington State produced but 8 percent of the Nation's wood pulp and 3 percent of the Nation's paper requirements in 1928; while Oregon and California produced but 5 percent of the wood pulp and 3.7 percent of the paper requirements. Rayon-pulp manufacture has just begun in Washington State.

The Middle Atlantic States with but 4.6 percent of the national pulpwood reserves, produced 23.2 percent of our total wood pulp and 29.2 percent of the Nation's paper. The New England States have 4.7 percent of our stand of pulpwood, but produced 27 percent of the wood pulp and 19 percent of our paper. The three Lake States contain 9.4 percent of the Nation's pulpwood reserves and produced 24.7 percent of the entire wood-pulp supply and 21.4 percent of the country's paper.

Among the North and Middle Atlantic States and the Central States, Maine alone is able to meet her own pulpwood requirements. Other States have adopted reforestation measures but it will be years before new forests have grown to meet current demands. No large rayon-producing State manufactures any of its spruce-wood pulp.

As a consequence, the United States imported 21 percent of its pulpwood, 28 percent of its wood pulp, and 16.5 percent of its paper in 1928. While imports of pulpwood have remaind stationary, propor-

tionately, in the last 20 years, imports of wood pulp and paper are increasing. These imports are chiefly of newsprint, or of mechanical and sulphite pulp or of spruce wood to be manufactured into newsprint. About 36 percent of our sulphate pulp for wrappings is imported. Newsprint, mechanical pulp, and spruce is imported chiefly from Canada. Sulphite pulp is imported in almost equal amounts from Canada and Sweden, while Finland, Norway, and Germany ship in appreciable quantities. Over 60 percent of the sulphate-pulp imports come from Sweden, Finland, and Norway, while 36 percent are shipped from Canada. More than half the rayon-spruce pulp is imported from Canada. These articles enter free of any duty.

Eastern Canada possesses the same natural resources for mechanical and sulphite pulp and newsprint-paper manufacture as does the Pacific Northwest, that is, extensive spruce forests, cheap hydroelectric power, and an abundance of water. It has the additional advantage of closeness to the largest American consuming markets. Canada's all-rail rate to New York points averages $6 while the Coordinator for Traffic, Federal Traffic Board, reports the freight rate from Seattle to New York to be $15. From Seattle to New Orleans, the entire freight charge is $8 while from New York and New England rates fall between $9.60 and $10.50. The newsprint market in Gulf and lower Mississippi States is entered by Pacific coast producers.

Sweden has been able to supply the American market with wood pulp because she has so correlated her lumber and pulp industries that most of her pulp is manufactured from logging and sawmill waste. Shipments to Atlantic seaports cost but $4.50 per ton. An importer's commission of 5 percent is usually paid.

Integration of the lumber and paper industry has begun in the State of Washington. Over 48 percent of all pulpwood used in 1928 was slabs and other mill waste. As lumber waste gains commercial value in pulp mills and as pulp mill rejects are applied to paper board and cheap wrapping paper, wood waste will become too valuable to burn at the lumber or paper mill as has been done in the past. Other fuels or electricity will be required in its stead.

PULP AND PAPER INDUSTRIES

The Development of the Pulp and Paper Industry in the United States

HISTORICAL DEVELOPMENT

1. *Original sources of material.*—The first paper mill was erected in Pennsylvania in 1690. The Revolutionary War hastened the establishment of paper mills in all the principal Colonies. Imported linen rags and cotton rags served as raw materials. These sources soon proved unequal to the demands for paper. Many experiments were undertaken to utilize corn husks, stalks, and cobs, seagrass, reeds, and other fibrous substances. In 1830 straw was successfully manufactured into paper. In 1855 pulpwood, treated with caustic soda, resulted in a satisfactory pulp; but active adoption of the soda process took at least 25 years. The grinding of wood into pulp began in 1867. The treatment of pulpwood by sulphur and lime was first done commercially in Sweden in 1874 and was adopted in the United States in

the early eighties. Estimates place the consumption of pulpwood at 2,000 cords in 1870, at 40,000 cords in 1880, and at 580,000 cords in 1890. In 1928, consumption exceeded 7,000,000 cords.

2. *Adoption of power machinery.*—Power-driven machinery preceded the use of wood fibers in paper making, for the beating engine, or machine to comb out fibers and cut them into uniform lengths, was introduced in 1775. These were driven by water wheels. A cylinder machine, which turned the wet stock into the finished sheet, appeared in 1817, and in 1827 the Fourdrinier paper machine was introduced. The general adoption of pulpwood as the principal source of paper material after 1880 led to a very rapid extension of the use of mechanical power and an improvement in machine design and machine speed.

3. In 1810, according to the United States Census of Manufactures, the annual production of paper in the United States was 3,000 tons; by 1860 it was 127,000 tons; by 1909, 4,200,000 tons, and by 1928, in excess of 10,000,000 tons.

LOCATION OF INDUSTRY

4. *Paper industry firmly established in New England, New York, and Pennsylvania.*—The colonial paper industry had been established in Berkshire County, Mass.; in Hartford County, Conn.; in Niagara and Columbia Counties, N.Y.; and in Austin and Delaware Counties of Pennsylvania; as well as in Maine, Virginia, and Maryland. The first wood to be turned into mechanical and sulphite pulp was spruce, while broad-leaved species were employed in soda pulp. The spruce forests of New York and New England, the hardwood forests of Pennsylvania, served existing paper mills adequately and led to the establishment of other mills in the same States. Some mills, especially in Massachusetts, continued to make fine papers from rags. An abundant water supply and nearness to consuming paper markets caused the paper industry to become firmly entrenched in these original paper manufacturing States.

5. *Paper industry in Lake States.*—As population moved westward, the spruce forests of Wisconsin, Michigan, and Minnesota were cut for newspaper and the hardwoods of Ohio and Indiana added to the pulpwood supply for book paper. Paper mills were established near these sources of raw material.

6. In 1909, three fifths of all pulp and paper was produced in New England, New York, and Pennsylvania, and about one fourth in the Lake States. This overcentralization, combined with heedless felling of trees, developed a shortage on the supply of spruce in these States. Paper mills turned to Canadian forests for a part of their supply.

7. *Beginnings of paper industry in South.*—In 1907, the sulphate process was developed whereby resinous pines could be utilized in the manufacture of heavy wrapping and other brown paper. This branch of paper making located in the South where stands of pines were very large.

8. *The Pacific coast pulpwoods demand attention.*—Gradually, the spruce, fir, and hemlock forests of the Pacific coast, the largest in the

country, are being cut, first to meet the needs for mechanical and sulphite pulp and paper on the Pacific coast and, more recently, to reach the South and Central Western markets.

9. In 1928, the original paper-making States in New England and in the Middle Atlantic section produced 48 percent of our paper. Lake States and Central States manufacture 38.8 percent, Southern States 6 percent, and Pacific Coast States 6.7 percent.

TABLE I.—*United States consumption and production of paper, wood pulp, and pulpwood during the last 20 years* [1]

Year	Paper			Wood pulp			Pulpwood		
	Apparent consumption (short tons)	Production		Apparent consumption (short tons)	Production		Consumption (cords)	Apparent production	
		Short tons	Percent of consumption		Short tons	Percent of consumption		Cords	Percent of consumption
1928	12,477,649	10,403,338	83.4	6,239,641	4,510,800	72.3	7,160,100	5,641,280	78.8
1927	12,345,470	10,002,070	81.0	5,960,865	4,313,403	72.4	6,750,935	5,213,207	77.2
1925	10,590,000	9,182,204	86.7	5,588,000	3,962,217	70.9	6,093,821	5,005,445	82.1
1923	9,340,000	8,029,482	85.9	5,149,000	3,788,672	73.6	5,872,870	4,636,789	78.9
1921	6,054,000	5,356,317	88.5	3,544,000	2,875,601	81.1	4,557,179	3,740,405	82.1
1919	6,493,000	6,190,361	95.3	4,019,696	3,517,952	87.5	5,477,832	4,445,817	81.2
1914	5,496,000	5,270,047	95.9	3,490,123	2,893,150	82.9	4,470,763	3,641,063	81.4
1909	4,224,000	4,216,708	99.8	2,826,591	2,495,523	88.3	4,001,607	3,207,653	80.2

[1] Compiled from U.S. Department of Agriculture Statistical Bulletin No. 21, and U.S. Bureau of the Census, Census of Manufactures, 1927 and 1928.

CHANGING STATUS OF UNITED STATES AS PRODUCER OF PAPER AND PAPER MATERIALS AND AS CONSUMER OF PAPER AND PAPER MATERIAL

10. Table I indicates clearly the changing status of this country in the last 20 years in the production of pulpwood, of wood pulp, and of paper, and in the consumption of the raw material, the semi-finished, and the finished product.

11. *Pulpwood.*—About 20 percent of the pulpwood which we consume has been imported regularly since 1909; our proportionate importations of this raw wood have not increased or decreased materially in 20 years. Table II shows that 80 percent of this imported wood is spruce from Canada, Newfoundland, and Labrador, and the remainder balsam, fir, and aspen.

12. *Wood pulp and paper.*—While our imports of pulpwood have not changed, proportionately, with the passage of the years, our imports of wood pulp and paper have increased greatly. In 1909 we manufactured 88 percent of the wood pulp consumed by paper mills; in 1928 we produced but 72 percent. Whereas almost all paper used in the United States was manufactured within its borders in 1909, in 1928 only 83.4 percent of all paper consumed was produced here. When, therefore, the paper and the wood pulp imported into this country are reduced to their pulpwood content, about 60 percent of the forest material for all paper used in the United States comes from outside our country.

NEWSPRINT IMPORTATIONS, THE TARIFF, AND CANADIAN POLICIES

13. Table II shows clearly that, not only are our pulpwood imports chiefly of woods to be used in newspaper manufacture, but that the type of wood pulp imported is for newsprint manufacture. And 97.3 percent of imported paper is newsprint. The reasons for such importations have an economic and a political origin.

14. In 1907, when the growing shortage of spruce in New England and New York made newspaper supply uncertain, the newspaper publishers of our country asked for a repeal of the tariff on paper so that they might have freedom in newsprint-paper purchase. In 1910 commissions of the United States and Canada worked up an agreement whereby paper, pulp, and pulpwood were to be placed on the free list except when they came from countries that had placed an export duty upon them. Our Congress passed this measure which was signed by President Taft, but it was rejected in the Canadian Parliament. The Underwood-Simmons Tariff Bill of 1913 operated to repeal the section of the act of 1911 that related to pulp and paper; it gave free entry to printing paper worth not more than $0.025 a pound and an ad valorem tax was placed on print paper worth more. The revenue bill of 1916 amended the tariff of 1913 by placing on the free list printing paper of values up to $0.05 a pound. The Tariff Acts of 1922 and 1930 place on the free list "standard newsprint paper."

15. *Canadian pulpwood.*—About 90 percent of the pulpwood lands in Canada are "crown lands," over which the Provincial Governments exercise control while letting the timber-cutting rights. In 1910, the Government of Quebec prohibited the exportation of any wood cut from crown lands. This policy has been followed by other provinces until only from freehold lands can pulpwood be shipped to this country.

TABLE II.—*Imports of paper, wood pulp, and pulpwood by country of origin, in 1928* [1]

Imports	All countries		Canada		Newfoundland and Labrador		Sweden		Finland	
	Short tons	Percent	Short tons	Percent	Short tons	Percent	Short tons	Percent	Short tons	Percent
Paper imports: Total	2,218,257	100.0	1,954,567	88.1	114,175	5.1	61,726	2.8	46,163	2.1
Newsprint	2,157,166	97.3	1,926,748	89.3	114,172	5.3	55,619	2.6	40,239	1.9
Wrapping	14,124	.6	167	1.2	3	(2)	5,532	39.2	------	------
Boards	37,378	1.7	27,581	73.8	------	------	277	.7	4,165	11.1
Other [3]	9,589	.4	71	.7	------	------	298	3.1	1,759	18.3
Wood pulp imports: Total	1,573,659	100.0	703,793	44.7	157	(2)	540,207	34.3	137,790	8.8
Sulphite	948,586	60.3	356,558	37.6	------	------	333,367	35.1	94,278	10.0
Sulphate	395,846	25.2	141,779	35.8	------	------	201,757	51.0	32,139	8.1
Mechanical	222,499	14.1	202,382	91.0	157	.1	2,286	1.0	11,273	5.0
Other	6,728	.4	3,074	45.7	------	------	2,797	41.6	100	1.4

TABLE II.—*Imports of paper, wood pulp, and pulpwood by country of origin, in 1928* [1]—Continued

Imports	Germany		Norway		Japan		United Kingdom		Netherlands		Other Countries	
	Short tons	Percent	Short tons	Percent	Short tons	Percent	Short tons	Percent	Short tons	Percent	Short tons	Percent
Paper imports: Total	17,019	0.8	11,543	0.5	440	(2)	2,121	(2)	8,330	0.4	2,173	(2)
Newsprint	9,166	.4	10,864	.5			231	(2)	10	(2)	117	(2)
Wrapping	2,462	17.4	631	4.5	5	(2)	24	0.2	4,806	34.0	494	3.5
Boards	1,847	4.9					14	(2)	3,385	9.1	109	.3
Other [3]	3,544	37.0	48	.5	435	4.5	1,852	19.3	129	1.4	1,453	15.2
Wood pulp imports: Total	65,369	4.2	84,662	5.4			3,392	.2	1,160	(2)	37,129	2.4
Sulphite	63,525	6.7	63,668	6.7			2,926	.3	1,160	.1	33,104	3.5
Sulphate	1,290	.3	15,761	4.0							3,120	.8
Mechanical	126	(2)	5,233	2.4			465	.2			577	.3
Other	428	6.4					1	(2)			328	4.9

Imports	All countries		Canada		Newfoundland and Labrador	
	Cords	Percent	Cords	Percent	Cords	Percent
Pulpwood imports: Total	1,546,338	100.0	1,532,466	99.1	13,872	0.9
Spruce	1,215,912	78.6	1,202,869	98.9	13,043	1.1
Other [4]	330,426	21.4	329,597	99.7	829	.3

[1] Compiled from U.S. Department of Commerce, Foreign Commerce and Navigation of the United States.
[2] Less than 0.1 percent.
[3] Does not include 5,845 tons of cigarette paper, cigarette books, and covers, or 1,402 tons of paper boxes. Ninety-eight percent of the former comes from France, also 62 percent of the latter; balance of boxes comes principally from Germany.
[4] Principal kinds include poplar 60 percent and balsam fir 31 percent.

16. *Newsprint manufacturing in Canada.*—The immediate effect of this legislation was to encourage paper manufacture in Canada and to depress the American newsprint industry. In 1911, prior to the enforcement of the pulp and paper agreement, Canada exported newsprint paper valued at $2,000,000 into the United States. In 1913 the value of her printing paper exports doubled and redoubled in 1914. In 1913 only 350,000 tons of newsprint paper was manufactured in Canada. In 1929, 2,728,827 tons were produced. Of this, 80 percent is exported to the United States.

17. *Newsprint manufacture in the United States.*—The effect upon American industry is clearly indicated on table III. From 1909 to 1929 our newsprint paper consumption increased over 227 percent. Our manufacture of newsprint paper increased but 18 percent. In all other kinds of paper our production not only kept pace with consumption but usually permitted an exportable surplus. Today, only 36.6 percent of newsprint paper consumed is manufactured in the United States. Only four newsprint-paper mills have been built in the United States since the reciprocity measure with Canada put newsprint on the free list.

18. *American firms manufacturing in Canada.*—After 1911 some of the newsprint plants in this country were reequipped for use on other

classes of paper. Special inducements in the way of long leases on timber lands and water-power rights in Canada led some American firms to build newsprint mills in Canada and to export the paper to United States newspaper producers.

19. The International Paper Co., once the largest producer of newsprint paper in the United States, owns and operates as the "Canadian International Paper Co." at Three Rivers, and at Gatineau, Quebec; as the "New Brunswick International Paper Co." at Dalhousie, New Brunswick; as the "Bathurst Power and Paper Co." at Bathurst, New Brunswick; and has purchased a plant at Corner Brook, Newfoundland. Its daily Canadian paper operating capacity is about 2,000 tons paper. Its operating capacity in New York and New England is 1,160 tons daily, of which but a small part is used. The company has rights to over 3,000,000 acres of timber lands in Canada. It owns the International Hydro-Electric System which controls the Canadian Hydro-Electric Corporation of which the Gatineau Power Co. is a subsidiary. Power is supplied to the Dalhousie plant from the Grand Falls hydroelectric development of the company on the St. John River.

20. The New York Times and the Kimberly Clark Corporation of Wisconsin operate a plant at Kapaskasing, Ontario, which supplies the New York Times with approximately 100,000 tons of paper annually. The Chicago Tribune gets its newsprint paper from its own factory at Thorold, Ontario. The Crown Zellerback Corporation owns the Pacific Mills at Ocean Falls, British Columbia. It has obtained rights to water power at Campbell River, Canada.

21. *Other paper manufacture.*—Manufacture of all kinds of paper other than newsprint has increased steadily in the United States. Book paper production increased 107 percent between 1909 and 1929, board production 409 percent, wrapping paper manufacture 116 percent, fine paper production 195 percent, and miscellaneous kinds 165 percent.

22. *Boards.*—The largest paper production and consumption in the United States is of "boards." Under this heading are included container boards, folding and set-up box boards, building board, cardboard, and all other types of board. Over 36 percent of all paper produced in the United States is for boxing purposes, while 41 percent is boards of all kinds. Michigan, Ohio, New York, New Jersey, Illinois, and Indiana are the leading board-producing States. Washington produced 69,045 tons of the 4,000,000 tons manufactured in 1928. Since that date several paper-board factories have been built in Washington, and even by 1929 the total United States board production reached 4,500,000 tons.

23. *Wrapping paper.*—More wrapping paper than newspaper is manufactured in the United States although the consumption of newspaper far exceeds that of wrapping paper. Wrapping paper represents 15 percent of our total paper production. Over 80 percent is kraft paper or the heavy brown paper made by the sulphate process. Under this heading are included kraft paper used for twine, tapes, sand paper, mulching, and numerous uses other than wrapping. A little over 3 percent is paper manufactured by the sulphite process. Wisconsin produces the largest amount of wrapping paper. Louisiana ranks high and production is increasing in Virginia, North Carolina,

and other Southern States. New York and Maine are also heavy producers of this type of paper.

24. *Book paper.*—Our book-paper production is almost equal to our wrapping-paper production; it totaled almost 1,500,000 tons in 1929. Included under this heading are all grades of printing paper other than newsprint paper. Magazine paper represents the largest item. Catalogues, printed wrappers, and paper used in book production add to the total. The variations in grade are, therefore, numerous. Ohio, Pennsylvania, New York, Michigan, Wisconsin, Massachusetts, and Virginia are all important book-paper providing States.

25. *Other papers.*—Fine papers, which are used chiefly for typing and stationery, form 5.4 percent of the total United States production. The finest of these papers always has been made largely from rags so that the paper mills have remained chiefly near the Atlantic seacoast where imported rags are easily available. Massachusetts and Pennsylvania are principal producers. Tissue papers represent over 3 percent of our total paper production, building paper over 5 percent, while hanging paper, absorbent paper, and other kinds are finding an ever-increasing market.

TABLE II.—*Principal types of paper consumed and produced in the United States since 1909* [1]

Year	Total		Newsprint			Boards			Wrapping		
	Apparent consumption (short tons)	Production (short tons)	Apparent consumption (short tons)	Production (short tons)	Percent of consumption	Apparent consumption (short tons)	Production (short tons)	Percent of consumption	Apparent consumption (short tons)	Production (short tons)	Percent of consumption
1929	13,184,152	10,894,000	3,798,186	1,392,000	36.6	4,454,587	4,500,000	101.0	1,635,515	1,649,000	100.8
1928	12,477,649	10,403,338	3,560,926	1,415,450	39.7	4,035,581	4,061,803	100.6	1,461,463	1,467,271	100.4
1927	11,944,202	10,002,070	3,491,666	1,516,929	43.4	3,767,484	3,773,608	100.2	1,521,100	1,525,305	100.3
1925	10,590,000	9,182,204	3,073,000	1,647,277	53.6	3,290,000	3,280,710	99.7	1,287,000	1,297,919	100.8
1923	9,340,000	8,029,482	2,814,000	1,521,080	54.1	2,802,000	2,792,832	99.7	1,177,000	1,150,556	97.8
1921	6,054,000	5,356,317	2,002,000	1,226,189	61.2	1,641,000	1,664,931	101.5	770,000	782,468	101.6
1919	6,493,000	6,190,361	1,892,000	1,374,517	72.6	1,940,000	1,950,037	100.5	825,000	869,631	105.4
1914	5,496,000	5,270,047	1,576,000	1,321,167	83.8	1,292,000	1,291,805	99.9	892,000	881,799	98.9
1909	4,224,000	4,216,708	1,159,000	1,175,554	101.4	883,000	883,088	100.0	763,000	763,067	100.0

Year	Fine			Book			All other		
	Apparent consumption (short tons)	Production (short tons)	Percent of consumption	Apparent consumption (short tons)	Production (short tons)	Percent of consumption	Apparent consumption (short tons)	Production (short tons)	Percent of consumption
1929	564,757	585,000	103.6	1,421,093	1,440,000	101.3	1,310,014	1,328,000	101.4
1928	537,555	550,472	102.4	1,322,071	1,334,326	100.9	1,560,053	1,574,016	100.9
1927	502,194	508,808	101.3	1,320,760	1,328,782	100.6	1,374,664	1,348,638	98.1
1925	472,000	473,804	100.4	1,365,000	1,367,595	100.2	1,103,000	1,114,899	101.1
1923	374,000	377,029	100.8	1,235,000	1,242,005	100.6	938,000	945,980	100.9
1921	230,000	242,485	105.4	707,000	725,992	102.7	704,000	714,252	101.5
1919	306,000	343,762	112.3	838,000	914,823	109.2	692,000	737,591	106.6
1914	244,000	247,728	101.5	926,000	934,979	100.9	566,000	592,569	104.7
1909	193,000	198,213	102.7	689,000	694,905	100.9	537,000	501,881	93.5

[1] Compiled from U.S. Department of Agriculture Statistical Bulletin No. 21, and U.S. Bureau of the Census, Census of Manufactures, 1927 and 1928.

WOOD PULP PRODUCTION AND CONSUMPTION

26. *Pulp consumption.*—Forty-two percent of all the pulp consumed in the United States is sulphite pulp, that is, a chemical pulp made by removing the incrusted matter in wood with a solution of bisulphide of lime. About 30 percent is mechanical pulp, ground into fibers without the employment of chemical; 20 percent is sulphate pulp in which salt cake is the chemical used; and 8 percent soda pulp applying caustic soda as the processing chemical. A beginning has been made in the new, or semichemical process. The use of sulphite pulp has increased over 100 percent in the last 20 years while mechanical pulp consumption in the United States is only 37 percent more in 1928 than in 1909 due to importations of newsprint paper. The consumption of sulphate pulp, first produced in 1907 and not recorded officially until 1914, increased almost nine times in that period. Soda pulp, the first wood pulp to be produced, shows only an increased consumption of about 50 percent in the last 20 years.

27. *Pulp production.*—The United States production of the several kinds of pulp does not correspond with the respective amounts consumed. We produce all our own soda pulp. We produce 86.6 percent of our mechanical pulp, 60.6 percent of our sulphite pulp, and 63.8 percent of our sulphate pulp. The proportion of sulphite pulp produced in this country has decreased continuously in the last 10 years. The proportion of sulphate pulp manufactured within our borders has increased steadily since it was begun.

28. *Pulp importations.*—Over half the sulphate pulp imported comes from Sweden, while 8 percent is shipped from Finland and 4 percent from Norway. Canada sends 36 percent. Sulphite pulp is imported in almost equal amounts from Canada and Sweden. Ninety-one percent of mechanical pulp imports are from Canada. (See table II.)

TABLE IV.—*Kinds of wood pulp consumed and produced in the United States*[1] *since 1909*

Year	Total		Mechanical			Sulphite		
				Production			Production	
	Apparent consumption (short tons)	Production (short tons)	Apparent consumption (short tons)	Short tons	Percent of consumption	Apparent consumption (short tons)	Short tons	Percent of consumption
1928	6,239,641	4,510,800	1,866,618	1,615,689	86.6	2,633,249	1,595,951	60.6
1927	5,960,855	4,313,403	1,865,413	1,618,638	86.8	2,596,955	1,588,132	61.2
1925	5,588,000	3,962,217	1,951,000	1,629,689	83.5	2,392,000	1,447,191	60.5
1923	5,149,000	3,788,672	1,878,000	1,580,553	84.2	2,230,000	1,448,690	64.9
1921	3,544,000	2,875,601	1,458,000	1,267,382	86.9	1,471,000	1,166,926	79.3
1919	4,079,000	3,517,952	1,733,000	1,518,829	87.6	1,669,000	1,419,829	85.1
1914	3,521,000	2,893,150	1,523,000	1,293,661	84.9	1,524,000	1,151,327	75.5
1909	2,854,000	2,495,523	1,322,000	1,179,266	89.2	1,235,000	1,017,631	82.4

[1] Figures from 1909 to 1925 inclusive were compiled from: U.S. Department of Agriculture, Statistical Bulletin No. 21. Figures for 1927 and 1928 were compiled from: U.S. Bureau of the Census, Census of Manufactures, 1927 and 1928.

TABLE IV.—*Kinds of wood pulp consumed and produced in the United States*[1] *since 1909*—Continued

Year	Soda			Sulphate			Semichemical		
	Apparent consumption (short tons)	Production		Apparent consumption (short (tons	Production		Apparent consumption (short tons)	Production	
		Short tons	Percent of consumption		Short tons	Percent of consumption		Short tons	Percent of consumption
1928	485,907	488,641	100.6	1,223,900	780,552	63.8	29,967	29,967	100.0
1927	485,208	487,478	100.5	1,001,306	607,172	60.6	11,983	11,983	100.0
1925	470,000	472,647	100.6	775,000	412,690	53.3			
1923	448,000	445,162	99.4	593,000	314,267	53.0			
1921	296,000	300,533	101.5	319,000	140,760	44.1			
1919	406,000	411,693	101.4	271,000	120,378	44.4			
1914	346,000	347,928	100.6	128,000	52,641	41.1			
1909	297,000	298,626	100.5						

[1] See footnote bottom p. 319.

SOURCES OF WOODS AVAILABLE FOR PAPER MANUFACTURE

29. One reason advanced by the newspaper publishers for the free importation of Canadian paper was "conservation of our own forest resources." The United States Forestry Service has carefully examined the timber reserves of the United States. In its Forest Products Laboratory, the pulping characteristics of a large number of American woods have been studied to ascertain the relative value of species not in common use for pulpwood that are available to the industry. Other bureaus of the United States Department of Agriculture and State agricultural colleges have worked on the utilization of waste farm products for paper.

WOOD SPECIES SUITABLE FOR PAPER PULP

30. The Forest Products Laboratories have been studying woods available for paper pulp manufacture since 1906. The results of these studies are embodied in their report entitled "The Suitability of American Woods for Paper Pulp", dated May 1927. These experiments are continuing. Dr. C. E. Curran, senior chemist at the Madison Laboratories, stated in 1929 that: "Although we admit that paper pulp can be produced from any fibrous raw material, no source of cellulose that can compete with wood, either from the standpoint of suitability for most types of pulp or of cost per unit weight, has yet appeared. While it is true that certain of the so-called 'pulpwoods' are becoming scarce and high priced because of the prodigal way in which they have been consumed, it is also true that these species are few in number and that behind them there is a tremendous reservoir of other woods, less favored for the time being, which at present are not utilized extensively for pulp, but just the same are compact sources of cellulose, needing merely proper technical handing to give them pulping value."

31. Briefly, the results of the Forest Products Laboratory experiments have developed the following facts concerning the availability of groups of woods from different types of paper pulp:

Softwoods.—All spruces tested produce pulp of best quality and may be used in any pulping process.

32. Hemlocks are available for chemical processes, western hemlock being more easily pulped than eastern hemlock. Western hemlock may be used for mechanical pulp but requires more power in grinding to produce a pulp of the same strength as spruce. More bleach is required on hemlock than on spruce wood.

33. Firs may be used in all processes, for their pulp is similar to that of spruce. Red fir gives a darker colored pulp.

34. *Pines.*—All pines are satisfactorily reduced by the alkaline processes and produce bleachable pulp.

Western yellow pine and lodgepole pine are capable of manufacture into excellent mechanical pulp.

Northern white pine, sugar pine, timber pine, and piños may be used successfully for mechanical pulp.

Jack pine, loblolly pine, lodgepole pine, Norway pine, Virginia pine, pond, and sand pine yield sulphite pulp of fair quality.

35. *Other softwoods.*—Douglas fir and larches are usable for the sulphite process although digested with more difficulty than hemlock. Bleaching requires larger amounts of chemicals. The Douglas fir is readily reducible by the sulphate process and if turpentine is recovered from the cooking, process may be economically feasible.

Redwood and cedars are very difficult to pulp or bleach by the sulphite process. They produce satisfactory unbleached wrapping paper in the alkaline processes but the yield is low.

36. *Hardwoods.*—All hardwoods may be reduced by the soda or sulphate processes.

Aspen and basswood are easily pulped and bleached; chestnuts, after extraction, elms, yellow poplar, willows, soft maples, beech, red alder, and balsa are fairly easily treated; while the birches, hard maples, gums, magnolias, buckeye, and butternut are treated with more difficulty but are still within the field of commercial feasibility.

The weakness of the pulp and the greater power consumption make them impractical woods for the mechanical process. The shortness of the fibers are not suited for strong paper. Some may be reduced by the sulphite process for such papers as envelope, books, and other hard-surfaced papers. Sulphite reduceable woods are aspen, willows, maples, birches, gums, magnolias, sycamores, and butternut.

37. *Bark.*—Spruce bark may be employed as a part of the material for manufacture of board and cheap wrapping papers.

Spruce and balsam fir barks in shredded form are used in the manufacture of heat-insulation material.

Southern pine bark added to sulphate pulp makes a satisfactory roofing felt.

Extracted hemlock and redwood tanbark may be used with rags for roofing felts.

QUANTITIES OF PULPWOOD AVAILABLE

38. The last published survey of pulpwood resources by the United States Forest Service is dated 1924; it precedes some of the work of its own laboratories which added new woods to our pulpwood resources. But wood has also been cut from our forests since the survey and new growth has continued. Table V, therefore, may be considered as an approximation of our pulpwood resources without being an accurate statement of such resources in 1930.

TABLE V.—*Total stand of timber of principal kinds, suitable for pulp, by regions*[1]

[Thousands of cords]

Kind of timber	United States	Pacific coast: Washington, Oregon, and California	Lower Mississippi: Mississippi, Louisiana, and Arkansas	South Atlantic: Virginia, North Carolina, South Carolina, Georgia, Florida, and Alabama	Rocky Mountain: Idaho, Montana, Nevada, Wyoming, Arizona, Utah, Colorado, and New Mexico	Lake: Wisconsin, Michigan, and Minnesota	Central: Illinois, Indiana, Ohio, Kentucky, West Virginia, Missouri, Iowa, and Tennessee	New England: Maine, New Hampshire, Vermont, Massachusetts, Connecticut, and Rhode Island	Middle Atlantic: New York, Pennsylvania, New Jersey, Delaware, and Maryland	Southeast Alaska (not included in United States totals)
Regional totals:										
Number	3,530,900	897,400	678,000	611,500	442,700	330,800	241,000	166,900	162,600	167,000
Percent	100.0	25.4	19.2	17.3	12.5	9.4	6.8	4.7	4.6	----
Softwoods suitable for all processes:										
Spruce and fir:										
Number	414,000	205,100	----	3,400	85,500	17,100	3,400	[2] 85,500	14,000	45,300
Percent	100.0	49.5	----	0.8	20.7	4.1	0.8	20.7	3.4	----
Hemlock:										
Number	311,100	200,900	----	6,400	2,500	51,300	19,700	6,400	23,900	121,400
Percent	100.0	64.6	----	2.1	0.8	16.4	6.3	2.1	7.7	----
Total:										
Number	725,100	406,000	----	9,800	88,000	68,400	23,100	91,900	37,900	166,700
Percent	100.0	56.0	----	1.4	12.1	9.4	3.2	12.7	5.2	----
Pines and larches: [3]										
Southern yellow pine	977,800	----	487,200	453,000	----	----	21,400	1,100	15,100	----
Tamarack and larch	69,300	12,800	----	----	34,200	21,400	----	900	----	----
White and sugar pine	209,300	81,200	----	4,300	42,700	21,400	2,500	35,000	22,200	----
Western yellow pine	521,400	384,600	----	----	136,800	----	----	----	----	----
Lodgepole pine	141,000	12,800	----	----	128,200	----	----	----	----	----
Jack pine	38,400	----	----	----	----	38,400	----	----	----	----
Total:										
Number	1,957,200	491,400	487,200	457,300	341,900	81,200	23,900	37,000	37,300	----
Percent	100.0	25.1	24.9	23.4	17.5	4.1	1.2	1.9	1.9	----

Hardwoods:										
Aspen and cottonwood	85,900		21,400	5,100	12,800	27,300	10,700	6,400	2,200	200
Birch, beech, and maple	381,200		16,300	16,200		136,800	102,600	29,000	80,300	100
Yellow poplar	47,000		1,000	15,400			29,900		700	
Basswood	34,300			1,700		17,100	10,700	2,600	2,200	
Red gum	168,400		97,400	51,300			18,800		900	
Black and tupelo gums	131,800		54,700	54,700			21,300		1,100	
Total:										
Number	848,600		190,800	144,400	12,800	181,200	194,000	38,000	87,400	300
Percent	100.0		22.5	17.0	1.5	21.3	22.9	4.5	10.3	

[1] U.S. Department of Agriculture Bulletin No. 1241, p. 91. 1924.
[2] Contains no allowance for reduction in stand by spruce bud worm, which amounts to 40 percent, or about 27,500,000 cords, in Maine.
[3] Contains no allowance for Douglas fir, although a small volume is now being used. The stand is very large, probably 2 or 3 times that of pine and other species suitable for sulphate pulp.

39. *Total reserve.*—In continental United States there are approximately 3,500,000,000 cords of wood suitable for pulp. In southeast Alaska there are an additional 167,000,000 cords. This timber, while available for pulp, is also used by the lumber industry. The pulp and paper industry has the advantage of being able to use small-sized trees and poorer grades of saw-log material. It can also use woods' and sawmill waste that cannot be saved in lumber manufacture.

40. *Spruce, fir, and hemlock.*—The supplies of pulpwood of greatest value for mechanical and sulphite pulp, that is, spruce, fir, and hemlock, total 725,000,000 cords in continental United States while almost all southern Alaskan wood is of these species. Reports state that Canada has over 1,000,000,000 cords of these three species.

41. *Pines.*—The pines, all of which are adaptable to the sulphate or soda-pulp processes, and a few of which may be used for other pulps, constitute our largest pulpwood reserves, totaling almost 2,000,000,000 cords in continental United States. Douglas firs, not included in the pulpwood resources listed on table V but upon which pulp experimentations are under way, would add almost 800,000,000 cords to our sulphate, and possibly our sulphite, pulp reserves. These are not true firs and are, therefore, never included under fir species.

42. *Hardwoods.*—The hardwoods listed on table V total approximately 850,000,000 cords, all of which are suitable for soda pulp. This reserve would be augmented if all hardwoods now regarded as of commercial value in soda-pulp manufacture were included. Canada's aspen reserves—the hardwood giving best results in the soda process—are stated to be 250,000,000 cords.[96]

LOCATION OF PULPWOOD RESOURCES

43. *Spruces, firs, and hemlocks—Pacific coast resources.*—About half of all spruce and fir, the ideal woods for mechanical and sulphite pulp, is growing on the Pacific coast. Hemlock, valuable for all chemical processes, is also found chiefly on the Pacific coast. While the firs are found in all the Pacific Coast States, the spruce and hemlock stands are almost entirely in Washington and Oregon. The logging operations in these States have frequently left these pulpwoods, so that it is possible to secure hundreds of thousands of cords of pulpwood from the area logged over annually. While these softwoods are usually mixed in the Pacific forests, in Alaska practically pure stands of pulp timber are found.

44. *Other resources.*—New England has 21 percent of the Nation's reserves of spruce and fir while the Rocky Mountain States also have about 21 percent. About a sixth of the Nation's hemlock resources are in Lake States.

45. It is obvious that 56 percent of our reserves of pulpwood, still regarded as best for newsprint-paper manufacture, are located in Washington, Oregon, and California, 12 percent are in the Rocky Mountain States, less than 10 percent are still found in the three Lake States, while but 18 percent of the total stands remain in the New England and Middle Atlantic States. The Pacific Coast States have not only the advantage of large virgin stands of these softwoods

[96] Kellogg, Royal. Pulpwood and Wood Pulp in North America.

but growth of spruce, fir, and hemlock is far more rapid in these States than in the East.

46. Canadian spruce is distributed as follows: Eastern Provinces 55 percent, Prairie Provinces 20 percent, British Columbia 25 percent. Balsam fir is found principally in the Eastern Provinces and hemlock in British Columbia.

47. *The pines.*—The Nation's reserves of pines suitable for sulphate or soda pulps are found in almost equal amounts on the Pacific coast, in the lower Mississippi region, and in the South Atlantic States. Large forests are also located in the Rocky Mountain States. The principal pulping pine of the South is southern yellow pine; the principal pulping pine of the West is western yellow pine which also makes excellent mechanical pulp.

48. Should pulp from Douglas fir be able to compete with pines in sulphate pulp production, a source of pulpwood would be added to Pacific reserves, for over half the stand of Douglas fir, known also as Douglas spruce, red pine, Oregon pine, and Puget Sound pine, is found in western Washington and Oregon.

49. *The hardwoods.*—The stands of hardwoods, suitable for soda pulp are distributed evenly in the three Lower Mississippi States, the three Lake States, and the eight Central States, each section having about 22 percent of the Nation's supply. Middle Atlantic States still have 10 percent and South Atlantic States 17 percent.

Relation of Pulpwood Reserves to Consumption Markets

KINDS OF PULPWOOD CONSUMED

50. In 1928, the United States consumed 7,160,100 cords of pulpwood. Spruce constituted 43 percent of this amount, hemlock 16.5 percent, fir 6.5 percent, southern yellow pine 13 percent, jack pine 2.5 percent, tamarack or larch 1 percent, aspen 6 percent, yellow poplar 1.7 percent, other hardwoods about 4 percent. Lumber-mill waste constituted 6 percent of the total pulpwood consumed.

Table VI.—*Principal kinds of pulpwood consumed in the United States since 1909* [1]

Year	Total		Spruce			Hemlock			Pines		
	Consumption (cords)	Consumption of domestic wood (cords)	Total consumption (cords)	Amount domestic: Cords	Amount domestic: Percent of consumption	Total consumption (cords)	Amount domestic: Cords	Amount domestic: Percent of consumption	Total consumption (cords)	Amount domestic: Cords	Amount domestic: Percent of consumption
1928	7,160,100	5,641,280	3,063,781	2,000,433	65.3	1,177,635	1,158,958	98.4	1,101,655	1,101,655	100.0
1927	6,750,935	5,213,207	3,026,109	2,077,893	68.7	1,143,831	1,138,783	99.6	923,909	923,909	100.0
1925	6,093,821	5,005,445	3,071,362	2,253,219	73.4	1,034,814	1,013,109	97.9	633,197	633,197	100.0
1923	5,872,870	4,636,789	3,249,668	2,195,395	67.6	970,102	[2] 970,102	100.0	488,292	488,292	100.0
1921	4,557,179	3,740,406	2,514,893	1,813,762	72.1	863,043	[2] 863,043	100.0	282,375	282,375	100.0
1919	5,477,832	4,445,817	3,187,214	2,313,419	72.6	795,154	[2] 795,154	100.0	293,610	293,610	100.0
1914	4,470,763	3,641,063	2,660,795	1,892,739	71.1	602,754	[2] 602,754	100.0	141,359	141,359	100.0
1909	4,001,607	3,207,653	2,421,581	1,653,249	68.3	559,657	[2] 559,657	100.0	90,885	90,885	100.0

[1] Figures from 1909 to 1925, inclusive were compiled from U.S. Department of Agriculture, Statistical Bulletin No. 21. Figures for 1927 and 1928 were compiled from U.S. Bureau of the Census. Census of Manufactures, 1927 and 1928.

[2] Importation, if any, negligible.

TABLE VI.—*Principal kinds of pulpwood consumed in the United States since 1909*—Continued

Year	Aspen			Balsam fir			All other [3]		
	Total consumption (cords)	Amount domestic		Total consumption (cords)	Amount domestic		Total consumption (cords)	Amount domestic	
		Cords	Percent of consumption		Cords	Percent of consumption		Cords	Percent of consumption
1928	547,803	347,932	63.5	359,666	287,379	71.6	909,560	884,332	97.2
1927	538,131	351,436	65.3	389,230	305,143	78.4	729,725	729,725	100.0
1925	402,920	206,982	51.4	267,190	214,600	80.3	684,338	684,338	100.0
1923	334,694	152,886	45.7	237,509	[2] 237,509	100.0	592,605	592,605	100.0
1921	246,680	131,038	53.1	226,726	[2] 226,726	100.0	423,462	423,462	100.0
1919	338,380	180,160	53.2	288,814	[2] 288,814	100.0	574,660	574,660	100.0
1914	390,157	328,513	84.2	125,296	[2] 125,296	100.0	550,402	550,402	100.0
1909	328,498	302,876	92.2	95,366	[2] 95,366	100.0	505,620	505,620	100.0

[2] Importation, if any, negligible.
[3] Slabs and mill waste included. They formed 66.6 percent of the total in 1928, 39.2 percent in 1927, 22.8 percent in 1925, 17.5 percent in 1923, 15.8 percent in 1921, 30.5 percent in 1919, 46.1 percent in 1914, and 49.2 percent in 1909.

51. *Decreased consumption of spruce.*—While our consumption of spruce far exceeds that of any other wood species, the 1928 figure of 3,063,781 cords represents a material decrease in the proportion of spruce employed over earlier years as well as a slight decrease in the actual amount of wood. For as late as 1922 the census reported a consumption of 3,032,890 cords of spruce which formed 54.7 percent of the total pulpwood consumption in that year. This decrease in spruce consumption was distributed through three major processes of wood-pulp production but, strange to say, was not found in the one process where but small amounts of spruce have been used, that is, in the soda process. In 1928, 82 percent of the wood entering into mechanical pulp was spruce as compared with 87 percent in 1922. The sulphite process took 53 percent in 1928 as compared with 60 percent in 1922; the sulphate process 4.5 percent as compared with 15.5 percent in 1922. The soda process, however, increased its spruce consumption from 1,121 cords to 35,549 cords.

52. Increased application of hemlock and aspen is chiefly responsible for the decreased consumption of spruce for mechanical pulp. Use of mill waste has increased materially in sulphite pulp mills since 1922. Hemlock, jack pine, and larch had come into extensive use in sulphate pulp mills since 1928.

53. *Pulpwoods used in other processes.*—Table VII shows the extent to which each species was employed in the several pulp-manufacturing processes in 1928. It is obvious that sulphate pulp reduction depends chiefly on the pines although 13 percent of this type of pulp was made of hemlock. Soda pulp still clings closely to aspen as its principal wood material.

54. An interesting development is the beginning of semichemical pulp production utilizing sawmill waste and jack pine. While this new process consumed but 40,790 cords of wood, yet its increased application may widen the types of commercial pulpwood by reducing manufacturing costs.

55. In 1922, less than 90,000 cords of waste wood was manufactured into pulp in this country; in 1928, this consumption had reached 455,605 cords; and 548,800 cords in 1929, a development taking place chiefly in the State of Washington in the production of sulphite pulp.

TABLE VII.—*Pulpwood consumption, by kind of wood and process of manufacture, 1928* [1]

Kind of wood	Total		Process of manufacture									
			Mechanical		Sulphite		Soda		Sulphate		Semi-chemical	
	Cords	Per-cent	Cords	Per-cent	Cords	Per-cent	Cords	Per-cent	Cords	Per-cent	Cords	Per-cent
United States	7,160,100	100.0	1,558,818	100.0	3,196,939	100.0	928,300	----	1,435,252	----	40,791	----
Spruce	3,063,781	42.8	1,283,831	82.4	1,680,513	52.6	35,549	3.8	63,888	4.5	----	----
Hemlock	1,177,635	16.5	108,885	6.9	875,610	27.4	4,770	.5	188,370	13.1	----	----
Yellow pine, southern	925,698	12.9	7,125	.5	7,205	.2	92,844	10.0	818,524	57.0	----	----
Aspen	425,065	5.9	21,935	1.4	13,098	.4	383,346	41.3	6,686	.5	----	----
Balsam fir	359,666	5.0	84,043	5.4	205,690	6.4	----	----	69,933	4.9	----	----
Jack pine	175,957	2.5	9,553	.6	20	(2)	100	(2)	151,339	10.5	14,945	36.6
Yellow poplar	122,738	1.7	53	(2)	----	----	122,685	13.2	----	----	----	----
Beech, birch, and maple	82,327	1.1	14	(2)	2,692	.1	76,530	8.3	3,091	.2	----	----
White fir	105,161	1.5	27,494	1.8	75,602	2.4	----	----	2,065	.1	----	----
Gum	72,611	1.0	----	----	----	----	70,422	7.6	----	----	2,189	5.4
Tamarack or larch	67,394	.9	----	----	327	(2)	----	----	67,067	4.7	----	----
Other wood [3]	126,462	1.8	2,389	.1	----	----	123,856	13.3	217	(2)	----	----
Slabs and other mill waste	455,605	6.4	13,496	.9	336,182	10.5	18,198	2.0	64,072	4.5	23,657	58.0

[1] Compiled from U.S. Bureau of the Census, "Census of Manufactures", 1928.
[2] Less than 0.1 percent.
[3] Basswood, cedar, chestnut, cottonwood, Douglas fir, box elder, buckeye, white pine, and willow.

PULPWOOD CONSUMPTION AND PULPWOOD PRODUCTION IN THE SEVERAL STATES

56. *Pacific Coast States.*—With 56 percent of our spruce, fir, and hemlock stands located in Washington, Oregon, and California, these States consumed but 600,000 cords of these woods out of a total United States consumption of 4,700,000 cords, or but 12.8 percent. With 25 percent of the pines available for sulphate pulp growing on the Pacific coast, less than 3 percent of the total consumption took place in these States. Washington State produced 8 percent of our wood pulp and 3 percent of our paper; Oregon and California, 5 percent wood pulp and 3.7 percent of the total paper in 1928.

57. The United States Forest Service states that "under proper timber-growing methods", Washington, Oregon, and Alaska can supply approximately 5,000,000 cords of spruce, hemlock, and fir annually,[97] or enough to meet all present needs of these pulpwoods.

58. *Middle Atlantic States.*—The Middle Atlantic States of New York, Pennsylvania, New Jersey, Delaware, and Maryland have 4.6 percent of our national pulpwood reserves. They consume 21.7 percent of all pulpwood. They produce 23.2 percent of our total wood pulp and 29.2 percent of the Nation's paper.

59. *New York.*—New York State produces more paper than any other State, or 1,454,000 tons. It ranks third in wood-pulp production. But less than 14,000,000 cords of spruce and fir, of which 7,000,000 are on State preserves where cutting is prohibited, are growing in the State; yet the consumption of spruce and fir pulpwood in 1928 totaled in excess of 655,000 cords. While the total stand of hemlock is about equal to that of spruce and fir, it is held by lumber companies and used chiefly for purposes other than pulp. Birch, beech, and maple are available but such domestic woods are not used.

[97] U.S. Department of Agriculture, Department Bulletin No. 1485. The Suitability of American Woods for Paper Pulp, p. 5.

60. Out of 802,115 cords of pulpwood consumed by New York pulp and paper mills in 1928, 596,378 cords were imported. In the total amount consumed 53 percent is imported spruce and 21 percent domestic spruce; 6 percent is imported fir and 1 percent domestic fir; 12.7 percent is imported aspen and 1 percent domestic aspen. New York is carrying out a program of extensive reforestation but for a number of years to come New York's pulp and paper mills will be dependent on pulpwood from sources outside the State.

61. *Pennsylvania.*—Pennsylvania ranks fifth in the production of paper and wood pulp. It is first in the production of soda pulp and ranks high in book-paper manufacture. It consumes 5.7 percent of our annual domestic pulpwood supply, produces 5 percent of the wood pulp, and manufactures 7 percent of our paper. Information concerning its pulpwood stands are inadequate though they include 9,500,000 cords of hemlock, about 2,000,000 cords of pitch pine, and 1,000,000 cords of aspen. Forest lands containing mixed hardwoods cover a large acreage.[98]

62. But few Pennsylvania mills secure their timber entirely from within the State. While 60 percent is imported, nearby States ship in other woods. Importations are chiefly of spruce and aspen. Domestic woods are largely southern pine and yellow poplar, beech, birch maple, and gum.

TABLE VIII.—*State consumption of pulpwood and production of wood pulp and paper in 1928* [1]

State	Pulpwood consumption				Wood-pulp production				Paper production	
	Total		Domestic	Imported	Total		From domestic pulpwood	From imported pulpwood	Total	Percent of total
	Cords	Percent	Cords	Cords	Tons	Percent	Tons	Tons	Tons	
United States	7,160,100	100.0	5,750,689	1,409,411	4,510,800	100.0	3,546,988	963,812	10,403,338	100.0
New England:										
Maine	1,309,988	18.3	1,126,407	183,581	970,600	21.5	834,668	136,022	987,201	9.5
New Hampshire	351,349	4.9	290,880	60,469	198,587	4.4	164,347	34,240	200,163	1.9
Vermont	20,081	.3	16,834	3,247	19,831	.4	16,649	3,182	72,198	.7
Massachusetts	51,325	.7	48,201	3,124	32,370	.7	30,415	1,955	541,268	5.2
Connecticut									180,887	1.7
Middle Atlantic:										
New York	802,115	11.2	205,737	596,378	633,182	14.0	162,326	470,856	1,453,597	13.9
Pennsylvania	405,276	5.7	171,143	234,133	218,598	5.0	92,246	126,352	712,874	6.9
New Jersey	(2)		(2)	(2)	(2)		(2)	(2)	552,963	5.3
Maryland	(2)		(2)	(2)	(2)		(2)	(2)	103,278	1.0
Virginia	342,813	4.8	296,432	46,381	189,925	4.2	164,223	25,702	219,235	2.1
Lake:										
Michigan	331,697	4.6	231,727	99,970	196,203	4.4	137,182	59,021	1,061,358	10.2
Minnesota	282,691	3.9	282,691		194,399	4.3	194,399		273,637	2.6
Wisconsin	1,225,630	17.1	1,053,852	171,778	720,781	16.0	619,665	101,116	893,017	8.6
Central:										
West Virginia	(2)		(2)	(2)	(2)		(2)	(2)	42,907	.4
Indiana									342,202	3.3
Illinois									528,138	5.1
Ohio	(2)		(2)	(2)	(2)		(2)	(2)	894,805	8.6
Pacific coast:										
Washington	651,657	9.1	641,307	10,350	349,107	7.7	343,741	5,366	309,164	3.0
Oregon	308,264	4.3	308,264		213,407	4.7	213,407		198,397	1.9
California									183,923	1.8
South Central: Louisiana	413,602	5.8	413,602		226,708	5.0	226,708		238,424	2.3
All other States	663,612	9.3	663,612		347,012	7.7	347,012		413,702	4.0

[1] Compiled from: U.S. Bureau of the Census, "Census of Manufactures", 1928.
[2] Not shown separately in order to avoid disclosing the output of individual establishments.

[98] U.S. Department of Agriculture. Department Bulletin No. 1241. How the United States Can Meet Its Present and Future Pulpwood Requirements.

63. *The New England States.*—The six New England States have 4.7 percent of the Nation's stand of pulpwood. Their mills required 24.3 percent of the entire pulpwood consumed in the United States in 1928. They produced 27 percent of its wood pulp and 19 percent of its paper.

64. *Maine.*—Maine is the largest pulpwood-consuming State in the country and also the largest wood-pulp-producing State. It consumed approximately 1,310,000 cords of wood in 1928, or over 18 percent of the total amount consumed in the United States. It has probably under 45,000,000 cords of spruce and fir, about 3,500,000 cords of hemlock, and 3,500,000 cords of poplar or aspen. Some pulpwood is shipped from Maine to New Hampshire, but some is also imported from Canada. Of the total pulpwood consumed in 1928, 65 percent was Maine spruce and 10 percent Canadian spruce; 4 percent was Maine fir and 2 percent Canadian fir; 4 percent was Maine hemlock and 11 percent Maine poplar or aspen.

65. *New Hampshire.*—New Hampshire finds use for 5 percent of our pulpwood. It has less than 6,000,000 cords of spruce and fir available for pulp and paper and, as it consumes over 300,000 cords annually, spruce is gotten from Vermont and Maine and some comes from Canada.

66. While Massachusetts and Connecticut produce together 7 percent of our paper, they count on rags as their principal source of raw material and are not heavy pulpwood-consuming States.

67. *Lake States.*—Michigan, Wisconsin, and Minnesota contain 9.4 percent of the Nation's timber reserves. These are largely hemlock and hardwoods. They consume 25.6 percent of our annual pulpwood and produce 24.7 percent of the entire wood-pulp supply and 21.4 percent of the country's paper.

68. *Michigan.*—Michigan ranks second as a paper manufacturing State in this country but manufactures but 4 percent of the wood pulp and, consequently, has a pulpwood consumption of but 300,000 cords. While it has stands of spruce, fir, and hemlock in the upper Peninsula these are more accessible to Wisconsin mills than to Michigan mills in the lower Peninsula. Also, it has jack pine and hardwoods. The woods actually consumed in 1928 were made up of 22 percent domestic spruce and 27 percent imported spruce; 17 percent domestic hemlock, 12 percent domestic fir, almost 10 percent jack pine and 6 percent larch. Slabs and mill waste formed 5 percent of the total woods converted into pulp.

69. *Wisconsin.*—Wisconsin, on the other hand, is second only to Maine in pulpwood consumption and wood-pulp production, and ranks fourth in paper production. Its supply of spruce and fir is small; hemlock stands contain about 30,000,000 cords. A large amount of spruce is secured, therefore, from Minnesota and northern Michigan, and also from Canada. Hemlock is drawn from its own supplies and from Michigan although competition for hemlock is had from the lumber industry. Jack-pine reserves are large but scattered. The 1,225,000 cords of pulpwood consumed by Wisconsin in 1928 were made up as follows: Domestic spruce constituted 19 percent, imported spruce 13 percent; domestic hemlock 43 percent, domestic fir 11 percent, jack pine 9 percent, and larchwood but 4 percent.

70. *Minnesota.*—Minnesota has less than 8,000,000 cords of spruce and fir, much of which is being attacked by insects. It has about 16,000,000 cords of jack pine, about 15,000,000 cords of aspen, and about 15,000,000 cords of tamarack. Its pulpwood consumption in 1928 was chiefly made up of its own spruce, fir, aspen, and jack pine. The State produces but 4 percent of our wood pulp and 3 percent of our paper.

71. *The Central States.*—The pulp wood reserves of the Central States are chiefly hardwoods. The pulp mills now producing in these States are so few that they are not listed by the United States Census. Paper production totals 17.4 percent, however, most of which is manufactured in Ohio and Illinois. Production in West Virginia is increasing. These mills manufacture chiefly book and board for which waste papers and rags, purchased sulphite pulp, purchased soda pulp, and some soda pulp manufactured locally in book-paper mills, are used.

TABLE IX.—*Pulpwood consumption in each State in 1928 by kinds of wood* [1]

State	Total		Spruce				Hemlock			
			Domestic		Imported		Domestic		Imported	
	Cords	Per cent	Cords	Per cent	Cords	Per cent	Cords	Per cent	Cords	Per cent
United States	7,160,100	100.0	2,000,433	27.9	1,063,348	14.9	1,158,958	16.2	18,677	0.3
Maine	1,309,988	100.0	845,837	64.6	135,374	10.3	55,561	4.2	3,681	.3
Wisconsin	1,225,630	100.0	233,151	19.0	156,047	12.7	522,721	42.6	9,307	.8
New York	802,115	100.0	170,836	21.3	426,793	53.2	9,884	1.2	3,533	.4
Washington	651,657	100.0	43,208	6.6	455	(3)	211,105	32.4	2,156	.3
Louisiana	413,602	100.0								
Pennsylvania	405,276	100.0	8,100	2.0	142,761	35.2	11,484	2.8		
New Hampshire	351,349	100.0	274,670	78.2	60,469	17.2				
Virginia	342,813	100.0	9,138	2.7	46,381	13.5	17,650	5.1		
Michigan	331,697	100.0	71,490	21.6	88,708	26.7	55,416	16.7		
Oregon and California	308,264	100.0	30,633	9.9			207,023	67.2		
Minnesota	282,691	100.0	198,086	70.1						
Massachusetts	51,325	100.0	41,084	80.0	3,113	6.1				
Vermont	20,081	100.0	3,508	67.3	3,247	16.2				
Other States [2]	663,612	100.0	60,692	9.2			68,114	10.3		

State	Yellow pine southern		Aspen				Balsam fir			
			Domestic		Imported		Domestic		Imported	
	Cords	Per cent	Cords	Per cent	Cords	Per cent	Cords	Per cent	Cords	Per cent
United States	925,698	12.9	225,194	3.1	199,871	2.8	257,379	3.6	102,287	1.4
Maine			143,254	10.9	21,277	1.6	47,369	3.6	22,860	1.8
Wisconsin			8,517	.7			130,627	10.7	6,424	.5
New York			9,025	1.1	102,136	12.7	11,078	1.4	46,816	5.8
Washington										
Louisiana	403,533	97.6								
Pennsylvania	50,404	12.4			76,447	18.9	900	.2	14,925	3.7
New Hampshire							8,520	2.4		
Virginia	198,115	57.8								
Michigan			217	(3)			38,190	11.5	11,262	3.4
Oregon and California										
Minnesota			31,431	11.1			17,369	6.1		
Massachusetts			7,117	13.9	11	(3)				
Vermont							3,326	16.5		
Other States [2]	273,646	41.2	25,633	3.9						

[1] Compiled from U.S. Bureau of the Census, Census of Manufactures, 1928.
[2] Arkansas 1 establishment, Delaware 1, District of Columbia 1, Maryland 2, Mississippi 1, New Jersey 1, North Carolina 3, Ohio 1, South Carolina 1, Tennessee 1, Texas 1, West Virginia 2.
[3] Less than 0.1 percent.

TABLE IX.—*Pulpwood consumption in each State in 1928 by kinds of wood*—Con.

State	Jack pine		Yellow poplar		Beech, birch, and maple				White fir	
					Domestic		Imported			
	Cords	Per cent	Cords	Per cent	Cords	Per cent	Cords	Per cent	Cords	Per cent
United States	175,957	2.5	122,738	1.7	65,227	0.9	17,100	0.2	105,161	1.5
Maine					24,321	1.9				
Wisconsin	108,658	8.9								
New York	100	(3)			414	(3)	17,100	2.1		
Washington									37,563	5.8
Pennsylvania			16,721	4.1	31,170	7.7				
Virginia			49,323	14.4	3,169	.9				
Michigan	31,798	9.6								
Oregon and California									67,598	21.9
Minnesota	35,401	12.5			34	(3)				
Other States [2]			56,694	8.5	6,119	.9				

State	Gum		Tamarack or larch		Other [4]				Slabs and mill waste	
					Domestic		Imported			
	Cords	Per cent	Cords	Per cent	Cords	Per cent	Cords	Per cent	Cords	Per cent
United States	72,611	1.0	67,394	0.9	118,334	1.7	8,128	.1	455,605	6.4
Maine					3,769	.3	389	(3)	6,206	.5
Wisconsin			48,758	4.0	217	(3)			1,203	.1
New York									4,400	.6
Washington					32,365	5.0	7,739	1.2	317,066	48.7
Louisiana									10,069	2.4
Pennsylvania	18,513	4.6			62	(3)			33,789	8.3
New Hampshire									7,690	2.2
Virginia	4,439	1.3							14,598	4.3
Michigan			18,266	5.5					16,350	4.9
Oregon and California									3,010	1.0
Minnesota			370	.1						
Other States [2]	49,659	7.5			81,921	12.3			41,134	6.2

[2] Arkansas 1 establishment, Delaware 1, District of Columbia 1, Maryland 2, Mississippi 1, New Jersey 1, North Carolina 3, Ohio 1, South Carolina 1, Tennessee 1, Texas 1, West Virginia 2.
[3] Less than 0.1 percent.
[4] Basswood, box elder, buckeye, cedar, chestnut, cottonwood, douglas fir, white pine, and willow.

72. *Southern States.*—The Southern States from Virginia to Texas have abundant reserves of pines and hardwoods. Two thirds of the timber stands of these States is regarded as suitable for pulp and the cut of pulpwood timber has been very small until recent years. The Forest Service states that with the adoption of forestry measures, the South can take care of all present and normal increases in the Nation's sulphate pulp needs; that the hardwood pulps now imported can be secured from southern forests continuously if forest management began with thinning out and improvement cuttings. Louisiana is already consuming 6 percent of our pulpwood and producing 5 percent of the wood pulp and 2.3 percent of the paper. The pulpwood consumption is almost entirely of yellow pine.

73. *Rocky Mountain States.*—The Northern Rocky Mountain States, that is, northern Idaho and northwestern Montana, have forests similar in character to those of Washington and Oregon. Spruce, fir, and hemlock stands are large. Farther south the stands are scattered. The lodge-pole pine, yellow pine, and the larch are numerous in Wyoming, Montana, Utah, and Colorado. While well-

developed lumbering industries are found in these Rocky Mountain States, pulp mills are few.

NATIONAL INDEPENDENCE IN PULPWOOD DEPENDS ON DEVELOPMENT OF INDUSTRY ON PACIFIC COAST AND IN SOUTH

74. Maine, our largest pulpwood consuming State, is the only State, therefore, in the North or Middle Atlantic or Central groups capable of meeting her own pulpwood requirements. New York and Michigan, the largest paper-producing States, must secure large amounts of raw materials from outside their borders. Pennsylvania, Wisconsin, and Ohio cannot supply pulpwoods for their own pulp and paper mills.

75. The Pacific Coast States have huge virgin stands of spruce, fir, and hemlock suitable, under forestry management, for the Nation's newsprint paper. They contain larger reserves of pine available for wrapping papers and boards. Southern States have ample reserves of pines for sulphate pulp, and possibly sulphite pulp, and much hardwood for book papers.

FOREST AND LUMBER MILL WASTE UTILIZATION

76. *Total waste.*—The United States Forest Service estimates the waste in logging and sawmill operations per year has run into the billions of cubic feet of wood. In the woods this is due to trees shattered or damaged in felling larger trees, defective logs, stumps, and tops, and other losses through careless handling. Only a little more than half of the log that enters the sawmill is used for manufactured products, the bark, saw kelp, slabs, edgings, and trimmings, as well as cuts, in many localities representing entire loss.

77. *Swedish use of waste.*—In Sweden the lumber and the pulp and paper industry have been so correlated that almost 3,000,000 tons of pulp and paper are manufactured in large part from logging and sawmill waste. Logs are diverted to sawmills, planing mills, box factory, charcoal, or paper plant as conditions warrant.

78. *United States.*—Beginnings of such integration are to be found in the United States with the grouping of plants making varied products from wood in a single location, and with removal of pulpwood from forests immediately following logging operations. In 1928 the pulp and paper mills of the United States turned 455,605 cords of slabs and other mill waste into wood pulp. Practically all of this waste was used in the sulphite and semichemical processes. The largest amount of such waste utilization took place in Washington.

79. *Following after the lumber companies.*—Washington is the largest lumbering State in the country, producing over a fifth of the Nation's lumber. Oregon is the second largest lumbering State. This lumber is shipped into eastern markets. Douglas fir is the species most used by the lumbering industry, but growing among the douglas fir stands are the finest pulpwood species. A survey made by one of the foresters revealed that in one timbered county alone, 70,000,000 feet of pulp material was left annually, and that if broken logs could be economically gathered this amount would be much greater.[98] One paper com-

[98] R. W. Vinnedge, president North Bend Timber Co., in address before National Conference on Forest Products. 1924.

pany, at least, is now gathering hemlock which remains after logging operations. The major obstacles to the more general adoption of such methods is the high freight rate charged to carry the lower-priced wood to pulp mills and the number of small logging companies operating in the Pacific Northwest.

80. *Use of sawmill waste.*—But the lumber and pulp industries are appreciating the value of amalgamation. The Olympic Forest Products Co., of Port Angeles, Wash., has a sawmill with a capacity of 160,000 feet of lumber every 8 hours, and an "all electric" bleached sulphite plant of 175 tons capacity. The Everett Sulphite Pulp Mill has a two-department mill. In one is installed equipment for cutting up hemlock logs for pulp; in the other logs will be cut up into lumber lengths. The profitableness of each market will determine the amount devoted to sulphite pulp produced. All rejects from the pulp mill are shipped to roofing mills. The Fir-Tex Board Mill, of St. Helens, Oreg., is manufacturing insulating board entirely from chips sent to it from sawmills along the Columbia River. The Western Board Products Co. is beginning operations at Salem, Oreg., to manufacture trunk board, container board, and other specialties from the waste of lumber and paper mills.

81. *Waste for sulphate pulp.*—The Great Southern Lumber Co., cutting yellow pine in Louisiana, sends its sawmill and woods refuse to a kraft pulp mill and a container board mill. All wood down to 3 inches in diameter is brought in from the forests for pulpwood. Two years before any trees are cut they are turpentined. Turpentine is also extracted by steam from lumber as it goes through dry kilns and from the wood chips going through the pulp mill.

82. *Correlated industries.*—Cloquet, Wis., once a lumber manufacturing center only, now has a correlated wood industry based on clearing the forests used of all species. Northern Minnesota furnishes white pine for lumber and spruce, jack pine, aspen, birch, and other hardwoods for paper. Short materials from the planing mills are worked up by a box factory. The paper mill makes newsprint, book, and wrapping paper from spruce, aspen, birch, tamarack, and jack pine. Small pieces of birch produce clothespins, tongue depressors, toothpicks, and other small wooden objects. Waste from the sawmill and paper mills is converted, in part, into insulating and sound-deadening board, part of which is used by the local refrigerator factory. Another mill uses the mill waste for manufacturing paper plugs, wire reels, and other specialties.

TABLE X.—*Paper material consumed in 1929* [1]

Chief materials	Quantity	
	Short tons	Percent
Total	11,522,131	100.0
Wood pulp	6,245,349	54.2
Paper stock	3,841,942	33.3
Rags	739,571	6.4
Straw	566,469	5.0
Manila stock: Rope, jute, bagging, etc.	128,800	1.1

[1] Compiled from: U.S. Bureau of the Census, Census of Manufactures, preliminary reports for 1929.

Other Sources of Paper Materials

WASTE MATERIALS

83. *Paper.*—Although wood pulp was our principal source of raw material, waste paper, to the extent of almost 4,000,000 tons, was used in the manufacture of board and book paper.

84. *Textiles.*—Rags were the original source of material out of which paper was made. They continue to be used for fine grades of paper. Approximately 700,000 tons were consumed in papermaking in 1929. Of this amount, 220,000 tons are imported, coming chiefly from European markets where linen is still in common use. Manila stock, such as rope, jute, bagging, to the extent of 129,000 tons, went into paper manufacture. The largest amount of this was imported.

TABLE XI.—*Imports and exports of paper stock other than pulpwood and wood pulp, in 1928* [1]

Imported from or exported to—	Imports						Exports	
	Rags		Waste bagging, waste paper, old rope, etc.		Total		Rags and all other miscellaneous paper stock (total)	
	Short tons	Percent	Short tons	Percent	Short tons	Percent	Short tons	Percent
Total	219,946	100.0	109,740	100.0	329,686	100.0	115,313	100.0
France	37,102	16.9	7,561	6.9	44,663	13.5	164	.1
Germany	32,471	14.8	9,269	8.5	41,740	12.7	839	.7
United Kingdom	30,126	13.7	33,013	30.1	63,139	19.2	5,154	4.5
Japan	28,394	12.9	3,269	3.0	31,663	9.6	2,617	2.3
Belgium	22,129	10.1	10,273	9.4	32,402	9.8	130	.1
Italy	16,853	7.6	3,116	2.8	19,969	6.1	1,181	1.0
Netherlands	13,378	6.1	9,043	8.2	22,421	6.8	347	.3
Canada	9,965	4.5	22,014	20.1	31,979	9.7	34,245	29.7
Spain	9,577	4.4	2,651	2.4	12,228	3.7	11	(2)
Egypt	3,466	1.6	29	(2)	3,495	1.1	0	------
Austria	2,870	1.3	280	.3	3,150	1.0	29	(2)
Java and Madura	------	------	------	------	------	------	20,509	17.8
Hong Kong	------	------	------	------	------	------	18,321	15.9
China	1,299	.6	110	.1	1,409	.4	12,575	10.9
British India	65	(2)	69	(2)	134	(2)	5,128	4.5
Philippines	30	(2)	33	(2)	63	(2)	4,661	4.0
Other countries	12,221	5.5	9,010	8.2	21,231	6.4	9,402	8.2

[1] U.S. Department of Commerce: Data compiled from Foreign Commerce and Navigation, 1928.
[2] Less than 0.1 percent.

85. *Cereal straws.*—Straw wrapping paper and strawboard have been manufactured in this country for almost a hundred years. The amount of straw entering into paper-making is approximately 566,000 tons. Board from cornstalks, board from bagasse, and bleached paper from cornstalks are being manufactured in a few factories today.

86. Many experiments have been conducted both by the United States Department of Agriculture, Iowa State College, and other colleges to find a method of utilizing this farm waste. While not only coarse paper but white paper has been made from straw and cornstalks, these materials have not succeeded commercially in meeting the competition from pulpwood in newsprint-, wrapping-, or book-paper manufacture.

87. *Quantities available.*—The supply of straws and cornstalks in the United States is very extensive. The yield of cured corn fodder, according to the Department of Agriculture, is from 1 to 2 tons per acre, giving from 100,000,000 tons to 150,000,000 tons of field-cured cornstalks annually. The usual production of field-cured wheat straw is approximately 50,000,000 tons. Bagasse production in Louisiana reaches 375,000 tons. The principal corn-producing States are Iowa, Illinois, and Nebraska; the wheat States are Kansas, North Dakota, Nebraska, Oklahoma, and Washington.

88. *Pulp yields.*—The yields of pulp from these straws vary widely, the range being from 30 percent to 50 percent. The density of the material permits the cooking of but about 3 pounds of cornstalks or bagasse in a cubic foot of digester space that will hold 10 pounds of chipped wood. The nonfibrous cellulose present in large amounts in cornstalks has value only where water resistance and hardness are essential.[99] Larger amounts of water and chemicals and more steam are usually required to produce bleached papers.

89. *Value in papers.*—These factors have not yet made commercial development of cereal straws for printing paper successful, although such paper has been manufactured by the Cornstalk Products Co. at Danville, Ill., and by the Meade Corporation of Chillicothe, Ohio. The profitable application of bagasse and cornstalks in insulating wall board, of straws for unbleached egg-case fillers and chip board has, however, been established.

90. *Manufacturers.*—A large manufacturer of straw board is the Steward Inso Board Co. of St. Joseph, Mo. The Maizewood Products Corporation at Dubuque, Iowa, produces a building insulation board and a lighter board for nonstructural insulation. The Celotex Co. of New Orleans holds the patents for manufacturing fiber board from bagasse.

Manufacturers of Pulp and Paper in the United States and in Canada

91. So much of Canadian pulp and paper enters the United States markets that the picture of manufacturing control would be incomplete without inclusion of the principal Canadian mills with those in the United States. Wood pulp is produced by paper mills either at the paper mill itself or at scattered plants, and it is also manufactured by firms producing wood pulp only. Paper mills do not confine their manufacture entirely to one type of paper, but the larger mills produce a number of kinds. Figures on number of plants producing any one type of pulp or any one type of paper are not, therefore, mutually exclusive.

92. In 1930 there were 259 pulp mills operating in the United States and 119 operating in Canada. The largest number in both countries were mechanical pulp mills. In the United States these totaled 105; in Canada, 67. The United States had 85 producing sulphite mills, 25 soda pulp mills, and 36 sulphate pulp mills. Canada had 43 sulphite, 1 soda, and 8 sulphate pulp mills in operation in 1930.

93. In the same year there were 757 paper mills producing in the United States and 84 operating in Canada. Some of these mills

[99] U.S. Bureau of Chemistry and Soils, Industrial Farm Products Division. Farm Wastes for Paper and Board Making. June 1929.

were, of course, using stock other than pulpwood. This is especially true of board mills where waste paper is the chief raw material. Others purchased stock from pulp mills in this country, but a large number of paper mills were dependent upon imported pulp for their operations.

94. States which have a number of paper mills but not a single pulp mill are Connecticut, Illinois, and Indiana; while Massachusetts, Michigan, New Hampshire New Jersey, Pennsylvania, and Ohio have many paper mills and but few pulp mills. Maine, on the other hand, has 38 pulp mills and 32 paper mills, while Washington State has 26 pulp mills and 14 paper mills, and in Oregon 10 pulp mills and 7 paper mills were operating in 1930. These pulp mills are selling, in most cases, sulphite pulp.

95. Twenty-one firms, operating a number of mills in the United States and Canada, had daily capacities of finished products of 500 tons or over per day. These were:

Company	Principal product	Location of mill	Daily capacity (tons of finished product)
International Paper Co.	Mechanical and sulphite pulp	New York, Maine, and New Hampshire.	5,000
	Newsprint paper	Quebec, New Brunswick, and Newfoundland, Canada.	
	Special sulphite pulp	Quebec, Canada	
	Book and fine paper	New York and Massachusetts.	
	Boards, ground wood, and sulphite pulp.	Ontario, Canada	
	Sulphate pulp, kraft, wrapping, and bag.	Alabama, Arkansas, Louisiana, and Mississippi.	
	Insulating and building board	Illinois and Indiana; Ontario and Quebec, Canada.	
	Hanging	Illinois and Maine	
	Specialties	Illinois, New York, and West Virginia.	
	Wrapper	Maine	
	Magazine	Maine and Massachusetts	
	Poster	Massachusetts	
	Tablet, bond, mimeo, litho, and ledger.	New York	
Canada Power & Paper Corporation.	Newsprint, wrapping, news halftone, pulpboard, kraft wrapping, ground wood, sulphite, and sulphate pulp.	Quebec, Canada	2,624
Crown Zellerback Corporation.	Newsprint, wrapping, ground wood, and sulphite pulp.	Washington and Oregon; British Columbia, Canada.	2,140
	Tissues and kraft, and sulphate pulp.	Washington; and British Columbia, Canada.	
	Boards	California and Washington	
Abtibi Power & Paper Co., Ltd.	Newsprint, board, ground wood, and sulphite pulp.	Ontario, Canada	2,100
Price Bros. & Co., Ltd	Newsprint, mill wrappers, wood board, ground wood, and sulphite pulp.	Quebec, Canada	1,293
Container Corporation	Container, chip and box boards, and liners.	Illinois, Indiana, Ohio, and Pennsylvania.	1,190
Minnesota and Ontario Paper Co.	Newsprint, insulating board, ground wood, and sulphite pulp.	Minnesota; and Ontario, Canada.	1,150
	Kraft, liner, wrapper, building board, and sulphate pulp.	Minnesota	
Kimberly Clark Corporation.	Newsprint	Ontario, Canada	1,144
	Book	Wisconsin and New York	
	Absorbent wadding and ground wood pulp.	New York	
	Catalog, wrapping, board, etc	Wisconsin	
	Ground wood and sulphite pulp	Wisconsin; and Ontario, Canada.	
Great Northern Paper Co.	Newsprint, wrapper, waxing, bag, and specialties; sulphite and ground wood pulp.	Maine	1,025

Company	Principal product	Location of mill	Daily capacity (tons of finished product)
Robert Gair Co	Miscellaneous board and liners	Massachusetts, New York, and Illinois.	995
	Chip and test jute liners	Connecticut	
West Virginia Pulp & Paper Co.	Book, writing, and soda pulp	Virginia, Pennsylvania, and Maryland.	815
	Magazine and specialties	Pennsylvania	
	Book and specialties	New York	
	Sulphite pulp	Virginia and New York	
	Sulphate pulp	Virginia	
Consolidated Paper Co	Miscellaneous boards and liners	Illinois and Michigan	740
	Auto panel board	Michigan	
Fraser Cos., Ltd	Core paper, boards, and specialties; ground wood and sulphite pulp.	New Brunswick, Canada	650
	Bond, ledger, catalog, boards, and specialties.	Maine	
Consolidated Water Power & Paper.	Newsprint, book, bond, wrapping, wall paper, crepes, and tissues; canary and white second sheets; ground wood and sulphite pulp.	Wisconsin	637
Kieckhefer Container Co	Chip and container board	New Jersey and Michigan	625
River Raisin Paper Co	Board, shipping cases, packing materials, and silicate of soda.	Michigan	600
Hinde, Dauch Paper Co	Test jute liner	New York, New Jersey, and Indiana.	590
	Straw papers for corrugating	Indiana, Iowa, and Ohio	
	Miscellaneous boards	Ontario, Canada	
United Paperboard Co	Straw paper for corrugating	Illinois and Indiana	533
	Miscellaneous boards and specialties.	New York, Maine, New Jersey, and Ohio.	
Brown Paper Mill Co., Inc	Kraft, wrapping, bag, board, and sulphate pulp.	Louisiana	500
Champion Coated Paper Co.	Coated papers and boards, mimeo, post card, etc.	Ohio	500
Powell River Co., Ltd	Newsprint ground wood, and sulphite pulp.	British Columbia, Canada	500

NEWSPRINT PAPER MANUFACTURERS

96. There are now only 38 newsprint paper manufacturers in the United States. These own or control 50 domestic mills that were in operation in 1928. Three companies produced 50 percent of the newsprint manufactured in the United States in 1928.

97. The largest newsprint manufacturer in the United States, the Great Northern Paper Co., of Millinocket, Me., owns three mills in Maine having a newsprint paper capacity of 970 tons daily. They produced 311,637 tons of paper in 1928. The company produces its own mechanical and sulphite pulp and also holds stands of spruce and fir in New England.

98. The Crown Zellerback Corporation, of San Francisco, acting as a holding company, owns or controls the Crown Willamette Paper Co., with newsprint mills at Camas, Wash., and West Linn, Oreg., and the Washington Pulp & Paper Co., with a newsprint mill at Port Angeles, Wash. These three American mills have a capacity of about 800 tons daily; they produced 211,085 tons in 1928, or 15 percent of the total United States newsprint production for that year. This company controls timber stands in Washington and Oregon having approximately 6,500,000,000 feet of timber. It also has timber leases to 3,500,000,000 feet in Canada and large acreage in the Tongas National Forest in Alaska.

99. The International Paper Co., of New York, produced only 165,405 tons of newsprint within the United States in 1928, although

it is regarded as the largest producer of newsprint paper in the world. Only 5 of its United States mills produced newsprint in 1928, although 15 have newsprint paper equipment and have a total newsprint paper capacity of 1,160 tons daily. Of the 5 mills operated, 2 are located in New York State, 1 in Maine, and 2 in New Hampshire. In 1930 only four plants were operated. The company owns timber in Maine, New Hampshire, Vermont, and New York. The capacity of its Canadian and Newfoundland newsprint plants is 2,275 tons per day, and its timber holdings in Quebec, New Brunswick, Nova Scotia, and Ontario total over 3,000,000 acres.

100. Other United States companies having plant capacities in excess of 100 tons newsprint pulp per day are:

Company	Location	1930 daily newsprint capacity (short tons)
Consolidated Water Power & Paper Co	Wisconsin Rapids and Biron Rapids, Wis.	328
Minnesota & Ontario Paper Co	International Falls, Minn	262
Maine Seaboard Paper Co	Bucksport, Me	250
St. Croix Paper Co	Woodland, Me	190
St. Regis Paper Co	Norwood, Norfolk, and Raymondsville, N.Y.	160
Finch, Pruyn & Co	Glens Falls, N.Y	144
Pejepscot Paper Co	Pejepscot and Lisbon Falls, Me	137
Escanaba Paper Co	Groos, Mich	135
Cushnoc Paper Co	Augusta, Me	133
Inland Empire Paper Co	Millwood, Wash	106
Algonquin Paper Corporation	Ogdensburg, N.Y	102
Gould Paper Co	Lyons Falls, N.Y	102
Hawley Pulp & Paper Co	Oregon City, Oreg	100

101. Canadian newsprint plants having capacities in excess of 100 tons newsprint per day are:

Company	Location	1931 daily newsprint capacity (short tons)
Abitibi Power & Paper Co. (merged in 1931 with Anglo-Canadian Pulp & Paper Mills).	Ontario, Manitoba, Quebec	2,480
Canada Power & Paper Group	Quebec	1,945
Thunder Bay Paper Co. (owned by 2 companies listed above).	Ontario	245
International Paper Co. (American company)	Quebec, New Brunswick, and Newfoundland.	2,275
Price Bros. & Co	Quebec	1,260
Dominion Securities Corporation	do	950
Minnesota & Ontario Paper Co. (American company).	Ontario	825
Powell River Co., Ltd	British Columbia	650
Spruce Falls Power & Paper Co. (American company).	Ontario	475
Ontario Paper Co. (American company)	Thorold, Ontario	340
Mersey Paper Co	Nova Scotia	240
Crown Zellerbach Corporation	British Columbia	230
J. R. Booth, Ltd	Ontario	160

102. It is obvious that Canadian newsprint mills are much larger than those operating in the United States. All operated by Canadian companies in Ontario and Quebec are members of the Newsprint Institute of Canada, organized through the efforts of the prime ministers of these Provinces to bring about a more even distribution of available business.

BOOK-PAPER MANUFACTURERS

103. There were, in 1930, approximately 40 large companies operating mills whose principal output was book paper, or print paper for other than newsprint consumption. In addition, some newsprint mills also produced book paper.

104. The largest of these companies is the West Virginia Pulp & Paper Co., having a daily capacity of 815 tons of paper, which is principally book. It also produces soda, sulphite, and sulphate pulp. It has plants in New York, Pennsylvania, Maryland, and Virginia, the largest being in the latter State. It specializes in supercalendered magazine papers.

105. Crocker, Burbank & Co., of Fitchburg, Mass., have plant capacities for 330 tons of book paper, most of which is supercalendered, magazine, and cover paper. The Mead Corporation, with plants in Ohio and Tennessee, has a capacity of 435 tons book paper. This company produces a large part of its soda pulp and bleaches some of the sulphite pulp purchased. The Kimberly Clark Corporation, of Wisconsin, produces mechanical and sulphite pulp and paper specialties, as well as having daily capacity for 425 tons of book paper. Other important book paper and soda pulp manufacturing plants are: The Castanea Paper Co., of Pennsylvania; the S. D. Warren Co., of New York; the Bryant Paper Co., of Michigan; the Jessup & Moore Paper Co., of Delaware; the Champion International, of Massachusetts; the Oxford Paper Co., of Maine; and the Everett Pulp & Paper Co., of Everett, Wash. This Washington company is listed as having a daily manufacturing capacity for 60 tons soda pulp and 65 tons of book, label, and writing paper.

WRAPPING-PAPER MANUFACTURERS

106. While southern and western wrapping paper manufacturers usually produce their own sulphate and sulphite pulp for manufacturing this type of paper, a number of northeastern manufacturers located on the St. Lawrence and the Great Lakes manufacture kraft paper from pulp imported chiefly from Scandinavia. Twenty-one manufacturers produced over 95 percent of all kraft pulp made in the United States in 1929.

107. The Brown Paper Mill Co., at Monroe, La., has the largest single sulphate paper mill in the United States. It can produce annually 150,000 tons of sulphate wrapping, bag, and liner board. The company also owns more than 300,000 acres of shortleaf pine in the South.

108. Among the other larger producers of kraft paper are the International Paper Co. at its southern plants; the Gulf States Paper Co. with plants in Alabama and Louisiana; the Bogalusa Paper Co., of Louisiana; the Advance Bag & Paper Co., with mills in Maine and Louisiana; the Albemarle Chesapeake Co., with over 400 tons daily draft capacity plants in Virginia; Union Bag & Paper Co., of New York; Central Paper Co., of Michigan; Nashua River Paper Co., of Massachusetts; Thilmany Pulp & Paper Mills and Falls Manufactur-

ing Co., of Wisconsin. Plants producing wrapping paper and wrapping paper pulp on the Pacific coast are:

Plant	Location	Daily capacity
Crown Willamette Paper Co	Lebanon, Oreg	340 tons wrappings.
St. Helens Pulp & Paper Co	Camas and Port Townsend, Wash	200 tons kraft liner and kraft.
Longview Fiber Co	St. Helens, Oreg	80 tons wrapping and envelope.
Willapa Pulp & Paper Mills	Longview, Wash	130 tons liner and wrapping.
St. Regis Kraft Co	South Bend, Wash	100 tons sulphate pulp.
	Tacoma, Wash	162.5 tons sulphate pulp.

109. The Pacific States Pulp & Paper Co. was building a 100-ton sulphate pulp plant at Priest River, Idaho, and had plans under way for a sulphite fiber plant at Aberdeen, Wash. This will be the first pulp mill in Idaho.

BOARD MANUFACTURERS

110. Because "board" is made of so many different raw materials, its manufacture is scattered throughout all the large centers of population, and many firms have fairly large plant capacities. Among the largest manufacturers are the Robert Gair & Co., of New York, with a daily capacity of 1,000 tons; the Consolidated Paper Co., of Michigan, with a daily capacity of 740 tons; the Fibreboard Products Co., of California, with a daily capacity at its several plants of 680 tons; the United Paperboard Co., of New York, with a daily capacity of 675 tons; the River Raisin Paper Co., of Michigan, having a daily capacity of 600 tons; the Minnesota & Ontario Paper Co., with 450 tons daily insulating board capacity; and the Celotex Co., of Louisiana having plant capacity of 500 tons bagasse board daily.

111. Five mills in the Pacific Northwest are manufacturing board. The two principal producers are the Fibreboard Products, Inc., of Port Angeles and Sumner, Wash., with daily capacities of 75 tons and 50 tons, respectively, and the Fir-Tex Insulating Board Co., of St. Helens, Oreg., with 75 tons daily insulating board capacity.

OTHER PACIFIC COAST PULP AND PAPER MILLS

112. As has been stated, there are several mills on the Pacific coast that produce pulp only. These are: The Puget Sound Pulp & Timber Co., with three Washington plants having total daily capacities of 330 tons bleached or unbleached sulphite pulp; Grays Harbor Pulp & Paper Co. with 150 tons daily capacity, at Hoquiam, Wash.; the Olympic Forest Products Co., having 175 tons daily sulphite pulp capacity, at Port Angeles; the Rainier Pulp & Paper Co., at Shelton, Wash., who are producing a good grade of rayon pulp, with 285 tons sulphite capacity; Willapa Pulp & Paper Mills, producing 100 tons sulphate pulp daily, at South Bend; the St. Regis Kraft Co., having capacity for 162.5 tons sulphate fiber at its Tacoma plant; the Shaffer Box Co., of Tacoma, producing sulphite fiber; Sitka Spruce Pulp & Paper Co., at Empire, Oreg., manufacturing 55 tons unbleached sulphite fiber; the Crown Willamette Paper Co., producing mechanical pulp only at its Oregon City plant; and the Spaulding Pulp & Paper Co., having a 60-ton sulphite fiber capacity plant at Newberg, Oreg.

113. Other Washington and Oregon plants that have not been mentioned elsewhere because they produce a number of paper products are: The Oregon Pulp & Paper Co., at Salem, which manufactures specialties, has a capacity of 120 tons of sulphite fiber daily; and the Columbia River Paper Mills at Vancouver. The latter plant has a capacity for 140 tons of ground wood and sulphite pulp and produces some newsprint paper, fruit wrappers, and other products.

Pulp and Paper Manufacturing Processes

PULP PRODUCTION IN MODERN MILLS

114. The standard processes by which pulp is manufactured do not differ in essentials from mill to mill, but equipment details and chemical formulas obtaining in individual mills cover a wide range. The descriptions of production methods that follow are those prevailing in new mills.

115. In the last 10 years many modifications of existing processes, and some new processes, have been patented. These patented processes are too numerous to include; only those known to have received commercial application are described.

116. *Barking.*—Sawmills are sometimes located at pulp mills and sometimes at lumber camps. As the case may be, wood is floated downstream, to be cut into 2- to 4-foot lengths at the pulp mill, or is delivered at the pulp mill already cut to size. The wood may be stacked or floated in the mill pond until needed. Electric drag rakes are used now to gather hundreds of pieces of wood from the pond, stack them, or deliver them to a conveyor. The pieces of wood are conveyed to drum or disk barkers. The "drum barkers" are revolving drums which require, on an average, 45 kilowatts power to remove bark from 100 tons of wood in 24 hours. The bark is removed by the rubbing of logs against each other and against the sides of the drum. In "disk barkers" logs are held against knives fastened to a revolving disk; these require less power than drum barkers, but remove some wood with the bark. The barked wood passes over screens which clean and sort it for further mechanical or chemical treatment.

MECHANICAL PULP

117. *Usual process.*—Wood is fed automatically into hydraulic magazine grinders. It is forced against a rapidly revolving stone by hydraulic pressure until the wood is reduced to pulp. As it comes from beneath the stone as a "slush" it collects in pits and flows to coarse screens that remove knots and larger pieces. It is further diluted and passes over diaphragm screens after which its water content is partially removed in thickners.

118. *Power requirements.*—Both artificial and natural grindstones are used. These are driven by electric motors, the power varying with the sharpness of the stone and the pressure used. An average consumption of energy required to operate the grinders is 1,160 kilowatt-hours per ton of pulp. The total energy required to grind the pulp, screen, and thicken it is about 1,250 kilowatt-hours. Adding, therefore, the power requirements of the wood sawing and bark-

ing room, 1 ton of mechanical pulp requires approximately 1,280 kilowatt-hours of electricity.

119. A greater fiber recovery is obtained by the mechanical process than by any of the other chemical processes. Usually, about 88 percent of the rossed wood is converted into pulp.

120. *Semichemical process.*—Mechanical pulp has a short fiber that does not produce strong paper; it is, therefore, combined with chemical fibers in paper making. Patents have been taken out which would produce a mechanical-chemical pulp that could be used without other kinds of pulp. According to the Bache-Wing process, the wood is first treated with sulphur dioxide under pressure and cooked in a salt or bisulphite solution. After such treatment, the wood is ground as in the mechanical process. By the Enge process, logs are heated with steam in a boiler and maintained at 147 or more pounds steam pressure for a number of hours before being ground. The United States Forest Products Laboratory has developed a process whereby the chips are first cooked with a liquor consisting of sodium sulphite and sodium bicarbonate, sodium carbonate or caustic soda, at a temperature reaching 140° to 160° C. They are then ground as in the regular mechanical process. Several mills have adopted this method in utilizing chestnut for corrugated boards.

121. *Sulphite pulp.*—Barked wood is washed well and sent through log and cant chippers which reduce it to chips from five eighths to one and three fourths inches long by knives set in heavy iron disks. Chips are cleaned by passing over an inclined wire screen through which dust passes and against which an air blast blows carrying the knots to a separate conveyor. Chips are stored above digesters preparatory to chemical treatment which removes lignin from the cellulose.

122. *Sulphite liquor.*—The cooking liquor used in the sulphite process is a solution of bisulphite of lime. Liquid sulphur dioxide may be purchased, or sulphur dioxide is produced by burning sulphur or iron pyrites in a furnace regulating the air supply so that for each unit of sulphur a corresponding unit of oxygen is supplied. The gases formed in the combustion chambers pass through water-cooled lead pipes to be cooled.

123. Many pulp plants use tower absorption apparatus. Towers are filled with marble, limestone, or dolomite lumps low in magnesium. These are moistened by water sprayed from the top. The sulphur dioxide gas enters at the towerbase and as it rises through the stone is absorbed by the film of lime water, producing bisulphite of lime. Others use partition tanks, or a 3-tank system in which the gas is mixed with milk of lime, made from lime high in magnesia.

124. *Cooking.*—Chips and bisulphite of lime are dumped into digesters which are brick-lined steel cylinders having capacities varying from 1 ton of fiber to 23 tons fiber. Quick cooking is done by steam at a pressure of about 80 pounds and at a temperature of approximately 365° F. In this so-called "quick" process from 2.4 to 4.5 pounds steam is required per pound of fiber. The sulphites, during this cooking, unite with the decomposed lignin, evolving gas which is blown off at intervals and its sulphur content recovered. Slow cooking uses less chemical, less steam, but requires more time.

125. *Blowing and washing.*—After cooking is completed, steam pressure of about 50 pounds forces the digested contents into pits

having screened bottoms through which the liquor drains. The pulp is then washed and drained to remove all remaining soluble, ligneous, and resinous matter. It passes over screens which take out uncooked chips, dirt, and other undesirable particles.

126. Frequently the sulphite mill combs the fibers apart on separators, blends tanks of pulp, passes it through rifflers whose partitions further remove solid substances, after which it is again screened. Water is removed and the pulp dried for dry shipment.

127. *Byproducts.*—Waste liquors are now purified in American mills by separating out the fibers and neutralizing the free acid with lime. But even so, many tons of waste are poured into streams. It is claimed that the waste liquor and reclaimed gases contain substances that will yield methyl, alcohol, acetaldelhyde, acetone, and other products of use in other chemical industries. Many other products from this waste are suggested but only a few are being produced. Tanning extracts, sodium lignin sulphonate to replace tartaric acid in mordanting wool, and alcohol are some of the materials that have been manufactured.

128. *Power required.*—No process in sulphite pulp production demands any unusual amount of power. The saws, barkers, chippers, pumps, and screens, as well as the conveying and other handling apparatus require small amounts, which total to approximately 185 kilowatt-hours per ton of pulp.

129. *Soda pulp.*—The vigorous action of the chemicals employed in this process make it possible to use waste lumber from lumber mills and round woodworking factories as well as logs of a number of species. The logs must have both inner and outer bark removed. They are cut up into chips by being held diagonally against the chipper disk from which several knives project. Waste lumber is chiped in a hogging machine very similar to the chippers. All chips are conveyed to shaking screens which screen out the sawdust; chips that are too large fall off into hog cutters for recutting. Chips of uniform size are blown to chip storage bins located above the digesters. Mill shavings received are freed of sawdust in revolving screens and are blown directly to the chipped wood storage bins without any chipping.

130. *Caustic liquor.*—Caustic soda under steam pressure is used to release the resinous and nonfibrous portions of the wood from the wood fibers. Caustic soda may be purchased, in which case it is a simple undertaking to dilute it to the proper consistency for cooking liquor. Or it may be made at the pulp mill by the electrolysis of salt or by causticizing soda ash. The electrolysis of salt has been described in detail on pages 289–291 of the section entitled "Power in the Manufacture of Chemicals and Metals from Brine." Because waste liquors are used in causticizing soda ash, this process will be described as it is carried on in paper mills. Sodium carbonate or soda ash is recovered from the black liquors, or liquors used in previous cooking operations. The water from this liquor is evaporated in triple-effect Swanson evaporators. The resulting mass is heated in a large rotating furnace, fired by special coal which gives a very hot fire without smoke. The furnace is open at each end so that the hot flames and gases pass over the sticky mass and burn out the ligneous and carbonaceous materials. The residue is leached, dissolving out the soda ash, while the carbon particles settle at the

tank bottom. About 85 percent of the soda ash is recovered. The heat generated in the incinerators is used to produce steam for the evaporators.

131. This recovered liquor is placed in large tanks. To it are added fresh soda ash, quick lime, and water. The mixture is brought to a boil and agitated. As the calcium carbonate formed is precipitated, the caustic soda is held in solution and syphoned out.

132. *Cooking.*—The digesters are the usual stationary or rotating types varying as to capacity, although modified types are on the market. In the stationary digester, the chips drop down from chip bins placed above the digesters, after which the lid is bolted firmly. For every cord of chips from 500 to 1,100 gallons of caustic liquor is pumped into the digester. Live steam effects the cooking; the pressure reaches 110 pounds, is reduced, and then allowed to come up again repeatedly to insure more even cooking. A 15-cord digester averages from 24,200 pounds steam in summer to 39,700 pounds in winter.[1] More than half of the wood weight is lost in the chemical reactions taking place in caustic cooking. Diciduous woods cook in 4 hours, coniferous in 6 hours.

133. *Washing.*—When cooking is completed, a valve is opened into iron pipes. The steam pressure inside the digester forces the cooked pulp through these pipes into wash tanks. Here a weak solution of spent caustic from previous washings is pumped over the cooked wood and the black liquor drained off goes to evaporators for recovery. The fresh water is run over the pulp, the drained liquor being recovered for use as a first wash water for the next cooked pulp. Additional washing is done until all waste is removed. The diluted mass is screened to remove uncooked pieces, knots, or other impurities. Surplus water is removed in the thickeners.

SULPHATE PULP

134. *Sodium sulphate cooking liquor.*—In general, the wood preparation and cooking equipment used in the sulphate process is similar to that required by the soda process. The major differences lie in the cooking liquor which permits the use of resinous woods and which gives slightly higher yields than does the soda process. Sodium sulphate or salt cake is the chief chemical used. About 320 to 395 pounds are required per ton of pulp produced. To this is added from 530 to 660 pounds lime. The sodium sulphate is purchased as it has been produced as a byproduct of hydrochloric acid manufacture for many years. Recent changes in the processes of manufacturing this acid have curtailed the production of its byproduct salt cake, so that importations have been large. The salt cake is manufactured in one United States chemical factory by the reaction of sulphuric acid on salt. Numerous natural deposits of salt cake exist in the Western States although only a few have been developed to date.

135. The cooked pulp is washed thoroughly to recover the highest possible amount of chemicals. Recovered black liquor is evaporated and burnt in a rotary furnace as in the soda process. But it must also pass through a smelting furnace from which the sodium sulphide formed flows to a dissolving tank containing water or dilute washings.

[1] Sutermeister, Edwin. Chemistry of Pulp and Paper Making.

After reaching the desired density, this so-called "green liquor" goes to the causticizing system.

136. When dark-colored fiber is to be produced, a part of the cooking liquor is made up of black liquor. When stock is to be bleached, fresh liquor is used.

137. *The explosion process.*—This process was patented in 1926. It makes possible the utilization of sawmill waste. Wood is reduced to uniform size in chippers. It is steamed, full pressure reaching 1,000 pounds for a few seconds, through the use of compressed air. At this pressure, the discharge valve is opened and the forced-out chips explode into fibers as they pass the valve.

138. This fiber is used in insulating board. The incrusted lignin or other substances which have been softened but not removed by the process, serve as binding agents after the board has been dried in hydraulic presses with steam-heated pattens.

139. *Chlorination processes.*—Wood or straw is given a preliminary cooking in a weak caustic soda solution. The liquor is removed and the pulp put under a vacuum after which chlorine gas is admitted for several hours. The wood is water washed and given a second alkaline treatment. It is then washed again and bleached with hypochloride.

OLD PAPER PULP

140. *For boards.*—The treatment afforded shavings from newspaper plants and other waste paper depends somewhat on the uses to which it is to be put. If it is to be made into board for which deinking and bleaching is not necessary, the bales are broken and fed into a breaker beater. As it is broken into shreds a continuous stream of water keeps the stock at a consistency of 5 percent or less. The paper is passed under a roll and flows out through perforations in the backfall into a regulator box. All trash larger than one fourth inch remains in the beater tanks from which it is removed by a rag catcher that is lowered into the tank.

141. *Power consumed.*—The power consumption of the breaker is dependent upon the size of the roll and its spud as well as upon the consistency of the stock. Mr. Humble, industrial fellow of the American Scandinavian Foundation, reported after visiting a number of American paper mills, that the average power consumption of the breaker per ton of pulp produced was 21 kilowatt-hours.

142. *For book paper.*—More careful preparation is necessary in reducing waste paper for reuse in paper that is to be printed. The old paper is sorted over at the paper mill as it passes over an endless belt conveyor into the knives of a shredding machine. The loose dirt is blown out by motor-driven fans into discharge vats. The shredded paper is soaked and agitated in a steam-heated soda ash solution to loosen ink and sizing. The softened paper is then circulated continuously through defibering tanks by powerful pumps. The violence of the agitation tears apart the separate fibers. The pulp is pumped along to rifflers which remove heavier foreign particles. From these it goes to vibrating screens which further remove solid matter and also keep the fibers separated. Ink and chemicals are then removed by a series of washings in tanks having wire mesh revolving drums.

143. It is ready for bleaching which is accomplished with a small amount of liquid chlorine bleaching solution. One ton of old paper produces approximately three fourths ton of pulp.

144. *Rag pulp.*—Bales of rags, chiefly from Europe, are opened and the rags are thrown into a thrasher where they are torn to pieces by the teeth on a revolving cylinder and on the cylinder case. After dust has been removed, the rags are sorted to remove all foreign matter. They are then cut by hand or by machine into pieces 2 to 4 inches square. Clean cut rags are boiled in a caustic soda, or lime and soda ash solution to free them of grease, dirt, and coloring matter. They are then washed in large engines and bleached.

145. *Straw pulp.*—Straw, which includes the stems and leaves of cereals, is dusted by air blasts and cut into short lengths. It is then cooked with milk of lime in rotary boilers at 35 to 45 pounds steam pressure for 8 to 10 hours. Only a small part of incrusting matter and mineral matter is removed by this treatment. The cooked pulp is permitted to age for several days, after which it is washed and passed through heaters. This yellow-brown pulp is suitable for egg-case fillers, coarse papers, and some wall board.

146. *Corn-stalk pulp.*—Baled stalks are broken into pieces and fed into a hammer mill shredder which reduces the stalks to from ½ inch to 6 inches. Foreign matter is separated out on a magnetic separator and a centrifugal fan blows out dust. The cleansed fiber is digested under steam pressure of 100 pounds. After washing, the fibers are cut, rosin sized, and go to the stock chests.

147. *Pulp bleaching.*—Wherever a white paper is desired, it is essential to oxidize out impurities which remain in all wood pulp regardless of the process employed in isolating the fibrous cellulose. As chlorine and some of its compounds liberate oxygen while in the presence of moisture, these are the principal commercial bleaching chemicals used on pulp.

148. *Calcium hypochlorite.*—Liquid chlorine is shipped to the pulp mill in tank cars. As required, it is passed into an evaporator, where, by the application of heat, chlorine gas is formed. This enters the base of a tank filled with partition tile. A solution of lime and water trickles down through the hollow tile while the chlorine gas rises. A continuous circulation is carried on until lime is completely absorbed by the chlorine. The solution settles in mixing tanks, any excess lime being precipitated.

149. It is not necessary, however, to gasify the chlorine, for liquid chlorine can be added directly to milk of lime in deep tanks where adequate circulation is maintained.

150. *Chlorine gas.*—Chlorine gas may be applied directly to moist stock in tightly closed receptacles. It is excellent to produce a clean pulp from muddy matter and to remove metallic particles. However, it is claimed that better color is produced when the chlorine gas bleach is followed by a hypochlorite bleach, the total chlorine consumed being less than when calcium hypochlorite alone is used.

Sodium hypochlorite, made by electrolyzing a cold solution of salt, has made no headway among paper-pulp producers in the United States.

151. *Bleaching.*—Bleaching of pulp takes place in tile-lined tanks, engines, or drains. Tanks are divided into three compartments, open at one end. At the closed end a pump is placed that delivers the

stock as received from the two outer compartments back to the central compartment through which it moves by gravity back to the outer compartments. This continuous agitation in bleaching liquor is kept up for about 12 hours by the slow bleaching process. The rapid bleaching process adds an excess of strong bleach liquor and requires less time but careful control. Air blasts are sometimes blown on pulp to speed agitation.

152. *Washing.*—Bleached stock must be thoroughly washed to remove all chlorine. This is sometimes done by pumping it through worm-washers, a spray of water being constantly played upon it. The pulp is then ready for the paper-making process, when the paper mill and the pulp mill are together. When the pulp is to be shipped to paper mills it is passed through riffles, over a battery of flat screens into thickeners. It is then dried by passing over steam-heated cylinders.

153. *Alpha fiber.*—Alpha fiber is a substantially pure cellulose recently produced to take the place of rag stock in paper making or to be used in the preparation of cellulose esters and ethers. It is a sulphite pulp bleached with chlorine or chlorine compounds and with caustic soda. For example, by one patented process the pulp is bleached with chlorine hypochlorate at about 10-percent density, and with up to 4.5 percent caustic soda per unit of pulp. By another, sulphite is bleached with 10 to 25 percent bleaching powder per unit weight, washed, and then subjected to a chlorine bleach.

Paper from this type of pulp is soft but has good tearing and folding qualities.

PAPER MAKING IN MODERN MILLS

154. Again, there is a general similarity in methods of manufacturing all papers, but many variations in detail produce the many kinds of paper consumed.

NEWSPRINT PAPER

155. *Preparing the pulp.*—Paper for newsprint is made from mechanical pulp and sulphite pulp. From 75 to 80 percent groundwood pulp and 20 to 25 percent sulphite pulp are thoroughly mixed in beating engines. Small proportions of fillers, such as talc and china clay, are added during the mixing. Sometimes blue or red aniline dyes are also introduced to give a white color to the paper. In addition to mixing pulps and chemicals, beaters serve to separate the individual fibers from the pulp lumps and reduce them to a nearly uniform length.

156. From beaters, the pulp goes to stuff-chests, where it is kept in agitation. Jordon engines are sometimes used to complete the fiber separation and to make the stock uniform, in which case a second set of stuff-chests are necessary, as these regulate the flow of pulp. From them the stock is pumped through weight regulators into mixing boxes where water is added, and to screens which remove any trace of impurities.

157. *Paper machine.*—The fourdrinier machine is almost universally used for newspaper making. It is especially designed to meet the needs of different papers and may have special parts, but the major features of operation are the same on all machines.

158. Screened stock enters a box at the head of the machine which extends across the full width of the machine. This head box keeps an even flow of pulp going onto an endless moving belt which carries stock into the machine rolls. This belt is made of woven copper wires and its width determines the width of the paper produced. Water in the pulp drains through the wire, such drainage as well as fiber felting being assisted at definite points by suction boxes placed under the wire. A sidewise motion of the belt also aids the fiber felting. At the end of the belt the fibers pass between a pair of rolls called "couch rolls" which squeeze out more moisture. The sheet of paper produced runs onto a felt belt which carries it through press rolls. Sufficient water is removed by these rolls to permit the paper to have sufficient strength to travel unaided through a series of steam heated iron cylinders which dry out the sheet. Finally, the sheet is finished by passing through polished calender rolls. The paper is then wound on reels ready for shipment.

159. A new vacuum drier is being installed in some mills which dries the pulp in the absence of oxygen at a temperature of approximately 100° F. A vacuum pump driven by electric motor provides the vacuum on the couch roll, while a flat box pump, water driven, exhausts the flat boxes. All heat used to dry the paper is condensed and returned as hot water for other mill purposes. It is claimed this drier requires less steam than the fourdrinier drier.

160. *Power consumed.*—The paper machine requires the largest amount of power in the paper mill. The actual amount varies with the width of roll, speed of machine, kind of drive, and composition of the paper. A machine 234 inches wide at a driven speed of 1,000 feet per minute, requires 448 kilowatts, or each ton of newsprint produced consumes 86 kilowatt-hours. Closely related equipment, such as beaters, jordons, screens, and pumps require approximately 746 kilowatts or 144 kilowatt-hours power per ton, making a total paper mill consumption of 230 kilowatt-hours per ton. To this must be added at least three fourths of the power necessary to produce a ton of mechanical pulp or 960 kilowatt-hours, and one fourth the power required to manufacture a ton of sulphite pulp or 149 kilowatt-hours. Or the mechanical power required to produce 1 ton of newsprint paper from pulpwood totals approximately 1,340 kilowatt-hours.

In addition, from 8,000 pounds to 14,000 pounds of low-pressure steam is required per ton of paper produced.

161. *Book paper.*—The wide variety of papers included under this heading, that is, all print paper other than newsprint, calls for differences in manufacturing detail. In general, however, book paper passes through the same manufacturing processes as newsprint. The chief distinctions are that book pulp is made up of bleached chemical pulp and that finishing processes are extensive.

162. A usual combination of pulp entering into book paper is 40 percent soda pulp, 35 percent sulphite pulp, and 25 percent old paper and rag stock. The soda pulp slush is first run into the beater; followed by the sulphite pulp, and as the process is completed, old paper pulp is added. Several chemicals necessary to impart desired characteristics to the paper are fed into the pulp during the beating operation, or the paper web as it goes through the paper machine may be led through troughs filled with chemical solutions.

163. *Sizing.*—When paper is to be made nonabsorbent of ink and water, sizing is added to the pulp or web which gives the final paper

ink and water resisting qualities. Sizing materials vary. Rosin is most often used in this country although gelatine, glue, cornstarch, and casein have their respective market demands.

164. *Rosin.*—Rosin has been secured as the residue after distillation of pine for turpentine. An increasing scarcity of this rosin has brought about the extraction of rosin from stumpage and other pine waste. This wood rosin, it is claimed, is inferior to the gum rosin in paper making. Rosin sizing is usually made by cooking lump rosin and a soda-ash solution in a steam-jacketed tank. The mixture is boiled until much rosin is saponified. Steam pressure then forces the soda-rosin soap and warm water through a very fine spray, which causes the sizing to emulsify.

165. *Alum.*—When added to the paper stock in the beaters, a precipitant must also be put into the mixture, for the rosin requires such an agent to become deposited evenly over all the fibers. That used most frequently is aluminum sulphate or alum. This is manufactured from aluminous clays or bauxite by the addition of sulphuric acid. It is usually purchased by paper manufacturers.

166. *Casein.*—Casein sizing does not make paper water-repellant but it imparts strength and a smooth surface. Casein is made from skimmed milk and buttermilk as a byproduct of the dairy industry. It is prepared for the paper beater by dissolving it in an alkali, after which it may be added to the rosin size or added directly to the beater. When coated paper, such as is used in half tones, is desired, casein mixed with clay or other fillers, is spread onto the sheets by a coating machine.

167. *Gelatine, glue, or starch.*—Pure gelatine and glue, made from bladders of fish, from hides, and from bones are used in surface sizing. These dissolve in hot water and jell on cooking. The papers so sized must be dried slowly. Starch is employed both in surface and in beating engine sizing. Cornstarch is the type used in this country while in Europe potato starch is employed. It may be added as a raw solution or after boiling to a paste.

168. *Fillers.*—Fillers are employed to fill in the interstices between fibers in the finished paper thereby making a high finish, such as is required for process cuts and half-tones, possible. Common fillers are china clay, talc, precipitated chalk, blanc fixe, heavy spar, asbestine, and different forms of calcium sulphate.

169. China clay is imported in large amounts from England, although good deposits are found in the United States. It is reduced to a powder, mixed with water, and strained for use in the beating engine to which it is usually added before the sizing.

170. Gypsum, a natural calcium sulphate, makes a soft paper. Different hydrated calcium sulphates, made by precipitating a solution of calcium chloride with sodium sulphate, are on the market under several trade names. Calcium carbonate, or precipitated chalk, is usually employed by mixing a solution of calcium chloride with the paper stock and then precipitating it with a soda-ash solution. Talc or hydrated magnesium silicate imparts a rag-like appearance to paper. Asbestine is a fibrous talc used extensively in New York.

171. *Coloring.*—Coloring agents are also added to book-paper stock during the beating process, for almost all papers require some coloring to produce white papers as well as colored papers. Aniline dyes are chiefly employed although natural mineral colors, such as ochre, and artificial color, such as chrome yellow, are used. Or,

pigments may be used in coating the paper, or by applying it to the surface of the web as it passes through calenders.

172. *Finishing.*—After leaving the winding rolls at the end of the paper machine, more glaze may be imparted to the paper by passing it through a super calender. This is made up of a number of heavy rolls one on top of the other. The bottom roll is driven by motor while all others operate by friction from contact with each other. Paper may be passed between these rolls a number of times to give the requisite polish to both sides. It is then slit to size and rewound on iron cores. Or, if sheet paper is desired, automatic cutters cut it into sheets and pile it up. This is inspected, counted, and wrapped in bundles.

173. For illustration printing, still smoother paper is required. Paper is coated on one side by brushes with a solution of clay mixed with casein as it passes through a coating machine. It passes over the machine roller and is caught up by a bar and carried to the ceiling. As the traveling chains moving the bar operate at a slower speed than the coating machine roll, the paper sags between the supporting bars. This permits the air to dry the coating. The paper must be run through the coating machine again if both sides of the paper are to be coated, in this type of machine. Another machine coats both sides at the same time and partially dries it by a blast of air before hanging.

174. *Special papers.*—When very delicate papers, such as tissues and cigarette, are to be produced, a paper machine is used which permits the stock to be supported by a long felt through the entire machine after leaving the wire screening. Such machines have but one set of press rolls and are otherwise adapted to the fine web they handle.

175. Some papers, such as bag paper, are produced on Yankee machines. These dry the paper on a large drying cylinder against which a set of press rolls operate. Paper becomes glossy on one side only.

176. *Board manufacture.*—The materials entering into board manufacture are numerous. While some box or wall boards are made entirely of straw pulp, others of corn stalks, others of bagasse, and still others of paper-pulp screenings, the larger amount of box board is built up out of waste paper mixed with sulphite, sulphate, or mechanical wood pulp.

177. The cylinder paper machine which is used to form board has wire-covered rolls that revolve in a vat of paper stock. The stock flows through the wires, fibers forming a film on it as the water drains off. This film is picked up by a felt which passes over a couch roll and is carried through the squeeze rolls to presses and driers as in the fourdrinier machine. When heavy boards are made, the felt may pass over a number of cylinders revolving in different vats, each time adding a layer of paper to its load. Other mills form the sheet on vacuum cylinders and run it through continuous plate presses. The finishing mill cuts the board into sizes for specific uses.

POWER EQUIPMENT OF PULP AND PAPER MILLS

178. An abundant water supply is essential to all kinds of paper and pulp manufacture. Early paper mills located on streams and secured their motive power from water wheels. A few mills continue

to operate water wheels today. But with the development of the steam engine and the steam turbine, and the adoption by the paper industry of the Fourdrinier paper machine, and of chemical pulp, both requiring steam pressure heat, steam prime movers were installed in many plants for driving machinery as well as for supplying thermal requirements.

179. *Boilers.*—Usually a separate set of boilers is employed, one to care for the constant steam pressure and uniform speed of the paper machine, and the other to supply the intermittent load required in cooking chemical pulp. When wood is barked at pulp mills, the refuse is available for boiler fuel. It is supplemented by anthracite or bituminous coal, oil, or gas, depending upon mill location.

180. *Steam engines and steam turbines.*—Steam generated from these boilers propels steam engines or turbo generators, or both. The latest figures on prime movers in pulp and paper mills indicate that present steam engine and steam turbine capacities are about the same, that is, 546,190 horsepower and 522,169 horsepower, respectively. Until recently, these drove the several machines and conveyors by slow-speed Corliss engines, belted direct to the line-shafts, by high-speed turbine units, driving through belts, or by high-speed turbines with speed-reduction gears.

181. Gradually, however, the electric motor drive is appearing even in steam engine and steam turbine operated mills. The advantages of independent control of each section of the paper machine, made possible by electrical sectional drives, is leading to the increased adoption of motor drives throughout the plant. The slowness with which electricity has gained footing in pulp and paper mills is due to the economies believed to result from use of steam prime movers, which furnish the low-pressure steam necessary for thermal requirements, for power purposes. With the use of higher steam pressures, an increasing number of kilowatts have been made available for mechanical power.

182. *Electrification.*—The larger number of plants have both electrical and steam equipment today, regardless of type of pulp or paper manufactured. Only where hydraulic turbines drive the main electric generator, are pulp and paper mills entirely electrified. The Electrical World of August 1929, estimated that 62 percent of the power capacity in pulp and paper mills was electrical, that there is still over 1,000,000 nonelectric horsepower equipment installed. Table XII gives the prime movers, motors, and generators in pulp and paper mills in 1927.

TABLE XII.—*Prime movers, motors, and generators in paper and pulp industry* [1]

Type	Number	Rated capacity (horsepower)
Prime movers, total	22,663	2,642,806
Steam engines	2,796	546,190
Steam turbines	566	522,169
Internal-combustion engines	48	6,047
Water wheels and turbines	1,975	899,157
Electric motors driven by purchased current	17,278	669,243
Electric motors driven by own plant	33,438	971,961
Electric generators (kilowatts)	1,293	692,451

[1] United States Bureau of the Census, "Census for 1927."

183. *A steam-electric plant.*—The following power equipment is found in a mill employing both steam and electric motor power and producing 150 tons book paper a day. Six boilers have a combined horsepower production of 5,000 horsepower. These require 180 tons of coal and 400,000 gallons of water per 24 hours. The generated steam propels steam engines and turbogenerators, serves for various pulp-cooking and paper-drying processes, and heats the plant in winter. Two turbogenerators are employed, one a straight condenser type and the larger an extractor type from which a portion of the steam entering the turbine is extracted for paper drying. These generators furnish 3,150 kilowatts of electrical energy, a part of which is converted into direct current by six motor-generator sets. Two excitor sets, one steam driven and one motor driven, are also provided to excite the generators on the steam turbines and the synchronous motors on the Jordon engines.

184. While variable speed motors are used on several paper machines and in the finishing room, small steam engines and pumps are operated in the pulp room, the beater room, for two paper machines, for plant heating fans, and for the Sunday lighting current, as well as for one excitor set.

185. *An electric pulp and paper mill.*—Several new mills are electrified throughout. Some purchase their current and others operate hydroelectric plants. A new pulp and paper mill producing 225 tons of newsprint a day operates two turbine-generator units in parallel with a hydroelectric system. "The main nonconducting turbine, using process steam from a throttle pressure of 400 pounds to 125 pounds back-pressure exhaust, is connected to a 7,500 kilovolt-ampere 6,600 volt generator." A standby condensing turbine generator is also installed. Motors are connected directly to grinders. Each paper machine (226 inches wide operating at 1,200 feet per minute) has a 1,000 boiler horsepower steam turbine operating at 125 pounds throttle pressure against a back pressure of 10 pound gage, connected to a direct-current generator and an excitor. All the various sections of the paper machine are started by a motor-generator set consisting of a 300 horsepower, 900 revolutions per minute, synchronous motor connected to a direct-current generator. The couch, the presses, the calender, and the reel have their own individual starting panels of full continuation type, while the drier section is driven in groups of six driers through drive-in shafts connected to eight 45-horsepower motors.

WATER AND CHEMICALS CONSUMED IN PAPERMAKING

186. *Water requirements.*—The quantity and quality of the water supply are a matter of vital importance to pulp and paper manufacture. While economic factors, such as the quantity available, reuse of water, cost of pumping and necessity of filtration, determine whether water is used lavishly or sparingly, plant engineers make definite allowances for water requirements when figuring on different types of mills. According to Power Plant Engineering of January 1930, allowances for each type of pulp should be as follows:

Fifty thousand gallons water per ton of mechanical pulp; 75,000 gallons water per ton sulphite pulp unbleached; 100,000 gallons water per ton bleached sulphite pulp; 100,000 gallons water per ton bleached soda pulp; 75,000 gallons water per ton sulphate pulp; 30,000 to 40,000 gallons water per ton paper all grades.

At these rates of consumption, the paper mills in the United States take over 600,000,000,000 gallons annually.

187. *Chemicals consumed in wood-pulp manufacture.*—Mechanical pulp requires only water and power as it is seldom bleached. Sulphite pulp is reduced by bisulphite of lime. The amount of sulphur required for the production of this lignin dissolvent is from 250 to 300 pounds per ton pulp, while 300 pounds lime is necessary, or, the total annual consumption of sulphur reaches approximately 250,000 tons and of lime 260,000 tons for sulphite pulp. While sulphite pulp applied to newsprint or wrapping paper is not bleached that used for book, tissues, and many miscellaneous paper products undergoes a chlorine bleach. The amount of bleach used depends on the whiteness of the paper desired, the length and temperature of cooking, and other plant factors. Roughly, it is estimated that 84,000 tons of liquid chlorine are consumed in sulphite-pulp bleaching. To this must be added the lime required to manufacture bleaching powder.

188. The soda process depends on caustic soda for its wood-fiber reduction. Caustic soda is purchased or it is produced electrolytically or by causticizing soda ash at the pulp mill. That purchased as caustic soda and that produced electrolytically totaled approximately 75,000 tons caustic soda in 1929. The soda ash consumed is not estimated, as recoveries of soda as high as 88 percent were effected in some soda-pulp plants. Lime consumption approximates 100,000 tons. Soda pulp is usually bleached, the liquid chlorine consumed totaling approximately 50,000 tons. How much bleaching powder is also purchased is not recorded.

189. Sulphate-pulp producers report a consumption of 205,670 tons sodium sulphate in 1928. Lime consumption by the same companies was approximately 20,000 tons.

CHEMICALS CONSUMED IN PAPER MANUFACTURE

190. According to the 1929 Census, preliminary reports, the paper industry purchased 38,390 tons of rosin to be made into sizing by the addition of soda ash and 98,423 tons of rosin sizing. It applied 468,191 tons of clay and 18,451 tons of casein as fillers and in paper coating. Minor amounts of other fillers were used. Aluminum sulphate consumption is not recorded, but is estimated to exceed 100,000 tons.

191. To sum up: The principal chemicals applied to pulp and paper manufacture were consumed in 1928–29 approximately in the following amounts:

	Tons
Liquid chlorine[1]	136, 500
Caustic soda[1]	75, 000
Soda ash[1]	110, 000
Sulphate	250, 000
Lime	380, 000
Sodium sulphate, see page 356	205, 670
Aluminum sulphate, see page 349	100, 000
Clays	468, 191
Casein, see page 349	18, 451
Rosin	38, 390
Rosin sizing	98, 423

[1] For manufacturing details see Power in the Manufacture of Chemicals and Metals from Brine.

COSTS OF PRODUCTION

192. Actual production costs of pulp and paper manufacture by different companies are frequently not comparable because of differences in bookkeeping methods. Paper companies owning their own forests may enter the cost of pulpwood used in paper manufacture at actual production costs, at production costs plus interest and all capital costs, or at the price of pulpwood sold in the open market. Paper mills operating their own pulp mills may charge pulp against paper costs by any of these methods.

As far as possible, duplication of capital costs and double interest have been avoided in the estimates that follow.

COST OF PRODUCING UNBLEACHED SULPHITE PULP

193. Sulphite pulp is consumed in larger quantities than other pulps. It enters into the manufacture of newsprint, book paper, board, wrapping, and many different kinds of paper. While some paper mills produce their own sulphite pulp, sulphite enters into the trade as pulp more extensively than other forms of pulp. Its production costs will be considered apart, therefore, from the cost of producing paper. While sulphite pulp varies in quality from wrapping to finished bleached pulp, costs given are for "strong unbleached," a medium grade.

194. *Wood cost.*—The major item of cost in producing sulphite pulp is the cost of the wood. Two tons are required per ton of pulp produced. The major differences in such costs are due to varying distances from forest to pulp mill, and to different kinds of wood used. It is roughly estimated that transportation makes up about one fourth the total cost of pulpwood at the mill. Spruce shipped from Canada to New York and Pennsylvania may carry a freight of $8.50 while that from Canada to Lake States may bear a $3.50 transportation cost. In the West, average transportation costs on pulpwood are figured at $2.[2] Rough spruce market prices average $13.90 in Maine, $14.54 in Michigan, and $15.40 in Wisconsin. The peeled wood spruce at Watertown, N.Y., was $18.50. The cost of the pulpwood used in sulphite pulp is reduced, however, through the use of hemlock, priced at $10 in New England and at lower prices in Wisconsin, and by the consumption of lumber mill wastes on the Pacific coast.

195. By correlating the lumber industry with the sulphite pulp industry, material savings in wood costs have been effected in Washington and Oregon and in Scandinavian countries. Pacific coast sulphite mills report the cost of spruce and hemlock waste necessary to produce 1 ton of sulphite pulp at $14; whereas in the Middle West, where hemlock is chiefly used, the cost of wood is $18, and in Eastern States, $24 when produced by the manufacturer of the pulp. When mills purchase imported pulpwood, costs would be several dollars higher than those quoted.

196. *Total costs.*—This differential in raw material cost, together with a lessened fuel and power cost, makes it possible to produce sulphite pulp for approximately $12 less in the Pacific Northwest than in the East, and for about $5 less than in the Lake States.

[2] Report of woodlands section of the American Paper and Pulp Association.

197. *Possible substitution of waste sulphur dioxide in West.*—It may be possible to further reduce the cost of sulphite pulp manufactured in Washington by the use of the new wasted sulphur dioxide available at zinc refineries in northern Idaho. The sulphite pulp mills purchase sulphur from Texas and Louisiana at $18 a ton and pay a freight rate of approximately $7 a ton additional; they install equipment to convert this sulphur into sulphur dioxide for absorption in limestone. The zinc refineries in Idaho waste sulphur fumes for lack of a market. As these fumes are deleterious to all vegetation, it is only a question of time before zinc refineries in Idaho will be compelled by law to collect these fumes as is now the case in Butte, Mont. Such fumes afford the cheapest source of sulphur dioxide. The pulp mill would also have less capital tied up in equipment and require less labor and fuel.

TABLE XIII.—*Approximate cost of producing 1 ton unbleached sulphite pulp in different manufacturing regions*

[Based on 100 tons daily mill capacity]

Item	Pacific coast	Eastern United States	Middle West	Canada
Capital cost: Amortization, taxes, insurance, and interest charged at 12 percent on $60 [1]	$7.20	$7.20	$7.20	$7.20
Production costs: [2]				
Spruce and hemlock	[3] 14.00	21.00	18.00	10.25
Sulphur (270 pounds)	2.40	2.40	2.40	2.65
Limestone (300 pounds)	.60	.60	.60	.60
Electric power	1.10	2.00	2.00	.75
Steam	2.50	4.00	4.00	3.00
Labor and salaries	17.40	17.00	16.00	17.00
Repairs and miscellaneous supplies	2.00	2.00	2.00	2.00
	40.00	52.00	45.00	36.25
Total cost	47.20	59.20	52.20	43.45

[1] Includes sulphur dioxide manufacturing plant.
[2] Manufacturers of Unbleached Chemical Sulphite Pulp, in hearings before the Committee on Ways and Means, House of Representatives. 1929.
[3] Largely sawmill waste.

198. The major competitors of Pacific mills for the eastern sulphite pulp markets are Canada and Scandinavia, for nearly 40 percent of the sulphite pulp consumed in the United States is imported. While 38 percent comes from Canada; Sweden, Finland, and Norway ship in 52 percent. Pacific coast producers believe production costs in Canada to be $36. Assuming capital costs are the same as in this country, this makes a total cost per ton of pulp $3.75 less than the present low cost on the Pacific coast. Scandinavian countries sell this grade sulphite pulp at an average price of $48 per ton on the Atlantic seaboard. To this must be added the import agent's commission of 5 percent or $2.40 making a total cost, including a $4.50 transportation cost, of $50.40.

199. *Cost of producing mechanical pulp.*—Mechanical pulp is usually manufactured by paper mill companies. Capital costs are, therefore, less than appear in the following accounting of independent pulp mills. At the Atlantic seaboard, domestic pulp brings from $26 to $30 and imported pulp $28 to $30 for moist pulp and $30 to $32 for dry pulp. These prices would not permit shipment of Pacific coast mechanical pulp into the eastern market unless production costs

could be materially reduced below those shown in the following estimate.

TABLE XIV.—*Estimated cost of producing 1 ton mechanical pulp on Pacific coast and in eastern Canada*

Item	Pacific coast	Canada
Capital costs: Amortization, overhead, interest, and taxes charged at 15 percent on $23	$3.45	$3.45
Production costs:		
Spruce and fir, 1.1 cord	11.20	10.40
Electricity, 1,300 kilowatts, at $0.003	6.90	6.90
Labor	3.00	2.50
Repairs and miscellaneous supplies	2.50	2.50
	23.60	22.30
Total cost	27.05	25.75

200. *Newsprint production costs.*—According to earlier studies of newsprint manufacturing costs, pulp production represents two thirds the total cost of manufacturing newsprint paper. On the basis of 80 percent mechanical pulp and 20 percent sulphite per ton of newsprint, production costs of newsprint would be approximately $35.85 on the Pacific coast and $33.45 in eastern Canada. If an allowance of 12 percent is made for all overhead, depreciation, insurance, taxes, and interest on a ton-year investment of $160, costs are brought to $55 and $52.65, respectively.

201. *Cost of producing sulphate pulp.*—The producers of sulphate pulp in this country usually manufacture it into its finished paper form. Firms desirous of selling pulp as such find themselves in very active competition with imports from Sweden, Norway, and Finland. Details of costs of Scandinavian production are not available. It is claimed these total $40 to which must be added an importer's commission of 5 percent, making a total of $42 without any freight cost. The production costs on the Pacific coast are approximately $40 while those in southern mills are nearer $35 per ton of sulphate pulp.

Market prices on kraft range from $42 to $55.

202. While as yet but little mill waste is used for sulphate pulp on the Pacific coast, the tendency is toward a closer relationship between this industry and the Douglas fir lumber mills. Such an integration of the two industries, together with the possible recovery of rosin and turpentine, would bring the Pacific coast production figures almost to the level of those prevailing in the South.

203. Another factor which may lower the production cost of sulphate pulp on the Pacific coast is the change which is taking place in the production of sodium sulphate or salt cake. This has been a byproduct of hydrochloric acid manufacture for many years. But changes in manufacturing processes are decreasing this byproduct production at the same time that demands for sodium sulphate are increasing. Heavy imports of the chemical have resulted from Germany where the salts are produced as byproduct from the Stassfurt potash minerals. Magnesium sulphate and sodium chloride (common salt) are subjected to a freezing process which gives a hydrous sodium sulphate or Glauber's salt. This is evaporated artificially to produce anhydrous sodium sulphate or salt cake. The United

States has natural deposits of sulphate of soda in eastern Washington, at Searles and Owens Lakes, Calif., in Nevada, Wyoming, and Utah. The difficulty of developing these deposits lies, at present, in the foreign competition offered, for German sulphate sells in New Orleans for $12 and in the Pacific Northwest for $13.50 per ton in bulk, and for $15.50 per ton sacked. However, the changes which are occurring in this country in methods of manufacturing hydrochloric acid and nitric acid are also under way in Germany and her production of the byproduct may be curtailed. It is, of course, always feasible to manufacture sodium sulphate directly from ocean brine, if the development of the natural deposits is delayed.

TABLE XV.—*Estimated cost of production of sulphate pulp in Pacific coast and southern mills*

Item	Pacific coast	Southern mills
Capital costs: Amortization, overhead, interest, taxes charged on $80 per ton-year, at 15 percent	$12.00	$12.00
Production costs:		
Pine, hemlock, and mill waste	14.00	10.50
Sodium sulphate (350 pounds)	2.55	2.55
Lime (500 pounds)	2.50	2.25
Labor, 1.4 man-days	6.30	5.60
Repairs and miscellaneous supplies	2.00	2.00
	27.35	22.90
Total cost	39.35	34.90

204. *Cost of manufacturing kraft paper.*—The cost of sulphate pulp manufacture represents 70 percent of the cost of producing kraft wrapping paper. The figures above would bring the cost of manufacturing sulphate paper to approximately $56 on the Pacific coast and to $50 in the South. The selling prices of "southern" kraft and domestic no. 2 ranges from $60 to $75.

205. *Cost of bleached soda pulp production.*—Paper mills manufacturing book paper frequently manufacture their own soda pulp although some is purchased from pulp manufacturers. Because many plants have their own equipment for manufacturing either electrolytic caustic soda and chlorine or for manufacturing caustic soda from soda ash as well as for the recovery of soda ash, the capital invested in such mills is higher than in pulp mills that purchase their chemicals ready for use.

TABLE XVI.—*Estimated cost of producing bleached soda pulp when causticization chemicals are manufactured at plant*

Item	Central States
Capital cost: Amortization, overhead, interest, taxes, etc., at 15 percent on $80	$12.00
Production cost:	
Wood, 2 cords	18.00
Soda ash (1,200 pounds, 75 percent recovered), at $18.90	2.85
Lime, at $7.30 ton	2.50
Chlorine bleach	4.20
Fuel and power	5.50
Labor	7.20
Repairs and miscellaneous supplies	3.35
	43.60
Total cost	55.60

Bleached soda pulp sells for from $58 to $64 a ton.

206. *Book paper costs.*—The numbers of print papers produced by each mill, the different kinds and quantities of raw materials applied, make it difficult to estimate the cost of producing any particular type of book paper. Market prices on such papers have a 100 percent range indicating the variation in value of the papers included in this heading. The large number of chemicals necessary for the finish of this paper, the several kinds of pulp employed, make material cost the largest item in its manufacture. Roughly, pulp and waste paper would represent 58 percent of production costs; chemicals, other than those used in producing pulp, 8 percent, fuel and power 5 percent, labor 14 percent, and such items as wires, felt, belting, 2 percent.

207. The following statement of the materials required per ton of book paper produced in a steam-electric plant manufacturing some of its soda pulp, purchasing some unbleached and some bleached sulphite pulp, bleaching some sulphite pulp and buying waste paper is indicative of book paper-mill requirements.

208. Quantities of materials required in the manufacture of 1 ton book paper were:

Fibrous materials:		Water.....gallons..	73, 685
Pulp wood.....cord..	0. 25	Lime.....pounds	164
Waste lumber- wood shavings and veneer -cord..	. 1	Soda ash.....do.....	40
Old papers and magazines.....pounds..	547	Liquid chlorine.....do.....	13. 7
White shavings.....do.....	50	Alum.....do.....	50. 5
Bleached soda pulp pounds..	80	Rosin.....do.....	8. 8
Bleached sulphite pulp pounds..	147	Clay.....do.....	336. 8
Unbleached sulphite pulp pounds..	168	Starch.....do.....	1. 1
		Sodium silicate.....do.....	. 04
		Dyes and color.....do.....	. 04

Pulp and Paper Markets and Freight Rates

Wood pulp markets and freights

209. Paper mills which must purchase wood pulp from distant localities in order to operate are located principally in New York State, in Michigan, in Pennsylvania, and in Ohio. Massachusetts, Connecticut, New Jersey, Maryland, Indiana, and Illinois purchase some pulp stocks, together with waste paper and waste textiles.

210. The wood pulp coming from Canada has gone into New York and Pennsylvania by rail. Paper mills locating on Lake Michigan have secured pulp by Lake shipment from western Ontario. Pulp from Scandinavian countries may go down the present St. Lawrence canal in small vessels. However, more is shipped to Baltimore, Norfolk, New York, and Boston.

211. *Sulphite pulp.*—Swedish costs of shipping sulphite or sulphate to the Atlantic seaports are $4.50 per ton. This, added to the Scandinavian production costs, plus the importer's commission (see p. 356) brings the cost of Swedish sulphite pulp delivered at the Atlantic seaboard, to $50.40.[3]

212. Pacific coast shipments to New York through the Panama Canal total $15 per ton when wharfage, overweights, and other items are included. Or, the cost of sulphite pulp delivered in New York

[3] Brief of the Pulp and Paper Trading Co. before Committee on Ways and Means, House of Representatives, 70th Cong., vol. XV., sec. 15, p. 8789.

from Seattle would be $62. Canada's all-rail rate to New York points averages $6 making the Canadian sulphite pulp cost $49.50 in the North and Middle Atlantic States. As the larger amount of sulphite pulp is now imported from Sweden, the possibilities of an Eastern market for Washington and Oregon sulphite depend upon a lower production cost than has as yet been achieved on the coast.

213. For the present, the Middle Western paper mills seem closed to Washington and Oregon sulphite pulp producers. The all-rail haul to Middle Western points is from $12 to $13 a ton, while Michigan mills can be supplied from Canada with pulp bearing a freight rate of $4.

214. *Sulphate pulp.*—Although sulphate pulp mills are usually owned by paper companies, there are a number of paper companies manufacturing sulphate paper or board that produce no pulp. These are located in the Northern and Middle Atlantic States and in the Middle West, in which sections Maine and Wisconsin are the only sulphate-pulp producing States. The Southern States of Louisiana, Virginia, Arkansas, Mississippi, Alabama, North Carolina, and Florida are the growing sulphate pulp producing States as are Washington State and Oregon. The Northern and Middle Atlantic paper mills have not counted on American sulphate pulp mills for their pulp supply but have secured approximately 60 percent from Scandinavia and 35 percent from Canada.

215. Scandinavian sulphate pulp has been put down ex-dock Portland, Maine; Boston, New York, or Baltimore from $48 to $49. The freight rate from usual Scandinavian points varies from $4.50 to $5 and some pulp must have an inland freight rate in the country of export. Seattle sulphate pulp could be sold in New York at $47 or $48. It would seem as though Pacific coast mills could compete in Middle and Northern markets with European sulphate ports.

216. *Wood pulp exported.*—In spite of our heavy imports of wood pulp we export 30,000 tons. Most of this, in the form of sulphite pulp, goes back to Canada. But Japan took 6,000 tons in 1928.

217. *Paper markets and freights.*—The size of paper markets in the United States is determined principally by the population in given areas. The final product, whether it be newspapers, magazines, paper boxes, wrapping paper, or building boards, is dependent for its consumption largely upon the size and character of specific retail purchasing markets. The New York City metropolitan area consumes far more paper than any other section. The printing and publishing business of all types of matter is largest in New York State; Illinois ranks second, Pennsylvania third, and Ohio fourth. Massachusetts and California follow. Such converted paper products as bags and boxes not made in paper mills, envelopes, patterns and card designs, and wall paper, find their heaviest production in New York. Ohio ranks second, New Jersey, Pennsylvania, and Wisconsin third, and Indiana, Missouri, and California fourth.

218. *Newsprint paper.*—New York City newspapers took approximately 700,000 tons of the 3,800,000 tons of newsprint available in the United States in 1929. The Chicago area consumes approximately 400,000 tons annually. In all of California, Oregon, and Washington, only 320,000 tons newsprint is consumed annually.

219. According to reports made to the Federal Trade Commission,[4] newspapers with daily circulations of over 100,000 required from 600

[4] Senate Document No. 214, Newsprint Paper Industry, July 1930, p. 71.

to 780 pounds of newsprint per 1,000 circulation. Newspapers with from 50,000 to 100,000 daily circulation used from 550 to 590 pounds per 1,000 circulation. Daily papers of less than this circulation varied in amount of paper consumed from 274 to 342 pounds per 1,000 circulation. Weekly papers reporting took 146 pounds of newsprint per 1,000 circulation.

220. Newspaper publishers make from 1- to 10-year contracts with newsprint paper mills for their supply of paper. The Hearst papers require the largest amount of newsprint paper or almost 15 percent of the total amount available in 1929 in the United States. This paper is purchased through the American Paper Co. of San Francisco and the Newspaper and Magazine Paper Corporation of New Jersey. The latter purchasing organization buys for all papers east of the Rocky Mountains in amounts totaling about 446,000 tons of paper. The San Francisco purchasing agent contracted for 115,000 tons during 1929 with the Crown Willamette Paper Co.

221. The Scripps-Howard newspapers, comprised of 27 dailies, require 261,924 tons of paper purchased from a number of manufacturers. The next largest consumer of newsprint is the Patterson-McCormick group which owns the Chicago Tribune and the New York Daily News. These two papers consume 224,502 tons of newsprint paper annually. As has been stated elsewhere, these publishers own a paper mill at Thorold, Canada. The Ochs papers (New York Times and Chattanooga Times) complete the group of newspaper publishers that take more than 100,000 tons of newsprint annually. That is to say, four publishers in the United States purchase about 30 percent of all newsprint paper available.

222. The large daily papers issued in cities purchase the bulk of the newsprint supply, or over three fourths of the total. Hundreds of small daily papers and thousands of weekly papers buy in less than ton lots through jobbers or through cooperative associations. These small publishers frequently buy paper in sheets instead of rolls and pay a differential of $5 per ton. Or they may buy ready-print sheets from companies sending out these printed sheets. Even such ready-print sheet producers as the Montana Newspaper Association of Great Falls, Mont., purchase only a little over 100 tons of paper a year. Only 13 percent of newsprint paper is sold on the open market.

223. *Distribution of Pacific coast newsprint.*—The three principal newsprint companies in Washington and Oregon have a combined capacity of about 1,000 tons newsprint daily. The Powell River Co., Ltd., has a capacity of 650 tons and the Pacific Mills (Crown Zellerback owned) of 230 tons, in British Columbia, or 1,880 tons of newsprint is available daily on that coast. California, Oregon, and Washington consume approximately 320,000 tons a year. Almost three fourths of this is supplied by the Crown Zellerback Co., the rest by the Inland Empire Paper Co., of Millwood, Wash., and the Hawley Pulp and Paper Co., Oregon City, Oreg. The latter companies sold one half their production outside the three coast States.

224. The Powell River Co., Ltd., sells 60 percent of its output in the United States through the George F. Steele Co. of New York City. This is not sold on the Pacific coast but is shipped via the

Panama Canal to Texas, Louisiana, Oklahoma, New Mexico, Arkansas, Nebraska, and Kansas publishers. Some also reaches Colorado.

225. *Distribution of eastern production.*—The New England and Middle Atlantic news publishing markets are served by the Great Northern Paper Co., the International Paper Co., from its Canadian and Eastern newsprint mills, and by small producers in Maine and New York, and by large producers of Canada. Many Canadian mills are represented by the Canadian Export Co. The New York Times secures almost all its newsprint from Canada; the Hearst Newspaper and Magazine Paper Corporation has contracts to purchase the entire output available for shipment to the United States of the Anglo-Canadian Pulp and Paper Mills, the Brompton Pulp and Paper Co., and the Lake St. John Power and Paper Co.; it also has similar contracts with New York newsprint mills.

226. The International Paper Company also sells in the Pittsburgh, Chicago, and South Atlantic markets, practically in all sections east of the Mississippi, and usually under 5-year contracts. The Great Northern Paper Companies sell in carload lots only, throughout the East. For the most part, Eastern mills count on the Eastern, Southern, and Southwestern markets, however, and leave the Middle Western market to Lake mills.

227. *Distribution of Lake States production.*—The Minnesota and Ontario Paper Co. is the chief local newsprint distributor in the Middle West. The largest newsprint paper manufacturer of Canada sells throughout the Central States through the George H. Mead Co. of Dayton, Ohio. While these Lake and Canadian mills sell in South Atlantic markets as well as in Gulf markets, their principal market is west of Pittsburgh.

228. Some newspapers in this area own their own newsprint mills. This was true of the Minneapolis Tribune and the St. Paul Dispatch. Almost all newspaper holdings of the International Paper Co. have been sold.

229. *Newsprint prices and freight rates.*—The International Paper Co. sets the market price for newsprint paper in all sections of the United States except the Pacific coast. Other producers await the announcement of this company's prices before changing their own price schedules. On the Pacific coast, control is exercised by the Crown Zellerback Corporation and the Powell River Co. of British Columbia.

230. The price holding to June 30, 1930, was $65 per ton f.o.b. mill, with the seller paying all freight to destination. All territory east of the Mississippi River was zoned, and the delivered price for customers in each zone named. The same practice was entered into by the Minnesota and Ontario Paper Co. Some of these prices are as follows:

$67.70 f.o.b. mill freight allowed to San Antonio, Tex.
$68.00 f.o.b. mill freight allowed to Enid, Okla.
$63.00 f.o.b. mill freight allowed to Omaha and Kansas City.
$65.00 f.o.b. mill freight allowed to Atlanta, Ga.
$62.00 f.o.b. mill freight allowed to New York, Baltimore, Washington, Detroit Pittsburgh, and Chicago.
$61.50 f.o.b. mill freight allowed to Boston, Albany, Rochester, Syracuse.
These prices were met by United States and Canadian producers.

231. Freight rates on newsprint from Canada to New England and Middle Atlantic points run from $4 to $7, or less than the cost of an all-water shipment from Seattle to the Atlantic seaboard. Rates from New York and New England to New Orleans fall between $9.60 and $10.50, whereas newsprint can be shipped from Seattle for $8. The Powell River Co. sells to Texas publishers at $58 per ton, c.i.f., Houston. It sells to Oklahoma publishers at $65 per ton or at better prices than received from Eastern producers.

232. From Eau Claire, Wis., to St. Louis the rail rate on a ton of newsprint is $4.90; to Kansas City, $6 per ton. From Seattle to Kansas City via the Panama Canal, the total shipment cost is $26.40. Obviously, such markets cannot be reached via the Panama Canal. The rate from Seattle to Cincinnati, St. Louis, and Chicago via Panama Canal and New Orleans is $14.60, while from Eastern points it averages $6.60 and $7.70, respectively. While States located near to Lake paper manufacturers such as Iowa enjoy a low freight rate, all-rail rates increase rapidly with the increasing distances.

233. Unquestionably, a market exists for Pacific coast newsprint along the Gulf coast and southern Mississippi points as well as in the Rocky Mountain States and a few of the mid-Central States.

234. *Paper exports.*—While our exports of paper are only 174,000 tons, the shipment of newsprint to the Philippines and China, and of wrapping paper to these countries and to Mexico, are of interest to Pacific coast paper manufacturers.

TABLE XVII.—*Exports of paper, wood pulp, and pulpwood in 1928* [1]

Exported to	Paper exports														Wood-pulp exports								Pulpwood exports, kind not specified	
	Total		News		Wrapping		Boards		Book		Writing		Other [2]		Total		Sulphite		Soda		Other			
	Short tons	Per-cent	Short tons	Per-cent	Short tons	Per-cent	Short tons	Per-cent	Short tons	Per-cent	Short tons	Per-cent	Short tons	Per-cent	Short tons	Per-cent	Short tons	Per-cent	Short tons	Per-cent	Short tons	Per-cent	Cords	Per-cent
Total exports	174,248	100.0	11,390	6.5	19,932	11.4	77,187	44.4	12,256	7.0	12,916	7.4	40,567	23.3	29,896	100.0	22,272	74.5	2,441	8.2	5,183	17.3	27,518	100.0
Canada	62,560	35.0	122	1.1	7,880	39.5	29,491	38.2	4,669	38.1	1,333	10.3	19,065	47.0	19,394	64.9	17,669	79.3	214	8.8	1,511	29.2	27,508	99.9
Newfoundland and Labrador	1,295	.7	2	(3)	11	(3)	270	.4	33	.3	64	.5	915	2.3										
Sweden	544	.3			6	(3)	363	.5	2	(3)	6	(3)	167	.4	1	(3)					1	(3)		
Finland	98	(3)			1	(3)	89	(3)	4	(3)			4	(3)	33	.1	33	.2						
Germany	2,234	1.3	2	(3)	50	.3	1,355	1.8	164	1.3	632	4.9	31	.1	115	.4	15	.1	20	.8	80	1.5		
Norway	596	.3			33	.2	510	.7	3	(3)	6	(3)	44	.1	5	(3)					5	.1		
Japan	3,577	2.1	191	1.7	309	1.6	1,255	1.6	131	1.1	419	3.2	1,272	3.1	6,304	21.1	2,627	11.8	1,467	60.0	2,210	42.6		
United Kingdom	17,320	10.0	17	.2	1,632	8.2	11,646	15.1	55	.5	617	4.8	3,353	8.3	920	3.1	170	.8	165	6.8	585	11.3		
Netherlands	1,808	1.0			3	(3)	1,427	1.8	4	(3)	82	.6	292	.7	30	.1	29	.1			1	(3)		
Argentina	6,769	3.9	1,796	15.8	174	.9	888	1.2	329	2.7	1,762	13.6	1,820	4.5	240	.8					240	4.6		
Philippine Islands	9,315	5.4	3,746	32.9	1,757	8.8	1,140	1.5	1,333	10.9	959	7.4	380	.9	2	(3)					2	(3)		
China	14,803	8.5	1,399	12.3	1,332	6.7	7,113	9.2	921	7.5	777	6.0	3,261	8.0	49	.2			49	2.0				
Cuba	15,043	8.6	1,900	16.7	1,793	9.0	4,713	6.1	2,416	19.7	2,237	17.3	1,984	4.9										
Venezuela	2,171	1.2	734	6.4	60	.3	595	.8	165	1.3	215	1.7	399	1.0										
Mexico	6,298	3.6	233	2.0	2,460	12.3	1,735	2.2	255	2.1	598	4.6	1,017	2.5	123	.4	27	.1	46	1.9	50	1.0	10	(3)
Other countries	29,817	17.1	1,248	10.9	2,431	12.2	14,597	18.9	1,772	14.5	3,206	24.8	6,563	16.2	2,680	8.9	1,702	7.6	480	19.7	498	9.6		

[1] Compiled from: U.S. Department of Commerce, Foreign Commerce and Navigation of the United States.

[2] Includes 16,975 tons of hanging paper, going principally to Canada, United Kingdom, and Newfoundland; 7,231 tons of tissue (crepe, toilet, towels, etc.) going chiefly to Canada, Argentina, and Cuba; and 7,427 tons building paper going chiefly to Canada, United Kingdom, Argentina, Japan, Australia, and Mexico. Does not include 14,224 tons of boxes and cartons going chiefly to Canada, Spain, Mexico, and Cuba, or 11,261 tons paper bags, adding-machine paper, vulcanized paper, etc., going chiefly to Canada, Philippines, Panama, Colombia, Cuba, Peru, and Mexico.

[3] Less than 0.1 percent.

240. *Producers of sulphite pulp for rayon.*—Canada exceeds all other countries in the manufacture of wood pulp for rayon manfuacture. The Canadian International Paper Co. at its Kipawa Mills, Temiskaning, Quebec, produced 100,000 tons annually of high-grade alpha pulp, or about one half of the world's supply. This plant is about 200 miles up the Ottawa River from Ottawa. The only large producer of rayon sulphite pulp in the United States is the Brown Co. of Berlin, N.H. This plant is on the Androscoggin River about 40 miles from the Canadian boundary. It has a capacity of 90,000 tons annually.

241. The only company manufacturing a rayon grade of sulphite pulp on the Pacific coast is the Rainier Pulp & Paper Co. of Shelton, Wash. This company is using hemlock and has a capacity of 285 tons of sulphite pulp daily.

242. In Europe, one of the principal rayon pulp producers is the Uddeholms Aktiebolag of Sweden. While the United States imports sulphite pulp from Sweden as well as from Norway and Germany, the amount that enters the rayon industry is not certain.

243. *Cotton linters.*—About 20 percent of the world's rayon and a number of the cellulose plastics employ cotton linters and short cotton fibers as their basic raw material. Staple cotton, such as is used for cotton materials, is too expensive to compete with wood pulp, but cotton linters obtained from a second ginning after the staple cotton has been removed in the first ginning, have proved very satisfactory. Approximately 36,000 tons of cotton linters and short fibers were used in the United States in 1929 for cellulose solutions.

244. The production of cotton by States is given in the following table. It is evident the States that can furnish the country with this raw material are not those that can furnish the nonresinous softwood pulp.

TABLE XVIII.—*Production of cotton in the several States in 1928* [1]

States	Number of 500-pound bales	States	Number of 500-pound bales
Texas	5,106,000	Tennessee	428,000
Mississippi	1,475,000	California	172,000
Arkansas	1,246,000	Arizona	149,000
Oklahoma	1,205,000	Missouri	147,000
Alabama	1,109,000	New Mexico	88,000
Georgia	1,030,000	Virginia	44,000
North Carolina	836,000	Florida	19,000
South Carolina	726,000	All others	7,000
Louisiana	691,000		

[1] U.S. Department of Agriculture 1930 Yearbook

245. *Purification of cotton linters.*—While cotton linters are sometimes freed of oil, fats, pectin, and other undesirable matter in the cotton districts, this purification takes place more often, at the rayon mill. The linters are shredded and freed of sand and dirt. They are then boiled in a solution of caustic soda under steam pressure for from 4 hours to 10 hours to remove the noncellulosic material and other impurities. After thorough rinsing the linter pulp is bleached in a sodium hypochlorite solution (NaClO). Sodium hypochlorite is made by passing liquid chlorine into a caustic soda solution. This bleach is used in preference to bleaching powder, or calcium hydrochloride, in order to avoid the elimination of lime which must be removed when the latter bleach is used.

246. It is then "soured", or bleaching solution is removed from the fibers by a dilute solution of sulphuric acid. The pulp is washed and dried as in sulphite pulp preparation. It must be stored under conditions permitting a controlled temperature and humidity.

Methods of Manufacturing Cellulose Solutions and Finished Products

247. In 1929, 84.1 percent of all rayon was produced in the United States by the "viscose process", 8.3 percent by the nitrocellulose process, 5.7 percent by the cellulose acetate process, and 1.9 percent by the cupra-ammonium process. Although the viscose process far outranks any other process, there is a slight but decided increase in the use of the acetate process. This is expected to grow, due to the entry of two large viscose manufacturers into cellulose acetate production.

Table XIX.—*United States rayon production by processes* [1] *(approximate)*

Year	Total		Viscose		Nitrocellulose		Acetate		Cupra-ammonium	
	Short tons	Percent	Short tons	Percent	Short tons	Percent	Short tons	Percent	Short tons	Percent
1929	61,565	100.0	51,790	84.1	5,125	8.3	3,500	5.7	1,150	1.9
1928	48,851	100.0	41,051	84.0	4,250	8.7	2,500	5.1	1,050	2.2
1927	37,525	100.0	31,850	84.9	3,750	10.0	1,750	4.6	175	0.5
1926	31,288	100.0	26,538	84.8	3,500	11.2	1,250	4.0	.....	.....
1925	26,105	100.0	22,755	87.2	2,600	9.9	750	2.9	.....	.....
1924	19,425	100.0	17,300	89.1	2,125	10.9	.....	.....	.....	.....

[1] Compiled from Rayon Yearbook, 1928 and 1930, published by Textile World.

248. *The viscose process.*—Sulphite pulp is the basic raw material employed in the viscose process. It reaches the rayon manufacturer in dry sheets which are analyzed and, if not of proper moisture content, are subjected to further drying. Some manufacturers add cotton linter pulp to the sulphite pulp.

249. *Preparation of viscose solution.*—Properly prepared pulp sheets are then soaked in a caustic soda solution of approximately 18 percent. A high quality caustic soda is required. It is purchased either in liquid form in 25 percent or 50 percent strength or in solid form shipped in 760 pound drums. The pulp combines with the caustic soda to form sodium cellulose ($C_6H_9O_4ONa$). Excess solution is removed by pressing out the sheets.

250. The sodium cellulose is then shredded to very finely lintered particles called "crumbs." These are aged in closed iron or steel cylinders which are kept at about 75° F. Ageing requires 48 hours to 72 hours. Crumbs are then ready for "xanthating." They are dumped into revolving drums which mix them with carbon disulphide (CS_2). The reaction results in cellulosexanthate, a jelly-like mass.

Transforming into Finished Products

251. *Transparent wrapping.*—This viscose solution may be transformed into a transparent moisture-proof sheet by passing it through a narrow slit into an acidulated glycerine bath which causes it to

coagulate. Such sheets may be dyed any color, printed, or cut into desired forms.

Or the viscose solution may be further treated by spinning it into filament form.

252. *Preparation of spinning solution.*—Cellulose xanthate is mixed with a dilute caustic soda solution until the mixture contains 61 percent cellulose and 8 percent caustic soda. Several batches are then run together in order to produce a uniform mixture. The viscose solution must be ripened, a process which takes 4 to 5 days. During this period, the solution is filtered so that all particles which might later clog the minute holes of the spinnerets are removed. This is accomplished by pressing it through a cotton wool or through woven or knit cloth. Lastly, all air bubbles must be removed from the viscose solution. This is done by subjecting the solution to a vacuum for 24 hours or more. The viscose is then ready for the spinning operation.

253. *Conversion into filaments.*—Through a pipe system the viscose solution is brought to the spinning machine. It is forced through holes in spinnerets either with direct air pressure or by means of hydraulic pumps. Spinnerets are cups usually made of platinum or other precious metal alloys and have from 1 to 1,000 holes per cup. The solution is passed through these holes into a coagulating bath which renders the molecules in solution immovable, thereby effecting a filament structure. The holes in the spinnerets may produce filaments of the exact diameter desired. Or they may be somewhat larger, in which case the filament is passed into a mildly coagulating bath where it is stretched to lessen its diameter during the process of gradual coagulation. Sometimes the complete coagulation takes place in this mild bath and sometimes the partially solidified filament passes to a more powerful bath for final coagulation.

254. The coagulating bath preparation is basically sulphuric acid. Sodium sulphate, zinc, and ammonium salts, are sometimes added. Manufacturers endeavor to keep secret the exact composition of this bath preparation.

255. *Spinning and cleaning the filament.*—These filaments are gathered up centrifugally and are wound about rapidly turning spools, reels, or bobbins on different types of spinning machines. Some twist is imparted to the filament in this process. As the threads still are in a semigelatinous condition, the bobbins are immersed in water which is pulled through them by suction. The rayon is then dried in heat-insulated chambers having careful humidity and temperature controls. A part of the moisture removed in drying is cooled and used again in order to facilitate the later spooling and twisting operations.

256. *Thread manufacture.*—From this point, machine operations are similar to those used in silk-yarn manufacture. The single filaments are twisted together to form threads. Threads are reeled into skeins for bleach. Before bleaching, however, remaining sulphur must be removed by treatment with an aqueous solution of sodium sulphide.

257. *Bleaching and finishing.*—Rayon skeins are bleached with either sodium or calcium hypochlorite containing about 1 percent available chlorine. The skeins are soured in a weak solution of hydrochloric acid and then washed thoroughly. When water has

been extracted, skeins are hung on frames and pass through a continuous drier. After sorting into grades, the skeins are made up into bundles of 10 or more pounds and packed into cases for shipment.

258. *Quantities of principal raw materials used.*—Although differences in manufacturing detail necessarily bring about a varying amount of materials applied to the manufacture of a ton of rayon, the importance of several materials in the manufacture of viscose rayon are indicated by the following rough estimates of requirements:

Principal materials required in the manufacture of 1 ton of rayon: [6]

Sulphite pulp	tons	122
Cotton linters	ton	0. 4
Caustic soda	tons	2
Carbon disulphide	pounds	1, 200
Sulphuric acid	tons	1. 5

THE NITROCELLULOSE OR CHARDONNET PROCESS

259. Although but 8 percent of the rayon manufactured in the United States is produced by the Chardonnet or nitrocellulose process, the cellulose nitrate made forms the basis of lacquers, photographic films, of celluloid and a number of the plastics, as well as of explosives.

260. Cotton linters serve as the raw material of this process in the United States. Wood pulp, however, was used in Germany during the World War, for the manufacture of nitrocellulose or gun cotton. Cotton linters are freed of their noncellulosic materials at the chemical plant by a treatment with caustic soda. After bleaching in a sodium hypochlorite solution, souring, washing, and drying, they are ready for nitration.

261. *Nitration of cotton.*—The solution necessary to nitrate cotton will vary in exact consistency from plant to plant and according to the final product desired. It may be made up of nitric acid, sulphuric acid, and water, in approximate proportions of 33 percent, 58 percent, and 9 percent, respectively. About 1,600 pounds of solution is applied to 35 pounds of bleached cotton. The time allowed for chemical reactions to take place varies from 15 minutes to 1 hour, depending upon the use to which the nitrate is to be put. Cellulose to be dissolved is not nitrated as long as is cellulose to be used as gun cotton. At the proper time, the mixture flows from the reaction pots into a centrifugal machine where acid is squeezed out to be used again in producing the new solution. The cotton is washed in cold water and then boiled to remove all free acid; soda ash may be added to aid in this process.

262. *Finishing.*—The matted material must next be reduced to a fibered pulp, which is accomplished by the revolving cutters of a shredding machine. Each fiber is then freed of remaining traces of free acid or of unstable nitrated decomposition products by a long boiling in slightly alkaline water. After a final washing the material from several batches is blended to secure an even mixture.

263. If the nitrated cellulose is to be shipped, it is dehydrated by forcing denatured alcohol under pressure through the wet cotton. Because the nitration of cotton carries with it a high explosion hazard, the manufacturers of lacquers and plastics usually buy their cellulose nitrate. Rayon plants carry on the nitration as well as the filament processes in the same factory. The further treatment of cellulose nitrate for rayon will, therefore, be considered first.

[6] Chemical quantities are given by Mois H. Avram in The Rayon Industry, 1929.

TRANSFORMING CELLULOSE NITRATE INTO RAYON

264. The nitrate is first removed from the cellulose nitrate by dissolving it in alcohol and ether. The proportions used in the solvent solutions as well as in the solvent mixture depend upon the type of spinning to follow. For wet-spinning, only 10 percent cellulose nitrate is desirable, while about double the amount is essential for dry spinning. Only a little ether is present in the first nitration type of spinning while it may constitute 60 percent of the solution used for drying spinning filament. The final solution is deaerated and forced by hydraulic presses through cotton and silk filtering cloths into pipes feeding the spinning machine.

265. *Spinning.*—In dry spinning, the solution is forced through spinnerets into air instead of a coagulating bath as in the viscose process. The ether evaporates and then nitrate containing cellulose hardens into filaments as soon as it is passed into the air. In wet spinning, the filament falls into water which dissolves the alcohol-ether content. In either case, solvents are recovered. The twisting and spooling processes are similar to those used in the viscose process.

266. *Denitration.*—The cellulose nitrate thread is highly inflammable and it is essential that the nitrate be removed before use. Usually a sodium hydrosulphide treatment is given the skeins, which are then washed, bleached, and dried in the usual manner.

TRANSFORMING CELLULOSE NITRATE INTO PLASTICS

267. Camphor is the principal chemical which converts the cellulose nitrate into a plastic material. When camphor is mixed with twice the amount of pulped nitrate the dissolved product is pressed into cakes, dried, and made into molding powder or into sheets, rods, or tubes. It may be mixed with aniline dyes or metallic pigments to produce any color. And when heated it may be pressed into any shape; or it may be turned, carved, ground, or bent into any form. It enters into many articles such as films, unshatterable glass, toilet articles, toys, pens, umbrella handles, and other "trade ware."

268. When manufactured into film, the cellulose nitrate acts as a backing for the gelatin coating. In glass manufacture, a sheet of cellulose nitrate is interposed between two sheets of glass. On the glass is sprayed a gelatinous cement or resinous lacquer which is dried. The cellulose nitrate may be put between the glass and fastened in place with tamplets, the whole placed in a sealed bag and subjected to heat and pressure. Or an intermediate bonding solution may be used to soften the plastic sheet and the lacquer coating on the glass before the three sheets are put into the press.

TRANSFORMING CELLULOSE NITRATE INTO LACQUERS

269. In the manufacture of lacquer, nitrated cellulose is mixed with resin, pigments, and a plasticizer and then dissolved in a mixed solvent. Dr. Stanley Smith gives the following formula of a well-known American lacquer:

	Parts
Cellulose nitrate	12
Resin (dammar)	8
Pigment	15
Plasticizer (castor oil and diethyl phthalate)	8
Solvent (made up of 50 percent butyl acetate, 15 percent alcohol, and 35 percent toluol)	100

270. A jet-black enamel formula quoted by Samuel P. Wilson [7] is as follows:

Cellulose nitrate or other lacquer cotton	4 parts 6 ounces.
Pigment	1. 75 parts.
Ester gum solution	0. 5 part.
Butyl acetate	0. 5 part.
Acetone	0. 5 part.
Tricresyl phosphate	0. 75 part.

THE ACETATE PROCESS

271. Like cellulose nitrate, cellulose acetate is used for purposes other than fiber manufacture. It was applied extensively to airplane wings during the war to give them a protective coating and is used in coating metals, to make photographic films, unshatterable glass, lacquers, molding powders, and transparent wrappings.

272. *Acetation of cellulose.*—Today, cotton linters are used as the basic cellulose material in this process. These are purified as in other processes by kier boiling. They are then treated with acetic anhydride in the presence of sulphuric acid, phosphoric acid, or some other chemical which aids in the synthesis of cellulose and acetic acid without entering into the combination. Acetic acid as such is too weak to unite with the cellulose to form the ester; therefore, acetic anhydride and a catalyst are used although acetic acid may be present in the solution.

273. In practice about 100 parts of cotton cellulose, 400 parts of acetic acid, and 10 parts of sulphuric acid are mixed and placed in a vessel which holds the temperature below 30° C. Four hundred parts of acetic anhydride are added while the mixture is agitated. To dissolve the cotton requires 12 or more hours at this temperature.

274. *Precipitation and purification.*—Cellulose acetate may be dissolved in chloroform. To make an acetone-soluble cellulose acetate, such as is used in rayon, the solution is thinned with acetic acid and water and allowed to stand. After desired solubility is obtained the cellulose acetate is poured into water, at which time the acetate is precipitated. The mixture is filtered and all uncombined acids are washed away. It is then carefully dried.

TRANSFORMING CELLULOSE ACETATE INTO RAYON

275. *Spinning solution.*—With acetone-soluble cellulose, the dried cellulose is placed in a closed mixer containing acetone and agitated until completely dissolved. It is then filtered, blended, and de-aerated.

276. *Spinning operation.*—The cellulose acetate solution is forced through spinnerets as in other rayon operations. In dry spinning, the spinneret is at the top of a narrow air chamber through which hot air is circulated. This warm air evaporates the solvent, leaving the cellulose acetate in filament form. The filaments are gathered upon a bobbin as in spinning viscose and after being twisted and wound are ready for the market without any further treatment.

277. *Quantities of raw materials consumed.*—Successful cellulose acetate plants are very secretive concerning the details of their processes. Rough estimates place the consumption of materials at the

[7] Wilson, Samuel P., "Pyroxylin Enamels and Lacquers."

following figures: Per ton of acetate rayon produced, 1.35 tons cotton linters are required which are treated with caustic soda and bleached in sodium hypochlorite. For acetation of the cellulose, 3 to 4 tons acetate anhydride, 200 pounds sulphuric acid, and 3 to 4 tons acetic acid are applied. The acetone solvent required totaled 4 to 6 tons per ton of acetate rayon; in actual practice less new acetone is used, as much is recovered from the air of the spinning by refrigeration or by absorption.

278. *Transforming cellulose acetate into plastics.*—Cellulose acetates may be applied to any manufacture for which cellulose nitrate is suitable except, of course, gun cotton. Usually benzol and alcohol are the solvents used to reduce it to a plastic substance. Other chemicals are added to impart specific qualities in the product, while pigments and filling materials may be used to produce the desired products. As it has been more expensive than the nitrate ester it has been substituted only where the explosive quality of the nitrate has proven hazardous. Motion-picture, X-ray and other films are being manufactured by use of acetate sheet as a backing. Its high dielectric quality makes it a valuable coating for electric insulation.

279. *Cupra-ammonium process.*—While cotton linters are most frequently employed in this process, wood pulp and cotton waste have been used successfully. The linters or pulp are purified and bleached in the same manner as for other processes. The solution to be used on the purified cellulose is made up of metallic copper or copper sulphate, caustic soda or soda ash, and ammonia.

280. *Preparation of the solution.*—When metallic copper is employed the solution is made by the action of ammonia on the metal in the presence of air. The copper hydroxide formed is dissolved by the ammonia. When copper sulphate is the basic constituent, it is precipitated by caustic soda or soda ash, washed free of salts and then dissolved in ammonia. The cupra-ammonium solution together with a small amount of caustic soda and the cellulose is agitated in a mixer until all cellulose is dissolved. The mixture is forced, by means of compressed air, through a filter press provided with very fine screening, in order to free it of all foreign matter.

281. *Spinning the solution.*—In this process, coagulation of the filament takes place in a caustic soda or a sulphuric acid bath. The alkali bath produces a stronger and less brittle liquid. Because this process is usually employed to produce very fine filaments, the 2-bath formation with a gradual stretching of the thread is employed. (See p. 367.) After winding on a bobbin or reel, the copper is removed from the rayon by a bath in dilute sulphuric or hydrochloric acid. Washing and drying follow as in the viscose process. The textile operations are the same.

282. *Recovery of metal.*—Efforts are made to recover the copper and the ammonia employed in this process. If caustic soda has been used in the coagulating bath, ammonia may be evaporated from the spinning waste and copper recovered by electrolysis. When sulphuric acid is employed in the bath, bars of iron suspended in the bath will recover the copper.

283. *Zinc-chloride process.*—This process is quite distinct from the four other methods of treating cellulose and its finished cellulose product does not compete with them in their respective markets. The cellulose so treated is used in the electrical field for spacing blocks

and radial segments, slat wedges, fuses, bases, tubes, and other mechanical purposes. It is called "vulcanized fiber" and finds competition chiefly from bakelite, a phenol-plastic.

284. The raw material employed is rags. These are cut up, boiled, washed, and beaten into pulp. The pulp passes through paper machines which form it into sheets, dry and roll it. These sheets are soaked in solutions of zinc chloride for extended periods. After this process is complete, sheets are air dried, flattened in steam-heated hydraulic presses, and hung for seasoning. They are cut up into rods and tubes.

285. *Other processes.*—Firms, both in this country and abroad, maintain research staffs which are engaged in perfecting present processes and in pure scientific research on cellulose. It is reported that the Franco-German Co. of France is treating cellulose with butyric acid but commercial production has not been announced as yet.[8]

Power Requirements in Rayon Manufacture and in Manufacturing Raw Materials for Rayon

POWER USED IN RAYON MANUFACTURE

286. The power requirements for rayon manufacture itself are entirely for mechanical operation of the machinery although process and conditioning steam is also necessary. Consequently, plants supplying their own power have usually installed steam turbines, in the past. These generate all electric power and are bled for necessary steam. But a number of plants find it convenient to purchase current where a 24-hour supply is available at a reasonable rate. The following table shows the power equipment in mills operating in 1927:

Table XX.—*Source of power supply in rayon industry* [1]

Equipment	Number	Capacity
		Horsepower
Total		155,803
Steam engines	66	7,228
Steam turbines	47	68,749
Internal-combustion engines	1	10
Electric motors driven by purchased current	6,251	46,419
Electric motors driven by current generated in plant	4,149	33,397
		Kilowatts
Electric generators	26	49,825

[1] U.S. Bureau of the Census, Census of Manufactures, 1927.

POWER REQUIREMENTS FOR CHEMICALS ENTERING INTO RAYON MANUFACTURE

287. Only when rayon is considered in terms of the chemicals entering into its manufacture does it become an industry of interest in power development.

288. *Caustic soda and chlorine.*—All pulp, whether made from wood or cotton linters, must be bleached for rayon manufacture regardless of process. This is usually done in chlorine or in sodium

[8] 1930 Rayon Year Book.

hypochlorite made by passing liquid chlorine through caustic soda. In the viscose process 2 tons of high quality caustic soda are used in the production of 1 ton rayon solution, while an additional amount is used in the sodium hypochlorite bleach of the final skeins. In the cupra-ammonium process a caustic soda bath may be used to coagulate the spinning solution. It is estimated that 115,000 tons of high-quality caustic soda were consumed in production of rayon in 1929. The manufacture of this caustic required approximately 287,500,000 kilowatt-hours of energy. While chlorine consumption in the rayon industry was much less than the consumption of caustic soda, this textile offers an outlet for a part at least of the chlorine manufactured in the process of caustic soda production.

289. *Sulphuric acid and carbon disulphide.*—The other chemicals essential to the manufacture of viscose rayon, namely, sulphuric acid and carbon disulphide, may be gotten from sulphur fumes produced in electrolytic zinc or copper plants. Carbon disulphide is manufactured by electrical heating of charcoal or other carbonaceous product in the presence of sulphur-dioxide gas. Although sulphuric acid is now used for the coagulating bath, a cheaper price on phosphoric acid might lead to a substitution of this electric furnace product. It is estimated that 145,000 tons of sulphuric acid and 33,000 tons of carbon disulphide were consumed in rayon manufacture in 1929.

290. *Nitric acid.*—Rayon made from cellulose nitrate consumed approximately one half ton nitric acid, nine tenths ton sulphuric acid, 1,080 pounds ethyl alcohol, and 1,680 pounds ether. Nitric acid is now made by the oxidation of ammonia. (See p. 149, Power in Fertilizer Material Production.)

The total nitric acid consumed was 2,700 pounds, ethyl alcohol 2,800 and ether 4,300 tons.

291. *Acetic chemicals.*—The acetate process is of importance because of its recent rapid growth and because of its possibilities in plastic manufacture. Each ton of rayon manufactured by this process required from 3 to 4 tons acetic anhydride, and the same amount of acetic acid. Estimates of the acetone requirements range upwards from 1.6 tons per ton rayon as acetone is recovered in the course of the process. In addition, about one tenth ton of phosphoric acid or sulphuric acid is required.

292. Until recently, the source of all acetic chemicals was pyroligneous acid, a byproduct of hardwood distillation, methanol being the principal product obtained. While acetic acid is gotten by treating the pyroligneous acid with milk of lime and then with sulphuric acid, when acetic anhydride is desired, it is treated with soda ash and the sodium acetate produced is acted upon by sulphur chloride. The hardwood-distillation plants ship out the sodium or calcium acetate to such chemical establishments as the Dow Chemical Co. who manufacture it into acetic anhydride and other chemicals.

293. Acetone was obtained from calcium acetate, but only 36 pounds is secured from 180 pounds of the acetate. Consequently, when Great Britain required acetone for the manufacture of her official smokeless powder, cordite, and acetone was also necessary for airplane-wing dope, efforts were made to obtain a cheaper source than the hardwood distillation product. While several plants were opened, operations ceased with the war and resumption of newer methods of manufacturing acetic chemicals have only come about

by the demands for acetates as solvents in the lacquer, rayon, and plastic industries.

294. In 1920 the Commercial Solvents Corporation at Terre Haute and later at Peoria, began the manufacture of acetone, butyl alcohol, and ethyl alcohol from low-grade corn. From 1 bushel of corn 10 to 11 pounds of mixed solvents are obtained, in the proportion of 30 percent acetone, 60 percent butyl alcohol, and 10 percent ethyl alcohol. The company is erecting a unit for the manufacture of acetic acid by the Langwell process. Farm waste of various kinds will be fermented and while butanol and acetone will be gotten first, the residue will be used for acetic acid. Waste hydrogen and waste carbon dioxide gases from the fermentation process yield methanol.

295. The Niacet Chemical Corporation, in 1928, began the manufacture of acetic acid from acetylene at Niagara Falls. Acetylene is obtained by placing calcium carbide in water, 1 ton of calcium carbide requiring over 3,000 kilowatt-hours of energy. As off-grade carbide can be used for acetic-acid manufacture, this is a valuable product from the viewpoint of the calcium-carbide manufacturer. (See p. 432 of The Original and Sane New Electric Furnace Products.) Research has been under way to produce acetylene from methané of natural gas but as yet efforts are still in the experimental stage. It is also reported that an electro-deposition of petroleum oils is being attempted.

296. Germany is stated to digest wood much in the same way as it is done for pulp manufacture to produce her acetic acid.

COST OF RAYON PRODUCTION

297. *Labor costs.*—Large American rayon factories not only produce rayon skeins by a chemical process, but carry on such textile operations as will render the threads in condition for the knit-goods manufacturer or the weaver. European firms usually ship rayon to this country in skeins, which must be dyed, twisted, and wound on cones, quills, cops, or spools by "converters" or rayon throwsters before reaching the knitting or weaving mill.

298. It is these textile operations that make labor costs such a large item in rayon production. The textile operations and inspection are done chiefly by women. The number employed varies with the fineness of the thread produced and is variously given as 350 women and 500 men in a 5-ton-a-day rayon mill to 1,000 employees in a 3-ton-a-day mill. This labor is, however, semiskilled. Rayon mills built in Tennessee and Virginia chose sections near small towns where there was no industry competing for semiskilled labor. They drew in mountain people from the mountains and the small towns and trained them to the industry.

299. The prevailing hours for men are 51, for women 49 per week; the prevailing wage scale is $0.50 an hour for men and $0.35 an hour for women. This data was procured by the United States Bureau of Labor Statistics from 21 rayon mills in 1930.

300. Even at these rates, it is estimated labor costs form from 40 to 50 percent of total costs; and engineering and administrative forces add another 10 percent to the salaries and wages roll.

301. *Raw materials.*—Raw materials represent the second item of cost, figured roughly at 25 percent of the total cost. Sulphite pulp and caustic soda are, of course, the chief items entering into this cost. Power, water, and coal are figured at 6 percent of total cost.

302. *Capital costs.*—Estimates vary greatly as to capital costs of a rayon plant. One engineer places the figure at $3,000,000 for a 3-ton-a-day plant; another places it at about the same figure for a 5-ton-a-day plant. The investment in equipment is heavy, although only the spinning machine represents a departure from regular chemical or textile equipment. Rayon machinery is usually charged off at 15 percent; engines, boilers, etc., at 10 percent.

303. The cost of manufacture of rayon in 1928 in a small plant of 1,000-ton yearly capacity was $0.894. This included selling cost. The average selling price during the same period was $1.15 a pound.

Development and Control of Industries

304. The cellulose-nitrate or pyroxylin plastic industry began in the United States with the establishment of a factory at Newark, N.J., in 1872. The rayon industry was first established in France in 1884, in Germany in 1890, and in England about 1900. The first rayon plant in the United States was established in 1910 at Marcus Hook, Pa., by an English company. As a consequence, while the cellulose plastic industry has developed as an American industry, the rayon industry has been built up in the United States largely by foreign companies operating under foreign patents. Cellulose lacquer had been used prior to the World War but the industry developed only after the close of the war when lacquers of low viscosity and high nitrocellulose content made possible their extended application.

CELLULOSE PLASTICS

305. *Pyroxylin.*—From its inception, pyroxylin, or cellulose nitrate, easily molded and shaped, has found extensive use. Today, there are only four firms manufacturing the basis material—that is, cellulose nitrate or "pyroxylin" as it is known in the trade. This is made up into sheets, rods, and tubes, part of which are fabricated into final marketed form in the original plant and part offered for sale to other manufacturers. In 1929 the total production of these four firms was 25,283,235 pounds, of which 4,856,625 pounds were consumed in the same establishment and 20,426,610 pounds, having a value of $18,063,154, offered for sale to manufacturers of toys, dolls, tooth brushes, fountain pens, combs, hairpins, brushes, and numerous other articles. Safety glass is the latest use of cellulose nitrate. A thin sheet of this material is placed between two sheets of glass and pressed together. This may be built up until bullet-proof glass is attained. In 1929, about 1,250 tons of pyroxylin sheeting was consumed in laminated-safety-glass production. The du Pont de Nemours Co. is the largest manufacturer of cellulose nitrate.

306. *Competitive products.*—Cellulose nitrate for plastic uses has been in competition with phenolic plastics, such as bakelite, for a number of years. Until recently, these phenolic plastics could only be manufactured in tones of amber, brown, and black, and were used chiefly for industrial purposes in telephone sets, radio tubes, and caps, and in other electric switches and plates. In 1931, however, comes the announcement that these synthetic plastics are to be produced in pastel shades and may, therefore, enter a number of fields now held by pyroxylin or cellulose-nitrate plastic. Urea formaldehyde plastics are

entering into table and household ware. Casein formaldehyde compounds have also reached the stage of active competitors in the plastic field.

307. *Cellulose nitrate.*—But cellulose nitrate plastics are threatened from another cellulose plastic—that is, cellulose-acetate plastic. The acetate plastic is nonexplosive and, therefore, possesses a great advantage over the nitrate. It was first made in this country in 1909 by the Eastman Kodak Co. for use as a film base. This firm is the largest producer of cellulose-acetate plastic today, the product being made at its plant in Kingsport, Tenn. But it has only been within the last 3 years that the cellulose acetate has been produced at a price to make it available in a larger market. In 1929, molded production from cellulose acetate totaled between 750,000 and 1,000,000 pounds.

The Rayon Industry

EUROPEAN CONTROL OF AMERICAN RAYON PLANTS

308. It is stated that 80 to 85 percent of the world's rayon production is controlled directly or indirectly by three companies: Courtaulds, Ltd., of England; Snia Viscosia, of Italy; and Vereinigte Glanzstoff-Fabriken, of Germany.

309. Samuel Courtaulds, Ltd., became interested in the development of the viscose process of rayon manufacture. While development started in the Courtauld factories in England in the early part of the twentieth century, the company established a branch in the United States in 1910, the Viscose Co., by far the largest producer of rayon in the United States.

310. The dominant firm in the German rayon industry is the Vereinigte Glanzstoff-Fabriken. While this company uses the viscose process, it controls the J. P. Bemberg A.G., leading producers of cupra-ammonium rayon, and is also interested in a plant producing acetate rayon. This company has built two plants in the United States. The American Glanzstoff Corporation began operation in 1928 at Elizabethton, Tenn., producing viscose rayon, while the American Bemberg Corporation produces cupra-ammonium rayon at Johnson City, Tenn.

311. The leading French producer of rayon is the Comptoir des Textiles Artificiels which, with E. I. du Pont de Nemours & Co., formed the Du Pont Fibersilk Co. in 1920. Later, this became the Du Pont Rayon Co. with present plants at Buffalo, N.Y.; Old Hickory, Tenn.; and Richmond and Waynesboro, Va. Cellulose-acetate yarn, to be produced at the last-named plant, will be made according to patents controlled by the Soie Rhodiaseta, a French company. The Du Pont Rayon Co. is considered a 100 percent American firm.

312. The Tubize Artificial Silk Co., with plant at Hopewell, Va., was organized by the Fabrique de Soie Artificielle de Tubize of Belgium to manufacture cellulose-nitrate rayon. All patent rights were purchased, however, by the American company and it now operates as an independent plant.

313. The Snia Viscosia of Italy was in part responsible for the establishment of the Industrial Rayon Corporation, of Cleveland, Ohio, and Covington, Va., but this company is now operating as an American factory under American control.

314. Other United States plants sponsored by European rayon manufacturers are:

American Chatillon Corporation, representing the Soie de Chatellon, of Italy; American Enka Corporation, representing the N. V. Nederlandsche Kunstzijdefabrick, of Holland; Celanese Corporation of America, subsidiary of British Celanese, Ltd., England.

AMERICAN RAYON COMPANIES

315. The basic patents for viscose rayon, cellulose nitrate, and cupra-ammonium rayon have expired, while some patents concerning these processes and the acetate process are made accessible to all by the Chemical Foundation. Many new patents have been taken out covering all phases of manufacture and new processes are being investigated by all large companies, so that European producers still own patent rights controlling many phases of various processes and American firms must pay royalties for the privilege of using them. However, the firm hold rayon has taken in the American market has led a number of new producers to enter the field in the last few years. While production was less in 1930 than in 1929, the manufacture of rayon in this year is listed by firms in order that new plants may be included.

Rayon manufacturers in United States in 1930

Firm name	Plant location	Process used	Estimated production, 1930 [1]
			Tons
Viscose Co.	Marcus Hook, Pa.	Viscose	22,500
	Lewistown, Pa.	do	
	Roanoke, Va.	do	
	Parkersburg, W.Va.	do	
	Meadville, Pa.	Acetate	
	Nitro, W.Va.	Cotton linters treatment plant.	
Du Pont Rayon Co.	Buffalo, N.Y.	Viscose	9,250
	Old Hickory, Tenn.	do	
	Richmond, Va. (new)	do	
	Waynesboro, Va.	Acetate	
Industrial Rayon Corporation	Cleveland, Ohio	Viscose	5,000
	Covington, Va. (new)	do	
Celanese Corporation of America	Amcelle, Md.	Acetate	5,000
Tubize Artificial Silk Co.	Hopewell, Va.	Nitrocellulose	4,925
American Glanzstoff Corporation	Elizabethton, Tenn.	Viscose	3,500
American Enka Corporation	Asheville, N.C.	do	3,000
Tennessee Eastman Corporation	Kingsport, Tenn.	Acetate	[2] 1,250
American Bemberg Corporation	Johnson City, Tenn.	Cupra-ammonium	1,000
Skenandoa Rayon Corporation	Utica, N.Y.	Viscose	1,000
Delaware Rayon Corporation	New Castle, Del.	do	875
Belamose Corporation	Rocky Hill, Conn.	do	800
Amoskeag Manufacturing Co.	Manchester, N.H.	do	750
New Bedford Rayon Co.[3]	New Bedford, Mass.	do	700
Woonsocket Rayon Co.	Woonsocket, R.I.	do	643
Acme Rayon Corporation	Cleveland, Ohio	do	483
American Chatillon Corporation	Rome, Ga.	Nitrocellulose; viscose	[4]
A. M. Johnson Rayon Mills, Inc. (new).	Burlington, N.C.	Viscose	500
The Rosland Corporation	Paterson, N.J.	Cupra-ammonium	[5]
The Furness Corporation	Gloucester, N.J.	do	[5]
Napon Rayon Corporation	Clifton, N.J.	do	[5]

[1] "Textile World", Feb. 7, 1931.
[2] Started operations October 1930. Capacity, when completed, will be 1,250 tons.
[3] Owned by Delaware Rayon Corporation.
[4] Included in Tubize Artificial Silk Co.'s figures.
[5] Production only beginning or plant still operating on laboratory scale.

316. The production of principal companies is given in the following table for the last 6 years.

TABLE XXI.—*United States rayon production, by companies, from 1924 to 1929*[1] [2]

[Short tons of rayon]

Company	1929	1928	1927	1926	1925	1924
Totals	61,565	48,851	37,525	31,288	26,105	19,425
The Viscose Co	31,000	27,000	20,500	18,500	17,500	14,000
Du Pont Rayon Co	12,250	9,116	7,550	5,450	3,381	2,000
Tubize Artificial Silk Co	4,375	4,250	3,750	3,500	2,600	2,125
Industrial Rayon Corporation	2,688	2,125	1,725	1,700	1,125	1,000
Celanese Corporation of America	3,500	2,500	1,750	1,250	750	.....
American Glanzstoff Corporation	1,925	175	.....	.....	.....	.....
American Bemberg Corporation	1,150	1,050	175	.....	.....	.....
Delaware Rayon Co	1,000	750	250	.....	.....	.....
Belamose Corporation	750	690	700	438	338	.....
American Enka Corporation	312	.....	.....	.....	.....	.....
Skenandoa Rayon Corporation	665	575	500	.....	.....	.....
Acme Rayon Corporation	450	370	250	200	161	.....
New Bedford Rayon Co	250	.....	.....	.....	.....	.....
American Chatillon Corporation	750	.....	.....	.....	.....	.....
Other companies	500	250	375	250	250	300

[1] Compiled from The Rayon Industry, by Mois H. Avram, 1929; Rayon Year Book, by Textile World, 1930; Textile World, Feb. 7, 1931.

[2] Total United States production for prior years were: 1923, 17,700 tons; 1922, 12,200 tons; 1913, 800 tons. Estimated production for 1930 is 59,500 tons.

317. *Rayon production compared with consumption.*—In 1914, we produced 1,200 tons of rayon and consumed twice as much. At the close of the World War, or in 1919, consumption had almost doubled while production increased two and a half times. From 1919 on, both production and consumption of rayon in the United States have increased steadily through 1929. But in each year consumption has exceeded production in the United States. In the latter year, we consumed 72,443 tons of the fiber, of which we manufactured 61,565 tons. While 1930 production is estimated to be less than 1929, this is to be expected in view of the lessened production in all consuming textile industries.

318. The United States consumed about 38 percent of the world's rayon and manufactured 32 percent. Its imports, therefore, amounted to over 10,000 tons. The table following lists the countries of export. It is amazing to see the number of countries prepared to supply this market with this relatively new textile material. The United States exports little rayon, although it does export some finished rayon articles.

TABLE XXII.—*United States imports of rayon in 1929 by country of origin*[1]

Imported from—	Tons[2]	Imported from—	Tons[2]
Total	10,878	Austria	200
		Belgium	185
Germany	3,227	Australia	46
Italy	2,038	British India	26
France	1,889	Hungary	21
Netherlands	1,227	Sweden	19
Switzerland	1,087	Czechoslovakia	17
Great Britain	427	Brazil	16
Japan	236	Others	12
Canada	203		

[1] Compiled from U.S. Department of Commerce, Foreign Commerce and Navigation, 1928, 1929.

[2] Includes waste, and yarns made from waste.

319. The reason for this is made obvious by a study of table XXII. In all large rayon producing European countries the production of rayon exceeds its consumption. While Italy, the world's second largest manufacturer of rayon, produces approximately 25,000 tons, she consumes but 9,500 tons. Although France manufactures 19,000 tons of rayon, she consumes but 13,600 tons; Great Britain produces 24,000 tons and consumes 21,000 tons; Germany, 22,000 tons produced and 21,000 tons consumed with exports of 9,500 tons and imports of 8,500 tons. Italy, Germany, Holland, and France are the chief exporting countries contributing about three fourths of the world's total exports. The only countries that consume noticeably more rayon than they manufacture, other than the United States, are Canada, South America, Australia, India, China, Spain, Sweden, Hungary, and Czechoslovakia.

TABLE XXIII.—*World production and consumption of rayon in 1929* [1] [2]

[In short tons]

Country	Production	Consumption	Imports	Exports
Total	194,465	189,768	50,353	55,050
United States	61,565	72,443	[3] 10,878	
Great Britain	24,250	21,375	1,125	4,000
Germany	22,000	21,000	8,500	9,500
France	19,000	13,625	625	6,000
Italy	25,000	9,500	500	16,000
Japan	7,000	7,000		
China		6,500	6,500	
Belgium	8,000	5,450	450	3,000
Spain	1,500	3,750	2,250	
India		3,750	3,750	
Switzerland	6,000	3,600	1,600	4,000
Canada	1,875	2,625	750	
South America	500	3,500	3,000	
Czechoslovakia	2,000	3,500	2,250	750
Holland	10,000	2,000	1,000	9,000
Poland	2,750	2,500	750	1,000
Australia		1,500	1,500	
Austria	2,000	1,500	1,000	1,500
Sweden	175	1,050	875	
Hungary	350	750	700	300
Others	500	2,850	2,350	

[1] Compiled from Rayon Year Book, Textile World, Feb. 7, 1930, and U.S. Bureau of Foreign and Domestic Commerce, Foreign and Domestic Commerce.
[2] Including estimate of 1928 excess production absorbed in 1929.
[3] Includes waste and yarn made from waste.

320. *The rayon market.*—The first quantitative use of rayon in the hosiery industry occurred in 1912. In the first years of the industry's expansion, hosiery took the major part of the production while plushes and cotton goods consumed about 15 percent each. Gradually its use in knit underwear expanded until latest figures indicate that about 29 percent of all rayon consumed in the United States enters into knit underwear, while 21 percent is manufactured into hosiery. Other knit goods, such as sweaters and ties, take 4 percent. The cotton industry weaves rayon into tablecloths, bedspreads, and numerous other cloths, so that it takes about 22.5 percent of our rayon, while the silk manufacturers consume 14 percent in the manufacture of silk goods, and the wool weavers 1 percent. Or, over three fourths of all rayon is consumed by knit-goods and cotton-goods manufacturers.

321. While viscose yarns have a wide market, some of the larger producers of other types of rayon have endeavored to meet specialized

demands. The first acetate rayon firm has featured fine dress materials, a nitrocelulose company has supplied the outer knit-goods market, and a cupra-ammonium rayon firm is centering on hosiery.

322. The following table indicates the consumption of rayon in the several States in the knit-goods and cotton-goods industries, as compiled from United States Census Reports. While this table accounts for only two thirds of the rayon produced, the complete figures would not change the relative importance of consuming centers. There has been a marked tendency for hosiery mills to locate near rayon-producing plants. This accounts for the growth in knit-goods manufacturing in North Carolina, Tennessee, and Virginia.

TABLE XXIV.—*Consumption of rayon by States* [1]

[Based on two thirds of the total consumption for 1927]

State	Total		Rayon used in knit-goods industry (short tons)[2]	Rayon used in cotton-goods industry (short tons)[3]
	Short tons	Percent		
Total [4]	30,741	100.0	17,339	13,403
New York	6,696	21.8	6,696	----------
Pennsylvania	5,712	18.6	2,944	2,768
Massachusetts	5,204	16.9	983	4,221
North Carolina	3,979	13.0	2,111	1,868
Rhode Island	1,914	6.2	340	1,574
Tennessee	1,086	3.5	1,086	----------
Connecticut	827	2.7	----------	827
South Carolina	798	2.6	----------	798
New Jersey	780	2.5	661	119
Virginia	753	2.5	697	56
Other States	2,992	9.7	1,821	1,172

[1] Compiled from U.S. Bureau of the Census, Census of 1927.
[2] Includes hosiery, underwear, and sweaters.
[3] Approximate.
[4] This total represents over four fifths of the total United States production for 1927, and about two thirds the total consumption for that year.

EXPORTS

323. Very little rayon yarn and thread is exported. In 1929 the total was 120 tons valued at $340,109. This was shipped principally to Mexico, Germany, and Canada, with smaller amounts to Venezuela, Cuba, and Peru. About $7,000,000 worth of rayon manufactures was exported in 1929. These consisted of dress and piece goods, hosiery, underwear, ribbons, braids, and trimmings, tapestry and drapery fabrics, etc., and went chiefly to Cuba, Canada, Mexico, Colombia, Philippines, and South Africa.

324. The table following shows the exports in detail:

TABLE XXV.—*Exports of rayon yarn and manufactures in 1929* [1]

Exported to—	Total value	Yarn and thread		Dress and piece goods, value	Hosiery, value	Underwear, value	Ribbons, braids, and trimmings, value	Tapestry and drapery fabrics, value	Other rayon manufactures, value
		Pounds	Value						
Total	$7,222,686	120	$340,109	$2,295,355	$3,200,488	$407,678	$106,518	$81,398	$791,140
Canada	1,521,934	15	57,199	514,961	441,684	48,303	49,089	47,986	362,702
Cuba	1,135,520	6	15,027	480,863	482,142	98,804	13,853	5,327	39,504
Mexico	678,587	42	130,128	372,334	34,298	7,761	1,851	8,232	123,980
Philippines	450,343	3	10,518	123,859	210,868	2,399	26,221	192	76,286
Columbia	425,731	3	8,981	115,209	262,261	25,285		1,474	12,524
South Africa	322,425	(2)	69	3,265	246,031	70,203	1,368		1,489
United Kingdom	172,601	(2)	3,024	76,978	66,341	1,054	1,628		23,576
Australia	163,090	1	10,667	56,189	70,074	423	5,997	5,377	14,363
Panama	161,049	(2)	359	34,958	80,299	22,972	108	752	21,601
Guatemala	125,925	1	3,575	62,437	46,045	3,288		913	9,667
Netherlands	100,253	(2)	125	3,119	95,835	955		196	23
Egypt	99,582			215	98,417	112			838
Argentina	94,262	(2)	2,894	9,918	51,737	24,760		1,028	3,925
Venezuela	93,539	8	19,893	29,615	36,741	1,498			5,792
Peru	55,142	6	20,643	2,386	27,203	921	25	1,705	2,259
Germany	54,596	28	42,087	1,411	2,405	42	2,317	320	6,014
China	32,767	(2)	1,750	1,610	21,364	6,411	108		1,524
Other countries [3]	1,535,337	3	13,170	406,028	926,743	92,487	3,950	7,886	85,073

[1] Compiled from U.S. Department of Commerce, Foreign Commerce and Navigation.
[2] Less than 1 ton.
[3] Principally to Central America, West Indies, and Jamaica, Java, and New Zealand, British India, and Syria.

THE CELLULOSE LACQUER INDUSTRY

325. *Production.*—Nitrocellulose lacquer production has increased over 400 percent since 1914. The growth of this industry is shown by the following data taken from the United States Census of Manufactures and from estimates of Chemical and Metallurgical Engineering:

Total production

Year	Gallons	Value	Year	Gallons	Value
1914	852,571	$1,308,796	1925	12,265,206	$27,254,796
1919	500,061	923,464	1927	30,836,168	60,269,673
1921 [1]	1,409,280	3,093,862	1929 [2]	41,000,000	
1923 [1]	3,255,857	6,944,366			

[1] Not strictly comparable with figures for 1925 and 1927. Does not include data for "thinners."
[2] Estimated.

326. Unlike the plastic industry, cellulose lacquers are manufactured by a number of firms. These firms buy the nitrocellulose and mix it with camphor and various solvents and pigments to produce quick-drying nitrocellulose lacquers. As these lacquers replaced the oleoresinous varnish and varnish enamels for automobiles and other finishes, their manufacture has been largely taken up by paint and varnish manufacturers since 1921, following upon the initial success of firms manufacturing the nitrocellulose and the lacquers.

327. The principal nitrocellulose lacquer producing States are New Jersey, Michigan, Ohio, and Illinois, although substantial production occurs in all sections of the country.

TABLE XXVI.—*United States production of cellulose lacquers in 1927 by States* [1]

State	Total		Lacquer enamels		Clear lacquers		Lacquer thinners	
	Gallons	Value	Gallons	Value	Gallons	Value	Gallons	Value
Total	30,836,168	$60,269,673	10,757,852	$30,187,332	7,738,079	$15,721,249	12,340,237	$14,361,092
New Jersey	8,962,312	18,436,769	2,825,324	9,197,745	1,943,997	4,382,154	4,192,991	4,856,870
Michigan	5,626,573	10,339,050	2,392,794	6,308,494	348,914	847,592	2,884,865	3,183,564
Ohio	3,674,958	7,043,907	1,409,527	3,302,150	1,070,504	2,326,945	1,194,927	1,414,512
Illinois	3,590,000	7,130,965	1,149,252	3,195,974	1,308,920	2,334,039	1,131,828	1,600,952
New York	1,791,961	3,738,327	586,456	1,650,482	745,018	1,439,855	460,487	647,990
Massachusetts	1,076,317	1,882,184	120,738	398,575	511,963	914,116	443,616	569,493
Kentucky	913,169	1,455,808			913,169	1,455,808		
California	778,706	1,305,072	287,639	699,901	160,604	260,671	330,463	344,500
Pennsylvania	767,329	1,523,173	530,351	1,094,445	108,691	235,538	128,287	193,190
Indiana	511,707	1,101,847	121,410	302,060	390,297	799,787		
Wisconsin	298,772	890,543	298,772	890,543				
Maryland and Missouri	1,476,069	2,020,100	[2] 158,962	538,046	[2] 149,527	514,615	1,167,580	967,439
Others	1,368,295	3,401,328	876,627	2,608,617	86,475	210,129	405,193	582,582

[1] Compiled from: U.S. Bureau of the Census, Census of Manufactures, 1927.
[2] Missouri only.

328. *Markets.*—Nitrocellulose lacquers found a ready market in the automobile industry, where quantitative production demanded a quick-drying finish. It is estimated that the consumption of cellulose lacquer in this industry in 1929 amounted to approximately 26,000,000 gallons. Their use has been extended to rolling stock of railroads, to finishing machinery, to such household articles as refrigerators, bathroom fixtures, porch furniture, and other furniture exposed to hard wear. The expansion and contraction of wood, however, has limited its extensive use in wood finishing. Consequently, nitrocellulose lacquer is sometimes mixed with synthetic resin lacquers.

329. Competition is also growing through the development of quick-drying synthetic resin varnishes and through the electroplating of metals and coating of other materials with plastics, so that lacquers, paints, or varnishes are no longer employed on a number of articles of commerce.

BIBLIOGRAPHY

PULP AND PAPER

Year	Author	Title
1924	Augustus, Ernest	Our Mill.
1923	Benson, H. K	Chemical Utilization of Wood in Washington.
1930		Paper Industry Demonstrates Its Appreciation of Science, Chemical and Metallurgical Engineering, January.
	Clapperton, Robert H., and Henderson, William.	Modern Paper Making.
1926	Hawley, L. F., and Wise, L. E	The Chemistry of Wood.
1921	International Paper Co	Newsprint.
1923	Kellogg, Royal S	Pulpwood and Woodpulp in North America.
1929–1930	Lockwood Trade Journal Co	Directory of Paper and Allied Trades.
1930		Paper Production Estimates, Paper Trade Journal, Dec. 25.
1930		Cost of Manufacture, Paper Trade Journal, Feb. 2.
1928		Making Board from Cornstalks, Paper Trade Journal, Oct. 30.
1930		Power Plant Engineering, Sept. 15.
1925	Rogers	Manual of Industrial Chemistry.

BIBLIOGRAPHY—Continued

PULP AND PAPER—Continued

Year	Author	Title
1928	Rommel, George M.	Farm Products in Industry.
	U.S. Department of Agriculture	Farm Wastes for Paper and Board Making
1930	do	Agricultural Year Book.
1928	Forest Service	American Forest and Forest Products, Statistical Bulletin No. 21.
1927	do	The Suitability of American Woods for Paper Pulp, Bulletin No. 1485.
1924	do	How the United States Can Meet Its Present and Future Pulpwood Requirements, Bulletin No. 1241.
1928	do	Lumber Used in Manufacture.
1924	do	Report of the National Conference on Utilization of Forest Products.
	U.S. Department of Commerce:	
1928, 1929	Bureau of Foreign and Domestic Commerce.	Foreign Commerce and Navigation of the United States.
1919, 1927, 1929	Bureau of the Census	Census of Manufactures.
1917, 1930	Federal Trade Commission	Report on Newsprint Industry.
1917	do	Report on Book Paper Industry.
	U.S. House of Representatives	Hearings Before the Committee on Ways and Means, Tariff Readjustment.
1921	do	Part IV.
1929	do	Vol. I., vol. XIII, vol. XV.
1928	U.S. Chamber of Commerce	Commercial Utilization of Certain Agricultural Wastes and By-Products.
1929	Sutermeister, Edwin	Chemistry of Pulp and Paper Making.
1927	do	Casein and Its Industrial Applications.
1930	Sweeny, O. R., and Arnold, Lionel	Production of Paper from Cornstalks.
1916	Weeks, Lyman, H.	History of Paper Making in United States.
1920	Witham, G. S., Sr.	Modern Pulp and Paper Making.
	Zon and Sparhowk	Forest Resources of the World.

OTHER CELLULOSE DERIVATIVES

1929	Avram, M. H.	The Rayon Industry.
	Cross and Bevan	Researches on Cellulose.
1931		Economic Problems Now Hold Ascendancy in Rayon, Chemical and Metallurgical Engineering, January.
1931		Plastics Use Moderate, Decline to Plan Ahead, Chemical and Metallurgical Engineering, January.
1930		Plastics New Fields Incite Multiplied Output, Chemical and Metallurgical Engineering, January.
1930		Rayon Increases 35 Percent in 1929, Chemical and Metallurgical Engineering, January.
1929	Darby, W. D.	Rayon and Other Synthetic Fibers.
1929	Plastic Publications	Plastics, Directory and Guide.
1928	The Silk Journal	The Artificial Silk Handibook.
1928	Smith, Stanley	The Cellulose Lacquers.
1928, 1929, 1930	Textile World	Rayon Year Book.
	U.S. Department of Commerce:	
1929	Bureau of the Census.	Census of Manufactures.
1929	Bureau of Foreign and Domestic Commerce.	Foreign Commerce and Navigation of the United States.
1929	U.S. House of Representatives	Hearings before the Committee on Ways and Means, Tariff Readjustment, vol. XII.
1929	U.S. Senate	Hearings before a Subcommittee of the Committee on Finance, Tariff Act of 1929, schedule 13, on H.R. 2667.
1929	U.S. Tariff Commission	Summary of Tariff Information, schedule I.
1928	The Viscose Co.	The Story of Rayon.
1925	Wilson, Samuel P.	Pyroxylin Enamels and Lacquers.
1931		Textile World, Feb. 7.

THE ELECTRIC FURNACE IN THE IRON AND STEEL INDUSTRY

CONTENTS

	Page
Present application of the electric furnace in iron and steel production	385
Electric furnace in reduction of iron ore	385
Electrothermal reduction	387
Foreign operating furnaces	387
California experiment	388
Low temperature reduction methods	388
Electrodeposition of iron	388
Electric iron castings	389
Production methods	389
Cost of production	389
Electric furnace production of ferro-alloys	390
Importance of ferro-alloys in steel manufacture	390
Power consumption and production costs	390
Ferrosilicon	390
Ferromanganese	391
Ferrochromium	391
Ferromolybdenum	392
Ferrovanadium	392
Ferrotungsten	392
Ferrouranium	393
Ferrotitanium	393
Electric furnace steel	393
Melting, refining, and super-refining	393
Types of furnaces used	394
Power consumption	395
Costs of production	395
Electric heat treatment and welding of steels	396
Types of furnaces and power consumption	396
Costs	397
Electric welding	398
Ore resources essential to iron and steel production	398
Iron ore deposits and production	398
Lake Superior reserves	399
Eastern reserves	399
Western reserves	400
Other American deposits	401
European iron reserves	401
Chinese reserves	401
World iron ore and pig iron production	402
Coke production and coal resources	403
State production of coal and coke	403
Western coal resources	404
Limestone and silica	405
Manganese ore reserves	405
Western reserves	406
South Atlantic resources	407
Low-grade manganiferous and ferruginous ores	407
Foreign reserves	408
Chrome ore	408
Production and imports	408
Deposits in western United States	408
Foreign reserves	409
Tungsten ores	410
Molybdenum ores	410
Vanadium ores	411
Uranium	411
Zirconium	412
Titanium	412
Production of ferro-alloys and iron and steel	412
Ferro-alloy manufacture	412
Development of industry	412
Producers of ferro-alloys	413
Kind and amount manufactured	414

CONTENTS—Continued

Production of ferro-alloys and iron and steel—Continued	Page
Pig-iron and steel-ingot and castings production	415
Pig iron produced in each State	415
Increase in electric furnace production of steel ingots andcasti ngs	416
Alloy steel-ingot and castings production	417
Total ingot and castings plant capacities and electric-furnace capacities in each State	417
Principal iron and steel companies	418
Western iron and steel works and rolling mills	419
Oregon and Washington foundries	420
Rolled iron and steel products	420
Steel markets	422
Domestic markets	422
Pacific coast production and consumption	423
Exports and imports	424
Ferro-alloys	424
Semifinished steel	424
Rolling-mill products	424
Bibliography	425

Demand for electricity is rapidly increasing in iron and steel and related industries. Ferro-alloys, all of which are electric-furnace products except ferromanganese, are now applied in small amounts to almost all steels for gas and impurity elimination. The growing use of alloy steels, in which ferro-alloys are used in larger quantities, has not only added to current requirements by increasing ferro-alloy manufacture, but also has extended the use of the electric furnace in alloy-steel ingot manufacture. The nonoxidizing atmosphere of the electric furnace is increasing its employment in melting steel scrap for castings. There is a marked tendency toward the use of electric furnaces in heat treatment of steels and an increasing application of electric arc welding. The electrification of mechanical operations in steel and rolling mills is progressing rapidly.

Electric-furnace production of ferro-alloys has developed as an industry distinct from the steel industry. Blast-furnace manufacture of ferromanganese is carried on in large measure by iron and steel producers. Ferrosilicon forms about 40 percent of all ferro-alloy manufacture. Its production increased 12 percent between 1928 and 1929. The manufacture of electric ferrosilicon in the United States in 1929 required approximately 1,000,000,000 kilowatt-hours of energy. Other electric furnace ferro-alloys were less than 5 percent of the total ferro-alloy tonnage in 1929, but this manufacture represented an increase of 24 percent in 1 year. The electricity consumed in this production exceeded 260,000,000 kilowatt-hours. While ferromanganese is produced in the blast furnace in the United States, the 78,000 long tons imported from Canada and Norway were electric furnace made. Had it been economically profitable to manufacture all ferromanganese consumed in the United States in the electric furnace, power to the extent of over 4,000,000,000 kilowatt-hours would have been consumed in such manufacture.

One percent of all steel ingots produced in 1929 in the United States was melted or refined in the electric furnace; this represented a 17-percent increase over 1928. The larger part of electric-furnace ingot production was alloy steel. While 26 percent of all iron and steel castings were melted in the electric furnace, almost 50 percent of those

alloyed were melted in this nonoxidizing furnace. Electric-furnace production of iron and steel ingots and castings consumed almost 400,000,000 kilowatt-hours of power in 1929. Steel annealing or steel hardening in electric furnaces added approximately 200 kilowatt-hours of energy per ton so annealed or hardened.

Although iron ore has been reduced to wrought iron and to steel of high quality in the electric furnace, such reduction has not been able to compete with blast-furnace practice. Some metallurgists believe that the depletion of Lake Superior hematite iron ores in about 30 years will result in the development of the country's magnetite iron-ore deposits and in their reduction by low-temperature processes. Such processes may be all electric, or preheating may be done in a rotary fuel furnace followed by melting and refining in an electric furnace. Present experiments place the energy requirements of the duplex process at less than 400 kilowatt-hours for 1 ton iron and at 600 to 850 kilowatt-hours per ton of steel. Some steel producers believe iron ore will be secured from South America and China and that blast furnace practice will continue but move nearer the coast.

Major operating units of the iron and steel industry were located near coking-coal supplies; ferro-alloy factories located near hydroelectric developments. As approximately 5.5 tons of raw materials and supplies enter into 1 ton of finished steel according to present practice, transportation costs become an important factor in present production costs.

The principal raw materials for pig iron are iron ore, coke, and limestone; for ferro-alloys, silicon, manganese, chromite, tungsten, vanadium, molybdenum, titanium, uranium, and zirconium. Limestone and silicon quartz are found in abundance in this country. Seven eights of all iron ore now comes from the Lake Superior region, a region without coking coals. The principal coking coal fields are in western Pennsylvania, a section without iron ore. Only in Alabama are coking coal and iron ore produced in adjacent fields. Manganese ore is imported chiefly from Soviet Russia, Brazil, India, and British West Africa; chromite is shipped from Rhodesia and Cuba; tungsten comes from China; vanadium from Peru; and uranium from the Belgian Congo.

Although some iron ore is mined in Wyoming, Utah, Colorado, and Washington, and a market for magnetite ores would materially add to the amounts available in Pacific Coast and Rocky Mountain States, the only western State now believed to have extensive and rich iron-ore deposits is Wyoming. Washington, Colorado, and Utah produced coke from their respective bituminous coal fields in 1929. These States have some excellent deposits of coking coal. Although Wyoming has large reserves of high-grade bituminous coal, this is not regarded as coking coal.

The small amounts of manganese ore produced in this country were mined in Montana, Arizona, Arkansas, Virginia, and Georgia. While deposits containing 35 percent or more manganese are not extensive in the United States, large reserves of lower grade ores are found in Washington, California, Nevada, Arizona, New Mexico, Montana, Colorado, and in Minnesota. Efforts to concentrate these ores to the grade demanded by the steel manufacturers are reported to be at the trial commercial plant stage.

California is the only State producing chromium. Deposits are numerous in California and in Oregon, while Washington and Wyoming have some known reserves. Tungsten is found in Colorado, Nevada, Arizona, New Mexico, California, Washington, and South Dakota. The largest known reserves of uranium and vanadium ores are in Colorado and Utah; Colorado also has largest molybdenum deposits, although these three minerals are also found in other Pacific Coast and Rocky Mountain States.

When the World War cut off our imports of these alloying minerals and of ferro-alloys, the Nation turned to the Pacific coast and to the Rocky Mountains for ferro-alloy materials.

At present, the market for ferro-alloys is in Pennsylvania and Ohio, where almost 60 percent of all steel is produced. The market for finished steel is also largely centered in Atlantic Coast and Lake States. The Pacific coast consumes approximately 2,500,000 tons of steel out of a total consumption of 56,000,000 tons. Only a sixth of Pacific coast demands are met by Pacific coast steel works. While these works fill approximately 60 percent of orders for merchant bar, they do not produce pipe for local oil, gas, and water companies; they produce only a small part of the tin plate for the Pacific coast canning industry. The growing demand of food industries for stainless steel, a chromium steel alloy which resists acids and salts, should interest Pacific coast mining and metal manufacturing, canning, and packing industries. The export market for United States steel products is largely in Canada, the Orient, our own insular possessions, and in South and Central America.

The Electric Furnace in the Iron and Steel Industry

THE ELECTRIC FURNACE IN REDUCTION OF IRON ORE

1. The reduction of iron ore in an electric furnace has been the object of much research. Iron and steel of highest quality have been produced in such a furnace both in this country and abroad. But only in Norway, Sweden, and Italy is electric-furnace iron being produced on a commercial scale. At present, it is claimed that there is so small a market for electric-furnace iron or steel in this country that such iron and steel cannot be produced in sufficient quantity to permit a satisfactory market price.

ELECTROTHERMAL REDUCTION

2. *Foreign operating furnaces.*—In Scandinavian countries, magnetite is the chief iron ore smelted; the furnace is the shaft type "Gronwall Electrometal." In this furnace, there is an arched smelting chamber surmounted by a shaft. Six electrodes extend into the ore and charcoal charge; they are supplied with 3-phase current from 3 transformers. Furnace gases are withdrawn from the top of the furnace, washed, and recirculated through the ore to aid in its reduction. The electric energy required in 4,000-horsepower furnaces of this type was between 2,000 and 2,500 kilowatt-hours per ton of iron, dependent upon the kind of iron made and the percentage of iron in the ore. While Swedish furnaces use about 0.4 ton of charcoal per ton of iron produced as the reducing agent, in Italy, coke is used in the charge.

3. *California experiment.*—Experiments were carried on at Pitt River in Shasta County, Calif., from 1907 to 1914. Very pure magnetite was available here, as was limestone. Charcoal was brought by rail. Silica had to be added to make a slag. A rectangular furnace was employed. In a furnace of 3,000 kilowatts, 2,200 kilowatt-hours were required per ton of pig iron. Operations were discontinued when the charge for power was raised from $12 to $25 per horsepower year, although some pig iron was again produced in 1918.

4. *Low temperature reduction methods.*—Some metallurgists are of the opinion that the rapid depletion of hematite ores in the Lake Superior region will bring about the development of the country's deposits of magnetite and pyrrhotite, ores not desirable for standard blast-furnace reduction but which lend themselves to low temperature-reduction methods. The processes patented for the reduction of magnetite ore employ a rotating tube or kiln form of furnace. The ore is reduced by carbon which is either mixed with the ore charge or by passing hydrocarbon gases through the charge. The oxide in the iron ore is reduced by carbon monoxide at a temperature of from 600° to 900° C. An electric furnace may be used to finish the metallic sponge, the gases formed in this furnace being employed to reduce and preheat the ore in the first rotary furnace. Or the magnetite may be fed into an electrically heated tube, electrical contacts of nichrome being used for heating. Crude oil is sprayed upon the magnetite which, upon gasification, serves to reduce the iron oxides.

5. It is claimed that if the carbon and magnetite ore is preheated before entering the electric furnace, less than 400 kilowatt-hours will be necessary for a reduction to sponge iron, and that only from 600 to 850 kilowatt-hours are required to produce 1 ton of steel. If, however, a standard type arc furnace is employed, about 2,000 kilowatt-hours are required per ton of steel produced.[9]

6. *Hydrogen in place of carbon monoxide.*—While iron ores are reduced by carbon monoxide, it has been established that hydrogen effects reduction of hematite ores more readily and at as low a temperature as 700° C. Hydrogen has not been applied because it has been too costly. Where byproduct hydrogen is available as at electrolytic caustic-soda plants, such application may become feasible as the hydrogen not only reduces the iron but removes phosphorus and sulphur in gaseous form.

7. *Electrodeposition of iron from iron ore.*—Other metallurgists are working upon the electrodeposition of iron from iron ore. The iron ore is placed in vessels through which an acid solution is circulated. Either a soluble or insoluble anode is used. The cathode revolves. It is estimated that at Grenoble, France, over 900 kilowatt-hours were required to deposit 1 ton of iron. Experiments have been under way at Emeryville, Calif.

8. *Electrodeposition of iron from scrap or cast iron.*—Electrolytic iron has been in use for magnetic purposes for a number of years. Only recently, however, has the process been extended to wider fields in the United States. The Niagara Electrolytic Iron Co. began the manufacture of iron tubes by electrodeposition in 1925 at Niagara Falls. Seamless tubes with very thin walls are produced.

[9] Smalley, Oliver, and Hodson, Frank, describe Pehrson-Prentice plant in Sweden and Scotland and Carsil process in paper presented before American Electrochemical Society, Apr. 28, 1927.

9. The cells are concrete troughs rendered waterproof with a liquid sulphur. The cathode is a revolving mandrel. Bars of cast iron placed below the cathode are the anode. Ferrous chloride forms the electrolyte. The current flowing from the anode through the electrolyte to the cathode deposits the iron on this revolving mandrel. When a desired thickness of deposit is obtained the mandrel is lifted out of the cell and the metal is annealed. The tube is then stripped from the mandrel which had been greased to facilitate this process. Final annealing takes place in an electric annealing furnace heated by nichrome-resistance elements to 1,900° F.

ELECTRIC IRON CASTINGS

10. The use of the electric furnace for the production of iron castings of superior strength and uniformity of grain is increasing in this country, especially for high-pressure valve castings and for castings suitable for severe service stress such as cylinder heads for Diesel engines. It is also being employed for alloy-iron castings the use of which is increasing.

11. *Production methods.*—Two methods of producing electric iron castings are employed. In one, the metal is first melted with a minimum of coke in a cupola. The molten metal is run into an electric arc furnace where desired alloy additions are made. After the metal reaches the desired temperature (1,385° to 1,550° C.), iron is tapped off. At regular intervals, fresh molten cast iron is added to the electric furnace. This process requires but approximately 115 kilowatt-hours per ton of iron employing a 3-ton furnace and 130 kilowatt-hours per ton with a 1-ton furnace. In the continuous melting process, a cold charge is melted directly in the electric furnace, the other steps being the same as in the Duplex process just described. About 550 kilowatt-hours are consumed by a 3-ton electric furnace for the second heat and about 650 kilowatt-hours for the first heat.

12. *Cost of production.*—The cost of manufacture of electric iron for stove plate by the continuous process is cited by G. I. Simpson, chief electrical engineer, Pittsburgh Furnace Corporation:

Cost per ton of electric iron

Scrap metal	$11.97
Alloys	1.27
Power	4.66
Refractories	.60
Electrodes	2.18
Water	.11
Melting loss	1.13
Furnace labor	1.08
Total cost of metal in ladle per ton [10]	23.00

13. As is pointed out by Mr. Simpson, when the cost of the continuous melting process and the Duplexing process are compared, it is not only the cost of electricity as compared with costs of coke and blast that must be considered, but the over-all investment, the floor space, the operating and maintenance labor costs, all of which are lower in the continuous process.

[10] Simpson, G. I., Electric Furnace Iron. Paper before American Electrochemical Society, May 1930.

The Electric Furnace Production of Ferro-Alloys

THE IMPORTANCE OF FERRO-ALLOYS IN STEEL MANUFACTURE

14. Ferro-alloys are essential raw materials in steel manufacture. They serve two functions: When added in small amounts, they act as scavengers removing undesirable elements from the steel; when added in larger amounts, they improve the properties of steel, forming alloy steels having varying characteristics.

15. *Scavengers.*—In open-hearth and Bessemer steel, oxygen or oxides are present in harmful quantities; by adding ferrosilicon, ferrozirconium, ferromanganese, or other alloys, the silicon, zirconium, and manganese unite with the oxygen, are precipitated out, and leave the steel. Sulphur is also eliminated by ferromanganese which is added to almost all steels now manufactured. Ferrosilicon is the principal deoxidizer employed in the open-hearth process and enters into 90 percent of all steel manufactured in the United States. Ferrozirconium, besides being a deoxidizer, is a corrective of nitrogen, sulphur, and phosphorus content. Calcium-silicon is often used after the application of cheaper ferro-alloys to remove the last traces of oxygen and sulphur.

16. *Alloy steels.*—When applied as alloys with steel, each ferro-alloy, or combination of ferro-alloys, imparts varying qualities to the steel. Steels containing 3.25 to 4.5 percent silicon have high magnetic permeability and high electrical resistance; they are manufactured into sheets for use in electrical apparatus. Duriron has 14 to 15 percent silicon and is used for castings which must resist acids and chemicals. Ferromanganese increases the strength and durability of steels. A steel containing 1.5 to 2 percent silicon and 1 to 2 percent manganese is made into springs.

17. Ferrochromium is applied to a number of steels in varying amounts. For heavy-duty machinery, metal-working steels, and for structural steels, from 1 to 2 percent chromium is used. High-speed tool steel contains approximately 4 percent, valve steel 7 to 9 percent chromium and 2.5 to 4 percent silicon. Stainless steel manufactured into cutlery contains 12 to 14 percent chromium. Tungsten is also added to high-speed steels in the proportion of 10 to 20 percent to maintain the cutting edge of steels at high temperatures. It is used in saw steels and in magnetic steels to increase the magnetic retentivity. Molybdenum, uranium, vanadium, titanium, tantalum, phosphorus, nickel, boron and aluminum ferro-alloys, in small amounts, add to the strength or increase other qualities imparted by the alloys used more extensively.

POWER CONSUMPTION AND PRODUCTION COSTS

18. Ferrosilicon and all other ferro-alloys, with the exception of ferromanganese, are electric-furnace products. Ferromanganese is a blast-furnace product although it can, of course, be produced in the electric furnace and is being so manufactured at Welland, Canada. As the production of ferrosilicon exceeds that of all other electric-furnace ferro-alloys, the process by which it is produced will be described first.

19. *Ferrosilicon.*—All ferrosilicon containing over 12 percent silicon is manufactured in the electric furnace. Open-top electric furnaces

are employed. Larger sizes have 3 carbon electrodes and take 3-phase current while smaller furnaces have but 2 electrodes and single-phase current. The electrodes for a 2,400 kilowatt-furnace are 24 inches by 8 feet in length and weigh over 2,000 pounds each. These electrodes hang above the furnaces and extend into the raw material to the depth of at least a foot. As the lower end is consumed, they are automatically lowered into the charge.

20. The charge to produce a 50 percent silicon alloy is generally composed of 50 percent silicon rock, averaging 98.5 percent silica, 27 percent coke breeze, and 23 percent steel turnings. Coke may be replaced by the cheapest carbonaceous material containing no phosphorus or arsenic. The silica is reduced to silicon by the coke at temperatures of about 6,000° F. It dissolves in the steel and is tapped from the furnace. The steel is necessary because the element silicon volatilizes at the temperature of its reduction and would be carried out of the furnace as a gas. When the alloy is cold, it is cleaned and broken into lumps for shipment to steel mills. Furnaces are charged and tapped at least every 2 hours.

21. The 50-percent grade ferrosilicon requires approximately 5,000 kilowatt-hours of energy, the 70-percent grade about 6,000-kilowatt hours. Power at $15 per horsepower-year forms about 20 percent of the cost of manufacture.

Estimated cost of producing 1 ton of 50-percent ferrosilicon

Electricity: 5,000 kilowatt-hours at $0.0023	$11.50
Quartz: 1.3 tons at $3.50	4.55
Coke: 0.7 ton at $2.75	1.93
Turnings: 0.6 tons at $9	5.40
Electrodes: 60 pounds at $0.07	4.20
Miscellaneous supplies	1.50
Labor	16.00
Capital charges on $50 per ton at 30 percent	15.00
Total	60.08

22. *Electric-furnace manufacture of ferromanganese.*—Ferromanganese, or the alloy containing about 80 percent of manganese, as well as spiegeleisen, the alloy with about 20 percent manganese, are usually manufactured in the blast furnace as the temperatures of the blast furnace are sufficient to reduce manganese ore or ferruginous manganese ores. When ferromanganese is produced in the electric furnace it is smelted with anthracite or coke, limestone and fluorspar being employed as fluxes. While iron is present in the ore, it may be necessary to add more iron trimmings. Graphite electrodes are consumed at a rate of 65 pounds per ton of ferromanganese. The current necessary to produce 1 ton of 75 percent ferromanganese is approximately 4,400 kilowatt-hours while the 80 percent grade may require as high as 6,600 kilowatt-hours.

23. *Ferrochromium.*—Chromite, or a chrome iron ore, is smelted with carbon in an electric furnace. The ore is usually self-fluxing although lime and fluorspar is sometimes employed. Carbon, equal to about 30 percent the weight of the ore, is mixed with chromite. A 60-percent ferrochromium requires approximately 6,000 kilowatt-hours of energy, while the 65 percent with an 80 percent recovery takes up to 9,000 kilowatt-hours. With power at $15 a horsepower-year, power costs from about 12 percent of the total cost of producing 60 percent ferrochromium.

24. The ores mined in California and Oregon contain a larger proportion of iron than those imported from Rhodesia or New Caledonia. Work undertaken on the electric-furnace smelting of these ores in 1918 developed more difficulties in securing a high chromium alloy with low carbon content. A ton of ferrochromium was produced containing 64 percent chromium and 5.6 percent carbon by the consumption of 7,200 kilowatt-hours of electricity. The charge was made up of 16,473 pounds of chrome ore, 4,215 pounds of coke, 452 pounds lime, 2,907 chromium slag, and 1,130 pounds of sand.[11]

25. *Ferromolybdenum.*—Molybdenite contains approximately 59.5 percent molybdenum and 40 percent sulphur, while wulfenite is made up of 26 percent molybdenum and 56 percent lead. The molybdenite is concentrated by flotation and wulfenite by ordinary milling methods. The wulfenite concentrate is treated with sodium sulphide forming sodium molybdate and lead sulphide, the latter going to the lead smelter. Either the concentrate molybdenite or the sodium-molybdate slag may serve as the concentrated ore for ferromolybdenum. These are smelted with carbon and lime, together with enough iron for the grade being manufactured, or with silicon. A single-phase electric furnace is used, a graphite electrode being suspended in the center. A 70 percent grade ferromolybdenum, made from molybdenite, required 8,000 kilowatt-hours per ton produced, while the same grade made from sodium molybdate required about 9,000 kilowatt-hours of energy.

26. The Climax Molybdenum Co., with plant at Langeloth, Pa., is manufacturing calcium molybdate by adding calcium chloride to sodium molybdate. They claim that calcium molybdate can be introduced directly to electric steel without being manufactured into ferromolybdenum.

27. *Ferrovanadium.*—Vanadium oxide, produced by a chemical process from the ore, is reduced in an electric furnace by silicon. Lime is added to flux the silica resulting from the oxidation of silicon while steel turnings are used to alloy with the vanadium. The resulting product containing 30 to 35 percent vanadium and 3 to 4 percent silicon requires about 6,800 kilowatt-hours of electricity per ton. The silicon content may be reduced by melting the electric furnace product with a vanadium oxide, lime, and fluorspar. Ferrovanadium may also be produced in an open-hearth furnace by use of aluminum shot, the alumina formed being slagged off by soda ash or fluorspar. Iron turnings are added.

28. *Ferrotungsten.*—Although tungsten powder is added directly to steel, it is more often applied as ferrotungsten. As tungsten has the highest known melting point of any metal, 3,350° C., or about 6,000° F., it is essentially an electric-furnace product. Concentrated ore is reduced by carbon in a small circular furnace having one electrode. Lime and fluorspar are employed as fluxes. The ores usually have sufficient iron content. The slag is poured off as it accumulates. The ferrotungsten is infusible; consequently, when a sizable button has been found, the furnace is cooled, torn down, and the button removed. This smelting process which produces a 70 to 75 percent grade of ferrotungsten requires about 4,200 kilowatt-hours per short ton. As this metal contains too much carbon, it is remelted

[11] Keeney, R. M., Manufacture of Ferro-Alloys, in Transactions American Institute Mining and Metallurgical Engineers, vol. LXII, 1920.

with an oxidizing charge. Usually tungsten ore concentrate and fluorspar are added to the ferrotungsten. This refining requires approximately 3,400 kilowatt-hours per short ton of metal. Or the manufacture of a ton of ferrotungsten from concentrated ore requires approximately 7,600 kilowatt-hours of electricity.

29. *Ferro-uranium.*—Ferro-uranium is used to only a limited extent in certain steels to increase toughness and elasticity. Uranium metal must itself be prepared in an electric furnace with carbon, calcium carbide, or silicon. Ferro-uranium has been obtained in an arc furnace by using a pure oxide of uranium and pure iron. A low-ash coke and lime and fluorspar were added. The hearth was water-cooled. From 6,000 to 10,000 kilowatt-hours of electricity have been required under varying conditions.

30. *Ferrophosphorus.*—Ferrophosphorus is a byproduct of the electric-furnace production of phosphoric acid. Over 200 pounds of 18 percent ferrophosphorus is obtained per ton of phosphoric acid when usual grades of phosphate rock and coke are employed. (See p. 173, Power in Fertilizer Material Production.) It is also manufactured in the blast furnace.

31. *Ferrotitanium.*—Ferrotitanium is obtained from titaniferous iron ores. These ores are heated in an electric-arc furnace to a temperature approaching 2,000° C. The ore, mixed with carbon, is usually placed on a bath of iron. The resulting product contains about 10 to 15 percent titanium and 5 to 8 percent carbon. While the carbon present does not interfere with the use of the ferrotitanium as a deoxidizer and nitrogen remover, it may be removed by the thermit process whereby powdered aluminum is mixed with the metal and ignited.

ELECTRIC FURNACE STEEL

32. More than a fourth of all steel castings manufactured in 1929 were produced in the electric furnace. About 1 percent of our steel ingots were made in the electric furnace. Yet the tonnage of electric steel ingots exceeded the tonnage of electric castings, for 532,392 long tons of electric steel ingots were produced as against 419,039 tons of electric steel castings in 1929.

33. *Melting in electric furnace.*—Production of steel in an electric furnace varies with the character of the charge and the type of steel to be made. It may be merely a melting process, where high grade steel scrap is charged and ferro-alloys may or may not be added. Some pig iron or iron ore may also be added if necessary, to lower the carbon content. After the molten steel has stood, impurities float on the surface and are removed. This molten steel may be poured into ingot molds or castings molds. An acid-lined furnace may be used for pure metal melting. The advantage of this process, as compared with open-hearth melting, is that oxidizing can be avoided more efficiently in the electric furnace. A steel results that is equal to the crucible furnace product. As electric-furnace melting is cheaper than crucible melting, the electric furnace has largely replaced the crucible furnace.

34. *Refining in electric furnace.*—Or the electric furnace may be used for refining an impure metallic charge. Steel scrap or pig iron containing more sulphur or phosphorus than is desired in the finished

steel is fluxed with limestone, 300 to 500 pounds being used for 6 to 8 ton charge of steel scrap while 600 to 800 pounds are necessary when some iron ore is employed. The furnace must have a basic lining; frequently burnt magnesite is employed. As the metal is melted, the limestone and oxide of iron will rise through the fluid metal forcing a slag to the top. Manganese and silicon are oxidized and join the slag. Phosphorus is then oxidized. This slag is skimmed off. Sulphur is removed by adding carbon to a slag containing no oxide of iron. Sometimes broken carbon electrodes are employed for this purpose and to raise the carbon content of the steel.

35. *Superrefining in electric furnace.*—Or the electric furnace may be used for a superrefining of steel from the open-hearth of Bessemer furnaces, replacing the old crucible furnace. It is less expensive to melt an impure charge in these furnaces than in the electric furnace; for, in the production of steel from pig iron, oxidizing conditions are essential to remove carbon. As the value of the electric furnace lies in its nonoxidizing atmosphere, it cannot oxidize out carbon without the addition of much steel scrap or ore. But after steel has been made in the Bessemer or open-hearth furnace, the electric furnace can remove oxides, sulphur, and dissolved gases from the molten metal more efficiently than other furnaces.

TYPES OF FURNACES USED

36. *Arc furnaces.*—Steel castings are usually melted in direct-heating arc furnaces in this country. The majority of such furnaces in use in 1929 had 3 tons or less capacity. The furnaces are boxlike in shape and, for the basic process, are lined with magnesite brick with an inner lining of calcined granular magnesite mixed with slag binder. Silica brick and silica sand are applied to the steel furnace for acid processes. Electricity is supplied through graphite or carbon electrodes introduced through the furnace roof. The metal charge is placed on a boxlike hearth. A short arc is produced between the charge and the electrodes. Many furnaces operate on 3-phase alternating-current with 3 electrodes, although single-phase furnaces with 2 electrodes are used for small tonnage. The distance between electrodes and the molten bath is regulated automatically to produce a steady heat.

37. Ingot production requires larger furnaces, 25 to 35 tons being usual. The power requirements per ton decrease with the size of furnace as heat losses are less in larger furnaces.

38. *Induction furnace.*—Use of the induction furnace is increasing for moderate tonnage work. The coreless type consists of a coil of copper pipe to which is supplied an alternating current. A graphite crucible containing the steel is placed within the coil but separated from it by insulation. The alternating current in the coil induces an alternating current in the crucible walls which heat its contents. High-frequency current is used.

39. Other induction furnaces have a primary winding above the secondary winding which consists of a ring of the molten steel to be heated. The transfer of current from the primary to the secondary windings is assisted by an iron core looping through the two windings making a closed loop around them. Electrodes are not required in induction furnaces.

40. *Power consumption.*—Major differences in power consumption are determined by the character of the charge. A molten charge from the open-hearth or Bessemer furnace requires much less heat to refine than does a cold charge that must first be raised to the melting point by electricity. For example: A 20-ton arc furnace employing graphite electrodes required 680 kilowatt-hours of energy to refine 1 ton of steel from a solid charge; a similar furnace took but 210 kilowatt-hours to refine a molten charge. Roughly, therefore, while melting requires about 500 kilowatt-hours, refining and deoxidizing takes but 200 kilowatt-hours. An induction furnace melting a solid charge of 18 tons required 865 kilowatt-hours per ton.

41. The following power consumption figures are compiled from a paper by Delton T. Waby which received the 1929 award from the Western Society of Engineers. It is evident that a 3-ton foundry furnace consumes about 600 kilowatt-hours per ton of castings.

TABLE 1.—*Electricity and electrodes consumed in melting iron and steel*

Product	Size of furnace	Furnace lining	Pounds of electrodes consumed per ton	Kilowatt-hours per ton
	Short tons			
Alloy steel ingots	25	Basic	10.5 graphite	525
	10	do	8 graphite	650
	3	do	17 carbon	600
Steel valve castings and fittings	6	do	11 graphite	625
	3	do	14 graphite	760
	2	Acid	4 graphite	600
Manganese steel castings	6	Basic	9.5 graphite	592
	3	do	do	590–660
	6	Acid		590
Miscellaneous steel castings	6	Basic	9.5 graphite 25 carbon	600 640
	3	Acid	5 to 5.5 graphite	500–564
		Basic	19.8 carbon	615
	2	Acid	9 graphite 16.5 carbon	600
	0.5	do	10 carbon	700

42. Dr. E. F. Northrup, inventor of the coreless induction furnace, gives the following figures for melting various charges of steel in this type of furnace:

Carbon-chromium steel, 710 kilowat-hours per ton.[12]
Manganese steel, 590 kilowatt-hours per ton.
2 percent nickel steel, 670 kilowatt-hours per ton.
Nickel-chromium steel, 525 Kilowatt-hours per ton.

43. The basic costs of producing a ton of foundry steel are estimated to include the following items:

Charge:	
Heavy scrap: 570 pounds at $0.007	$3. 99
Light scrap: 1,760 pounds at $0.007	12. 32
Power: 615 kilowatt-hours at $0.003	1. 85
Carbon electrodes: 20 pounds at $0.05	1. 00
Labor: 1 man at $1 per hour; 2 men at $0.60 per hour	2. 30
80 percent ferromanganese: 13 pounds at $0.04	. 52
50 percent ferrosilicon 11 pounds at $0.04	. 44
Total	22. 42

44. These figures do not take into account general plant labor, repairs, or miscellaneous supplies; nor do they consider overhead,

[12] First heat of day in cold furnace.

depreciation, or capital charges. It is obvious, however, from these figures that power costs at 3 mills form less than 8 percent of the operating cost in electric steel production.

Electric Heat Treatment of Steels

45. Almost all alloy steels and many carbon steels are heat treated, or subjected to heating and cooling in a solid state, in order to impart specific characteristics to the steel. Heat-treatment may take the form of annealing, toughening, hardening, tempering, drawing, carburizing, and casehardening. There is a marked tendency toward the use of electric furnaces in these operations.

46. *Annealing.*—Annealing treatment is given to steel castings to refine their coarse-grain size and thereby increase strength and elasticity; to cold-worked steel to restore ductility; to cold-drawn wire to permit further drawing; to hot-forged steel to relieve internal stresses produced in the forging. The steel is gradually heated above the critical stage (790° to 925° C.—1,454° to 1,697° F.) and held at this temperature for about 45 minutes per each inch of thickness of the object.[13] When the grain has been refined, the object is cooled, slowly if a soft, ductile metal is desired, and quickly by quenching, if strength and elasticity are necessary. Sometimes objects are reheated and cooled.

47. *Toughening, hardening, and tempering.*—Structural steels are frequently "toughened" by heating the steel above the critical range, quenching in water or oil, drawing by heating below the critical range, and cooling in air or oil. Tool steels are "hardened" by slow heating and rapid cooling, and tempered at reheating temperatures below 316° C. Machine parts, which must withstand friction and shock, are carburized and casehardened which involves hardening on the outside by increasing the carbon content. Low-carbon steels or iron are heated in contact with carbonaceous material below their respective melting points and absorb some of the carbon. The objects are cooled, reheated, and quenched in water or oil. They are then tempered in an oil or salt bath.

TYPES OF FURNACES

48. Electric furnaces for annealing, toughening, hardening, drawing, tempering, or carburizing are built in the same designs as those developed for fuel-fired furnaces. They may be of the batch type, where batch after batch of castings or forgings or sheets are placed in the furnace and renewed. They may be of the continuous type where objects are loaded into one end of the furnace and move slowly through the furnace; or a car may pass through the furnace; or they may have revolving hearths.

49. Electric heat-treating furnaces are usually of the metallic-resistor type. The resistor is made of alloys of chromium and nickel or of carbon and graphite. It is heated by the electric current and in turn heats the steel. Furnace heat is automatically controlled.

50. For example: An electric continuous furnace for annealing plate or cold-rolled steel holds the carbon resistors in carbonaceous troughs on piers. Carbon electrodes at each end of the trough lead

[13] Committee on heat treatment of American Society for Testing Materials.

the current to the carbon resistors. The material is placed on cars which pass slowly through the furnace. The arched furnace roof, together with the carbonaceous troughs and the carbon resistors, radiate their heat to the steel on the cars. The heat of the steel is also utilized to heat cold material on cars coming in the opposite direction in tunnels at each end of the furnace. This furnace requires about 400 kilowatt-hours of energy per ton of strips or sheets heated to 1,200° F.

51. Other furnaces have heating elements around the side of the furnace chamber, the low-resistance terminals coming through sealed bushings in the walls. Only 216 kilowatt-hours of energy was required to anneal laminating plates in such a furnace filled with nonoxidizing gas (15 percent hydrogen and 85 percent nitrogen).

52. *Power consumption.*—R. M. Cherry of the General Electric Co. gives the following figures on electrical consumption for various electric furnaces operating continually.[14]

Process	Temperature	Type furnace	Kilowatt-hours per ton
	° F.		
Steel annealing	1,500	Batch or continuous	182–286
		Continuous counterflow	133–200
Hardening	1,500	Batch or continuous	182–286
Drawing	600	Batch or continuous	57–100
		Continuous counterflow	40– 67
Steel casing and annealing	1,650	Batch	200–250
Carburizing	1,650	Batch or continuous	182–500
Cast iron	1,350	Batch	182–333
		Continuous counterflow	80–133

He states that furnace ratings should be 15 percent above these actual requirements.

53. *Costs.*—Comparisons of costs of annealing sheets in elevator-type furnaces heated by electricity and by oil are reported by A. N. Otis of the General Electric Co. in a paper presented before the American Society for Steel Treating, October 1928. Sheets were loaded on steel plates in the electric furnace while long pots were employed in the oil furnace. Plates cost $18 each and lasted through 30 anneals of 3.5 tons each; pots cost $400 each and lasted through 50 anneals. Or plates cost $0.17 per ton and boxes $2.28 per ton. Two hundred and sixteen kilowatt-hours electricity cost $2.70; 57.80 gallons of oil $3.30. Labor costs were approximately the same. Or direct operating costs varied by $2.71 per ton in favor of the electric furnace.

54. The same engineer gives the following cost data for annealing tool steel in covered boxes, employing a car-type furnace of 10-ton capacity. Continuous operation is assured and heating temperatures range from 1,450° to 1,650° F.; the treating requires 15 to 24 hours for heating and 20 to 30 hours for cooling.

Costs of annealing 1 short ton tool steel bars

Capital costs: 16 percent on $10	$1. 60
Power, 400 kilowatt-hours at $0.015	6. 00
Boxes	. 65
Labor	2. 20
Total annealing costs	10. 45

[14] Electrical World, Dec. 7, 1929.

55. A new method of treating high-speed steel has been announced. A salt bath is heated by current flowing through the bath from an immersed electrode.

56. *Extensive application of electric heat treatment.*—The Bethlehem Steel Co. has installed an all-electric heat-treating equipment in its alloy steel plant for alloy and special steels. Bars from the rolling mills enter a roller hearth furnace on a continuous roller line whose rolls oscillate back and forth eight times each minute. The furnace consists of two chambers placed end to end. The first is a preheating chamber operating at 800° F.; the second, a high-temperature chamber which can reach 1,650° F. As the hot steel bars are discharged from the high-temperature chamber, a crane lifts them from the roller line to the quenching tank. The length of time in the quenching tank is controlled by a time switch which causes the crane to automatically lift them out on to unloading skids. Two pit furnaces are used for annealing, having a capacity of 1,098 kilowatts. From these furnaces, bars are given a mild heat treatment in two car-bottom annealing furnaces with a capacity of 675 kilowatts, after which they are ready for the straightening and testing machines.

57. At the Fordson plant of the Ford Motor Co., electric furnaces are used for heat treating and forming of spring leaves, heat treatment of crank shafts, connecting rods, gears, and other parts, and for heating forging stock. These forging furnaces, operating at 2,350° F., produce a ton of forgings with a consumption of 500 kilowatt-hours of electricity.

58. *Electric arc welding.*—Pipe and structural steel mills are employing electric arc welding on a large scale. In the older method of welding, a metal electrode is melted into a space between the two pieces to be welded, the pieces melting sufficiently to effect the juncture. The newer method is a resistance welding process requiring no welding metal. The two edges of the skelp are fused into a continuous seam by alternating current at high amperage in a welding machine. Electrical consumption is given as 0.25 kilowatt-hour per linear foot of welded joint.

Ore Resources Essential to Iron and Steel Production

59. More than 73,000,000 long tons of iron ore, more than 42,000,000 net tons of coke, 13,000,000 bushels of charcoal, and over 15,000,000 tons of limestone were consumed in blast furnaces in the production of pig iron in 1929.

IRON-ORE DEPOSITS AND PRODUCTION

60. *Iron-ore shipments.*—Almost seven eighths of all iron ore shipped from mines in the United States in 1929 came from the Lake Superior iron-ore region. Minnesota shipped 61.5 percent of all iron ore, Michigan 22.3 percent, and Wisconsin 2.4 percent. Alabama was the only other State in which appreciable amounts of iron ore were mined, her shipments totaling 6,600,000 long tons. Wyoming mined 639,000 long tons; Utah, 325,000; Colorado, 50,000; and Washington State, 5,000, or less than 0.1 percent of the total tonnage of the United States. Some 3,000,000 tons of iron ore were imported. More than one half of this came from Chile. Other ores were im-

ported from Cuba, Algeria and Tunisia, Spain, Sweden, Greece, Canada, and Newfoundland.

TABLE II.—*Iron ore shipped from mines in the United States* [1]

State	1925, gross tons	1926, gross tons	1927, gross tons	1928, gross tons	1929	
					Gross tons	Percent
Total	63,924,763	69,292,832	61,232,473	63,432,826	75,602,734	100.0
Alabama	6,891,081	6,871,412	6,508,419	6,159,863	6,637,299	8.8
California	352	282				
Colorado	8,642	35,535	32,206	52,713	50,754	(2)
Georgia	79,488	51,642	50,312	73,052	59,316	(2)
Michigan	15,254,003	16,699,984	14,532,831	14,241,102	16,838,568	22.3
Minnesota	38,022,237	40,961,361	35,563,177	38,129,018	46,470,243	61.5
Missouri	40,043	124,371	78,605	94,899	171,456	.2
Montana	3,672	724	2,837	1,640		
New Jersey	164,523	212,152	202,720	350,616	285,115	.4
New Mexico	172,959	216,269	214,747	184,623	171,585	.2
New York	413,517	659,741	936,850	767,743	875,564	1.2
North Carolina	22,011	14,798	32,528		30,575	(2)
Ohio	2,410					
Pennsylvania	917,255	1,088,634	1,124,883	1,013,791	1,151,130	1.5
Tennessee	164,073	138,307	121,220	128,478	101,796	.1
Utah	268,529	296,943	222,879	320,655	324,885	.4
Virginia	76,302	49,703	66,897	27,970	232	(2)
Washington	830	1,702	550	1,012	5,018	(2)
Wisconsin	933,214	1,238,885	937,935	1,394,371	1,789,721	2.4
Wyoming	489,622	630,387	602,877	491,280	639,477	.8

[1] U.S. Bureau of Mines: Compiled from Iron Ore, Pig Iron and Steel.
[2] Less than 0.1 percent.

61. *Character of commercial ores.*—Iron rarely occurs native but is a part of other minerals, the most used of which are the iron oxides and the carbonates. The commercial value of ore depends on the kind and quantity of its impurities. Copper and titanium are so objectionable that ores containing them are rarely used. Too high a phosphorus or sulphur content is undesirable. Volatile impurities, such as water, carbon dioxide, and organic matter, add weight and, consequently, increase the cost of transportation and the cost of firing the furnace. Ore of great value in blast-furnace practice contains enough lime to be self-fluxing.

62. *Lake Superior iron ores.*—Hematite, an anhydrous oxide ore, has been the principal iron ore used in United States blast furnaces. It occurred in great abundance in the Lake Superior region of Minnesota, Michigan, and Wisconsin; in smaller amounts in central New York and in the Appalachian region of Alabama, Georgia, Tennessee, and Virginia, and in eastern Wyoming. Small deposits were found in Pennsylvania, Maryland, eastern Wisconsin, Utah, and California. The hematite of the Lake Superior district averaged 51 percent iron content in 1929. The ore reserves in Minnesota were estimated to be 1,242,060,000 tons by the United States Bureau of Mines; the reserves of Michigan, 168,350,000 tons. At the present rate of consumption of these ores, this supply will last less than 25 years. The large steel companies have merged with iron-ore producers, so that control of this Lake Superior ore is largely held by the United States Steel Corporation, the Bethlehem Steel Corporation, the Republic Steel Corporation, and the National Steel Corporation.

63. *Southern Appalachian ores.*—The Alabama ore is also chiefly hematite and is nearly self-fluxing. The iron content of ore from

Jefferson County, the chief producing county, averages 36.67 percent iron, although higher contents are found in some sections. Brown ore is widely distributed in Alabama but is not pure enough to have present commercial value. While some iron ore is produced in Georgia, Tennessee, and Virginia, deposits are small and distinctly subordinate. North Carolina has several types of iron ore widely distributed, but in relatively small quantities. Reserves of magnetite ores with titanium content are believed to be approximately 600,000 tons.

64. *North Atlantic ores.*—The predominating iron ore of New York, Pennsylvania, and New Jersey is magnetite, a crystalline compound of oxides of iron, although some hematite is produced in New York for pigment use and carbonate ore is mined in Pennsylvania. Pennsylvania was the largest producer of magnetite, the ore averaging about 40 percent iron, but it is high in sulphur and must be roasted before smelting. New York and New Jersey ores range from 61 to 67 percent iron. While these ores contain more iron than those in use in this country, their phosphorus content is higher than that of ores in the Lake Superior region. Large bodies of titaniferous magnetite are located at Lake Sanford, N.Y.; these may be of value in the future.

WESTERN IRON ORES

65. *Wyoming.*—Wyoming has several rich iron deposits. Ore being produced in 1929 was hematite containing 53.5 percent iron, some manganese, but little phosphorus, and no sulphur. Hematite is found in Carbon County, north of Rawlins; this is said to contain 65 percent iron and no phosphorus. In the Seminole Mountains there are large deposits containing from 55 to 68 percent iron, and in Fremont county, near Atlantic City, are located other large deposits. There are large dikes of titaniferous iron ore in Iron Mountain in Albany County; this contains 55 percent iron, but the 14 to 25 percent titanium oxide present makes the deposit valueless for present blast-furnace conditions. Cast iron was produced electrically from this ore in 1905–6. Two tons of this iron and 1 ton of briquets made from Pacific coast magnetite sands were smelted, with a consumption of 3,760 kilowatt-hours of power.[15]

66. *Utah.*—In 1929 Iron County, in Utah, produced hematite containing 52 percent iron, 2 percent manganese, and 0.29 percent phosphorus. It is estimated that about 40,000,000 tons of iron ore are to be found about 35 feet below the surface in the southwestern corner of the State in Iron and Washington Counties.

67. *Colorado and New Mexico.*—The only iron property operated in Colorado in 1929 was near Villa Grove in Saguache County. This ore is brown ore, or a hydrate ferric oxide, and averages about 44 percent iron. New Mexico produced magnetite ores carrying 51 percent iron and some manganese near Fierro, Grant County, in 1929. Other deposits of value are in Jarilla Mountains near San Pedro, about White Oaks, Capitan, and Jicarilla Mountains; at Ticalate and in the Gallinas Mountains; in the Cuchillo range near Glorieta; and at Silver City.

68. *Washington.*—The only iron mine active in Washington State in 1929 was the Big Iron mine in Stevens County; this pro-

[15] Ball, Sydney H. Titaniferous Iron Ore of Iron Mountain, Wyo. 1906.

duced a magnetite ore low in phosphorus and of high iron content. In Kittitas County, both magnetite and hematite ores are reported with low sulphur and phosphorus content. Iron ores have been reported from other sections of the State but are scattered.

69. Small quantities of brown ore are mined from time to time in California, Idaho, Nevada, and Montana, ore which is used either as flux in smelting copper and other nonferrous metals, or in pigment manufacture. California has magnetite ores.

70. *Other American deposits.*—Development of Brazilian iron deposits is beginning. The Italoira Ore Co., Ltd., has signed a contract with the Government of Brazil to mine 3,000,000 tons of iron ore annually from deposits situated in the State of Minas Geracs. The concession comprises a mountain estimated to contain 190,000,000 tons of hematite. The ore is hematite containing 67 to 68 percent iron. The company is partially financed by Americans. The Bethlehem Steel Co. owns rich mines in the Province of Coquincho, Chile, from which 1,500,000 tons of iron ore were shipped in 1928. Dutch and Swedish interests are prospecting in the south central part of Chile. It is believed that iron-ore deposits are extensive in both Brazil and Chile.

71. Cuba has been mining hematite since 1884 at Firmesa. Other deposits of soft ore are located on the north coast, while the Province of Pinar del Pio has small deposits of high-quality ore.

Canada produces titaniferous ores. Newfoundland has great beds of iron ore which dip under Conception Bay.

72. *European reserves of iron ore.*—Since the acquisition of Lorraine, France is second to the United States in the mining of iron ore. While this section produced 43,000,000 metric tons in 1927, the northwestern coast of France produced but 2,000,000 tons of iron. Lorraine ores are a brown hematite high in phosphorus. Germany, since the loss of Lorraine, has but scattered iron deposits.

73. The United Kingdom mines red hematite in parts of Lancashire, Cumberland, and Cornwall, but her best ores are imported from Spain, where deposits of hematite have been worked for many years. British interests have acquired heavy interests in Brazilian deposits.

74. Belgium mines limonite ore near Antwerp. Austria, Hungary, Yugoslavia, and Czechoslovakia are fairly well supplied with good iron ore. Sweden has about 1,750,000,000 tons of iron ore in Lapland and in the central part of the country. In the extreme northwest of Norway mines are estimated to contain 1,000,000,000 tons of iron ore. Polish deposits are low-grade.

75. While known iron resources of Russia are said to have over 1,000,000,000 tons of iron content, actual iron reserves in the Kunsk region, in the Ural Mountains, and in northern and western Russia are believed to contain many more billions.

76. *China.*—Iron-ore production in China is estimated to be about 1,500,000 tons per year. Her iron-ore reserves are very extensive, however, estimates of reserves capable of large scale production running close to the billion mark, of which 555,000,000 tons are classed as potential reserves. The richest and most accessible iron region lies along the Yangtze River below the Gorges. The ores in this region are a mixture of hematite and magnetite containing about 60 percent iron and are adapted to open-cut mining.

While the best-known ore body, Tayeh, contains but 32,000,000 tons, other bodies carrying smaller iron content extend farther downstream.

77. Other deposits are located in South Manchuria along the watershed between the Hun-ho and the Yahu Rivers. But the ore bodies are not continuous. Farther west there are larger bodies of ore, the largest of these being at Kungchangling, Niaverkhou, and Anshan. In the Hsuanlung district of the "Peking Grid", hematite ore of good grade and adapted to open-cut mining is found. North Shantung has some workable deposits in close proximity to a coal field; this ore is self-fluxing.[16]

78. *Iron-ore deposits of other countries.*—The iron and manganese ore depsits in Algeria and Tunisia are demanding attention. The Onenza reserve in Algeria is said to have 50,000,000 tons. In Tunisia ores are high in arsenic. Hematite reserves in the Marampa Hills of Sierra Lione are reported to be extensive. Southern Australia produced about 600,000 tons of iron ore in 1918.

79. *World iron-ore and pig-iron production.*—The United States mined 39 percent of the world's iron ore, while France mined 27 percent in 1929. Great Britain and Sweden were the only other countries mining as much as 5 percent of the world's supply. But while the United States produced 44 percent of the entire pig iron, France manufactured but 13 percent. Much of French iron ore was turned into pig iron in Germany, where blast-furnace production exceeded in small measure French production. Sweden, too, manufactured but a small amount of her iron ore into pig iron. Belgium, however, produced 4 percent of the world's pig iron. Such countries as Cuba, Newfoundland, Chile, Spain, Algeria, Tunisia, and Morocco exported most of their iron ore.

TABLE III.—*World iron-ore and pig-iron production in 1929* [1]

Country	Iron-ore production		Pig-iron production [2]	
	Metric tons	Percent	Metric tons	Percent
Total	188,159,821	100.0	98,543,330	100.0
North America	76,423,244	40.6	44,486,974	45.1
Canada	(3)		1,189,037	1.2
Cuba	682,095	.4		
Newfoundland	1,541,334	.8		
United States	74,199,815	39.4	43,237,937	43.9
South America	1,842,343	1.0	70,000	.1
Brazil	30,000	(4)	[5] 70,000	.1
Chile	1,812,343	.9		
Europe	103,227,434	54.9	50,160,285	51.0
Austria	1,891,381	1.0	458,973	.5
Belgium	(3)		4,095,940	4.2
Czechoslovakia	1,807,663	1.0	1,644,515	1.7
France (including Alsace-Lorraine)	51,028,000	27.1	12,550,940	12.7
Germany	(3)		13,397,000	13.6
Hungary	251,860	.1	367,951	.4
Italy	866,480	.5	672,280	.7
Luxemburg	7,571,206	4.0	2,906,093	2.9
Netherlands	(3)		253,776	.3
Norway	650,000	.4	[5] 134,000	.1
Poland	659,207	.4	704,437	.7
Russia (including Russia in Asia)	7,100,000	3.8	4,000,000	4.1

See footnotes at end of table.

[16] Smith, Wilfred. A Geographical Study of Coal and Iron in China. 1926.

TABLE III.—*World iron-ore and pig-iron production in 1929*—Continued

Country	Iron-ore production		Pig-iron production	
	Metric tons	Percent	Metric tons	Percent
Europe—Continued.				
Spain	6,546,648	3.5	752,618	0.8
Sweden	11,000,000	5.8	489,677	.5
Great Britain	13,427,043	7.1	7,701,200	7.8
Yugoslavia	427,946	.2	30,885	(4)
Asia	2,306,952	1.2	3,340,314	3.4
China	[5] 1,000,000	.5	[5] 300,000	.3
Chosen	551,814	.3	155,514	.2
British India	(3)		1,370,000	1.4
Unfederated Malay States	755,138	.4		
Japan			1,514,800	1.5
Africa	4,358,592	2.3	16,510	(4)
Algeria	2,196,182	1.2		
Belgian Congo	50,000	(4)		
Morocco—Spanish	[6] 1,061,424	.6		
Rhodesia—Northern	3,613	(4)		
—Southern	3,406	(4)		
Southwest Africa	38,697	(4)		
Tunisia	977,000	.5		
Union of South Africa	38,270	(4)	16,510	(4)
Australia	1,256	(4)	337,975	.3
Queensland	1,256	(4)		
All other countries			[5] 131,272	.1

[1] Compiled from U.S. Bureau of Mines, Iron Ore, Pig Iron, and Steel in 1929.
[2] Includes ferro-alloys.
[3] For the following countries, 1929 iron-ore production is not available: Mexico, British India, Japan, French Morocco, New South Wales, South Australia, New Zealand, Belgium, Greece, Netherlands, Portugal, Rumania, Switzerland, Northern Ireland, and Germany. Germany's production of iron ore has been as follows in recent years: 1925, 5,742,542 metric tons; 1926, 4,594,939 metric tons; 1927, 6,315,186 metric tons; 1928, 6,296,261 metric tons.
[4] Less than 0.1 percent.
[5] Approximate production.
[6] Exports.

80. *Coke production and coal resources.*—Although some charcoal is applied in special types of iron production, coke made from bituminous coal is quite generally used in smelting. The axiom "Iron comes to coal" still holds today. From 12 to 15 percent of the annual output of bituminous coal is carbonized.

81. *Coke production and coal mining by States.*—Pennsylvania is the largest coke-producing State, as well as the largest coal-producing State. Ohio ranks second in coke; part of its coking coal is shipped from Pennsylvania, Kentucky, and West Virginia. Indiana also secured coking coals from these three States. Alabama, which ranks fourth in coke production, consumes only Alabama coal in such production. New York, ranking fifth in coke, is dependent on Pennsylvania and to some extent on West Virginia, Kentucky, and Virginia for her coal supply.

82. Colorado is ninth in coke production. All bituminous coal used in the manufacture of her coke comes from her own Trinidad fields. Utah manufactured about 300,000 tons of coke in 1929, most of which was produced from Carbon County, Utah, coals. Washington States' production of coke was 65,600 tons, all of which was carbonized from Washington bituminous coal chiefly from Pierce County. Pierce County coals are analyzed as having 51 percent

fixed carbon with heating value of 13,000 B.t.u.; Carbon County, Utah, coals have 47.8 percent fixed carbon with 12,500 B.t.u.; while Trinidad District high grade bituminous coals have 58.7 percent fixed carbon with heating value of 13,780 B.t.u.

TABLE IV.—*Production of coke and bituminous coal in 1929 by States*[1]

State	Production of coke		Production of bituminous coal	
	Short tons	Percent	Short tons	Percent
Total	59,490,600	100.0	532,352,000	100.0
Pennsylvania	19,592,900	32.9	142,400,000	26.7
Ohio	8,480,300	14.3	23,712,000	4.5
Indiana	6,392,700	10.7	17,970,000	3.4
Alabama	4,738,800	8.0	17,690,000	3.3
New York	4,201,800	7.1		
Illinois	4,179,000	7.0	60,085,000	11.3
West Virginia	1,934,000	3.3	138,015,000	25.9
New Jersey	908,300	1.5		
Colorado	719,000	1.2	9,890,000	1.9
Virginia	309,000	.5	13,138,000	2.5
Utah	299,000	.5	5,250,000	.9
Tennessee	199,400	.3	5,750,000	1.1
Washington	65,600	.1	2,530,000	.5
Kentucky			60,575,000	11.4
Wyoming			6,600,000	1.2
Iowa			4,130,000	.8
Missouri			3,860,000	.7
Oklahoma			3,484,000	.7
Montana			3,183,000	.6
Kansas			3,040,000	.6
New Mexico			2,640,000	.5
Maryland			2,660,000	.5
North Dakota			1,950,000	.4
Arkansas			1,800,000	.3
Texas			1,060,000	.2
Michigan			770,000	.1
Other States, Alaska	7,470,800	12.6	170,000	[2]

[1] Estimated by the U.S. Bureau of Mines.
[2] Less than 0.1 percent.

WESTERN COAL RESOURCES

83. *Washington coals.*—Washington State contains coals ranging from lignite to anthracite at Cowlitz Pass, Carbonado, and Glacier. In King County, there are large areas of coal-bearing strata varying from subbituminous to coking bituminous along the western edge of the Cascade Mountains. The eastern portion of Pierce County has both coking and noncoking coals as well as a small area of anthracite. Other deposits, either small in size or of low quality, are found in Kittitas, Lewis, and Thurston Counties.

84. *Oregon and Idaho coals.*—The most important coal region in Oregon is the Coos Bay coal field. This is a subbituminous coal of little present market value. The coal used in the State is shipped from Wyoming, Utah, and Washington. Although Idaho has a small coal area near the Wyoming line, it is badly faulted. Consequently, it is cheaper to secure necessary coal from Utah and Wyoming.

85. *Montana and Wyoming coals.*—While the State of Montana has large reserves of coal, it is chiefly subbituminous and lignite. Only a little coking coal is available within the State. Wyoming also has large reserves of coal, some of which is high-grade bituminous. Along the western edge of the State, in the southwestern section called the

Green River region, lower zones contain bituminous coal but it is not a coking coal.

86. *Utah and Colorado coals.*—The Uinta coal field of Utah, extending from Provo into Colorado, has high-grade bituminous coal of coking quality. Other sections of the State have large coal deposits of somewhat lower grade. Colorado has a large number of coal areas of varying quality. In the southwestern portion of the State high-grade bituminous coal is found. Some coal near Durango is excellent coking coal. In south central Colorado where the Trinidad District is located, there are extensive areas of coking coal.

87. Western British Columbia has important coal producing areas, and Alberta is believed to have very great coal reserves of many types.

88. *Limestone.*—Limestone, essential in blast-furnace practice for fluxing iron ore, is available in large quantities in all States except North Dakota. The extent of limestone deposits are so enormous that no effort has been spent in estimating the available tonnage. Production occurs near the particular point where a demand exists.

89. *Silica.*—Silica applied to the manufacture of ferrosilicon is obtained from quartz and quartzite, that is, massive rock quartz, vein quartz, or quartz crystals. The quartz must be quite free of lime, alumina, arsenic, and phosphorus, and have a very high silica content.

90. As quartz is distributed quite generally in the Appalachian States and in the Western States, and as it is mined from open cuts, it is a cheap commodity that can carry only small freight charges. Consequently, it is usually quarried close to local consuming centers. In fact, manufacturers of ferrosilicon frequently quarry their own silica rock. The only importations come from Canada by boat to electrometallurgical plants near the international boundary.

91. States which produced quartz in 1929 were: California, Nevada, Arizona, and Colorado; Maine, Massachusetts, and Connecticut; New York, Pennsylvania, Maryland, and Virginia; North Carolina, Tennessee, and Alabama; and Michigan and Wisconsin. Only a part of this production was consumed in ferrosilicon manufacture, much being a lower grade quartz used for copper smelting. Quarrying began at Marblemount, Wash., November 1930, to supply the Northwest Mineral Products Co. of Burlington, Wash., with quartz containing 99.5 percent silica.

92. Quartzite is chiefly produced in central Pennsylvania near Mount Union and Hollidaysburg. While much is used for refractory purposes, some enters into ferrosilicon production. Quartzite is also mined near Canon City, Colo., near Anaconda, Mont., in New York, Virginia, Alabama, North Carolina, and Wisconsin.

93. Location of quartz or quartzite deposits is usually shown by State reports so that a manufacturer requiring this mineral in quantity need only determine the purity and extent of local deposits.

94. *Manganese ore.*—Approximately 724,648 tons of manganese ore containing 35 percent or more manganese was consumed in the manufacture of ferromanganese in 1929. Of this amount, 664,269 tons were imported and 60,379 tons were produced in the United States. Approximately nine tenths of all domestic ore came from Montana, Georgia, Arkansas, and Virginia. Soviet Russia, Brazil, India, and British West Africa were the principal countries from

which imports were received. Domestic shipments of ferruginous manganese ore containing from 10 to 35 percent manganese and used to manufacture spiegeleisen in the blast furnace, totaled 78,191 tons. Shipments of manganiferous iron ore containing from 5 to 10 percent manganese and employed in manufacturing manganese pig iron were 1,110,067 tons in 1929.

95. Manganese forms a part of many minerals and is widely distributed. But deposits of ore containing 35 percent manganese, known as "manganese ore" which is necessary for the production of ferromanganese, are not extensive in the United States. A committee of Government and private geologists, metallurgists, and engineers investigated 1,850 deposits in 1925 and reported the known tonnage of this grade ore in the United States ranged from 1,400,000 to 3,000,000 tons. Maximum production of manganese ore was reached in 1918 when 305,869 long tons were mined.

WESTERN RESERVES

96. *Montana.*—Montana is, at present, the largest producer of manganese ore, four companies including the Anaconda Copper Mining Co. being engaged in mining manganese ore. The manganese districts center around Butte and Philipsburg. In the Butte District where rhodochrosite ore is mined, the ore averages 37.6 percent manganese which is concentrated to a sinter averaging 57.8 percent. The reserves of two mines in the district were estimated at 497,000 tons and 100,000 tons, respectively. Chemical ore is mined in the Philipsburg District. Late estimates place these reserves at 1,780,000 tons of which about 30 percent is crude ore containing 35 percent or more manganese.[17]

97. *Arizona.*—Three companies were producing manganese ore of 35 percent content in 1929 in Arizona, one being a copper mining company, the Phelps Dodge Corporation. The high grade ore is near Bisbee and is estimated to be about 50,000 tons. Production for 1929 totaled 3,905 long tons. Low grade or ferruginous manganese ore deposits are extensive and development is beginning near Congress and Winslow as well as at Bisbee.

98. *California.*—California has produced some manganese ore from time to time, principally from the old Ladd Mine, San Joaquin County. Colorado has widely distributed ferruginous manganese ore deposits in the Leadville District which are reported to produce 45,000 tons. Idaho has a high-grade deposit of manganese ore near Cleveland, Bannock County, but is believed to be small. In 1929, 3,181 tons were mined by the Western Manganese Co. Two other companies are located at Lava Springs. Some manganese is produced in the Las Vegas field of Nevada; this totaled 1,357 long tons in 1929.

99. *New Mexico.*—New Mexico has a number of deposits of manganiferous ore, manganiferous silver ore, and ferruginous iron ores. These deposits occur in Socorro, Luna, Grant, Lona Ana, and Sierra Counties. Production is being carried on by three companies near Deming, and 2,190 long tons of high grade ore were shipped in 1929, while shipments of ferruginous manganese ore were the largest made by any State, or 56,624 long tons. Utah has very small known deposits of high grade ore.

[17] U.S. Geological Survey Press Release. 1929.

100. *Washington.*—In Washington State, developed deposits in the Olympic Peninsula were exhausted. In the early part of 1928 a new lens was cut having a tenor of better than 50 percent manganese. No production is officially reported.

SOUTH ATLANTIC RESOURCES

101. *Georgia.*—Georgia ranked second in the mining of manganese ore in 1928, 1 company producing 4,727 long tons; but in 1929, 2 companies produced but 489 tons. Carterville is the chief producing district where hydraulic mining is done. A new concentrator installed in 1929 will have an annual capacity of 140,000 tons of ore averaging 40 to 50 percent manganese. Occurrences of manganese are found in a number of other counties in Georgia.

102. Arkansas produced 2,605 tons in the Batesville-Cushman District. The deposits are irregular and usually in numerous pockets surrounded by clay containing no ore. Alabama developed some deposits during war years but only a little production has been continued by two companies. Tennessee deposits of manganese ore are in the area including Carter County; three companies mined but 498 tons in 1929.

103. In Virginia, five companies operating in 1929 produced 2,583 long tons of manganese ores. Mining operations have been confined chiefly to Bland, Frederick, and Smythe Counties.

LOW GRADE MANGANIFEROUS AND FERRUGINOUS ORES

104. Domestic reserves of low grade ferruginous and manganiferous ores, that is, ores containing less than 35 percent manganese are extensive. Much effort has been expended in developing processes by which such ores, which vary greatly in kind, can be concentrated to higher content at a cost that will permit them to compete with foreign manganese ores. Efforts are also being made to manufacture ferromanganese directly from manganiferous ores.

105. Reports of the Bureau of Mines list our low-grade deposits as follows:

Extensive deposits of bentonite, a manganese silicate, have been located in the Olympic Mountains, Wash.

Large tonnages of silicate and carbonate manganese are disclosed after deep mining in San Joaquin County, Calif.

In Nevada, there are large bodies of ferruginous manganese ore, some of which is now utilized at Provo, Utah, in the manufacture of pig iron.

Deposits of both ferruginous and manganiferous ores are extensive in Utah.

New Mexico ore reduction problems are similar to those of the Cuyuna ores of Minnesota; at present, New Mexico mines large amount of ferruginous ore.

Montana has large quantities of a mixture of carbonates and silicates of manganese and quartz which must be separated.

Colorado ores also are extensive but present metallurgical problems.

The Cuyuna Range of Minnesota has very extensive deposits of manganiferous iron ore, which must be separated from associated iron and phosphorus and waste materials. The Bradley process of separa-

tion based on leaching with ammonium sulphate is being brought to the commercial production stage. The Bureau of Mines station at Minneapolis is investigating the feasibility of producing ferromanganese from these manganiferous iron ores.

The manganiferous zinc residues obtained from franklinite beds in New Jersey, after their zinc content is washed out, is the present largest source of ferruginous manganese.

FOREIGN RESERVES OF MANGANESE ORES

106. Russia has very extensive deposits of high-grade manganese ore. The Tchiaturi deposits in the Republic of Georgia are regarded as the largest in the world estimated to contain from 44,000,000 to 200,000,000 tons. The Nikopol deposits in southwestern Russia are believed to contain 10,000,000 tons of commercial ore; they have been leased to German companies.

107. Known deposits of India are also large. Brazil's largest developed deposits are in the Lafayette District west of Rio de Janeiro, and are estimated to contain over 9,000,000 tons. Many undeveloped, and at present, inaccessible deposits are believed to exist in Brazil. Chile also has deposits which are difficult to reach, at present. Cuba is estimated to have reserves amounting to 700,000 tons chiefly in the Orienta Province.

108. The Gold Coast of Africa is estimated to hold at least 10,000,000 tons of high-grade ore. Morocco, Tunis, and Algeria are producers of some high-grade manganese. South Africa is believed to have rich deposits which are just being investigated.

109. *Chrome ore.*—Commercial chromium is secured from the mineral chromite, which in a pure condition, contains 68 percent chromic oxide (Cr_2O_3) and 32 percent iron oxide (FeO). The content of commercial chromite, however, varies from 35 to 55 percent chromic oxide, the higher grades being used for ferrochromium and in the chemical industries.

110. *Production and imports.*—The ferro-alloy manufacturers desire ores containing at least 45 percent chromic oxide and an iron content of not more than one fourth the combined iron and chromic oxides. Out of total of 317,810 long tons of ore consumed in the United States, only 180 tons were shipped from mines in this country. This ore came from California. More than half the imports were from Rhodesia. Cuba exported 53,000 tons; French New Caledonia, Greece, and British India between 21,000 and 27,000 long tons; while the Union of South Africa shipped 17,500 tons to the United States.

111. Prior to the World War, New Caledonia was the principal source of chromium. In 1918, under the stress of wartime conditions, United States mines shipped 82,430 long tons. California and Oregon were the largest producers, while some mining was done in Washington, Montana, Wyoming, Pennsylvania, Maryland, and North Carolina. With the cessation of hostilities, ore was imported again from foreign countries. Pacific coast operations could not compete in New York, New Jersey, and Pennsylvania markets with this foreign ore.

112. *Deposits in western United States.*—The Klamath Mountains in northwestern California and southern Oregon contain chromite ore

in abundance. It is scattered in the Sierra Nevada range and in the coast range of California from Santa Barabara to the mouth of the Klamath River. The Blue Mountains in eastern Oregon also contain deposits. The chromite mined in 1918 varied in grade. The largest deposits of 45 to 55 percent chromic-oxide ore were located in Eldorado, Placer, and Calaveras Counties of California. Grant County, Oreg., shipped the largest amount of ore. The counties of Oregon that shipped chromite ore in 1918 were: Baker, Coos, Curry, Douglas, Grant, Jackson, Josephine, and Wheeler Counties.

113. Some chromite ore was shipped from Cypress Island, Wash., in 1917 and 1918. Other deposits are reported to contain from 44 to 51 percent chromic oxide near Mount Hawkins, Kittitas County. Workable deposits are also said to exist near Nighthawk in Okanogan County.

114. Chromite is found in Boulder Creek, Colo., and in southern Montana. This ore, however, contains less than 40 percent chromic oxide and about 18 percent iron oxide and is, therefore, below the grade demanded by ferro-alloy manufacturers.

115. In Wyoming, chromite occurs abundantly at Deer Creek. It has been mined from time to time since 1908 and has been used both in refractories and in ferro-alloys.

116. At one time, Maryland supplied the United States with chromite. Deposits are small, however, It is stated that high-grade ore is to be found in North Carolina but that deposits are scattered. In 1929, the Southern Chromium Co. began prospecting in Troup County, Ga.; first shipments analyzed 33.8 percent chromic oxide.

117. While Alaskan deposits are believed to be extensive, little surveying has been done in this peninsula.

118. *Other American deposits.*—In the last few years, chromite has been found in the Sudbury Basin Mines and west of Armstrong Station, Ontario. The latter ore is reported to assay over 48 percent chromic oxide; it will be exploited by the Consolidation Chromium Co. Ore is also found in Quebec and on Scottie Creek, British Columbia.

119. In Cuba, the Bethlehem Steel Co. operates a deposit at Camaguey, yielding a refractory grade of ore. It is stated that higher-grade ore is available at other mines and that much chromiferrous ore is available.

120. *African deposits.*—Southern Rhodesia produces half the world supply of chromite. The ore in the Selakive district assays between 45 and 50 percent chromic oxide, while that in the Umarukwes and Darwendale areas contains over 50 percent chromic oxide. These deposits are reported to be very large. Transportation facilities from mines to the seaport are being improved. The Union of South Africa is a sharp competitor of Rhodesia in the world chromite market. The reserves are not as high grade but as they are large and near transportation facilities, such ores are sold at a lower price.

121. *Other countries.*—Turkish chromite dominated the world's market prior to 1903. A Swedish company holds two claims from which first shipments were made in 1930 and British and French interests are seeking concessions.

122. In New Caledonia, the Tiebaghi Mine at the northern end of the island has been one of the world's richest producers. Deposits are

operated in British India, but lack of transportation facilities hampers production. Extensive low-grade deposits occur in Indo-China.

123. Greece produces annually a number of thousands of tons of chromite, principally from Thessaly and the Khaldike Peninsula. The ore carries from 38 to 40 percent chromic oxide and is used mainly as refractory material. Production of chromite is beginning in Russia after a 13-year interruption. In the Ural Mountains there are large reserves of low-grade ore. Only high-grade ore, from other sources or from the concentration of low-grade ores, has been exported to the United States.

TUNGSTEN ORES

124. *United States resources.*—Tungsten minerals found in the United States are ferberite, an iron tungstate; wolframite, an iron-manganese tungstate; hubnerite, containing more manganese than wolframite; and scheelite, a calcium tungstate.

125. The largest deposits of ferberite are in the Boulder district of Colorado where several firms are operating. Wolframite and hubnerite are found in largest amounts in Nevada, Arizona, New Mexico, and South Dakota. The Nevada-Massachusetts Co., operating in the Eugene Mountains of Nevada, were the largest producers of tungsten concentrates in the United States. Scheelite is located in San Bernardino and Inyo Counties of California where some production is taking place. A few tons of tungsten ore was mined at Jardine Mountain. Tungsten ore of the several types has been mined in Stevens County, Wash., it is also reported in Okanagan, Ferry, and Yakima Counties.

126. *Foreign resources.*—But while 830 short tons of tungsten concentrate (60 percent WO_3) were produced from United States mines in 1929, 4,978 tons of concentrate were imported. This imported ore came largely from China where wolframite is obtained by surface mining; although importations from South America and Australia increased.

127. The principal producing counties of China are Kiangsi and Kwangtuang. At present the industry is disorganized, due to internal disturbances with the resulting stimulation of production in other countries. The tungsten industry of South America is located in the Argentine, in Bolivia, and in Peru. While valuable wolfromite deposits have been developed the industry cannot compete with Chinese ore when the Chinese price is low. The Malay Peninsula also has important deposits near Tavoy, Nugari, Moulmein, and Thalan.

128. Tungsten deposits are extensive in Portugal; there are three calciners who ship arsenic as a by product of the tungsten industry. Large reserves are believed to exist in Russia although only a little prospecting has been done. Tungsten ore was produced in the provinces of Central Australia, New South Wales, Queensland, Tasmania, and Western Australia, in 1929. South Rhodesia also produced some tungsten.

129. *Molybdenum ores.*—The United States is the largest producer of molybdenum ores. Molybdenum occurs chiefly in molybdenite (MOS_2) and wulfenite ($PbMoO_4$). Molybdenite is widely scattered in western States. The largest deposit being worked commercially is at Climax, Colo.; while smaller deposits occur in Nevada, California, New Mexico, and Arizona. Wulfenite is also scattered in the

southern Rocky Mountain States, the largest developed deposit being at Mammoth, Ariz.

130. In 1929, the molybdenum content in concentrates averaging 75 to 90 percent molybdenite, totaled 2,015 tons. More than four fifths of this was produced by the Climax Molybdenum Co. operating at Climax, Colo. The Molybedenum Corporation of America produced at Sulphur Gulch, N.Mex.; the Southern Copper Mining Co. at Helvetia, Ariz.; and the Minerals and Metals Corporation, near Sahuarita, Ariz.

131. In 1929, the Molybdenum Mines Co., of Yakima, Wash., prospected properties at Deep Creek, Yakima County, and at Omak, Okanogan County. The deposits at Deep Creek are said to contain a high-grade ore while those at Omak are similar to beds at Climax, Colo., where ore averages 1 percent or less molydenum. Deposits are reported also from Chelan, Ferry, Pend Oreille, and Stevens Counties.

132. The major problem of the molybdenum industry is not in finding sources of ore but in securing an adequate market for such ore. Molybdenum exports are increasing.

133. *Vanadium ores.*—Vanadium now used in the United States is secured largely from the ore patronite, an impure vanadium sulphide, found in Minazraga, Peru. The mines are operated by the Vanadium Corporation of America. Importations totaled 9,760 tons in 1929.

134. A vanadium mica mineral, roscoelite, is worked in Colorado. The United States Vanadium Corporation, a Union Carbide and Carbon Co. subsidiary, is the leading producer. The United States Vanadium Corporation shipped some gold-silver vanadium ore to Europe via San Pedro, Calif., in 1929. Concentrates from its Colorado mines are shipped to the electrometallurgical plants of the company.

135. Carnotite, important because of its radium and uranium content, also carries some vanadium oxide; this is found in southwestern Colorado (near Rifle) and in eastern Utah. Production of these ores for their vanadium content has begun. A lead vanadate, vanadinite, is scattered in Western States. In Arizona, this occurs with wulfenite, or lead molybdate; other deposits are located in California, Nevada, and New Mexico.

136. Southwest Africa is second to Peru in the production of vanadium ore and ships to European markets. A ferrovanadium plant has been built in Rhodesia.

137. *Uranium.*—Pitchblende, carnotite, autunite, and torbernite are the principal uranium ores. All these ores contain radium, so that uranium has become a byproduct of radium production. Pitchblende has been found in Gilpin County, Colo.; in North Carolina, South Carolina, South Dakota, Texas, and Connecticut; the Colorado deposit is the only one of commercial importance. Carnotite deposits of southwestern Colorado and eastern Utah, however, form the largest known source of radium-bearing ores in the United States. These occur southwest of Green River in Utah and to the west of the LaSal Mountains; in Colorado, deposits occur in Dolores, San Miguel, and Montrose Counties.

138. In 1929, shipments of 13 short tons of uranium ores were made from Moab, Utah, and from Colorado. It was reported that claims near Thompsons, Grand County, Utah, and an old property in Gilpin County, Colo., would be operated in 1930.

139. Over 136 short tons of uranium oxide and salts were imported in 1929. In Katanga, Belgian Congo, exceptionally rich uranium oxide minerals are being mined. In Cornwall, England, in Austria, and in Saxony, the mineral is associated with nickel-cobalt veins. Portugal has granted 90 or more concessions for mining radium ores. Uranium ores are also found in several localities in Australia.

140. *Zirconium.*—Zircon contains about 67 percent zirconium oxide or zirconium and 33 percent silica. It is widespread in its occurrence but is found in commercial quantities at only a few places. Pablo Beach, Fla., produced several thousand tons yearly, but activity was discontinued during 1928. Henderson County, N.C., has an abundant supply of zircon crystals but they are scattered. Virginia, New Jersey, and Oklahoma are reported to contain zircon-bearing ores and rocks. Mr. Paul M. Tyler of the United States Bureau of Mines states that at this time no zirconium is being mined in the United States.

141. The mineral baddeleyite, containing iron, silica, and zirconium oxide is found in quantity in Brazil, although it occurs in Ceylon, Sweden, Italy, and Montana.

142. *Titanium.*—Rutile and ilmenite are the principal commercial ores of titanium. A subsidiary of the Metal & Thermit Corporation shipped both types of ore from Nelson County, Va., in 1929. The Vanadium Corporation of America acquired properties in Nelson and Amherst Counties, Va., and a third company was drilling in Nelson County. Beach deposits of California are being examined.

143. Ilmenite sand is reported from Travancore, India, and from Senegal. Imports amounted to 25,072 short tons in 1929. Rutile is imported from St. Urbain, Quebec, and from Norway.

144. Large deposits of titaniferous ores occur in New York State, North Carolina, Wyoming, and smaller quantities are found in several other States.

Production of Ferro-Alloys and Iron and Steel

Ferro-alloy production

145. *Development of industry.*—Ferrosilicon was first manufactured in this country at Spray, N.C., in 1898. At about the same time, the production of ferrochromium was begun at this plant to meet the demand for armor plate in the building of a new American Navy after the Spanish-American War. Other plants were erected at Holcomb Rock, Va., and at Kanawha Falls, W.Va. In 1907, the Union Carbide Co. purchased these three plants, together with the patents on ferrosilicon, ferrochromium, silicon carbon, metallic silicon, and titanium carbide, and formed the Electro-Metallurgical Co. of America, which is our largest manufacturer of ferro-alloys today.

146. Demand for alloy steels during the war brought about the establishment of ferro-alloy plants in the following States:

Ferrosilicon	California, Iowa, Massachusetts, Maryland, New York, Pennsylvania, and Tennessee.
Ferromanganese	Washington, Oregon, California, Montana, and Alabama.
Ferrochromium	California, Iowa, Pennsylvania, and New York.
Ferromolybdenum	California and Pennsylvania.
Ferrotungsten	Colorado, Pennsylvania, and Maryland.
Ferrotitanium	New York.
Ferrouranium	Pennsylvania.
Ferrovanadium	Pennsylvania.

147. While many of these companies could not meet competitive conditions after the World War, the location of plants operating in periods of stress has its importance. The ferromanganese production at Washington State was done in electric furnaces, smelting manganese ores from Philipsburg, Mont., with coke, limestone, and metallic iron.

148. *Manufacturers of ferro-alloys.*—In 1929, the following producers, other than blast furnace producers, were manufacturing ferro-alloys in the United States:

Location	Company	Products
Alabama: Anniston	Federal Phosphorus Co. of America	Ferrophosphorus.
Iowa: Keokuk	Keokuk Electro-Metals Co	Ferrosilicon.
New Jersey: Jersey City	Metal and Thermit Corporation	Ferrotungsten. Ferrotitanium. Ferrochromium. Ferrovanadium.
New York: Niagara Falls	Electro-Metallurgical Co. (unit of Union Carbide & Carbon Corporation)	Ferrosilicon. Ferrochromium. Calciumsilicon. Ferrozirconium. Siliconzirconium. Tungsten, vanadium, and other alloys.
	Norton Co	Ferrosilicon.
	Pittsburgh Metallurgical Co	Ferrosilicon. Ferrochromium. Ferromanganese. Ferrosilicon-aluminum.
	Titanium Alloy Manufacturing Co	Ferrotitanium.
	Vanadium Corporation of America	Ferrosilicon. Ferrochromium. Ferrosilicon-manganese. Ferroaluminum-silicon.
Ohio:		
Columbiana	United States Vanadium Corporation (owned by Union Carbide & Carbon Corporation).	Ferrovanadium.
Philo	Ohio Ferro-Alloys Co	Ferrosilicon. Ferromanganese. Ferrophosphorus.
Pennsylvania:		
Kirway	Vanadium Corporation of America	Ferrovanadium. Ferrotungsten. Ferromolybdenum. Ferrochromium. Ferrotitanium and zirconium.
Langeloth	Climax Molybdenum Co	Calcium molybdate.
Washington	Molybdenum Corporation of America	Ferromolybdenum. Ferrotungsten.
York	York Metal and Alloy Co	Ferrotungsten. Ferromolybdenum. Ferrovanadium.
Tennessee: Chattanooga	Southern Ferro-Alloys Co	Ferrosilicon.
Virginia: Holcomb Rock	Electro-Metallurgical Co. (unit of Union Carbide & Carbon Corporation).	Ferrochromium.
West Virginia: Glen Ferris	Electro-Metallurgical Co. (unit of Union Carbide & Carbon Corporation).	Ferrosilicon. Ferrochromium.

The Baltimore Electro-Alloy Co., Baltimore, Md., was idle in 1929.

149. It is obvious that ferrosilicon production takes place principally at Niagara Falls, N.Y., and in Tennessee and West Virginia, while the manufacture of ferrochromium and the other ferro-alloys occurs in nine States.

150. *New plants.*—The Union Carbide & Carbon Corporation is building two new power projects in West Virginia to serve a new plant to be erected for the Electro-Metallurgical unit at Boncar, W.Va. The hydroelectric power plant is being built on the New River between Hawk's Nest and Gauley Junction. It will have 4

units of 35,000 horsepower each and transmission lines will run 6 miles to Boncar. It is estimated that 80,000 horsepower will be delivered to the Boncar plant for manufacturing ferro-alloys. At Boncar there will be a steam electric plant made up of two steam turbo-generators, each having a capacity of 22,000 kilovolts.

151. This company manufactures ferromanganese in Norway under a long term contract with the Norwegian Government. It pays $8 per horsepower year for power, gets coals from Newcastle, iron from the White Sea coast, and manganese from Central Africa where it has developed a manganese property.

152. While the Electro-Metallurgical Co. is by far the largest producer of ferro-alloys, other companies have a firm hold on certain metals entering into alloy production. The Vanadium Corporation of America not only owns vanadium properties in Peru, but owns 50 percent of the capital stock in the Rhodesian Vanadium Corporation which has acquired chrome ore reserves in Rhodesia. It also owns titanium reserves in Virginia. With the acquirement of the United States Ferro-Alloys Corporation of Niagara Falls, deposits of silica rock were secured at Lewiston, N.Y., and deposits of chrome ore at Black Lake, Quebec. The Climax Molybdenum Co. operates the largest molybdenum mines in the United States at this time.

PRODUCTION BY KIND AND AMOUNT

153. *Increases in production.*—The manufacture of ferro-alloys is steadily growing in the United States. Since 1913, production has increased 146 percent, since 1919, 81 percent. Between 1928 and 1929 there was a growth in production of approximately 14 percent. All kinds of ferro-alloys share in this increase although in varying degrees. Ferrosilicon manufacture has increased 223 percent since 1913, ferromanganese and spiegeleisen 107 percent, and other ferro-alloys 213 percent. Since 1919 the increase in each group has been more nearly equal or from 88 percent for ferrosilicon to 78 percent for ferromanganese and spiegeleisen. In the last year the "other ferro-alloys," including chiefly chromium, vanadium, zirconium, titanium, tungsten, and molybdenum gained 24 percent as against 12 percent for ferrosilicon.

TABLE V.—*Production of ferro-alloys in the United States* [1]

Year	Total (gross tons)	Ferrosilicon		Ferromanganese and spiegeleisen		Other ferro-alloys	
		Gross tons	Percent of total	Gross tons	Percent of total	Gross tons	Percent of total
1929	856,768	341,222	39.8	476,655	55.6	38,891	4.6
1928	754,066	303,595	40.3	419,213	55.6	31,258	4.1
1927	707,413	278,277	39.3	394,346	55.7	34,790	5.0
1926	674,312	245,605	36.4	395,106	58.6	33,601	5.0
1925	584,255	226,472	38.7	325,784	55.8	31,999	5.5
1919	472,556	181,751	38.4	269,603	57.1	21,202	4.5
1915	391,424	131,617	33.6	247,406	63.2	12,401	3.2
1913	347,983	105,715	30.4	229,833	66.0	12,435	3.6

[1] Compiled from American Iron and Steel Institute, Annual Statistical Report for 1929.

154. *Ferromanganese.*—In view of the fact that ferromanganese is added to almost all steel for sulphur removal as well as to structural

or other very hard steels, it is not surprising to find that it forms more than half of the total tonnage of ferro-alloys produced. As that manufactured in the United States is not an electric-furnace product, it is only of indirect interest here. About half of the ferromanganese produced in blast furnaces is for the maker's own use. But the ferromanganese imported from Norway and from Welland, Canada, is an electric-furnace product manufactured by American capital.

155. *Ferrosilicon.*—Ferrosilicon forms about 40 percent of all ferro-alloy manufacture. Approximately one half of this is made in the electric furance, a small proportion is a byproduct in the manufacture of fused alumina abrasives, and the remainder, or low silicon-content alloy, is manufactured in the blast furance. This, too, enters into many steels as a scavenger. It is also combined, in the electric furnance with zirconium and with calcium to produce a more effective scavenger. And it is used by itself or combined with ferromanganese, or with aluminum, or with chromium, to produce special steel alloys. In addition to our own production of 341,222 long tons of ferrosilicon, we imported 8,704 tons from Canada and 1,849 tons from Norway.

156. *Other alloys.*—Unfortunately, separate production figures are not available for other ferro-alloys. Altogether, such manufacture formed less than 5 percent of the total tonnage of ferro-alloys. Ferrochromium has the largest application of these alloys, entering into stainless steel and iron, valve steels, high-speed steels, metal-working steels, structural steels, nitric acid plant apparatus, seamless tubing, and a number of other products.

PIG IRON AND STEEL INGOT AND CASTINGS PRODUCTION [18]

157. *Pig iron produced in each State.*—Out of a total production of 41,757,215 long tons of pig iron in 1929, all but 9,013,852 tons was for the "maker's own use." Pennsylvania manufactured a third of all pig iron, and Ohio 23 percent; but Ohio held foremost rank as a seller of pig iron to foundries and other independent manufacturers. Utah and Colorado, together, produced 1.4 percent of the Nation's pig iron.

TABLE VI.—*Production of pig iron by States* [1]

States	1913 [2]	1919 [2]	1925	1926	1927	1928	1929	
	Long tons	*Long tons*	*Long tons*	*Long tons*	*Long tons*	*Long tons*	*Long tons*	*Per cent*
Total	30,966,152	31,015,364	36,116,311	38,698,417	35,858,232	37,401,648	41,757,215	100.0
Pennsylvania	12,954,936	12,276,585	12,239,776	13,231,890	11,466,457	12,052,405	14,016,015	33.6
Ohio	7,129,525	7,102,627	8,767,772	9,261,405	8,407,243	9,017,025	9,702,005	23.2
Indiana and Michigan	1,775,883	2,715,659	4,119,811	4,377,068	4,199,517	4,583,065	5,085,615	12.2
Illinois	2,927,832	2,558,213	3,604,255	3,656,688	3,588,463	3,942,412	4,357,905	10.4
New York [3]	2,187,620	2,070,288	2,070,854	2,599,517	2,615,556	2,366,890	2,804,698	6.7
Alabama	2,057,911	2,130,092	2,815,688	2,933,796	2,758,387	2,517,485	2,704,733	6.5
Maryland and Virginia	631,774	563,411	799,243	881,561	941,501	1,028,596	1,124,762	2.7
West Virginia and Kentucky [4]	315,731	413,091	650,483	513,994	697,184	862,706	862,001	2.1
Colorado and Utah [5]			484,420	608,834	613,627	600,366	602,106	1.4
Wisconsin and Minnesota	367,326	605,619	468,479	537,499	455,727	339,267	379,162	.9
Tennessee	280,541	190,514	95,530	96,165	114,570	91,431	118,213	.3
All other States [6]	337,073	389,265						

[1] Compiled from American Iron and Steel Institute. Annual Reports.
[2] Includes ferro-alloys.
[3] In 1913 and 1919, New Jersey production was included; from 1925 to 1929, Massachusetts production was included.
[4] In 1913 data was included from Mississippi; in 1919, from Georgia and Texas.
[5] In 1913 and in 1919, production for Colorado was included in All other State production.
[6] Includes California, Colorado, Connecticut, Iowa, Maine, Massachusetts, Missouri, Montana, Oregon, and Washington.

[18] All statistics on iron and steel production are compiled by the American Iron and Steel Institute.

158. *Increase in electric furnace production of steel ingots and castings.*—In 1929, 142 plants in the United States were producing steel ingots and 295 plants in the United States and United States possessions were manufacturing steel castings. The total production of all plants was 56,433,473 long tons. Of this amount, 951,431 tons were made in electric furnaces, the highest record as yet attained.

159. *Castings.*—Out of a total tonnage of 1,580,000 castings, 26 percent, or 419,039 tons, was made by the electric process. The use of the electric furnace is exceeded only by the open hearth process for steel castings production. In 1915, but 3 percent of all steel castings were manufactured in the electric furnace, in 1918, 8 percent, and in 1928, 28.6 percent. While proportional increases do not occur each year, the tendency is to increase the use of the electric furnace and to lessen the employment of the crucible and bessemer furnaces in steel castings production. The increase from 1928 to 1929 was 20 percent.

160. *Ingots.*—Only 1 percent of steel ingots, or 532,000 long tons, was produced in electric furnaces in 1929. But in 1915, only 0.1 percent was so manufactured, and in 1918 only 0.9 percent. The increase in the application of the electric furnace in ingot production from 1928 to 1929 was 17 percent.

TABLE VII.—*Production of steel ingots and castings by processes* [1]

STEEL INGOTS

Year	Total gross tons	Electric		Crucible	Bessemer	Open hearth	Miscellaneous
		Gross tons	Percent of total				
1929	54,850,433	532,392	1.0	5,762	7,091,680	47,220,599	----------
1928	50,325,393	453,692	.9	6,516	6,591,745	43,273,440	----------
1927	43,776,717	371,278	.8	7,696	6,153,703	37,244,040	----------
1926	46,936,205	325,278	.7	13,452	6,891,502	39,705,973	----------
1925	44,140,738	335,978	.8	17,729	6,670,128	37,116,903	----------
1924	36,811,157	225,977	.6	21,096	5,846,153	30,717,931	----------
1923	43,485,665	279,914	.6	42,127	8,416,576	34,747,048	----------
1922	34,568,418	191,057	.6	27,561	5,871,565	28,478,235	----------
1921	19,224,084	84,404	.4	6,877	3,977,129	15,155,357	317
1920	40,881,392	346,956	.8	70,536	8,778,107	31,685,495	298
1919	33,694,795	272,942	.8	62,563	7,172,743	26,186,174	373
1918	43,051,022	403,068	.9	113,782	9,215,392	33,318,561	219
1917	43,619,200	239,632	.5	122,882	10,320,688	32,935,737	261
1916	41,401,917	126,048	.3	120,341	10,916,248	30,238,978	302
1915	31,284,212	46,348	.1	99,026	8,194,737	22,943,770	331

CASTINGS

1929	1,583,040	419,039	26.5	883	30,829	1,132,289	----------
1928	1,218,787	348,568	28.6	1,253	28,450	840,516	----------
1927	1,158,468	294,809	25.4	1,340	38,024	824,295	----------
1926	1,357,558	326,445	24.0	2,041	43,066	986,006	----------
1925	1,252,786	279,534	22.3	1,833	53,834	917,585	----------
1924	1,120,782	206,549	18.4	1,377	53,437	859,419	----------
1923	1,468,031	235,958	16.2	1,952	67,512	1,152,609	----------
1922	1,034,508	154,982	15.0	1,045	47,733	830,748	----------
1921	559,713	85,095	15.2	736	38,809	434,445	628
1920	1,251,542	155,196	12.4	1,729	104,980	986,400	3,237
1919	976,437	111,510	11.4	1,009	98,819	762,520	2,679
1918	1,411,410	108,296	7.7	1,330	160,844	1,140,830	110
1917	1,441,407	64,911	4.5	3,834	159,272	1,213,156	234
1916	1,371,763	42,870	3.1	9,351	142,791	1,176,449	302
1915	866,824	23,064	2.7	14,756	92,476	735,332	1,196

[1] Compiled from American Iron and Steel Institute, Annual Statistical Report for 1929.

161. *Alloy-steel ingots and castings production.*—The increase in ferroalloy manufacture is reflected in the increase in alloy-steel production. In 1929, 3,957,207 long tons of alloy steel was manufactured, 3,764,287 tons being in ingot form and 192,920 tons in castings. This represented 7 percent of all steel manufactured in 1929, 6.9 percent of all ingots, 12.2 percent of all steel castings. This manufacture took place in 30 States as well as in the District of Columbia and Alaska.

162. The electric furnace plays a much more important part in the production of these alloy steels than in total steel production. For 11 percent or 415,963 long tons of all steel ingots produced was melted in the electric furnace and almost half of alloy-steel castings (94,067 tons) was made by the use of electricity as compared with 1 percent and 26 percent, respectively, of all ingots and all castings manufactured.

163. *State production.*—Pennsylvania produced over 20,000,000 tons of the 56,000,000 tons of steel ingots and castings made in 1929; Ohio manufactured 13,000,000 long tons, or, almost 60 percent of the United States steel production occurs in these two States. Indiana and Illinois rank next with productions of 6,663,000 and 4,784,000 tons, respectively. Production for Western States is not given separately. Washington is grouped with Colorado, Oklahoma, and Kansas, these four States manufacturing 887,692 long tons of steel. Oregon and Utah had a production of 18,288 long tons and California, Canal Zone, and Alaska of 527,301 tons.

TOTAL PLANT CAPACITIES AND ELECTRIC FURNACE CAPACITIES

164. *Steel ingot capacity.*—The total ingot capacity of the United States as determined by a special survey committee of the American Iron and Steel Institute, was in excess of 63,000,000 long tons; 773,890 tons was electric-furnace ingot capacity. Pennsylvania and Ohio had 59 percent of the total ingot capacity, and 59 percent of the electric-furnace capacity. California has eight steel ingot manufacturing plants with a capacity of 642,700 tons of which 2 percent is electric-furnace capacity. Colorado has but one plant of 800,000 tons capacity, none of which is electric. Utah has one ingot manufacturer. Washington State steel mills have a capacity of 155,000 long tons of ingots, of which almost 10 percent is electric-furnace capacity.

165. *Steel-castings capacity.*—The 295 operating castings plants have an annual capacity of 2,098,000 long tons. One fourth of this is electric-furnace castings capacity. While Pennsylvania has 30 percent of the total capacity it has but 15 percent of the electric-furnace castings capacity. Ohio and Illinois rank almost on an equality in total castings capacity while Illinois has 14 percent of the electric-furnace capacity.

166. Oregon has four all-electric steel castings plants with a combined possible production of 9,450 long tons. California can produce 41,700 tons of electric castings in 19 of her 21 castings mills. Washington and Utah have an electric castings capacity of 15,500 long tons.

Data for all other States is given on the following table.

TABLE VIII.—*Annual capacity of steel ingots and steel castings in 1929 by States* [1]

State	Steel-ingot capacity						Steel-castings capacity					
	Total capacity			Electric-furnace capacity			Total capacity			Electric-furnace capacity		
	Number of plants	Annual capacity	Percent of country's capacity	Number of plants	Annual capacity	Percent of country's capacity	Number of plants	Annual capacity	Percent of country's capacity	Number of plants	Annual capacity	Percent of country's capacity
		Long tons			*Long tons*			*Long tons*			*Long tons*	
Total	142	63,067,546	100.0	46	773,890	100.0	297	2,097,995	100.0	186	528,415	100.0
Alabama	4	2,032,000	3.2	0	0		5	22,700	1.1	3	4,200	.8
California	8	642,700	1.0	3	14,500	1.9	21	62,200	2.9	19	41,700	7.9
Colorado	1	800,000	1.3	0	0		3	10,700	.5	2	5,700	1.1
Connecticut	1	140,000	.2	0	0		5	6,850	.3	4	4,100	.8
Delaware	1	340,000	.5	0	0		[2] 4	[2] 22,500	1.1	[2] 2	[2] 6,800	1.3
District of Columbia	1	1,800	(3)	1	500	(3)						
Georgia	1	92,000	.1	0	0		[4] 4	[4] 6,950	.3	[4] 3	[4] 4,950	.9
Illinois	11	5,455,000	8.7	4	87,600	11.3	19	322,900	15.4	11	74,600	14.1
Indiana	5	7,320,600	11.6	1	8,000	1.0	10	86,860	4.1	4	11,910	2.3
Kentucky	2	850,000	1.3	0	0							
Maryland	2	1,759,200	2.8	1	15,000	1.9	(2)	(2)	(2)	(2)	(2)	(2)
Massachusetts	1	190,000	.3	0	0		[5] 12	[5] 27,255	1.3	[5] 5	[5] 13,940	2.6
Michigan	2	520,000	.8	2	14,000	1.9	16	55,600	2.7	14	32,500	6.2
Minnesota	1	540,000	.9	0	0		8	17,950	.9	4	10,250	1.9
Missouri	2	305,000	.5	0	0		[6] 11	[6] 148,050	7.1	[6] 6	[6] 17,750	3.4
New Jersey	2	230,000	.4	1	25,000	3.2	5	16,910	.8	2	11,000	2.1
New York	11	2,827,650	4.5	8	126,450	16.3	14	136,060	6.5	7	21,200	4.0
Ohio	24	14,903,100	23.6	3	225,000	29.1	32	325,850	15.5	20	65,950	12.5
Oklahoma	1	45,000	(3)	0	0		[7] 5	[7] 13,200	.6	[7] 4	[7] 12,200	2.3
Oregon							4	9,450	.5	4	9,450	1.8
Pennsylvania	51	22,304,996	35.4	18	230,640	29.8	68	638,280	30.4	31	82,460	15.6
Rhode Island	1	38,000	(3)									
Texas	1	7,500	(3)	1	7,500	1.0	[8] 11	[8] 14,240	.7	[8] 8	[8] 11,805	2.2
Utah	1	23,000	(3)				[9] 15	[9] 17,850	.9	[9] 13	[9] 15,500	2.9
Virginia	2	4,700	(3)	2	4,700	.6	4	4,400	.2	3	3,900	.7
Washington	2	155,000	.3	1	15,000	1.9	(9)	(9)	(9)	(9)	(9)	(9)
West Virginia	3	1,540,000	2.4	0	0		3	26,800	1.3	2	2,800	.5
Wisconsin							16	102,550	4.9	14	62,750	11.9
Canal Zone							2	1,890	(3)	1	1,000	.2

[1] Compiled from Report of Committee on Special Survey of Capacity, American Iron and Steel Institute, Annual Statistical Report for 1929.
[2] Maryland included in figures for Delaware and District of Columbia.
[3] Less than 0.1 percent.
[4] Includes Tennessee and Florida.
[5] Includes New Hampshire.
[6] Includes Iowa.
[7] Includes Arkansas, Nebraska, Kansas.
[8] Includes Louisiana.
[9] Figures for Utah include Washington.

PRINCIPAL STEEL-INGOT PRODUCERS

167. More than 80 percent of the steel-ingot capacity in the United States is controlled by 11 steel companies. The United States Steel Corporation is by far the largest manufacturer, having an ingot capacity of over 24,000,000 long tons. In 1929 this corporation produced 41.6 percent of the iron ore of the country, 29 percent of the coke, 22 percent of ferromanganese, spiegeleisen, and other ferroalloys, and 39 percent of the pig iron. Its production of steel ingots and castings was 38.75 percent of the total United States production. It manufactured 50 percent of the steel rails and 35 percent of all

rolled products. Thirty-nine percent of tinplate and terneplate was produced in its mills.[18]

168. United States Steel Corporation plants include the following:

American Bridge Co., with plants at Ambridge, Pen-coyd, Pittsburgh, Pa.; Chicago; Canton and Toledo, Ohio; Gary, Ind.; Minneapolis, Minn.; Elmira, N.Y.; Trenton, N.J.

American Sheet & Tin Plate Co., with operating plants in 10 towns in Pennsylvania, in 4 Ohio towns, in Gary and Elwood, Ind., and in Chester, W.Va.

American Steel & Wire Co., with plants in 5 Pennsylvania towns; in Cleveland, Ohio; in Anderson, Ind.; in DeKalb, Waukegan, and Joliet, Ill.; in Worcester, Mass.; New Haven, Conn.; in Trenton, N.J.; in Fairfield, Ala.; and in San Francisco, Calif.

Carnegie Steel Co., with plants in 11 Pennsylvania cities and towns and in 3 Ohio cities and towns.

Illinois Steel Co., with plants at Gary, Ind.; Joliet and South Chicago, Ill.; and at Milwaukee, Wis.

Lorain Steel Co., of Johnstown, Pa.

Minnesota Steel Co., of Duluth, Minn.

National Tube Co., with plants at McKeesport, Elwood City, and Pittsburgh, Pa.; Lorain, Ohio; and Gary, Ind.

Tennessee Coal, Iron, & Railroad Co., of Alabama.

United States Steel Products Co., manufacturing foundry and basic pig iron at Ironton, Utah; steel ingots, castings, and hot-rolled products at Pittsburgh, Calif.; electric steel, carbon, and alloy steel castings at Portland, Oreg.; and ingots, castings, and hot-rolled products at Torrance, Calif.

169. The second largest steel manufacturer is the Bethlehem Steel Co. with an ingot capacity of 8,000,000 long tons. Its plants are located chiefly in Pennsylvania, although there are single plants at Lackawanna, N.Y., and at Wilmington, Del.; and shipbuilding and ship-repairing plants at Baltimore, Md.; Quincy and Boston, Mass.; and Alameda, San Francisco, and Los Angeles, Calif. Its subsidiary, the Pacific Coast Steel Corporation, produces steel ingots, blooms, billets, and finished rolled and forged products at Vernon and South San Francisco, Calif., and at Seattle, Wash.

170. The Republic Iron & Steel Co. has an ingot capacity of 4,900,000 long tons. Its plants are in Alabama, Illinois, Indiana, and Ohio. The capacity of the Youngstown Steel & Tube Co. is 3,240,000 long tons. Mills are located in Illinois, Indiana, and Ohio. The Inland Steel Co. has plants in Indiana, Illinois, and Wisconsin, with a total ingot capacity of 1,800,000 long tons. The American Rolling Mill Co.'s works are located at Ashland, Ky.; at Butler, Pa.; and in Ohio.

171. The Colorado Fuel & Iron Co. produces pig iron, ferromanganese for own use, wire products, gray iron pipe and castings, and hot-rolled products at works in Pueblo, Colo. Their total capacity is 1,138,000 long tons.

172. Other large steel companies are the Corrigen, McKinney Steel Co.; the Wheeling Steel Corporation; Jones & Laughlin Steel Corporations, and the National Steel Corporation. These have capacities ranging from 1,000,000 to 3,000,000 tons.

173. *Western iron and steel works and rolling mills.*—The taking over of Pacific coast iron and steel works by the United States Steel Corporation and the Bethlehem Steel Co. was an interesting development of 1929. Western plants are listed below. The capacities given are approximate only and sometimes exceed those reported for States by the American Iron and Steel Institute. They indicate only in a general manner the size of existing plants.

[18] American Iron and Steel Institute. Annual Statistical Report for 1929.

Location	Company	Approximate plant capacity
California:		
Emeryville	Botchford Steel Co	60,000 tons ingots.
Huntington Park	Southern California Iron & Steel Co. (subsidiary of Bethlehem Steel Corporation).	85,000 tons ingots.
Pittsburg	Columbia Steel Corporation	192,000 tons ingots and castings.
Torrance	Columbia Steel Corporation (United States Steel Corporation subsidiary).	171,000 tons ingots and castings.
Sacramento	Southern Pacific Co	9,000 tons ingots.
San Francisco	Pacific Coast Steel Corporation (Bethlehem Steel Co. subsidiary).	155,000 tons ingots.
Do	Simmons Co	10,000 tons merchant bars and finished goods only.
Do	American Steel & Wire Co. (United States Steel Corporation subsidiary).	Wire products only.
Colorado: Pueblo	Colorado Fuel & Iron Co	800,000 tons ingots.
Utah:		
Ironton	United States Steel Products Co. (United States Steel Corporation subsidiary).	175,000 tons foundry and basic pig iron.
Midvale	Western Steel & Foundry Co	46,000 tons ingots.
Washington:		
Lowell	United Steel Co	3,600 tons finished products only.
Seattle	Northwest Steel Rolling Mills	15,000 tons ingots.
Do	Pacific Coast Steel Corporation (Bethlehem Steel Corporation subsidiary).	140,000 tons ingots.

174. In addition to these ingot steel works, the following foundries are located in the Pacific Northwest:

Location	Company and product	Approximate plant capacity
Oregon:		*Short tons*
Portland	Electric Steel Foundry Co., manganese-alloy and carbon-steel castings.	3,120
Do	Tennent Steel Corporation, carbon and alloy steel	1,200
Do	United States Steel Products Co. (United States Steel Corporation subsidiary), electric castings.	1,800
Washington:		
Bremerton	United States Navy Yard, castings for marine use	240
Everett	Tennent Steel Corporation, carbon and alloy steel	1,200
Hoquiam	Lamb-Grays Harbor Co., steel jobbing	420
Seattle	Olympic Steel Works, jobbing foundry	1,200
Do	Pacific Car & Foundry Co., railway equipment	7,416
Do	Washington Iron Works, carbon- and alloy-steel castings	4,200
Do	Tennent Steel Corporation, carbon and alloy steel	1,920
Sedro-Woolley	Skagit Steel & Iron Works, steel castings	600
Spokane	Union Iron Works, steel castings for own use	180
Tacoma	Atlas Foundry & Machine Co., general jobbing and sawmill castings.	240
Do	Lidgewood Pacific Co., machine castings	1,500
Do	Tennent Steel Corporation, carbon and alloy steel	1,800

ROLLED IRON AND STEEL

175. Steel ingots are usually subjected to further treatment before they are ready for the consuming market. In 1929, over 40,590,000 long tons of steel and 475,000 tons of iron were rolled into smaller sections and different marketable shapes.

176. *Plates and sheets.*—Three tenths of this tonnage was finished as plates and sheets. In this are included black plates for tinning. Although the largest number of plate and sheet works are in Ohio

and Pennsylvania, Washington has 1 mill making universal plates, and California has 3 mills: 1 making black plates on tin mills; 2, black sheets on sheet or job mills; and 1, universal plates. Two thirds of all plates are purchased by railroads, for building construction, or by oil, gas, and mining operators. While a fourth of our sheet production enters the automobile industries, sheets are used extensively in a number of industries.

177. *Merchant bars.*—Merchant-bar tonnage, or bars made in standard dimensions for supplying the open market, reached 6,471,000 long tons in 1929. These were rolled in 128 bar mills in 22 States.

178. *Structural shapes.*—Structural shapes, applied principally to building construction and to railroads, were manufactured in 56 mills in 17 States. Pennsylvania rolled 59.5 percent of the total tonnage of 4,780,000 long tons. California had four works; Washington, Utah, and Colorado each had one structural iron and steel mill.

TABLE IX.—*Finished products of iron and steel rolling mills in 1929* [1]

Products	Total		Iron (long tons)	Steel (long tons)
	Long tons	Percent		
Total	41,069,416	100.0	475,049	40,594,367
Plates and sheets	12,436,312	30.3	3,127	12,433,185
Merchant bars	6,471,146	15.8	154,690	6,316,456
Structural shapes	4,778,020	11.6	71	4,777,949
Skelp, flue, and pipe iron or steel	3,517,238	8.6	151,556	3,365,682
Wire rods	3,134,409	7.6	375	3,134,034
Rails	2,722,138	6.6		2,722,138
Hot-rolled strips and flats for cold-rolling	2,502,793	6.1		2,502,793
Blanks or pierced billets for seamless tube	1,382,171	3.4		1,382,171
Bars for reinforced concrete work	952,350	2.3	557	951,793
Long angle splice bars, tieplate bars, etc	924,803	2.3	49,375	875,428
Rolled forging blooms, billets, etc	527,336	1.3	2,701	524,635
Bands and cotton ties	384,706	0.9	1,982	382,724
Hoops	204,246	0.5		204,246
Rolled sheet piling (not including fabrication)	102,494	0.3		102,494
Blooms, billets, sheet bars, etc., for export	40,015	[2]		40,015
Railroad ties	13,718	[2]		13,718
Nail and spike plate	9,827	[2]	12	9,815
Other finished hot-rolled products	965,694	2.4	110,603	855,091

[1] Compiled from American Iron and Steel Institute, "Annual Statistical Report for 1929."
[2] Less than 0.1 percent.

179. *Pipe and tube material.*—Skelp for welding into tubes and pipes was rolled in 35 plants in seven States. Production totaled 3,500,000 tons. Manufacture of blanks or pierced billets for seamless tubes reached 1,382,171 tons in 1929.

180. *Other rolled products.*—Rails found 6.6 percent of total rolling-mill production. Only 723 tons were of electric furnace steel. Titanium entered into 486 tons and other alloys into 1,479 tons of steel rails. Wire rods were rolled by 48 works in 15 States. Production was 7.6 percent of the total rolled iron and steel. The production of other rolled forms is given in table IX.

PRODUCTION BY STATES

181. States rank in the same order for the production of finished rolled products as they do in the production of ingots. Pennsylvania, Ohio, Indiana, and Illinois manufacture 78 percent of all rolled

products. No other State produces as much as 5 percent of the total. Together, Washington, Utah, and Colorado steel mills turned out 701,000 tons of rolled products; California and the Canal Zone, 378,788 long tons.

TABLE X.—*Production of rolled forms of iron and steel by States in 1929* [1]

States	Total		Iron (long tons)	Steel (long tons)
	Long tons	Percent		
Total	41,069,416	100.0	475,049	40,594,367
Pennsylvania	14,860,360	36.2	193,406	14,666,954
Ohio	8,811,822	21.5	63,388	8,748,434
Indiana	5,144,991	12.5	59,685	5,085,306
Illinois	3,232,611	7.9	54,932	3,177,679
New York	1,869,302	4.6	20,036	1,849,266
West Virginia	1,298,332	3.2	1,727	1,296,605
Delaware, Maryland, and Virginia	1,248,607	3.0	18,059	1,230,548
Alabama	1,216,334	2.9		1,216,334
Michigan, Wisconsin, and Minnesota	848,827	2.1	4,084	844,743
Colorado, Utah, and Washington	701,218	1.7		701,218
Kentucky, Tennessee, Georgia, and Texas	692,243	1.7	10,493	681,750
California and Canal Zone	378,788	0.9	514	378,274
Missouri and Oklahoma	301,552	0.7	17,480	284,072
Maine, Massachusetts, Rhode Island, and Connecticut	266,592	0.6	2,565	264,027
New Jersey	197,837	0.5	28,680	169,157

[1] Compiled from American Iron and Steel Institute, "Annual Statistical Report for 1929."

STEEL MARKETS

DOMESTIC MARKETS

182. *Major consuming industries.*—The building and construction industry and the automotive industry now vie with each other for first place as steel consumers. In 1928 and 1929, the largest amount of iron and steel was purchased for automobile manufacture; in 1927 and 1930, the largest tonnage of rolled products went into building and construction. Railroad companies afford the third largest outlet for rolled products at present, although from 1922 to 1926 they ranked first as steel consumers. These three industries absorb approximately 50 percent of all rolled steel.

183. The construction industry is especially interested in structural shapes, while it takes from 10 to 20 percent of bars, plates, sheets, pipe, wire, and strip steel.[19]

184. The automobile industry buys heavily of strip steel and consumes from 25 percent to over 30 percent of all steel sheets and bars. The railroads consume from 10 to 20 percent of plates, bars, and structural shapes. Under "railroads" is included trackwork, buildings, bridges, cars, and locomotives.

185. *Minor consuming industries.*—Oil, gas, and water companies are the heaviest consumers of pipe, and rank with the construction industry in the use of plates. Almost three fourths of all tin plate is made into metal containers. Agriculture requires approximately 18 percent of all steel wire produced.

186. According to the calculations of "The Iron Age," [20] industries consumed the following proportions of rolled steel in 1930:

[19] These figures are quoted from "The Iron Age," which collects annually sales figures from 57 steel producers, representing 96 percent of the industry.

[20] "The Iron Age," Jan. 1, 1931.

	Percent
Building and construction	19
Automobile and automobile parts manufacture	15. 5
Railroads	15
Oil, gas, water, mining, and lumber industries	11. 5
Metal containers	6
Agricultural machinery and implements	4
Exports	5. 5
Machinery, other than agricultural	3
Electrical manufacture	2
Stoves and metal furniture	2
Shipbuilding	1. 3
Miscellaneous	15. 2

187. *Consumption of alloy steels.*—The growth in alloy-steel production is due to the use of this steel in automobiles, for at least seven tenths of all alloy steel enters into their manufacture. Tools, both hand and machine, require less than 3 percent of all alloy steel produced, and agricultural implements but 2.5 percent.

188. *Pacific coast market.*—While major consuming markets are in the East and Middle West, the interest of large steel companies in Pacific coast plants is indicative of the increasing demand for steel due to the growth of population and the greater diversification of western industries. Only about a sixth of Pacific coast steel market needs are met by Pacific coast plants at the present time.

189. The Pacific coast, including British Columbia, is estimated to consume 425,000 tons [21] of tin plate, or about one fifth of the total amount produced in the United States, in its canning industries. Only about 10 percent of this tin plate is manufactured on the Pacific coast. The all-rail freight rate on tin plate from Pittsburgh to San Francisco, Los Angeles, Portland, and Seattle is $0.75 per 100 pounds.

190. The pipe and seamless tubing market on the Pacific coast is estimated to be about 400,000 tons, none of which is produced on the Pacific coast. The oil, gas, and water companies consume the largest amount of pipe. Freight rates on pipe are $1.15 per 100 pounds from Pittsburgh and $1 per 100 pounds from Chicago to Pacific coast cities.

191. Rail consumption on the Pacific coast is estimated by Mr. Simpson to be 200,000 tons, plate consumption 175,000 tons; neither rails nor plates are produced locally. Structural steel consumption is approximately 225,000 tons, of which 20 percent is manufactured by Pacific coast mills; sheets to the extent of 175,000 tons are consumed, of which 30 percent is produced locally.

192. About 270,000 tons of merchant bars for general work are produced on the west coast while consumption reaches about 450,000 tons. Total consumption of rolled steel is estimated to be approximately 2,500,000 long tons.

193. Mr. John A. Topping, vice president American Iron and Steel Institute, states in his brief to the Committee on Ways and Means, House of Representatives, "High transportation costs narrow our market, so much so in fact, that many mills are unable to market their products at Gulf, Atlantic, and Pacific seacoast points at anything like a reasonable profit, and in many cases at a loss." He speaks of European competition on rolled products, and Indian and Chinese competition on pig iron in the Pacific coast markets.

[21] Estimates by William Simpson, president Simpson Construction Co. Given in address before convention of iron, steel, and allied industries of California, 1930. Quoted in Iron Trade Review, Feb. 27, 1930.

EXPORTS AND IMPORTS OF IRON AND STEEL AND FERRO-ALLOYS

194. Exports of iron and steel products of all types totaled in excess of 3,000,000 tons in 1929 while imports totaled 736,000 tons. While 46,000 tons of pig iron were exported chiefly to Canada and Japan, 147,760 tons were imported principally from British India, England, and the Netherlands.

195. *Ferro-alloys.*—Exports of ferro-alloys were as follows: 1,574 tons of ferromanganese and spiegeleisen chiefly to Canada; 46 tons of ferrotungsten, tungsten metal, and wire chiefly to Germany; 5,772 tons of ferrovanadium and other ferro-alloying ores and metals, chiefly to Canada, Germany, and England.

196. Manganese alloys estimated on basis of 80 percent manganese were imported from Norway, England, and Canada to the extent of 78,481 long tons. Ferrosilicon, with a content of 9,424 tons silicon, came in from Canada and Norway. Tungsten and alloys, with a content of 3,040 tons tungsten, were shipped chiefly from China and England. Ferrochromium, chromium metal, and chromium-vanadium imports reached 667 tons, coming chiefly from Sweden, Switzerland, and Norway.

197. Steel in the form of ingots, blooms, billets, slabs, or sheet bars was exported only to a small extent and then chiefly to Canada. Japan and Italy purchased between 150,000 and 188,000 tons of steel in this condition. Iron- and steel-scrap exports totaled 557,000 long tons, however.

TABLE XI.—*Exports of iron ore, pig iron, and steel ingots, blooms, slabs, and sheet bars during 1929 by country of destination* [1]

Country	Iron ore		Pig iron		Steel ingots, blooms, billets, slabs, and sheet bars	
	Tons	Value	Tons	Value	Tons	Value
Total	1,304,417	$4,774,842	46,357	$830,225	42,578	$1,499,644
Belgium			590	18,654		
Canada	1,295,178	4,741,457	23,431	447,122	23,496	983,130
Chile			848	16,962	2	85
China	25	120	50	1,915	175	10,450
Cuba	27	732	261	5,879		
France			898	28,081		
Germany			531	16,988		
Italy			90	3,551	7,019	155,765
Japan			16,930	224,658	7,120	187,903
Kwantung					401	19,465
Netherland West Indies					105	5,282
New Zealand			14	470	2,415	63,967
Panama			392	10,831	78	6,022
Peru			711	13,501	25	1,842
Philippine Islands			880	20,457	1,410	44,919
Spain					177	3,371
United Kingdom	9,186	32,518	209	7,512	40	2,082
All others	1	15	522	13,644	115	15,361

[1] Compiled from U.S. Bureau of Foreign and Domestic Commerce, Foreign Commerce and Navigation of the United States, 1929.

198. The larger amount of exports was in the form of finished rolling-mill products. Tin plate, terneplate, and structural shapes exceeded all other finished forms exported. Tin plate and terneplate was shipped principally to Japan and Canada, China, Argentina, Mexico, British India, Siam, Cuba, Chile, and other South American countries.

Structural shapes go chiefly to Canada. Plates and sheets go in largest measure to Canada, Japan, and the Philippine Islands. Wire goes in large quantities to the Argentine. In fact, the principal markets for United States iron and steel mill products are Canada, our own insular possessions, Japan, China, South America, and Central American countries.

THE ELECTRIC FURNACE IN THE IRON AND STEEL INDUSTRY

BIBLIOGRAPHY

Year	Author	Title
1929	American Iron & Steel Institute	Annual Statistical Report.
1923	do	Do.
1929	do	Directory.
1930	Bailey, T. F. (Baily Furnace Co.)	Production of Gray Iron from Steel Scrap in the Electric Furnace. Paper presented before the American Institute of Mining and Metallurgical Engineers, February.
1929	Barrett, E. P., Joseph, T. L., Wood, C. E.	Research Aids in Fostering Domestic Industry. Engineering and Mining Journal, Feb. 23.
1928	Boylston, H. M.	Iron and Steel.
1928	Brewster, M. W. (General Electric Co.).	Economies in Automatic Welding. Iron Age, Aug. 2.
1929	Finlayson, F. E. (General Electric Co.).	Anneals Magnetic Iron Electrically. Iron Age, Oct. 17.
1927	Hodson, Frank; Smalley, Oliver	Development in the Low Temperature Reduction of Iron Ore. Paper presented before American Electrochemical Society, April.
1927	do	Manufacture of Steel in "One Process" Direct from Ore. Paper presented before American Electrochemical Society, April.
1926	Liddell, Donald M.	Handbook of Non-Ferrous Metallurgy.
1927	Longmuir, Percy	The Direct Production of Pure Iron. Paper presented before the American Electrochemical Society, April.
1930	MacBain, J. T. (electrometallurgical division, Union Carbide & Carbon Corporation).	Ferro-Alloys as Factors in Steel Production. Address before Toronto section of Canadian division of Mining and Metallurgy, February.
1917	New York State Museum	Bulletin 193.
1931	Northrup, Dr. E. F. (vice president, Ajax Electrothermic Corporation).	Tonnage Melting by Coreless Induction. Iron Age, Jan. 15.
1931	do	Power Problems in High-Frequency Melting. Iron Age, Jan. 22.
1931	do	Typical Installation of Coreless Induction Furnaces. Iron Age, Jan. 29.
1928	Otis, A. N. (General Electric Co.)	Progress Made in the Use of the Electric Furnace for Heat Treating. Paper presented before American Society for Steel Treating, October.
1930	Pike, Robert D.; West, George H.; Steck, L. V.; Cummings, Ross, Little, B. P.	Electrolytic Iron from Sulphide Ores. Paper presented before American Institute of Mining and Metallurgical Engineers, February.
1920	Rodenhauser, W.; Schoenawa, J.; Vom Bauer, C. H.	Electric Furnaces in the Iron and Steel Industry.
1928	Roush, G. A.	The Mineral Industry During 1928.
1929	do	The Mineral Industry During 1929.
1930	Scott, Wirt S. (Westinghouse Electric & Manufacturing Co.).	Comparative Heat Treating Costs. Electrical World, May 17.
1930	do	Economic Use of Electric Furnaces. Electrical World, Dec. 26.
1930	Simpson, G. L. (Pittsburgh Electric Furnace Co.).	Electric Furnace Iron. Paper presented before American Electrochemical Society, May.
1924	Sisco, Frank	The Manufacture of Electric Steel.
1926	Smith, Wilfred	A Geographical Study of Coal and Iron in China.
1923	Stansfield, Alfred	The Electric Furnace for Iron and Steel.
1930	Steel Founders Society of America	Directory.
1930	Tyler, Paul M. (U.S. Bureau of Mines).	Minor Metals. Engineering and Mining Journal, Feb. 8.
1929	United States Department of Commerce: Bureau of Foreign and Domestic Commerce.	Commerce Reports, Sept. 9.
1930	do	Commerce Reports, Apr. 9.
1920	do	Foreign Commerce and Navigation of the United States.
1916	Bureau of Mines	Mineral Resources of the United States.
1918	do	War Minerals Investigation.
1926	do	Mineral Resources of the United States.
1927	do	Do.
1929	do	Chromite in 1928.
1931	do	Chromite in 1929.
1930	do	Iron Ore, Pig Iron, and Steel in 1929.
1930	do	Rare Metals in 1929.

Bibliography—Continued

Year	Author	Title
	Department of the Interior:	
1906	Geological Survey	Titaniferous Iron Ore of Iron Mountain, Wyoming, in contributions to Economic Geology.
1908	Bulletin 359	Magnetite Deposits of the Cornwall Type in Pennsylvania.
1910	do	Manganese Deposits of the United States.
1919	do	The Deposits of Manganese Ore in Mexico, in contributions to Economic Geology.
1920	do	Chromite in 1918.
1921	do	World Atlas of Commercial Geology.
1922	Bulletin 735	The Magnetite Ores of Western North Carolina and Eastern Tennessee.
	House of Representatives:	
1921	Committee on Ways and Means	Hearings on General Tariff Revision.
1929	do	Hearings on General Tariff Readjustment.
1927	Waby, Delton T	Electric Iron and Steel Performance. Electrical World, Dec. 7.
1929	do	Electric Steel Melting in Europe. Electrical World, Aug. 17.
1930	Yersen, T. D	Electrolytic Iron from Sulphide Ores. Mining and Metallurgy, April.
1926	do	Large Ferro-Alloy Output in South. Iron Age, Aug. 19.
1928	do	Electrolytic Iron—Its Inception and Development. Engineering, Mar. 23.
1929	do	Byers New Process for Wrought Iron. Iron Age, Aug. 8.
1930	do	New Process Wrought Iron Mill Opened. Power, Oct. 21.
1930	do	Electric Annealing Chosen After Trying Oil and Gas. Electrical World, Sept. 13.
1930	do	Bethlehem's Heat Treatment Shop. Metal Progress, December.
1930	do	Producing Electric Welded Pipe. Steel, Aug. 14.
1930	do	Great Changes Overtake Steel. Magazine of Wall Street, Nov. 15.

THE ORIGINAL AND SOME NEW ELECTRIC FURNACE PRODUCTS

CONTENTS

	Page
Power requirements of original electric-furnace products	427
Calcium carbide	428
Development of industry	428
Originally a source of illuminating gas	428
Use in metal and organic chemical industries	428
Position as a basic raw material threatened	429
Present production in United States	429
Manufacturing processes	430
Power consumption	430
Costs of production	430
Organization of industry	431
Plants manufacturing calcium carbide	431
Subsidiary plants producing acetylene, oxygen, and welding equipment	431
Subsidiary plants producing organic chemicals and gases	432
Competitive conditions	432
European developments	432
Excess capacity in United States	433
Electric furnace abrasives and refractories	433
Demand for hard abrasives and superrefractories	433
Production	435
Silicon carbide and fused alumina	435
Mullite refractory producers	436
Manufacturing processes and power consumption	436
Silicon carbide	436
Fused alumina abrasives and refractories	437
Mullite	439
Sources of raw materials	439
Sand	439
Petroleum coke	440
Bauxite	440
Mullite minerals	441

CONTENTS—Continued

	Page
Fused quartz	441
Silicon and calcium	442
Graphite	442
Production	442
Markets	443
Manufacturing processes and power consumption	443
Bibliography	444

When hydroelectric service was made available at Niagara Falls in 1895, the manufacture of products requiring such high temperatures as to be commercially practical only in electric furnaces, began on a commercial scale. Silicon carbide for abrasives, calcium carbide for acetylene lighting, and crystalline graphite for electrodes were among the first industries to become established at the Falls. Fused alumina and other electrometallurgical industries located there in the early years of the twentieth century.

While new plants have been established at other locations, these industries still center about Niagara Falls consuming from 2,000 kilowatt-hours to 8,000 kilowatt-hours of energy per ton of electric-furnace product.

The demand for silicon carbide and fused alumina is growing, not only because of the increased need for hard abrasives in machining alloy steel, but also because both materials make excellent high-temperature refractories. The electrical energy consumed in crude silicon-carbide production in the United States and Canada in 1929 was approximately 227,000,000 kilowatt-hours. Crude fused alumina production in the two countries required in excess of 150,000,000 kilowatt-hours. While almost all crude abrasives are made into abrasive wheels and papers or into refractory shapes in the United States only one third of the crude alumina is fused in the United States and less than one seventh of crude silicon carbide is formed in United States plants. The remainder is made on the Canadian side of Niagara Falls and at Shawinigan Falls, Canada, by American companies.

Calcium carbide production in the United States consumed approximately 720,000,000 kilowatt-hours in 1929. The present capacity of calcium carbide plants in the United States and in foreign countries exceeds the demand for the material which finds sharp competition in every market in which its finished products enter. The position of calcium carbide as a commercial source of acetylene is also threatened by the production of acetylene from methane. American firms manufacturing calcium carbide have entered upon the manufacture of organic chemicals, gases, ferro-alloys and other products.

Crystalline graphite production requires approximately 7,600 kilowatt-hours per ton. As only one company was engaged in its commercial production prior to 1929, total production figures are not available. Plants consuming a large number of graphite electrodes in electric furnace production are beginning to manufacture their own electrodes from petroleum coke.

Silicon and metallic calcium find small commercial application. Fused quartz, however, is finding extended demand not only as equipment for acid manufacture but also in optical and photographic lenses and in ultra-violet and infra-red ray transmission glass. A ton

of transparent quartz would require over 10,000 kilowatt-hours of electricity for fusion; it is still manufactured by the pound.

Calcium Carbide

DEVELOPMENT OF THE INDUSTRY

1. Calcium carbide, although a manufactured product itself, serves as the raw material for a number of chemicals. The development of the calcium carbide industry is inextricably tied up with the changes in demand for compounds af which it is the basic material. Only recently has its position as an essential raw material been threatened.

2. *Source of light.*—When in contact with water, calcium carbide gives off an illuminating gas, acetylene. Although calcium carbide was discovered as early as 1862, it gained commercial significance as a source of this gas only after its accidental rediscovery by Thomas L. Willson at Spray, N.C., in 1892. As gas was being used for lighting at this time, the discovery was immediately seized upon and patents were sold to a company which licensed their use.

3. By 1896, the first calcium carbide manufacturing plant began operations at Niagara Falls. The carbide was shipped to Philadelphia to the Acetylene Light, Heat & Power Co. to augment the city's gas supply. A second carbide plant was built by another company at Sault Ste. Marie, Mich. Both plants and licenses were taken over by the Union Carbide Co. which enlarged the plants to meet the great demand for lighting acetylene. This company was protected by the original patents until the time of their expiration in 1912.

4. The increased use of electricity for lighting, not only in cities but also in rural regions, has greatly decreased the value of acetylene as an illuminating gas. Today, only where electricity is not available and where abundant light must be generated quickly does acetylene find a market because of its portability and the speed and ease with which it produces a bright light.

5. *Source of heat.*—A second use of acetylene was developed, however. When acetylene is burned with oxygen instead of air, an intensely hot flame is generated which is used to weld and cut metals. As firms using acetylene for this purpose also required a supply of oxygen, many oxygen-producing firms became subsidiaries of corporations controlling calcium-carbide production, acetylene production and distribution, and manufacture of oxy-acetylene welding equipment.

6. But in this field, too, acetylene has come in competition not only with other gases but also with electricity. While it gives the hottest of chemical flames (7,878° F.), hydrogen with or without oxygen is used for some purposes and electric welding is gaining in importance in the nonpressure field.

7. *Base for organic chemicals.*—However, a new use for acetylene was discovered during the war. At that time there was a heavy demand for acetone, necessary for the manufacture of cordite, the type of smokeless powder used by the British fighting forces. The existing production of acetone by the distillation of wood could not meet the demand. A plant was erected at Shawinigan Falls, Canada, for the

production of acetone from acetylene. As a new need had arisen for pure acetic acid in airplane dope, this plant produced the acetic acid from acetylene instead of carrying the process to the acetone stage. (Acetone was produced from corn and rice in other plants.) While production ceased, temporarily, with the signing of the armistice, the production of synthetic glacial acetic acid from acetylene began again in the latter part of 1928 at Niagara Falls, N.Y., as well as at Shawinigan Falls, Canada.

8. With acetylene as a base, a series of combinations are possible that result in some of the most complicated compounds of organic chemistry. As a consequence, carbide companies have erected organic chemical factories. The extent to which these may be able to compete with similar products derived from other sources will determine the position of acetylene in the years to come. At present not more than 10 percent of the calcium carbide produced in the United States enters into the production of synthetic organic chemicals.

9. *Fixation of nitrogen.*—The use of calcium carbide for the fixation of nitrogen began at Niagara Falls, Canada, in 1909. As only one Canadian firm produced calcium carbide for the sole purpose of manufacturing calcium cyanamide and fertilizers, the details of this manufacture are reported in the section "Power in the Fertilizer Industry."

10. *Position as a basic material threatened.*—The position of calcium carbide as the sole commercial source of acetylene is threatened by experiments under way at the Kaiser-Wilhelm Institute fur Kohlenforschung. German chemists have succeeded in producing acetylene from methane in low-pressure-discharge apparatus. While no commercial production has, as yet, taken place, commercial success of the methanol acetylene would challenge the position of calcium carbide seriously.

11. Recently, the Union Carbide Co. of Niagara Falls has been collecting carbon monoxide gas produced in the manufacture of calcium carbide and has been turning it into synthetic methanol.

12. *Production in the United States.*—The production of calcium carbide in the United States totaled 201,955 tons in 1927, the latest year for which official figures are available. A little less than 2,000 tons were imported from Canada in 1929. Exports, chiefly to the Philippine Islands, Mexico, Panama, Cuba, and other Central and South American countries exceeded 2,000 tons.

TABLE I.—*Calcium-carbide production in the United States* [1]

Year	Short tons produced
1923	90,750
1925	170,773
1927	201,955
1929	225,000

[1] Figures reported by the U.S. Bureau of the Census. Calcium-carbide production figures for 1929 and years prior to 1923 are not separable from figures for other calcium compounds. 1929 quotations are estimates made by "Industrial and Engineering Chemistry."

Manufacture of Calcium Carbide

13. *The charge.*—Limestone, containing 96 percent or more of calcium carbonate, is partially crushed and heated in a rotary or vertical kiln. The calcium carbonate is decomposed forming calcium oxide or burnt lime. About 1,800 pounds of burnt lime and dry carbon in the form of foundry or petroleum coke, or anthracite coal, are coarsely ground, mixed, and fused in an electric furnace producing calcium carbide and waste carbon monoxide. Soft-burned coke containing not more than 6 percent ash and not more than 0.5 percent moisture is the carbon chiefly used in this country. Petroleum coke, either by itself or mixed with byproduct coke, is employed to a limited extent. In Europe, anthracite coal is extensively applied. While the low electrical conductivity of charcoal and its small ash content facilitate furnace operation and give good output the expense involved in charcoal handling has practically eliminated it from commercial carbide furnace use. The life of the electrode is dependent upon the carbon employed; its consumption is lowest with coke. Furnace voltage and energy supplied is also determined by type of furnace charge.

14. *The electric furnace.*—The early small electric carbide furnaces were of the block type wherein the solidified calcium carbide was drawn off from underneath the working zone of the furnace. Tapping furnaces have superseded these. They may be single-phase or three-phase furnaces. Units double the latter size are constructed by including 2 three-phase electrode systems in 1 furnace jacket. This gives an 18,000-kilowatt furnace with 6 electrodes, each carrying up to 45,000 amperes. For such a loading, the contact must be kept cool by circulating cold water through hollow bolts and contact plates. Consequently, electrodes of coarse anthracite that will withstand water cooling at a furnace temperature of about 3,000° C. are preferred.

15. Large furnaces can work continuously without shutting down for serious repairs. Because they can be operated with load variations, night current is used in some European plants. As the molten carbide is tapped from the electric furnace, at hourly or longer intervals, it goes to cooling floors and then to breakers and mills. It is crushed and graded in the sizes required for particular purposes and is then packed in airtight metal drums for shipment.

16. *Energy consumption.*—The amount of energy consumed by the carbide electric furnace varies with the size and type of furnace and the kind of carbonaceous material employed. The largest furnaces in this country require approximately 2,600 kilowatt-hours of energy to produce 1 ton calcium carbide. A 5,000-kilowatt furnace requires approximately 3,200 kilowatt-hours per ton of carbide. Tapping furnaces of but 1,400-kilowatt capacity take as much as 4,000 kilowatt-hours per ton produced.

17. *Costs of production.*—The raw materials required for the manufacture of calcium carbide are abundant and are secured from the sources nearest to the operating plant. Power is purchased at Niagara Falls under contract for $20 per horsepower-year. The Union Carbide & Carbon Co. operates the Michigan Northern Power Co. which supplies power to the carbide plant at Sault Ste. Marie. Other companies purchase their power. A subsidiary of the Union

Carbide & Carbon Corporation, the National Carbon Co., manufactures the electrodes for carbide furnaces.

18. While details concerning operating costs are not disclosed by individual companies, the following estimates apply current market prices to quantities of material and labor required in the production:

Capital costs: 15 percent on $60 per ton-year	$9.00
Production costs:	
Limestone, 2,880 pounds at $1.50 per ton	2.22
Bituminous coal, 540 pounds at $4 per ton	1.08
Coke, 1,200 pounds at $5.83 (New York)	3.50
Electrodes, 20 pounds at $0.05 pound	1.00
Power, 3,200 kilowatts at $0.003	9.60
Labor and other operating expenses	5.50
Total estimated cost	31.90

Organization of the Industry

Plants Manufacturing Calcium Carbide

19. The manufacture of calcium carbide is carried on at 6 plants in the United States by 3 companies. These plants have combined capacities in excess of 350,000 tons calcium carbide, while production is but 220,000 tons. The largest producer is the Union Carbide & Carbon Co. whose subsidiary, the Union Carbide Co., operates plants at Niagara Falls, N.Y., and Sault Ste. Marie, Mich., while a second subsidiary, the American Carbolite Co., produces calcium carbide at Duluth, Minn. This corporation also manufactures calcium carbide at Welland, Ontario.

20. The Air Reduction Co. operates carbide plants at Keokuk, Iowa, and at Ivanhoe, Va. The third producer is the Federal Carbide Co., a Swann Corporation subsidiary, with plant at Anniston, Ala.

Subsidiary Plants Producing Acetylene, Oxygen, and Acetylene Welding Equipment

21. Calcium carbide for lighting or organic-chemical production may be shipped in drums directly from carbide factories to points of consumption. If, however, it is to produce acetylene for welding and cutting, the acetylene must be compressed and dissolved in acetone, as acetylene in itself is explosive.

22. The carbide manufactured by the Union Carbide & Carbon Corporation plants is turned into dissolved and compressed acetylene by its subsidiary, the Prest-O-Lite Co., with main plant at Indianapolis and 50 other plants. This company also markets the dissolved acetylene in returnable steel cylinders. As users of acetylene for welding of metals require a supply of oxygen to produce the welding flame, a third subsidiary, the Linde Air Products Co. with 68 plants scattered about the country, produces oxygen and delivers it to users in steel cylinders. The apparatus essential for welding is manufactured by a fourth subsidiary, the Oxweld Acetylene Co.

23. The Air Reduction Co., incorporated in 1915, has been acquiring, through lease or purchase, a number of plants that produce dissolved acetylene and oxygen. Its oxy-acetylene welding equipment is produced by a subsidiary, the Davis-Bournonville Co., of New Jersey. The Air Reduction Sales Co. operates about 100 oxygen

plants located in Oregon, California, Texas, Louisiana, Kentucky, West Virginia, North Carolina, Virginia, as well as in Middle Western and eastern industrial States. Acetylene plants are located in a number of these States. The company acquired a group of French patents (including the "Claude" patents) covering basic processes for the separation of air by liquefaction, together with the exclusive rights for their development in the United States.

24. A number of independent companies buy their carbide and produce acetylene for welding purposes.

SUBSIDIARY PLANTS PRODUCING ORGANIC CHEMICALS AND GASES

25. The Carbide & Carbon Chemicals Corporation of West Virginia is the organic chemical branch of the Union Carbide & Carbon Co. It is not only using calcium carbide as a raw material but is working with natural gas and other hydrocarbons. When off-grade calcium carbide is converted to acetylene and acetylene added to water in the presence of sulphuric acid and a mercury salt, a transitional chemical, acetaldehyde, is obtained. This may be oxidized to acetic acid as is being done by the Niacet Chemical Corporation at Niagara Falls. Acetic acid plus heated lime results in acetone which is manufactured by the Carbide & Carbon Chemicals Corporation. It is estimated that the rayon industry alone consumed 11,000 tons of acetic acid, 11,000 tons of acetic anhydride, and 5,600 tons of acetone in 1929.

26. The Niacet Chemical Corporation produces not only acetic acid and acetaldehyde but also acetaldol, crotonaldehyde, paroldelhyde, and paraldol—chemicals having varying uses in medicine and in industry. The Carbide & Carbon Chemicals Corporation also produces a long list of organic chemicals.

27. The Air Reduction Co. not only separates oxygen and nitrogen by liquefaction and subsequent fractionation of air, but also secures other constituent gases of the air. Isolated argon is used as a filler in electric-light bulbs. Neon fills vacuum tubes when a brilliant red light is desired for harbor lights or in advertising display. Helium, krypton, and xenon are very rare elements obtained. A subsidiary of this company also produces carbon dioxide for soda water, fire extinguishing, and refrigeration.

COMPETITIVE CONDITIONS

EUROPEAN PRODUCTION

28. Calcium carbide is manufactured in Canada, Norway, Sweden, Switzerland, France, and Germany. Plans for the increased development of the large power plant in Dalmatia by the French company, Phosphates Tunisiens, include the establishment of a calcium carbide plant as well as of other types of electrochemical and electrometallurgical factories. European trade articles indicate that there is fear lest this lead to an overproduction of calcium carbide, which is avoided only with difficulty at this time.[22]

[22] Chemical Age (London), Sept. 7, 1929. The Carbide Industry.

UNITED STATES PLANT CAPACITY EXCEEDS MARKET DEMANDS

29. While the larger part of European calcium carbide is applied to the fixation of nitrogen, and our producers are protected by a 1 cent per pound tariff on carbide, United States calcium carbide plant capacity also exceeds present productive demands. Calcium carbide meets competition in every market in which its finished products are consumed.

30. The census reports the production of 989,228,000 cubic feet of acetylene in 1929. This required approximately 99,000 tons of carbide. The larger part of this acetylene was used in oxyacetylene welding and cutting. Such welding and cutting is done on pipe lines, for repairing railway trackage, and other metal equipment; and has become a unit manufacturing process in the production and assembling of railway cars, automobiles, storage tanks, and metal furniture. It can be used also for applying bronze and abrasive resisting materials to worn surfaces.

31. While it has been recognized that oxyacetylene welding and cutting were essential for emergency work because more heat units could be supplied to scattered points at lessened cost, and that it was more effective on light metals and on destructive work due to its greater cutting speed, the atomic hydrogen flame using no oxygen as well as electric arc welding are being applied extensively. The reduced cost of hydrogen made possible by dissociation of ammonia or of any methane gas by means of electrically heated equipment is responsible for the increased use of atomic hydrogen.

32. Calcium carbide as a source of acetic acid and acetone is meeting increasing competition from the acid made by fermentation of farm waste as well as from synthetic acetone obtained from natural gas.

Electric Furnace Abrasives and Refractories

DEMAND FOR HARD ABRASIVES AND SUPERREFRACTORIES

33. *Manufactured abrasives.*—The production of the manufactured abrasives, silicon carbide and fused alumina, made possible precision grinding and extended the scope of grinding operations into the field of hard-alloy and high-carbon steels. Although commercial production of silicon carbide (SiC), a material second only to the diamond in hardness, was begun in 1891 with the idea of substituting this material for diamond dust in polishing of precious stones, it was soon found to be superior to the natural abrasive, emery, in valve grinding. Its use in grinding and cutting metals has increased rapidly with the demand for precision tools, for carefully machined parts, and for alloy steels. Silicon carbide grit can successfully grind the next hardest known substance, cobalt-tungsten carbide alloy, which is beginning to find use in tool steels.

34. As silicon carbide is brittle, it is applied successfully only to metals of low tensile strength and to nonmetals. Fused alumina, ranking fourth in hardness, has been employed chiefly to grind metals of high tensile strength. It has an advantage over silicon carbide in that its hardness and toughness are controllable by the addition or extraction of several substances. Consequently, fused alumina finds

more varied application than silicon carbide. Not only is it used in metal working, but it is also replacing garnet in abrasive belts in wood-working industries. These two manufactured abrasives offer severe competition to such natural abrasives as corundum, emery, and garnet.[23]

35. *Superrefractories.*—Demand for materials reduced only at high temperatures and employment of higher pressures in the chemical industries has necessitated the production of refractory materials which can withstand much higher temperatures than the ordinary fire-clay refractories. The high-fusion point of silica and alumina makes these minerals inherently excellent refractory materials.

36. *Amorphous silicon carbide or silicon oxycarbide.*—In commercial practice an amorphous silicon carbide is formed during the process of manufacturing the crystalline silicon carbide abrasive, although it may also be made in a specially constructed furnace. This by-product has high heat-resisting characteristics and is an excellent heat conductor. As it can carry severe loads and is acid resistant, it is rapidly finding its place among refractory materials. When made into brick, this silicon carbide is used in furnaces and kilns where high temperatures, rapid change of temperatures, flame impingment, or heat transmission are essential. It is made into muffles for porcelain-enameling and pigment-calcining furnaces, and into electric heating elements for heat-treating furnaces and ceramic kilns, and into terminal mountings and accessories.

37. *Diaspore refractories.*—Alumina is also an excellent refractory material, neither strongly acidic nor strongly basic. Dehydrated bauxite and diaspore refractories have been made for some time, but because they have not been heated sufficiently during their manufacture they have shrunk at high temperatures during use. Studies of the shrinking characteristics of specific alumina clays under varying temperatures and heat-treatment periods are under way. It is not yet ascertainable to what extent electric furnace heat will be essential for shrinking diaspore, bauxite, or other alumina materials in order that refractories made up of these materials will be stable under high-temperature range.

38. *Fused alumina refractories.*—Fused alumina, such as is employed as an abrasive, is resistant to extremely high temperatures; it has been used, however, only where severe conditions that cannot be met by cheaper refractories are encountered. The enamel industry and ceramic industries are employing it either as linings of enameling furnaces or for saggers. In powdered form, fused alumina mixed with a bonding material is used as a furnace cement.

39. *Mullite refractories.*—While mullite is present in fire-clay refractories, only recently have efforts been made to manufacture mullite refractories. Mullite shapes made in the electric furnace have given excellent results in glass-melting tanks, in forging furnaces, and in brass-melting and special alloy-melting furnaces. Made from special mullite minerals, mullite has been used in oil refineries for lining sludge oil incinerators.

40. Other superrefractories that are being tried out are electrically sintered magnesite, giving the highest-grade magnesia refractory for basic open-hearth furnaces and electric-furnace linings; a combination

[23] Metallic abrasives such as steel wool, steel shot, and the metallic oxides, rouge and crocus, are not included in this report, as they are not electric furnace products.

of chromium oxide and silica, and zirconium. Electric-furnace graphite has long been recognized as an excellent high-temperature refractory under nonoxidizing conditions.

PRODUCTION

SILICON CARBIDE AND FUSED ALUMINA

41. *Companies.*—The Carborundum Co. began the manufacture of silicon carbide in 1891 at Monongahela, Pa. In 1895 it erected a plant at Niagara Falls, N.Y.; a subsidiary was established on the Canadian side of the Falls. Later, its largest factory for manufacturing silicon carbide was located at Shawinigan Falls, Quebec. Fused alumina is produced at the Niagara Falls plants. The crude materials are converted into marketable abrasives at Niagara Falls; into refractories at Perth Amboy, N.J.; and into furnace heating elements and other furnace accessories by a subsidiary, the Globar Corporation, at Niagara Falls. The Carborundum Co. remains the world's largest producer of silicon carbide, even though basic patents have expired.

42. The Norton Emery Wheel Co., of Worcester, Mass., took over the original patents for the manufacture of fused alumina abrasives and began commercial production at Niagara Falls, N.Y., in 1901. Its New York plant was sold in 1930 and all production of fused alumina and silicon carbide transferred to its factory at Chippewa, Ontario, just south of the Falls. Here it produces more fused alumina abrasive than any other company. This, together with silicon carbide, is shipped to its Worcester (Mass.) plant for cleaning and grading and manufacturing into grinding wheels, abrasive papers, and refractories.

43. In addition to the Carborundum Co. and the Norton Co., silicon carbide is manufactured by the Federal Abrasive Co., at Anniston, Ala., and by the Exolon Co. at Thorold, Ontario, with cleaning and grading plant at Blasdell, N.Y. Fused alumina abrasives are produced by the Norton Co. in Canada, by the Carborundum Co., at Niagara Falls, by the Federal Abrasive Co. at Anniston, Ala., by the General Abrasive Co. of Niagara Falls, N.Y., by the Exolon Co. at Thorold, Ontario, and by the Abrasive Co. at Hamilton, Ontario. As all basic patents have expired, each company markets its products under trade names, such as carborundum, crystolon, carbolon, alundum, aloxite, exolon, and carbofrax.

44. *Quantities manufactured.*—Because of the relation between United States producing plants and Canadian plants, production figures for both countries are given together. Out of a total production of 126,712 short tons of crude artificial abrasives manufactured in the two countries, 72,614 tons, or 57.3 percent, were fused alumina, 30,309 tons, or 24 per cent, silicon carbide, and the remainder, metallic abrasives. The silicon carbide and fused alumina accounted was manufactured not only into abrasives but also into refractories. As both applications are made by the same companies, separate figures are not available as to the amount entering into each marketed product.

45. While 1929 Canadian figures have not been secured, in 1928, 39,413 tons of fused alumina and 19,008 tons of silicon carbide were

manufactured on the Canadian side of Niagara Falls or at Shawinigan Falls, Quebec, or about two thirds the combined production of fused alumina in the United States and Canada and 86 percent of the combined production of silicon carbide is produced in Canadian plants. Although Canadian factories ship their output of crude abrasive refractory material to the parent plants in the United States to be crushed, cleaned, graded, and manufactured into grinding wheels, abrasive papers, furnace and kiln brick, tile, muffles, and saggers, the United States is really dependent upon Canada for the major part of its manufactured abrasives and high-grade super-refractory materials.

TABLE II.—*Production of artificial abrasives and refractory materials in the United States and Canada* [1]

Year	Total manufactured abrasives (short tons) [2]	Crude silicon carbide		Crude fused alumina	
		Short tons	Percent of total	Short tons	Percent of total
1929	126,712	30,309	23.9	72,614	57.3
1928	99,731	22,162	22.2	59,103	59.3
1927	90,626	26,289	29.0	50,973	56.2
1926	73,603	17,026	23.1	43,967	59.7
1925	88,530	24,112	27.2	53,253	60.2
1924	60,097	17,792	29.6	33,708	56.1
1923	80,769	21,149	26.2	51,391	63.6
1922	53,935	16,233	30.1	31,898	59.1
1921	13,199	2,707	20.5	7,325	55.5
1920	42,437	6,887	16.2	32,891	77.5
1919	50,518	28,435	56.3	19,723	39.0
1915	57,911	(3)		(3)	
1913	16,745	(3)		(3)	

[1] Compiled from U.S. Bureau of Mines: Abrasive Materials in 1929, and Mineral Resources of the United States, 1926.
[2] Includes metallic abrasives, silicon carbide, and fused alumina applied to refractories.
[3] Separate figures not available for 1913 and 1915.

46. *European production.*—Imports of silicon carbide and fused alumina from Europe are small, coming principally from France. There are five plants manufacturing silicon carbide in Europe, the largest being located at Eydcham, Norway. The Electro-Chimique de Mercus of France has the heaviest production of fused alumina of the seven European manufacturers.

47. *Mullite-refractory producers.* –The Corning Glass Works developed the process of manufacturing mullite in the electric furnace. This is now being produced for the general market by the Corhart Refractories Co. of Louisville, Ky. It is marketed under the trade name of Electrocast. Mullite refractories from special ores are produced in Los Angeles, Calif., by the Vitrefrax Co. and are marketed as brick called Durox.

MANUFACTURING PROCESSES

SILICON CARBON

48. *The furnace.*—Open electric furnaces supported on piers are employed in the manufacture of silicon carbide. Water-cooled graphite electrodes are introduced through permanent brick furnace ends. The furnace sides are taken down after each run.

49. *The charge.*—The charge is made up of approximately 53 to 56 parts of silicon, from 28 to 34 parts of coke, 7.5 parts of sawdust, and sometimes 1.5 parts of salt. Silicon is secured from good-quality glass sand containing 99 percent or more silica and almost free of iron, lime, phosphorus, and magnesium. Salt is added to eliminate any iron or oxides that may be present; it combines with these, forming volatile chlorides which escape into the air. Highest-grade silicon carbide is made from petroleum coke; bituminous coal coke is employed only for lower grades. Sawdust produces a porous mass which is easily broken up and permits accumulated gases to escape.

50. *The core.*—The mixed charge is loaded into the furnace to the level of the electrodes. From electrode to electrode a trench is made which is filled with a graphite and granular coke core. This core offers high resistance to the passage of current, thereby creating intense heat. After the core is complete, the remainder of the charge is added.

51. *Power consumption.*—The starting voltage varies with the core resistance, but usually is from 300 to 330 volts. At a temperature of 1,460° C. the carbon and silica begin to combine, forming an amorphous carbide. From 1,840° C. to 2,220° C. crystalline carbide is formed. If the charge is heated above 2,220° C. the silicon carbide decomposes into amorphous graphitic carbon and volatile silicon. After 36 hours the current is turned off, the furnace is cooled, and the sides are taken down. An outer crust of impurities is first removed. Beneath this is a layer of unconverted charge which is used in the next batch. From 2 to 4 inches of amorphous silicon carbide is then found, which is used for refractories. The fourth layer is the crystalline silicon carbide abrasive. The central core has become amorphous graphite. From a 22-ton charge approximately 6 tons of crystalline carbide of good abrasive grain is obtained, while 2 tons of refractory amorphous carbide has been produced as a byproduct. The run of 36 hours requires from 40,000 to 50,000 kilowatt-hours, or each ton of abrasive produced demands from 6,666 to 8,333 kilowatt-hours of electricity.

52. The silicon carbide lump removed from the electric furnace is crushed and screened. It is then washed with steam and water, caustic soda, and hydrochloric acid to remove any silicon, graphite, or iron present. After drying, silicon carbide is graded according to the size of the individual grain.

53. When amorphous silicon carbide is made in a separate furnace less carbon is used, so that the silica will not be completely reduced. More than one core is built up in the furnace for a more even distribution of heat, or it may be made in a closed arc furnace.

FUSED ALUMINA ABRASIVES

54. Alumina abrasives are made from bauxite, corundum, or pure alumina. By combination with other substances, a series of special abrasives are obtained. The larger tonnage, however, is made from bauxite according to the following methods.

55. *The charge.*—Bauxite, containing at least 50 percent alumina, and water, silica, iron, and titanium oxide, is crushed to ½-inch pieces. It is then calcined to remove its water content. A careful analysis determines the quantity of remaining substances and the consequent

amounts of coke and iron essential for the reduction and elimination of impurities. Bituminous coal coke is used to reduce the impurities to metallic form. Iron added unites with the silicon, forming a button of ferro-silicon, and also renders magnetic other impurities for later removal by means of an electromagnet. Mr. Eardley-Wilmot states that a typical charge might be made up of 80 percent calcined bauxite, 16 percent iron borings, and 4 percent coke. Actually, for every ton fused alumina produced in 1928, 1.09 tons bauxite, 0.08 ton coke, and 0.11 ton iron were consumed.

56. *The furnace.*—Open-bucket or cone-shaped electric furnaces are used for the fusion. The bucket—or the hearth in the case of cone furnaces—is on a truck, so it can be wheeled under the electrodes. These are of carbon and are raised or lowered mechanically into the charge to give a fixed current. The hearth is built up of bauxite dust and old carbon electrodes cemented together with pitch, or of pitch and coke, after each run. The cone-shaped, water-cooled shell is lowered onto the hearth after it has been wheeled beneath the electrodes, when a bucket furnace is not used. Only part of the charge is added at a time. After this has fused, more is dumped in and fused, and this continues until the entire furnace is filled, a process requiring 24 to 36 hours, depending upon the power used. The electrodes are lifted to a new level after each charge.

57. *Power consumption.*—Fusion requires an internal heat of approximately 3,500° F. Furnaces are of varying size. Alternating current is used. Approximately 2,000 to 2,540 kilowatt-hours of energy are required per ton of crude aluminous abrasive produced.

58. After the current is turned off, cooling is given careful attention. Water is circulated on the outside of the furnace walls for several hours. When the furnace is cooled, it is wheeled out from under the electrodes; the shell is removed in the cone furnace, or the ingot dumped out of the bucket furnace. After the ingot has cooled for about a week, it is broken up. The ferro-silicon button, weighing 2 to 3 tons, is removed and the alumina crushed and screened. An electromagnet takes out the magnetized impurities after which a further roasting renders the nonmagnetic iron content magnetic for further magnetic separation of impurities. The clear alumina is graded according to size.

59. *Special alumina abrasives.*—The titanium content of bauxite is not eliminated by this process of manufacture. As this mineral renders the abrasive tough and resistant to fracture, it cannot be used successfully for all purposes. Consequently, for some abrasives, either high-grade corundum or a pure amorphous alumina powder is employed. As the pure alumina is almost free of impurities, it requires little reduction and is charged and fused rapidly. Graphite electrodes are used. After cooling, it is roasted to remove any traces of aluminum carbide.

60. As natural corundum contains some silicon and iron, as well as water, it is mixed with sufficient iron borings to make the ferro-silicon produced magnetic. Coke also must be added to reduce these impurities.

61. The abrasive temper is not only affected by the degree of purity of the raw material, but also by the addition of minor amounts of several oxides. While all types are fused in the electric furnace, details of reduction and cooling vary.

62. *Grinding wheels and coated abrasives.*—The graded abrasives are bonded together by various means in the form of grinding wheels or abrasive paper. The larger number of grinding wheels are still made by the vitrified process. Ball clays, fireclays, kaolin, other clays, and feldspar are used as bonding materials. These are combined with the abrasive grain, mixed with water, and poured into molds or pressed into shape by hydraulic pressure. The green wheel is shaped and then fired in kilns, heated by coal or producer gas. The bakelite wheel, which is now much advertised, is replacing the vitrified wheel to some extent. Bakelite, a synthetic phenol plastic, is mixed with the abrasive and a special solution added to make the mixture plastic. After the mixture has been forced through a sieve, it is pressed into shape by hydraulic pressure either in electrically or steam heated presses or in a cold press. The wheels are baked to about 300° F.

63. In the manufacture of coated abrasives, a heavy kraft paper, manila fiber paper, cotton drill, or a combination of drill and paper is employed. The roll of backing is run through a heated aperture over a roller which revolves in a heated hide-glue trough. After the glue deposit has been evened up by a vibrating brush, the heated abrasive grain falls through a regulated aperture upon the glue-covered paper. A steel roll forces the grain into the glue. After the paper is dried a regluing operation takes place.

64. *Refractories.*—The graded, ground electric-furnace products are bonded with a small amount of ceramic bonding material, are pressed into desired shapes, and kiln baked.

65. *Mullite.*—In the manufacture of mullite refractories, a mineral containing more than 68 percent alumina and silica are melted in an electric furnace. The mobile mass is poured into sand molds to form the finished shapes or into ingot molds. Ingots are crushed, mixed with a binder, and formed into desired shapes. All shapes are annealed slowly under regulated temperatures and after this refiring are ready for shipment. Details of this process are not disclosed by the company applying it.

66. Several minerals, namely, sillimanite, dumortierite, cyanite, and andalusite, upon being subjected to high temperatures, develop the mullite crystallization. These are formed into brick of 72 percent or more mullite ($3Al_2O_32SiO_2$) composition. This method of obtaining a mullite refractory is being used in California, where andalusite, dumortierite, and cyanite are found.

Sources of Raw Materials

for silicon-carbide manufacture

67. A ton of silicon carbide requires approximately 1.9 tons silica mineral, 1.3 tons petroleum coke, 0.02 ton salt, and 0.4 ton sawdust.

68. *Sand.*—Finely crushed quartz or sand containing not less than 99 percent silica is the source of silica for these manufactured abrasives. It must be almost free of magnesia, phosphorus, and lime, and low in iron. These sands are obtained, at present, chiefly from Pennsylvania and Illinois, and from a sandstone quarry at St. Canute, Quebec. However, as this quality is similar to a good type of glass sand, it occurs in a number of States. While production of glass sand is heaviest in Illinois, West Virginia, and Pennsylvania, it

has occurred also in California. Because sand deposits are abundant, no data has been assembled as to the purity of deposits in different sections of States. But as quartz is so often found with feldspar, the Intermountain Experimental Station of the United States Bureau of Mines in cooperation with the department of mining and metallurgical research of the University of Utah, has devised a method whereby feldspar particles are floated off. The reagents used are easily obtained.

69. *Petroleum coke.*—Petroleum coke is the solid residue from the destructive distillation of petroleum. It is produced either as a by-product of the coking still or of the cracking process. In 1927, over 1,000,000 tons was produced in the United States. Texas marketed the largest amount while California, Wyoming, Colorado, and Montana produced 123,000 short tons. The following table gives production by States and average value per ton. The value is determined in large measure by the market for this byproduct. Silicon carbide, as well as calcium carbide and graphite, afford high priced markets, while pulverized coke for industrial fuel brings a low price.

70. The extensive adoption of the hydrogenation process by the petroleum industry may affect the production of petroleum coke. For, by this process, motor fuels and lubricants are obtained without simultaneous formation of coke.

TABLE III.—*Production of petroleum-coke by States in 1927* [1]

State	Number plants	Quantity produced (short tons)	Average value per ton
Total	92	1,243,510	$5.76
Arkansas, Kentucky	3	8,516	3.98
California	3	61,641	2.00
Colorado, Montana	3	3,237	4.25
Georgia, South Carolina, West Virginia	3	10,354	5.81
Illinois	5	100,964	5.34
Indiana, Missouri	4	171,697	6.90
Kansas	7	103,150	3.83
Louisiana	5	134,348	10.54
Maryland, New York, Rhode Island	5	37,007	8.29
New Jersey	5	51,461	9.58
Ohio	6	61,691	7.02
Oklahoma	11	119,797	2.36
Pennsylvania	8	76,766	7.99
Texas	19	244,768	4.07
Wyoming	5	58,113	4.71

[1] U.S. Department of Commerce, Bureau of the Census.

71. Common salt in powdered form is used in the manufacture of silicon carbide. While hardwood sawdust is preferred, any coarse, granular sawdust is effective.

72. *For fused alumina manufacture.*—Bauxite is the important mineral essential to fused-alumina production. It should contain at least 50 percent alumina, less than 3 percent iron, and less than 6 percent silica. In 1929, 113,015 tons were consumed by the abrasive and refractory industries. This was shipped from Alabama and Arkansas deposits. The Norton Co. of Worcester, Mass., largest manufacturer of fused alumina, owns and operate its own mines near Bauxite, Ark.

73. Utah ships a small tonnage of by-product alumina from Marysvale potash developments to California for use in the manufacture of high alumina refractories. From Missouri comes most of the diaspore manufactured into such refractories. A detailed description of bauxite deposits will be found in "Power in Aluminum Production", pages 119–121.

Iron borings or any convenient source of iron is used to create proper iron content.

74. *For mullite production.*—Andalusite, one of the minerals which invert to mullite upon heating, occurs in commercial quantities in Nevada and California. Cyanite is found in the Inyo range of California, in other Pacific Coast and Rocky Mountain States, and along the Appalachian Plateau. The only known deposits of sillimanite are in India.

Fused Quartz

75. Fused quartz, produced in the electric furnace, was first manufactured on a commercial scale in England in 1906. Although its production is too small to be recorded separately in official reports, characteristics of fused quartz are such that it will probably play an increasing part in present industrial developments.

76. *Uses.*—As it resists sudden heating and the action of acids, fused quartz was first used for laboratory basins, beakers, pipes, and other vessels, but now enters into commercial chemical manufacturing equipment. In some fire-extinguishing apparatus, it is the frangible link in sprinkler jets. The electrical industry employs it in apparatus in which high vacuum and high insulating properties are essential. Transparent fused quartz is made into telescope lenses, photographic lenses, and into window glass which transmits ultraviolet rays and infrared rays.

77. *Sources of raw materials.*—Transparent fused quartz is made of rock crystal, which is free of all discoloration and water clear. This material comes from Brazil and Madagascar. Opaque quartz is made of the best quality glass sand or other pure quartz. (See pp. 439 and 440.)

78. *Manufacturing processes.*—In transparent-quartz manufacture, the lumps of rock crystal are carefully sorted and cleaned. Perfect pieces are used for lenses and prisms for optical and photographic instruments and slightly inferior crystal for quartz glass. For lenses, pieces are packed as closely as possible into graphite crucibles which are placed in a vacuum furnace. For window panes, the crystal is fused on flat graphite disks between squared graphite slabs. Quartz fuses at 3,200° F. After fusion, nitrogen is introduced into the furnace at a pressure of 150 pounds per square inch and causes any bubbles which have formed to collapse. When tubes or other shapes are to be made, the molten quartz is forced into shape by a graphite plunger. Quartz fusion requires from 5 to 8 kilowatt-hours per pound.[24]

79. The opaque form of fused quartz is made about a carbon rod. Quartz sand is heated by the carbon rod until it has fused. While silicon carbide is formed nearest the rod, this adheres to the carbon, while the fused quartz in tube form is removed and remelted for various apparatus.

[24] Berry, E. R., Clear Fused Quartz Made in the Electric Furnace.

80. The General Electric Co. is manufacturing fused quartz in the United States. The Thermal Syndicate, an English company, is marketing it as "Vitreosil" in the United States.

SILICON

81. Silicon in a free state is made by The Carborundum Co. High-grade silica and petroleum coke are reduced in an arc furnace with a consumption of electricity approximately 12,000 kilowatt-hours per ton of silicon. While it will unite with a number of metals to form compounds named silicides, and is a reducing agent as well as a substitute for carbon in such organic compounds as silicon methyl and silicon ethyl, it has only small commercial application.

CALCIUM

Calcium can be obtained in a metallic state by the electrolysis of fused calcium chloride, employing a carbon anode. It is a hydrogenation catalyst. When alloyed with lead by use of a lead cathode, a bearing metal is secured.

Electric Furnace Graphite

PRODUCTION

82. The manufacture of graphite was begun in 1897 at Niagara Falls under patents obtained by Dr. A. G. Acheson, the discoverer of silicon carbide. The same company, now known as the Acheson Graphite Co., remained the sole manufacturer of graphite for sale until 1929 when the Exolon Co. of Blasdell, N.Y., and Thorold, Ontario, manufacturers of electric-furnace abrasives, and the American Cyanamid Co., manufacturers of calcium cyanamide and nitrogen fertilizers, announced they were producing graphite for sale. Other companies, however, have begun manufacturing graphite electrodes for their own consumption. The Acheson Graphite Co. is now a subsidiary of the Union Carbide & Carbon Corporation, and operates plants at Niagara Falls, Ontario, as well as at Niagara Falls, N.Y., and at Buffalo, N.Y.

83. The production figures quoted by the United States Bureau of Mines are figures of Acheson graphite production, only.

TABLE IV.—*Production of manufactured graphite in United States and Canada* [1]

Year	United States (short tons)	Canada (short tons)	Year	United States (short tons)	Canada (short tons)
1913	6,817	1,092	1921	[2] 2,944	[2] 188
1914	5,228	617	1922	[2] 6,516	[2] 362
1915	[2] 2,542	[2] 249	1923	[2] 13,381	[2] 777
1916	[2] 4,199	[2] 263	1924	[2] 5,493	[2] 408
1917	[2] 5,237	[2] 548	1925	[2] 6,068	[3]
1918	[2] 4,591	[2] 904	1926	[2] 10,582	[3]
1919	[2] 4,082	[2] 179	1927	[2] 6,129	[3]
1920	[2] 3,700	[2] 103			

[1] Compiled from U.S. Department of Commerce, Bureau of Mines, Graphite in 1928.
[2] Powdered graphite only; electrode material not included.
[3] Not reported.

MARKETS FOR MANUFACTURED GRAPHITE

84. The largest demand for manufactured graphite is as electrodes to convey current in electric furnaces. In this field it encounters competition from amorphous carbon electrodes which are gas or electric furnace baked at lower temperatures. The manufactured graphite electrode is preferred in a number of processes because of its higher conductivity and ease with which it may be machined. The extended application of the Söderberg continuous electrode, which is baked by current passing through the electrode casing and by heat from the furnace as the electrode's lower end is consumed in the furnace itself, may affect the use of graphitic electrodes.

85. Manufactured graphite is also used in dry batteries where it gives conductivity to the manganese dioxide. It is considered superior to natural flake graphite and amorphous carbon for this purpose, although its higher cost permits the employment of these less expensive forms. It is also made into brushes for direct current motors while both carbon and natural graphite find extensive use as brushes for turbogenerators, battery charging and other machines where quietness of operation is desirable and low mechanical strength permissable.

86. Powdered manufactured graphite, mixed with water, oil, or grease adheres to metallic surfaces thus reducing their friction, or while in suspension, keeps bearings from rubbing against each other. It is used, therefore, as a very effective lubricant. It is also a boiler scale preventative. All types of graphite enter into paint manufacture, opinion varying as to the relative merits of manufactured graphite.

87. *Manufacturing processes.*—Graphite is made of petroleum coke or anthracite coke. It is manufactured in powdered form or as electrodes. A furnace similar to the silicon carbide furnace is employed. The electrodes enter at either end of the furnace and the current is conducted through a central core of carbon rods, or other carbon conductor.

88. *Powdered graphite.*—When powdered graphite is produced, lumps of coke and some iron oxide are imbedded in coke dust. The charge is covered with silica and coke to exclude air. As the iron oxide is reduced, the iron sinks to the furnace bottom; as the temperature rises, it is vaporized and combines with the carbon to form a carbide. Carbide is volatilized at higher temperatures leaving carbon in the form of graphite. The temperature and length of the heating period depend upon the quality of graphite to be produced, the amorphous carbon being gradually converted into graphite. When the current is cut off, the coke and silica cover is removed, the furnaces cooled, and a layer of carbide taken off before graphite is found. The graphite is ground into condition for the special purposes it is to serve.

89. *Graphite electrodes.*—Because purity is essential in most processes which employ graphite electrodes to lead electric current, petroleum coke or specially prepared anthracite coke forms the basis of these electrodes. Petroleum coke is often preferred because of its low ash content and high fixed carbon. This coke as it comes from oil refineries is crushed, screened, and calcined in gas-heated or electric-heated calciners to drive off volatile constituents. The

electric calciner has a series of suspended carbon electrodes which form arcs with an electrode imbedded in the bottom of the furnace shell. The coke is fed in around the electrodes and as it becomes conductive, the electrodes are raised. The calcined coke is mixed with binding materials such as tar and pitch and with a small amount of carbide-forming substance such as oxide of iron. When large electrodes are made, the mixture is compressed by automatic rams into molds. For small rods it is extruded under high pressure in a hydraulic press into desired form and size.

90. *Electric consumption.*—The floor of the electric furnace is covered with pulverized carbon. When rectangular electrodes are graphitized they are packed in heaps separated by pulverized coke. Rounded electrodes are surrounded by an inner shell of ground coke; coke and sand form the outer covering. This carbon dust acts as a resistor and carries the current. Initial voltage is from 200 to 210; as the resistance of the coke is lowered, voltage is reduced to maintain a constant heat. Graphite for electrodes is 99.5 percent pure while for dry battery fillers and other uses 92 percent purity is sufficient. The higher the purity, the longer the heat treatment required. Theoretically, but 3,580 kilowatt-hours of energy are necessary to convert 1 ton of coke into graphitic electrodes; the low efficiency of the open graphite furnaces is such, however, that actual consumption of current is close to 7,600 kilowatt-hours. In Germany, electrical consumption is placed at over 9,000 kilowatt-hours per ton of graphite produced.

BIBLIOGRAPHY

CALCIUM CARBIDE

Year	Author	Title
1930		Manufacture of Calcium Carbide. Canadian Mining Journal. Apr. 4.
1929		The Carbide Industry. Chemical Age. Sept. 7.
1925	Coulson-Smith, C., M., Sc	Calcium Carbide. The Chemical Trade Journal. June 12.
1927	Fitzgerald, F. A. J	The Use of Electric Furnace at Niagara Falls 1902 to 1926. Paper before American Electrochemical Society, Apr. 29.
1929		Is this Industry Wanted. Industrial and Engineering Chemistry. October.
1925	Thompson, M. D	Theoretical and Applied Electrochemistry.
1898		Producing Calcium Carbide. Western Electric. May 16.
1923		Calcium Carbide—Its Manufacture and Application. The Electrical Review. Jan. 26.

ELECTRIC FURNACE ABRASIVES AND REFRACTORIES

1923	Abrasive Co	Manufacture of Aluminous Abrasives. Chemical and Metallurgical Engineering. May 14.
1926	Buckman, Henry H	The Electric Furnace in Non-Ferrous Metallurgy, in Handbook of Nonferrous Metallurgy, vol. I.
1918	Carborundum Co	Manufacture and Properties of Carborundum. Chemical and Metallurgical Engineering. Sept. 27.
1929	Canada Department of Mines, W. L. Eardley-Wilmot.	Artificial Abrasives and Manufactured Abrasive Products and Their Uses.
1928		Some New Refractories Now in Process of Development. Engineering and Mining Journal. June.
1927	Jacobs, F. B	Manufacture of Artificial Abrasives and Their Trade Names. Abrasive Industry. June.
1928	Knibbs, N. V. S	The Industrial Uses of Bauxite.
1902	Richards, J. W	Niagara As an Electrochemical Center.
	United States Department of Commerce, Bureau of Mines:	
1930	Bowles, Oliver	Abrasive Materials in 1929.
1927	Bulletin 266, Wiegel, W. M	Technology and Uses of Silica and Sand.
1924	Serial no. 2587, Myers, W. M	New Uses of Non-Metallic Minerals.
1929	White, Harold E	Refractories Then and Now. Mining and Metallurgy. December.
1918	Carborundum Co	Better Refractories for High Temperatures. Chemical and Metallurgical Engineering. Sept. 28.

Bibliography—Continued

FUSED QUARTZ

Year	Author	Title
1924	Berry, E. R.	Clear Fused Quartz Made in the Electric Furnace. Paper presented before American Electrochemical Society, Apr. 26.
1927	Hutton, R. S.	Development of the Fused Quartz Industry. Paper presented before American Electrochemical Society, Apr. 27.
1924	Paget, R. A.	Preparation of Fused Quartz. Chemical Age. Feb. 2, 1924.
1930	Paget, R. A.	Fused Quartz. General Electric Review. January.

GRAPHITE

1908	Acheson, E. G.	Seventeen Years of Experimental Research and Development.
1920	Canada Department of Mines	Graphite.
	United States Department of Commerce:	
1928	Bureau of Mines	Graphite in 1928.
1930	Economic Paper No. 9	Petroleum Coke.
1929	Miller, B. S.	Graphite. Canadian Mining Journal. Jan. 29.

ELECTRIC REDUCTION OF GOLD AND SILVER AND RARE OR MINOR METALS

CONTENTS

	Page
Gold and silver	445
Sources of metals	446
Occurrence of gold and silver in United States	446
Gold mining in the several States	447
Silver mining in the several States	448
World production of gold and silver	448
Extracting and refining of gold and silver	449
Electrolytic refining of silver	450
Electrolytic refining of gold	450
Production and refinement of gold and silver	450
Quantities refined at mints and by private refineries	450
Private refineries	450
World consumption	451
Gold	451
Silver	452
Rare or minor metals	453
Tungsten and molybdenum	453
Cobalt alloys	454
Tantalum	454
Barium	455
Cerium	455
Lithium	455
Beryllium	455
Bismuth	456
Metals refined electrolytically in countries other than the United States	456
Nickel	456
Tin	456

Gold and Silver

The production of gold and silver is affected vitally by the fact that monetary uses constitute so important a market. Particularly is this true of gold, for while certain populous countries like China make silver the money standard of half the people of the world, yet gold is the standard of the majority of all important nations, measured by political influence and by financial and commercial importance. Furthermore, the price of gold in the United States is fixed

at $20.67 a fine ounce and the world's supply of gold is sharply limited The price of silver varies in this as in other countries with fluctuations in supply and demand.

The United States produces approximately 11 percent of the world's gold and consumes 57 percent of the gold supply. It mines 23 percent of the world's silver and consumes 15 percent of the world's silver supply. Electrolytic processes are employed only in the refinement of these precious metals. The United States mints have become the larger refineries of new gold, although private refineries refine the largest proportion of silver. Although the unit consumption of electricity for such electrolytic refinement is relatively high, production in fine ounces is so small in the United States that only about 45,000 kilowatt-hours of energy are consumed in gold refining and approximately 1,280,000 kilowatt-hours in silver refining annually.

Sources of Gold and Silver

1. *Occurrences of metals in the United States.*—Gold is usually found in nature as an alloy with silver. These precious metals are associated with quartz in dry and siliceous ores or in gravel, or they are found in complex ores which have value because of their copper, lead, or zinc content as well as for their silver and gold content. Gold is found in greater quantity in siliceous ores than in complex ores, while the latter are the principal source of silver. Approximately 56 percent of all gold mined is secured from dry and siliceous ores, 19 percent from placer gravels, while but 25 percent is obtained from refining complex ores. On the other hand, four fifths of all silver was secured through the refining of lead, copper, or zinc ores and only one fifth was recovered from dry and siliceous ores.

Table I.—*Gold and silver produced in the United States by sources of ore* [1]

GOLD

Year	Total (fine ounces)	Placers	Dry and siliceous ore	Copper ore	Lead ore	Zinc ore	Copper-lead and copper-lead-zinc ores	Lead-zinc ore
1928:								
Amount	2,148,064	416,832	1,195,804	414,771	35,959	130	6,973	77,595
Percent	100.0	19.4	55.7	19.3	1.7		0.3	3.6
1927	2,107,032	451,215	1,162,404	367,639	41,504	1,563	2,631	80,076
1926	2,232,526	457,717	1,295,570	365,223	45,724	1,194	3,335	63,763
1925	2,307,374	436,251	1,414,446	348,025	50,378	375	5,515	52,384
1919	2,753,282	704,377	1,780,567	186,701	41,945	86	1,043	38,563
1915	4,754,475	1,077,432	3,212,298	343,226	84,449	4,975	2,496	29,599
1913	4,311,103	1,075,784	2,864,901	275,634	73,880	896	4,697	15,311

SILVER

Year	Total (fine ounces)	Placers	Dry and siliceous ore	Copper ore	Lead ore	Zinc ore	Copper-lead and copper-lead-zinc ores	Lead-zinc ore
1928:								
Amount	57,872,443	46,276	11,140,496	14,733,852	13,416,396	117,532	2,207,200	16,210,691
Percent	100.0		19.3	25.5	23.2	0.2	3.8	28.0
1927	59,625,682	49,829	11,775,384	14,556,572	15,762,197	1,685,764	2,171,792	13,624,144
1926	62,487,219	49,890	13,567,095	17,039,546	15,528,454	313,119	1,415,699	14,573,416
1925	66,710,080	50,303	17,099,876	18,051,937	18,777,853	181,886	970,370	11,577,855
1919	51,899,460	78,401	19,043,515	12,880,624	14,351,293	39,480	232,157	5,273,990
1915	72,353,730	154,968	25,709,505	18,781,365	19,828,533	1,136,220	234,047	6,509,092
1913	71,187,228	123,739	28,010,875	18,250,253	18,629,246	86,432	752,563	5,334,120

[1] Compiled from U.S. Department of Commerce, Bureau of Mines, Gold and Silver in 1928, and U.S. Department of the Interior, Geological Survey, Mineral Resources of the United States, Part 1, for 1913 and 1915.

2. *Gold mining in the several States.*—The largest gold mining States and Territories are California, Alaska, South Dakota, Utah, Colorado, Arizona, and Nevada. The Homestake Mining Co. of South Dakota is the biggest single producer, followed by the Alaska Juneau Gold Mining Co., the Golden Cycle Mining and Reduction Co. of Cripple Creek, Colo., the Yuba Consolidated Goldfields of Marysville, Calif., and the Utah Copper Co., of West Mountain, Utah.

3. In California, 32 counties reported gold production. Yuba County, the largest producing county, and Sacramento County, fourth in rank, obtained most of their gold by dredging. Nevada County, the second county in quantity of gold mined in California, produced gold from the siliceous ores of the Grass Valley district. Amador County ranked third in gold production. Almost one half the gold production in Alaska occurs in southeastern Alaska and more than one fourth in the Yukon River Basin. Lawrence County, S.Dak., mines about 14 percent of the entire gold mined in the United States.

4. In Utah, Salt Lake County is the principal gold-mining county, while Cripple Creek in Teller County, Colo., produces more than half of Colorado's gold. The larger amount of Arizona's gold was secured from copper mining. Maricopa and Cochise Counties produced two thirds of the State's gold. In Nevada, while more gold is secured from siliceous ores than from copper and lead ores, considerable amounts are secured from complex ores. Here, too, gold production is heavily concentrated in one county, for White Pine County produced 40 percent of all Nevada's gold although Esmeralda County mined 20 percent.

5. The 20,337 fine ounces of gold mined in Idaho came principally from placer and dry and siliceous mining in Boise and Custer Counties. The larger part of Montana's gold was secured from copper ores in Silver Bow County. Oregon mines gold in Grant, Jackson, Baker, Coos, Curry, Josephine, and Malheur Counties. Washington's gold came chiefly from Ferry County.

TABLE II.—*Mining of gold in the several States in 1929* [1]

State	Total	Lode mines		Placer mines			
				Dredges		All other	
		Ounces	Percent of total	Ounces	Percent of total	Ounces	Percent of total
	Ounces						
Total	2,059,085	1,650,742	80.2	330,556	16.0	77,787	3.8
Alabama	10					10	100.0
Alaska	375,437	176,278	46.9	141,835	37.8	57,324	15.3
Arizona	202,318	202,045	99.9			273	.1
California	412,477	225,237	54.6	173,630	42.1	13,610	3.3
Colorado	213,690	211,472	98.9	1,862	.9	356	.2
Georgia	125	32	25.6			93	74.4
Idaho	20,337	16,117	79.2	2,999	14.8	1,221	6.0
Montana	54,753	54,161	98.9			592	1.1
Nevada	163,711	161,594	98.7			2,117	1.3
New Mexico	35,177	35,097	99.8			80	.2
North Carolina	244	192	78.7			52	21.3
Oregon	17,092	5,145	30.1	9,939	58.2	2,008	11.7
Pennsylvania	836	836	100.0				
South Dakota	316,837	316,837	100.0				
Tennessee	565	565	100.0				
Texas	1,279	1,279	100.0				
Utah	240,419	240,373	99.9			46	(2)
Washington	3,730	3,434	92.1	291	7.8	5	.1
Wyoming	48	48	100.0				

[1] Compiled from U.S. Treasury Department, Annual Report of the Director of the Mint for the fiscal year ended June 30, 1930.

[2] Less than 0.1 percent.

6. *Silver mining in the several States.*—Utah and Montana outrank all other States in production of silver in 1929. In Utah, three fourths of all silver is gained from copper ores, while in Montana 57 percent is taken from copper ores and 33 percent from lead ores. Consequently, Utah silver comes from the same counties that produce large amounts of lead or Juab, Utah, Wasatch, and Salt Lake Counties. Eighty-eight percent of Montana's silver is from Silver Bow County's mines. The Anaconda Copper Co. is the largest single producer of silver.

7. Idaho produced over 9,000,000 ounces of silver in 1929 almost entirely as a byproduct of lead mining in Shoshone County. Arizona ranked third in silver production, seven eighths of the silver being secured in the course of copper concentration. Cochise, Pinal, and Yavapai Counties are large silver-mining counties.

8. Nevada and Colorado secured silver from complex as well as from the dry and siliceous ores while two thirds of Washington silver came from copper ores and three fourths of Oregon silver from dry and siliceous ores.

TABLE III.—*Mining of silver in the several States in 1929* [1]

State	Total	Dry and siliceous ores [2]		Lead ores [3]		Copper ores	
		Ounces	Percent of total	Ounces	Percent of total	Ounces	Percent of total
	Ounces						
Total	60,851,908	11,153,036	18.3	31,750,158	52.2	17,948,714	29.5
Alabama	1	1					
Alaska	472,800	121,200	25.6			351,600	74.4
Arizona	7,543,283	403,550	5.3	540,747	7.2	6,598,986	87.5
California	1,176,895	568,213	48.3	61,499	5.2	547,183	46.5
Colorado	4,397,374	2,098,774	47.7	1,513,668	34.4	784,932	17.9
Georgia	16	16					
Idaho	9,414,403	31,869	.3	9,314,124	99.0	68,410	.7
Illinois	3,700			3,700	100.0		
Michigan	20,795					20,795	100.0
Missouri	181,638			181,638	100.0		
Montana	12,716,977	1,198,602	9.4	4,229,368	33.3	7,289,007	57.3
Nevada	4,923,526	2,829,562	57.5	1,838,710	37.3	255,254	5.2
New Mexico	1,113,546	54,031	4.8	789,130	70.9	270,385	24.3
North Carolina	21,106	8	(4)			21,098	99.9
Oregon	30,009	23,119	77.0			6,890	23.0
Pennsylvania	5,972					5,972	100.0
South Dakota	85,182	85,182	100.0				
Tennessee	81,281					81,281	100.0
Texas	1,020,516	1,017,746	99.7	99	(4)	2,671	.3
Utah	17,592,396	2,714,126	15.4	13,269,700	75.4	1,608,570	9.2
Vermont	3,284					3,284	100.0
Washington	47,182	7,030	14.9	7,775	16.5	32,377	68.6
Wyoming	26	7	26.9			19	73.1

[1] Compiled from U.S. Treasury Department, Annual Report of the Director of the Mint for the fiscal year ended June 30, 1930.
[2] Includes small quantity of silver from placer mines.
[3] Includes silver in lead, silver-lead, lead-zinc, copper-lead, copper-lead-zinc, and zinc ores.
[4] Less than 0.1 percent.

WORLD PRODUCTION OF GOLD AND SILVER

9. *Gold.*—Over 57 percent of the world's gold production in 1928 came from South Africa as is shown on table IV. The United States accounted for but 10.86 percent of the 1928 world production of gold. What is of equal importance is the fact that gold production in this country has steadily declined relatively for the last 7 decades and since

1915 the actual amount of gold produced has shown a steady decline except for a very slight upward swing during 1923 and 1924.

10. *Silver.*—The greatest silver-producing country in the world is Mexico which accounted for 42 percent of the total world production of 257,925,154 fine ounces in 1928. The United States ranks second with 22.65 percent. As South America produced over 11 percent and Canada 8.5 percent, the Western Hemisphere is the source of approximately 85 percent of the silver production of the world.

TABLE IV.—*World production of silver and gold in 1928* [1]

Country	Silver		Gold	
	Fine ounces	Percent	Fine ounces	Percent
Total	257,925,154	100.00	19,755,622	100.00
North America	188,899,718	73.23	4,734,414	23.96
United States	58,426,004	22.65	2,144,720	10.86
Canada	21,936,407	8.50	1,890,592	9.57
Mexico	108,537,307	42.08	699,102	3.53
South America	28,883,310	11.20	416,734	2.11
Asia	15,080,065	5.85	1,222,476	6.19
Europe	10,933,682	4.24	1,361,010	6.89
Oceania	10,304,420	4.00	687,528	3.48
Central America	2,558,548	.99	60,469	.31
Africa	1,265,411	.49	11,272,991	57.06

[1] Compiled from U.S. Treasury, Annual Report of Director of Mint for fiscal year ended June 30, 1930.

EXTRACTION AND REFINING OF GOLD AND SILVER

11. *Extraction.*—Although the production of gold and silver is intertwined, processes of great importance in the extraction of one metal are of lesser significance in the production of the other metal only because gold predominates in dry and siliceous ores and silver in complex ores. Amalgamation, cyanidation, and placer dredging are the principal processes used to produce gold bullion, while copper, lead, and complex ore concentration and refining results in the procurement of the largest amount of silver.

12. The pulverizing of siliceous ore, bringing it in contact with mercury or dissolving it in sodium cyanide, separating the amalgam or filtering and decanting the cyanide solution are methods requiring only limited amounts of electricity. While electrolysis has been tried as a method of precipitation, it is not in active use. Nor is the electric furnace applied to any extent in refining the dry cyanide precipitate or the retort bullion. It is not, therefore, until gold and silver bullion from dry and siliceous ores reaches the refining stage that the electric cell becomes a factor of importance.

13. The methods by which copper and zinc refineries separate gold and silver from the ore treated are described in the reports on "power in copper and copper alloy production", and "power in zinc and lead production." As these reports carry precious-metal treatment through the dore furnaces in which these metals are separated from major impurities, this description of gold and silver refining will begin with the "parting" of the precious metals. Although this is still done by sulphuric acid in small plants, larger refineries and the mints employ electrolysis.

14. *Electrolytic refining of silver.*—The dore from copper, lead, or zinc refineries is received at the parting plant in the form of anodes. These are placed in pine boxes having perforated false bottoms covered with muslin. The crystals are washed with water and some ammonia until the absence of copper is assured. They are dried and placed in baskets covered on inner and outer sides with cotton duck.

15. The electrolytic cells are in series and newer cells operate at 40 amperes per square foot of anode surface. The voltage is variable but averages about 3 volts. Five anodes are placed in a cell. The electrolyte is made up of silver and copper nitrate. Graphite or steel plates serve as the cathodes. When the current passes through the anode, the silver is deposited as crystals on the cathode from which it is periodically scraped. These crystals are washed, melted in a retort, and cast into bars of 1,100 troy ounces. The energy consumption per pound of silver deposited varies from 0.357 kilowatt-hours in Thum cells to 0.158 kilowatt-hours in Moebius cells. Or, 1 fine ounce requires from 13.2 to 28 watt-hours.

16. *Gold slime.*—The gold and impurities remain undissolved in the muslin lining of the basket. This lining is removed periodically and the electrolyte drained out. The gold slime is boiled with sulphuric acid to remove any silver. It is washed, melted, and cast into anodes for refinement.

17. *Electrolytic refinement of gold.*—Gold anodes from silver refineries or from gold-mining operations are placed in a cell containing an electrolyte of gold chloride and hydrochloric acid. The gold is deposited on cathodes of pure gold. Silver sinks as an insoluble chloride and any platinum present remains in solution and is recovered. The yield is approximately 180 pounds gold of 999.8 fine in 24 kilowatt-hours or 1 pound gold requires in final refinement 0.133 kilowatt-hours; 1 fine ounce gold 11 watt-hours.

Production and Refinement of Gold and Silver

QUANTITY PRODUCED AND REFINED

18. While the United States Bureau of Mines gives figures on gold and silver content of ores mined, the United States Bureau of the Mint quotes as domestic production the total unrefined domestic gold reaching the United States mints, assay offices, and private refineries within a given year. According to the Bureau of the Mint, the domestic production of gold during 1929 was 2,208,386 fine ounces. Silver production reached 61,327,868 ounces as compared with 58,462,507, ounces in 1928. Of this amount, 1,229,774 fine ounces of gold and 61,016,943 ounces of silver were new domestic product of private refineries, and 978,612 fine ounces of gold and 310,925 fine ounces of silver were deposited at mint or assay offices.

19. Private silver and gold refineries in turn deposit much of their gold at mints and a small amount of their silver. The mints, therefore, become the largest refineries of gold. Because not all bullion received is refined immediately, because much old gold and silver is refined over again each year, because foreign bullion is also refined, the actual amount of gold and silver that is treated electrolytically each year may not be identical with that received by the Government and private refineries. For example, during the fiscal year end-

ing June 1930, the United States mints at San Francisco, Denver, and New York produced 2,755,400 fine ounces of gold for the market and 1,332,603 fine ounces of gold were re-refined for use in the electrolytic refining process. Or, in these three units alone, more marketed gold was electrolytically refined than had been received from the mines.

20. The mint refinement of gold for the market required, therefore, only 30,309 kilowatt-hours of electricity while a total of 45,000 kilowatt-hours electricity was consumed at mints in order to make possible such market production.

21. While mints become the big refineries of gold, private refineries continue to handle the mass of silver. For the year ending June 1930, private refineries refined 61,016,943 fine ounces of silver while mints report an output of 3,156,096 fine ounces, making a total of 64,173,039 fine ounces refined silver. Or, marketed silver required approximately 1,283,500 kilowatt-hours of energy.

22. *Companies refining silver and gold.*—As has been stated, new gold refining takes place to a large extent at the mints in San Francisco, Denver, and New York. Large amounts of silver and some gold are refined by the American Smelting and Refining Co. in its plants at Selby, Calif.; Baltimore, Md.; and Maurer, N.J.; The Anaconda Copper Co. at Raritan, N.J.; the Balbach Smelting and Refining Co. at Newark, N.J.; the United States Metals Refining Co. at Carteret, N.J.; and the United States Smelting Lead Refinery Incorporated, at East Chicago, Ind.

23. In addition there are numbers of small firms refining old gold and silver. The United States Census lists 57 firms engaged in "reducing and refining not from the ore." These are located chiefly in New Jersey, Rhode Island, and New York.

World Consumption

CONSUMPTION OF GOLD

24. A little over 71 percent of all the gold consumed in 1928 was used in coinage, though this proportion does not hold throughout the several countries as is shown by table VI. In fact, the most conspicuous feature of the table is the complete reversals of proportions of gold used in coinage and industrially by countries reporting gold consumption. However, the largest consumers of gold use it in coinage principally. The United States which accounted for over 57 percent of the world's consumption in 1928 (though it furnished less than 11 percent of the world's production in the same year) converted over three fourths of all the gold it used into money. The British Empire—which is the next largest user—consumed almost 90 percent in coinage.

25. *Competitive conditions.*—Because gold is the monetary standard of the most important nations of the world, because the world's supply of gold is conspicuously limited, because the production of gold in the United States has been steadily declining since 1915, and because in this country the price of gold is fixed at $20.67 a fine ounce, the precious metal does not have to face the competition which confronts the output of every other industry not excluding the output of silver mines. The nations of the world compete for gold. Its market is always assured.

TABLE V.—*World consumption of gold in 1928* [1]

[Value in United States dollars]

Country	Grand total		Use in coinage		Used industrially	
	Value	Per-cent	Value	Per-cent	Value	Per-cent
Total	[2] $413,732,129	100.00	$294,500,867	71.18	$119,231,262	28.82
United States	236,440,659	57.12	177,360,000	75.01	59,080,659	24.99
British Empire	109,059,889	26.36	97,179,986	89.11	11,879,903	10.89
France	21,268,539	5.13	249	[3]	21,268,290	100.00
Mexico	13,509,350	3.26	13,409,650	99.26	99,700	.74
Egypt	9,104,122	2.20	9,886	.11	9,094,236	99.89
Switzerland	[4]		[4]	[4]	6,978,300	[4]
Rumania	3,547,239	.85	3,474,000	97.94	73,239	2.06
China	[4]		[4]	[4]	3,099,708	[4]
Austria	2,947,309	.75	1,513,767	51.36	1,433,542	48.64
Germany	[4]		[4]	[4]	1,715,040	[4]
Portugal	[4]		[4]	[4]	1,562,456	[4]
Netherlands	[4]		1,310,248	[4]	[4]	[4]
All other countries [5]	3,183,270	.78	243,081	7.64	2,940,189	92.36

[1] Compiled from Report of Director of the Mint for year ended June 30, 1930.
[2] Including amounts used only in coinage or industrially by 5 countries as noted.
[3] Less than 0.1 per cent.
[4] No report.
[5] No other country consumed as much as $1,000,000.

26. *Consumption of silver.*—Almost four fifths of the world's total consumption of silver in 1928 was used in coinage, though in some countries industry and the arts absorbed more silver than did coinage. China, which consumed more than half of all the silver produced in that year, put over 99 percent of it into coinage. On the other hand, the United States, which is the next largest consumer (though it absorbed less than 15 percent of the world total consumption for 1928) converted over four fifths of what it did use to industrial and art purposes. The sterling-silverware industry is the largest consumer, while chemical and photographic-film industries together absorb about 10,500,000 ounces. France and Switzerland also used more silver in the industries and art than in coinage. Table VI following shows the world consumption for 1928 by principal absorbing countries.

27. *Competitive conditions.*—Because silver is a commodity (and important as a commodity) as well as a monetary metal, it is affected by price fluctuations based on variations in supply. This, in turn, is greatly affected when an important country changes its monetary standard from silver to gold and melts down silver coins into bullion for the general silver market. The British Empire made this change for India in 1925. The debasement of India silver and its influx into the market as a competitor with the regular silver-mine production has been one of the principal causes for the decline in the price of silver to a record low level. The last Congress authorized a commission charged with the duty of bringing about some agreement with the British Government and other countries concerned looking to the rehabilitation of the world's silver market. No prediction, of course, can be made as to the outcome.

TABLE VI.—*World consumption of silver in 1928* [1]

Country	Grand total		Used in coinage		Used industrially	
	Fine ounces	Percent	Fine ounces	Percent	Fine ounces	Percent
Total	[2] 276,850,322	100.00	216,093,260	78.05	60,757,062	21.95
China	143,032,373	51.66	142,343,174	99.52	689,199	.48
United States	41,975,986	14.80	6,428,323	15.31	35,547,663	84.69
British Empire	21,311,436	7.70	12,747,731	59.82	8,563,705	40.18
France	17,492,290	6.32	6,985,220	39.94	10,507,070	60.06
Germany	[3]	[3]	12,315,955	[3]	[3]	[3]
Nicaragua	[3]	[3]	11,395,322	[3]	[3]	[3]
Austria	6,192,695	2.20	5,535,002	89.38	657,693	10.62
Italy	[3]	[3]	5,439,434	[3]	[3]	[3]
Japan	[3]	[3]	4,422,072	[3]	[3]	[3]
Netherlands [4]	[3]	[3]	3,186,906	[3]	[3]	[3]
Irish Free State	[3]	[3]	1,656,818	[3]	[3]	[3]
Switzerland	1,641,659	.59	469,792	28.62	1,171,867	71.38
Egypt	[3]	[3]	[3]	[3]	1,363,761	[3]
All other countries [5]	5,423,615	1.94	3,167,511	58.41	2,256,104	41.59

[1] Compiled from "Report of Director of the Mint for year ended June 30, 1930."
[2] Including amounts used only in coinage and industrially by countries as noted.
[3] No report.
[4] Includes Netherland East Indies.
[5] No other country consumed as much as 1,000,000 fine ounces.

RARE OR MINOR METALS

28. There are a number of metals which may be reduced electrolytically or electrothermally but which are produced only in small quantity or which have not been manufactured, as yet, commercially. A short accounting of such metals as are being produced in this country is given, not because their manufacture is of any present significance in the development of the Nation's water power, but because normal growth may make such industries valuable adjuncts to other larger producing units.

TUNGSTEN

29. Although the largest amount of tungsten is employed as ferrotungsten in the manufacture of tungsten steel described on pages 392–393 of "The Electric Furnace in the Iron and Steel Industry", a small but increasing tonnage is made into electric-lamp filaments and into contact points in electric ignition equipment.

30. The nearly pure tungsten metal is either refined from the ore by an electrothermal process or is obtained from tungstic acid by the alumino-thermic process described in "Power in Aluminum Production."

31. When metallic tungsten is manufactured in an electric furnace the ore is first pulverized and fused with sodium carbonate to produce sodium tungstate and oxides of associated manganese and iron. These oxides are dissolved from the mixture and the sodium tungstate is treated with hydrochloric acid to precipitate tungstic acid. This acid is purified by several conversions to a salt and back to an acid, after which it is heated to an oxide of tungsten.

32. The oxide of tungsten is reduced to metallic tungsten in the hydrogen atmosphere of an electric furnace. Hydrogen conbines with the oxygen and volatilizes, leaving metallic tungsten in powdered form. This powder is pressed into bars, each of which is sintered to

incandescence by passing a heavy current through it in a hydrogen atmosphere. A 99.95 percent pure tungsten results.

33. This bar is worked into rods after being heated in a third electric furnace. Rods are cut into disks with abrasive wheels. These disks are welded to screws and rivets by means of brazing copper in a fourth hydrogen-atmosphere electric furnace.

MOLYBDENUM

34. Molybdenum is also a metal that is consumed principally as ferromolybdenum but when pure is valued as filaments and as grid wires of radio tubes. A molybednite concentrate is roasted in a current of air, the sulphur in the concentrate being burnt off as sulphur dioxide. The oxide of molybednum remaining is condensed. It is refined and reduced to metallic molybdenum by a stream of hydrogen in the electric furnace. This powdered metal is pressed into bars and sintered before being formed into rods or sheets. Final operations convert it into fine wires and into plates and cathodes for vacuum tubes.

35. The two largest producers of the pure metal tungsten and of the pure metal molybdenum are the Fansteel Products Co. of North Chicago, Ill., and the Tungsten Electric Corporation with plants in Union City, N.J.

COBALT-TUNGSTEN ALLOYS

36. Tools made of tungsten carbide cemented with cobalt are attracting wide attention because their life is many times greater than that of high-speed tungsten machine tools. Alloys of cobalt, chromium, and tungsten in varying proportions are being employed in acid- and heat-resistant equipment. The metal cobalt may be obtained from its oxide (which has been obtained through a series of operations from cobalt ores) by electric-furnace reduction. Coke is added to reduce the oxide. Chromium metal is manufactured commercially by the chemical extraction of chromium oxide from chromite and by the reduction of the oxide by the thermit process.

37. The three metals, tungsten, cobalt, and chromium are melted together in an electric furnace at over 1,500° C. These alloys are produced by the Haynes Stellite Co., now a subsidiary of the Union Carbide and Carbon Corporation.

38. *Sources of cobalt.*—The world's cobalt was produced chiefly by the Union Miniere du Haut Katanga in the Belgian Congo, and Deloro Smelting and Refining Co., Ltd., of Canada. The United States producers received their ore from the Cobalt District of Canada. The lead ores of Missouri are associated, however, with cobalt as well as with nickel and copper.

TANTALUM

39. Tantalum has not as assured a position in industry as the foregoing metals, but it is applied to a limited extent in several industries. The Fansteel Products Co. of Chicago is manufacturing it.

40. Tantalum is used as elements in amplifying tubes, to maintain high vacuums in radio tubes, as spinnerets in rayon thread formation, and for equipment in chemical laboratories. The metal is derived from the ore "tantalite" found in Western Australia although it may

be secured from the ore columbite of South Dakota. Ore is pulverized and fused with potassium hydroxide to make soluble tantalates and columbates. After these have been dissolved and filtered, the solution is treated with hydrofluoric acid which gives a double fluoride of tantalum and potassium and potassium fluorycolumbate. After precipitation of the tantalum-potassium fluoride, it is reduced to a pure metal tantalum in an electric furnace. The potassium fluorycolumbate may also be electrolyzed to metallic columbium.

It is possible also to reduce tantalum by the thermit process.

BARIUM

41. Domestic production of metallic barium began in 1929 for use in high-nickel alloys. It is also being used as a "getter" in radio vacuum tubes in competition with tantalum. While American methods of manufacture are not known, the metallic barium produced in Germany is made electrolytically. Barium chloride is electrolyzed and the amalgam formed is distilled to pure barium.

42. As barite has been mined extensively for use in the lithopone industry, the mining branch of the barium industry is well established in the United States. California, Missouri, Georgia, North Carolina, Tennessee, and Virginia are the principal mineral producing States.

CERIUM

43. The metal cerium is usually made from the accumulated residues of the gas-mantle industry which employs thorium nitrate in the making of incandescent mantles. The residue, an oxide of cerium, is dissolved in hydrochloric acid. Phosphorus and sodium compounds are removed with barium chloride, while iron, manganese, and chromium are removed with ceric oxide. After evaporation and fusion in cast-iron pots, the mixture is electrolyzed at 850° C.

44. When alloyed with iron, ferro-cerium is the ignition element in miner's safety lamps and the sparking element in cigar lighters. It was made by the New Process Metals Co. of Newark, N.J., which is now a part of the Tungsten Electric Corporation.

LITHIUM

45. A small percentage of lithium added to lead produces a good bearing metal. It is also alloyed with aluminum, and research is underway concerning its use in copper-wire bars. It is a deoxidizing agent in the refining of copper. Large deposits containing small amounts of lithium occur in California, Arizona, New Mexico, and South Dakota.

46. Lithium is extracted as a carbonate from its minerals by a chemical process. From the carbonate, bromide, chloride, hydride, and other salts are prepared. In the presence of potassium chloride, the fused lithium salts are electrolyzed to the metal lithium. The General Electric Co. has produced some lithium.

BERYLLIUM

47. Beryllium is used as a window in X-ray tubes. But experiments are underway by the Beryllium Corporation of America in the utilization of the metal as a constituent of light alloys. Beryl, the metal, is found in Colorado, Maine, and South Dakota.

48. The reduction involves the electrolysis of a mixture of beryllium oxyfluoride and barium-fluoride requiring 45 kilowatt-hours per pound, or of fused beryllium chloride requiring much less current.

BISMUTH

49. The bismuth produced in this country is recovered electrolytically from the slags of lead refineries. It is consumed in low-melting alloys and by the pharmaceutical industry. As the supply available if all were recovered from lead refining exceeds the demand, the United States Bureau of Standards is working on potential uses of the metal.

50. In the electrolytic refining, sheet lead covers the cell bottom and acts as the cathode. The anodes are in a basket lined with duck. Bismuth chloride and free hydrochloric acid solution form the electrolyte. The bismuth is deposited as nodules on the cathode and the deposits are broken down every 8 hours.

METALS REFINED ELECTROLYTICALLY IN COUNTRIES OTHER THAN THE UNITED STATES

51. *Nickel.*—Although nickel is fairly widespread in its occurrence, over 90 percent of the world's production comes from the Sudbury Field in the Province of Ontario, Canada. All production is by one company, The International Nickel Co. of Canada, Ltd. Refining of nickel is accomplished electrolytically at Port Colborne, where plants have a capacity of 43,200 short tons per annum. Platinum is recovered from such refining. This is shipped to a precious-metals refinery at Acton, England.

52. *Tin.*—Tin was refined electrolytically in the United States during and after the War at Perth Amboy, N.J. But in 1923 the industry was abandoned, as it was not commercially feasible to operate a tin smelter in this country. All virgin tin had to be imported, the Federated Malay States, Bolivia, and Netherlands East Indies, being the principal tin mining countries. And the mining and smelting industry was well controlled by British, Dutch, and German interests.

APPENDIX II

STUDY OF COST OF POWER TRANSMISSION FROM COLUMBIA RIVER PLANTS TO MARKET CENTERS (100 TO 250 MILES)

Prepared by E. A. LOEW, *Professor of Electrical Engineering, University of Washington, Seattle, Wash.*

Introduction.—The investigation herein discussed was undertaken for the purpose of determining as closely as possible the probable cost of transmitting electrical energy from the several proposed generating sites on the Columbia River to adjacent markets. These markets include the Puget Sound region lying between Bellingham and Portland and the Inland region tributary to Spokane. Inspection of the map showing the locations of the proposed power plants covering the Columbia Basin project, indicates that to transmit power to these markets from the various proposed power sites on the

river, will require transmission lines varying in length from perhaps 100 to 250 miles. The bulk of the power will probably not need to be transmitted more than 150 miles. It is therefore necessary to determine transmission costs for distances up to 250 miles.

DISCUSSION OF THEORY

Kelvin's Law.—When a line of given length is operated at some fixed voltage and is used to transmit a certain amount of power, the cost of delivering a kilowatt-hour of energy over the line depends upon the size of the conductor used. When the conductor is too small the line is relatively inexpensive, but owing to the high line resistance the losses are excessive and the cost of transmission is too high; when the conductor is too large the losses are greatly reduced but the investment in conductors is excessive; the interest and depreciation annually chargeable against the investment in conductors is a larger amount than the value of the losses annually saved will warrant, and hence the line is again uneconomical. Obviously, the condition of maximum economy for a particular line and a particular load occurs when the conductor used is the one for which the value of the energy annually wasted as line loss, added to the interest and depreciation on the sum of all items of line investment that vary with the size of the conductor used, is a minimum. This law of economics, as applied to transmission lines, is known as Kelvin's Law.

Kelvin's law of economy assumes a fixed line voltage. If the voltage on the line is raised, however, the line current is decreased and the line losses are reduced in proportion to the square of the increase in voltage. When the voltage is doubled the line losses are reduced to a fourth of their former value. On the other hand, if the losses are kept at the original level, the size of conductor may be reduced to one quarter of the original value, thereby effecting a large saving in the cost of conductors and supporting structures. The use of a higher voltage, however, entails additional outlay for transformers, switches and line insulation. The higher voltage is better than the lower one only when the saving in line loss annually effected by its use exceeds the increase in annual outlay chargeable to the additional investment required to make the saving possible.

Modified Kelvin's Law.—Kelvin's law is therefore not a complete statement of the law of economy affecting transmission-line design. A proper statement of the law must assume the line voltage to be variable and must express equality between the annual value of the energy wasted as line loss and all items of line cost whose values vary either with the conductor diameter or with the line voltage used. Such a statement of the law is found in the papers mentioned in references [25] and [26] below. A slightly modified form of expression is used herein as a basis for making line calculations.

Conductor size limited by corona.—Two other limiting conditions need to be mentioned as determining factors affecting line design, namely, corona and power limit. The latter will be briefly treated in a later paragraph.

When the voltage on a transmission line is gradually increased from a low to a high value, the voltage gradient at the conductor surface

[25] Economy in the Choice of Line Voltages, by E. A. Loew. Journal, American Institute of Electrical Engineering, August 1928.
[26] Electrical Power Transmission, E. A. Loew. McGraw-Hill Book Co., January 1928.

increases. The absolute value which this gradient attains with a given impressed voltage varies inversely with the conductor size. The gradient is independent of the conductor spacing, provided the latter, as well as the conductor diameter, is proportional to the voltage, as it should be. When the voltage gradient finally reaches a critical value, corona forms on the line conductors and electrical energy escapes into the surrounding air. Practical transmission lines are so designed that the gradient at the conductor surface is held below the critical or corona-forming value. This means that for every line voltage there is a minimum size of conductor that can be used, independent of how little power is tranmitted over the line. For stranded cable the limiting conductor diameter in inch units is approximately equal to the line voltage (in kilovolts) divided by 210.

Based on the above criterion, the minimum conductor diameters that should be used with the several standard voltages above 100 kilovolts are roughly as follows:

TABLE I.—*Minimum cable diameters as determined by corona*

Voltage	Conductor diameter	Circular mils (A.C.S.R.) (nearest standard size)
Kilovolts		
110	0.523	211,600
132	.629	266,800
154	.735	336,000
220	1.050	715,500
330	1.570	1,590,000

Power limits.—The amount of power that can be transmitted successfully over a given transmission line is limited by conditions of operation, and by the constants of the circuit. The limit set by these conditions is quite independent of the size of the conductor used.

When the load on a line is gradually increased from a low to a high value, the excitation voltage vector of the receiver end motors gradually swings more and more out of exact phase opposition to the generator excitation voltage vector. The amount of this phase displacement is determined almost entirely by the load on the line and by the total amount of reactance in the circuit. This includes the synchronous reactance of the motors and generators, the reactance of step-up and step-down transformers and the reactance of the line itself. Theoretically, when the load is gradually applied, it may be increased until the angle of phase displacement between the excitation voltage vectors at the two ends of the line reaches 90°; beyond this any further increase of load will cause the synchronous machines at the two ends of the line to fall out of step. The load for which this condition prevails is called the steady-state power limit of the line.

Obviously, lines cannot be operated at or even very close to their steady-state power limits, for lines so operated would be very unstable and would lose synchronism under the slightest disturbance. An accidental short circuit may suddenly add a very heavy load to an already loaded line. If the line is operating near its steady-state power limit, a short circuit will so overload the line that the machines at the two ends will fall out of step before the circuit breakers can

operate to open the circuit. Many factors influence the behavior of the system during the interval of time between the instant when the short circuit is first applied and the instant when either (*a*) the machines fall out of step, or (*b*) circuit breakers clear the line, and the system recovers. Some of these factors are the following:

(1) It is important that the voltages at the ends of the line should be maintained during and after the clearing of line faults. The system of excitation should be designed to respond quickly; that is, high-speed excitation is desirable.

(2) During the first moments of a fault, while the system frequency is dropping, energy is delivered by the energy of rotation (Wr^2) of the machines. The inertia of the rotating equipment is thus a factor in stability.

(3) The governors of the prime movers should respond quickly.

(4) The time elapsing between the beginning of the fault and the opening of the circuit breakers should be small. Improvement in the speed of operation of circuit breakers has made it possible to reduce this interval to a little over one tenth of a second.

The maximum load at which a line can be operated without having the machines lose synchronism at times of fault, is called the load limit of the line as determined by transient stability. This is the load limit that governs the practical operation of a line. The load thus found is less than the steady-state power limit mentioned above. It may roughly be calculated when all of the data for a given system are available. For the purpose of the present investigation average operating conditions are assumed and the power limits of the proposed lines are predicted on the basis of the performance of other existing lines whose approximate power limits are known.

The practical design of short transmission lines (under 100 miles in length) is determined almost entirely by the principle of economy embodied in the modification of Kelvin's law, as discussed briefly in the earlier pages of this report. The total reactance in the circuit between the generating source and the point of consumption is so small that there is generally little likelihood of trouble from instability in the operation of such lines except for loads considerably in excess of those for which the lines are ordinarily designed. The design of long lines, on the other hand (lines from 100 to 300 miles long), cannot be based wholly on this simple principle. As the length of line increases, the load that a line can carry, with stability in operation, decreases quite rapidly. The load which a proper application of Kelvin's modified law predicts as the most economical one for a given line is then often in excess of the maximum load the line can carry without exceeding its limit of stability. The stability limit must then fix the maximum load for which the line is designed.

As previously pointed out, a minimum conductor diameter is required, independent of load, in order to eliminate excessive corona loss as well as to make possible the rigid construction needed to withstand heavy ice loads. The conductors of long lines therefore usually operate at low current densities and have correspondingly low losses per mile of circuit.

As a rough approximation one may state that the steady-state power limit of a line depends directly upon the square of the line voltage, and inversely upon the total reactance in the circuit. Components of the latter are the reactance of the line itself, the equiva-

lent reactance of step-up and step-down transformers, and the reactances of the equivalent generators and motors representing the machines at the generating and receiving ends of the line, respectively.

The diameters of transmission line conductors (assuming a given type of cable) are proportional to the line voltages. The spacing between conductors is likewise generally proportional to the line voltage. When this is the case the total reactance per mile of transmission line is approximately constant, irrespective of the voltage or conductor size. The reactance per mile of line is in the neighborhood of 0.75 ohms; accordingly, the total reactance of a line is approximately equal to 0.75 L, where L is the length of line in miles.

Consider next the reactance introduced by the transformers and by the equivalent generator and motor representing the simplified system. If a fixed percent reactance be assumed for each of these (e.g., 40 percent for generators and 12 percent for transformers), the equivalent reactance of each will be inversely proportional to the rated capacity. The latter, in turn, should be inversely proportional to the length of line for all cases, however, since the steady-state power limit varies inversely as the length of line. Therefore, when the rating of the terminal machinery is proportioned to the steady-state power limit of the line, the total equivalent reactance which generator, transformer, etc., introduce is also proportional to the length of the line. Accordingly, when the above-outlined principles of design are employed, all lines operating under given conditions of stability will have approximately the same angular displacement between the voltage vectors at receiver and supply ends, regardless of the length of line or its operating voltage. This is the principle upon which the assumed loads for the several lines considered in the latter part of this report are determined.

Equation of transmitted power.—Equations (1) and (2) below are the familiar vector voltage equations of the transmission line. In (1) the receiver voltage (E_r) is the vector of reference, while in (2) the supply voltage (E_s) is the reference vector.

$$E_s = E_r A + I_r B \tag{1}$$
$$E_r = E_s A - I_s B \tag{2}$$

Let θ be the angular displacement between receiver-end and supply-end voltage vectors E_r and E_s. From equation (1), using the polar form of expression for E_s and writing I_r in terms of its two components, one obtains:

$$E_s \epsilon^{j\theta} = E_r A + \left(\frac{P_r}{E_r} + j\frac{Q_r}{E_r}\right) B$$

or

$$\frac{P_r}{E_r} + j\frac{Q_r}{E_r} = \frac{E_s \epsilon^{j\theta}}{B} - \frac{E_r A}{B} \tag{3}$$

Similarly, from (2), using E_s as reference

$$\frac{P_s}{E_s} + j\frac{Q_s}{E_s} = \frac{-E_r \epsilon^{-j\theta}}{B} + \frac{E_s A}{B}$$

Let $k = E_s/E_r$, the ratio of supply to receiver voltage. Then in terms of receiver voltage, equations (3) and (4) above become

$$P_r + jQ_r = kE^2{}_r \epsilon^{j\theta}/B - E^2{}_r A/B \tag{5}$$
$$P_s + jQ_s = -kE^2{}_r \epsilon^{-j\theta}/B + k^2 E^2{}_r A/B \tag{6}$$

Equation (5) represents the line output in active and reactive power, while equation (6) represents the line input in similar terms. Adding these equations, dividing by 2, and multiplying and dividing by j yields

$$\begin{aligned} P_m+jQ_m &= jkE^2_r\ (\epsilon^{j\theta}-\epsilon^{-j\theta})/2jB+E^2_rA\ (k^2-1)/2B \\ &= E^2_r/B\left[kj\ \sin\theta+\frac{A}{2}\ (k-1)\right] \qquad (7) \\ &= \frac{E^2_r}{b^2_1+b^2_2}\left[kj\ (b_1-jb_2)\ \sin\theta+\frac{l}{2}\ (a_1+ja_2)\ (b_1-jb_2)\ (k^2-1)\right] \end{aligned}$$

whence

$$\begin{aligned} P_m &= E^2_r/(b^2_1+b^2_2)\left[kb_2\ \sin\theta+\frac{l}{2}\ (a_1b_1+a_2b_2)\ (k^2-1)\right] \\ &= E^2_r\left[kb_2n^2\ \sin\theta+\frac{l}{2}(k^2-1)\right] \qquad (8) \end{aligned}$$

P_m in equation (8) is approximately equal to the amount of power passing the midpoint of the line; it is greater than the receiver input by approximately one half the line loss and is less than the supply output by about the same amount. P_m is therefore only a few percent greater than the receiver input. The last term in (8) disappears when k is unity, and for any practical case is a small and quite negligible quantity. Omitting this term has the effect of bringing P_m nearer in value to the receiver input. Hence the receiver input is approximately

$$P_m = E^2_r\ b_2kn^2\ \sin\theta \qquad (9)$$

Since b_1 is small as compared with b_2, the quantity $b_2/(b^2_1+b^2_2)$ is approximately equal to $1/b_2$ and, hence, very closely

$$P_m = E^2_r/b_2\ (k\ \sin\theta) \qquad (10)$$

The values of b_1 and b_2 may be computed for any assumed length of line. For reasons already explained, b_2 and, therefore, n depend primarily upon the length of line, and are nearly independent of voltage and conductor size, even when calculated for the equivalent circuit, including transformers and generator.

Economical current density.—The most economical current to use with a given cable is determined by the law of economy already mentioned. When this law is correctly applied it turns out, as is to be expected, that the current is proportional to the size of cable. Stated in another way, the current density is approximately constant for all lines of a given length regardless of the line voltage. Since to prevent corona the diameter of the cable must also be proportional to the line voltage, the cable area, and hence the current carried, should be proportional, theoretically, to the square of the line voltage. Under this arrangement, assuming that no practical maximum operating load limit is reached, the transmitted kilovolt-amperes are porportional to the cube of the voltage.

As an example, consider five lines, each 200 miles long, one each operated at 110, 132, 154, 220, and 330 kilovolts. Let the cables used be the minimum sizes given in table I and let the conductor area per ampere of current be 2,000 circular mils in every case. The loads on

the lines (at unity power factor) will then be those given in the last column of the following table:

TABLE II

Line voltage (kv)	Circular mils A.S.C.R.	Amperes	Kw at unity P.F.
110	211,600	106	20,200
132	266,800	133	30,400
154	336,000	168	44,800
220	715,500	358	136,000
330	1,590,000	795	454,000

Table II forcefully illustrates the advantage of using the higher voltages when large amounts of power are to be transmitted. This apparent advantage cannot always be fully realized, however, for the following reasons:

First. The theoretically most-economical load shown in the last column of table II may be greater than the permissible operating load limit of the line, as indicated in the curves of figures [27] 5, 6. When this is the case, the permissible load limit must control the design. The optimum condition prevails when the most economical load as determined by the modification of Kelvin's law is equal to the operating power limit of the line. As already pointed out, and as table II illustrates, in comparison with the curves of figures 6,[27] e.g., the theoretically most-economical loads for the extra-high-voltage lines are usually less than the permissible operating load limits, and the divergence increases with the line voltage. Thus the hoped-for increase in economy, which one might be led to expect would naturally accompany the use of higher and higher line voltages, does not exist in fact.

Second. From a practical standpoint it is necessary to have several lines feeding a given important load center in order that continuity of service may be assured. Suppose, for example, that four similar equally loaded 220-kilovolt lines supply a given load center. Should one line accidentally fail, the load which it originally carried may be divided among the remaining three by increasing the load on each by one third without endangering their satisfactory performance and until such time as the faulty line is again put into service. Thus service is maintained. If, on the other hand, 330-kilovolt lines were used, two lines, each carrying twice as much power as one of the 220-kilovolt lines would be electrically equivalent to the latter. These two lines cannot, however, supply service equivalent to that supplied by the four 220-kilovolt lines. Should one line fail, the load on the remaining line would have to be doubled to maintain service. This additional load, however, would probably be more than the remaining line could satisfactorily carry, and accordingly, service would be partly interrupted or it must be supplied from some other source until it may again be renewed over the faulty line.

The two above-mentioned reasons constitute very strong arguments against the use of line voltages in excess of 220 kilovolts and will probably make them impractical, at least until such time as the

[27] Not printed.

amounts of power to be transmitted to a given load center reach the order of 600,000 to 800,000 kilowatts.

COMPUTATIONS

Curves for economical RI drop.—For conditions of maximum economy, the root-mean-square of transmitted current should be that given by equation (11)[28] below. This equation reduces to equation (12) when the conductor resistance per mile is substituted in terms of conductor diameter. The constants used have the values given in the tabulation; thus:

$$I' = d^2_s\left[\frac{1}{\rho A}\left(\frac{0.03}{bc^2}\cdot Bp_1+\frac{0.01\ p_2{}^M}{b}+\frac{0.01\ p_3k_{11}}{bl}\right)\right]^{\frac{1}{2}} \qquad (11)^{29}$$

But the resistance per mile of one conductor is

$$R/\text{mi}=\frac{5280\ \rho c^2}{10^6 d_s}$$

and, hence,

$$RI/\text{mi.}=\frac{5280\ \rho c^2}{10^6}\left[\frac{1}{\rho A}\left(\frac{0.03}{bc^2}\cdot Bp_1+\frac{0.01\ p_2{}^M}{b}+\frac{0.01\ p_3k_{11}}{bl}\right)\right]^{\frac{1}{2}} \qquad (12)$$

Assume that steel-reinforced aluminum cable (A.C.S.R.) will be used, and assign the following values to the constants:[30]

$p_1=p_2=p_3=p=6.83$ for the case of public money;
$=8.77$ for the case of private money
$A=$value of 1 kw-hr. of energy at receiver bus$=\$0.005$.
(The reason for choosing this figure is found on the following page.)
$l=$length of line in feet
$L=$length of line in miles
$c^2=1.23^2=1.51$ for aluminum cable (A.C.S.R.)
$p=17.9$ the resistivity of aluminum in ohms per mil-foot
$k_{11}=3k_{11}v^2=3\times20\times10^{-6}\times122^2\times10^6$ (the terminal equipment constant)
$M=0.30$ the tower constant
$b=40\times10^{-6}$
$B=0.265$ for 15¢ copper
$=0.30$ for 17¢ copper
$k_r^2=p/A$ or $k_r=\sqrt{p/A}$

Substituting the above values in equation (12) and solving yields the following forms of the equation:

$$RI/\text{mi.}=0.925\ k_r\ (0.275+55/L)^{\frac{1}{2}} \text{ (for 15¢ copper)} \qquad (13)$$
$$RI/\text{mi.}=0.925\ k_r\ (0.300+55/L)^{\frac{1}{2}} \text{ (for 17¢ copper)} \qquad (14)$$

It is apparent from equations (13) and (14) that 2 cents difference in the price of copper affects the results obtained from the equations only slightly. The curves of figures 5 and 6,[31] which are drawn for an assumed price of 17 cents per pound for copper, may be used without appreciable error for all prices of copper between 15 and 19 or 20 cents per pound. These equations show that the economical *RI* drop per mile of conductor depends upon the length of line (L), upon the value of a kilowatt-hour of energy (A), upon the interest

[28] See footnote 25, p. 457.
[29] It is important to note that the current I used in this and the following equations is the root-mean-square value as obtained from the average annual day-load curve and is not one third of the power delivered to the receiver divided by the receiver voltage to neutral.
[30] These values of p are derived in the manner shown on a later page.
[31] Not printed.

and depreciation rate (p) and upon the cost per pound of conductor material (B). With the help of one of these equations the curves of figure 1[31] were prepared. From these the economical size of conductor for any assumed conditions may quickly be obtained.

As an illustration, assume a line 200 miles long, let $p=6.83$ and $A=0.005$. Then $k_r^s=6.83/0.005=1,366$, and from the curve the economical RI drop per mile is seen to be approximately 26 volts. When I_{RMS} is known, the resistance per mile of conductor is found from the quotient $26\div I_{RMS}$.

For the purpose of this investigation it is assumed that energy must be sold in competition with steam-generated energy, which latter is available at the load center for 5 mils per kilowatt-hour. Accordingly, a kilowatt-hour of energy transmitted over the line is assumed to be worth 5 mils, or $\$0.005\div A$. If the transmission system is to be built with public money, it is assumed that 6.83 percent is a fair rate to cover interest, depreciation, and amortization; while if private money is to be used in the construction, the corresponding rate to cover interest, depreciation, and Federal and State taxes is 8.77 percent. These rates are made up approximately as follows:

Public money	Percent	Private money	Percent
Interest	4.00	Interest	6.00
Amortization	1.05	Depreciation reserve	1.27
Depreciation reserve	1.78	Taxes	1.50
Total	6.83	Total	8.77

The following values of k_r^s therefore apply:

$$\text{For public money } k_r^s=\frac{6.83}{0.005}=1,366$$

$$\text{For private money } k_r^s=\frac{8,77}{0.005}=1,754$$

Economical transmission voltage.—The economical RI drop obtained from the curves of figure 1[31] may be used to calculate the most economical voltage suitable to transmit any assumed load over a line of any length. The formula in which the relating of these factors is shown is derived below.

I = R.M.S value of the average line current at full load
R = ohms resistance per mile of 1 conductor
d_s = diameter of stranded conductor in inch units
l = number of feet per mile = 5,280
ρ = resistivity of A.C.S.R. = 17.9 ohms per mil-foot
kw = root-mean-square kilowatts transmitted over the line at full load
E_n = average line voltage to neutral in kv.
E = $\sqrt{3}E_n$, the average line-to-line voltage
v = a constant $\left(\frac{1}{1000}\times\right.$ constant in table 23, p. 259, of reference in footnote 26 on. p. 457 of this document.$\left.\right)$
= 122.5
= $E_n\div d_s$
p.f = average line power factor at full load—assumed to be 0.90.

[31] Not printed.

Then

$$RI=\frac{R\times kw}{3\times 0.9\ E_n}$$

$$=\frac{\rho l\ c^2\cdot kw}{10^6 d^2_s\cdot 2.7\ E_n}$$

$$=\frac{\rho l\ c^2 v^2\ kw}{10^6\times 2.7\ E^3_n}$$

or

$$E^3_n=\frac{\rho l\ c^2 v^2\ kw}{10^6\times 2.7\ RI} \qquad \left[\begin{array}{l}\rho=17.9\\ l=5280\\ c^2=1.51\\ v^2=15.000\end{array}\right]$$

$$E_n=\sqrt[3]{793\times}\sqrt[3]{\frac{kw}{RI}}$$

$$=9.26\sqrt[3]{\frac{kw}{RI}} \qquad (15)$$

$$E=16\sqrt[3]{\frac{kw}{RI}} \qquad (16)$$

With the help of equation (16) and the curves for the economical *RI* drop per mile (in figure 1),[31] the line voltage which it is most economical to use for any assumed transmitted load in root-mean-square kilowatts can be found approximately.

If it be assumed that the generating plant output is at all times proportional to the system demand, then the root-mean-square kilowatts delivered by a given generating station is the product of the following factors:

1. Kilowatts of installed generating capacity
2. Average annual day-load factor
3. Form factor of the average day-load curve for the year

The 1929 average day-load curves for the city of Seattle, the Puget Sound Power & Light Co., and the Washington Water Power Co. are shown in figures [31] 2, 3, and 4, respectively. From these curves the following data are obtained:

	Average annual load factor	Form factor
	Percent	
City of Seattle	44.8	1.04
Puget Sound Power & Light Co.	58.5	1.06
Washington Water Power Co.	58.7	1.00+

In the calculations that follow, a load factor of 55 percent and a form factor of 1.05 were assumed. Figure 5 [31] contains a set of curves computed on the assumption that public money is used ($p=6.83$); while figure 6 [31] is a similar set of curves for the assumption of private money ($p=8.77$).

With the aid of these curves it is possible very quickly to obtain the most suitable voltage to use for a given length of line and a given load. From figure 6,[31] for example, it is clear that to transmit a load of from 25,000 to 45,000 root-mean square kilowatts over a 100-mile line it is more economical to use 154 kilovolts than it is to use either 110 kilovolts or 220 kilovolts. On the other hand, 220 kilovolts should be used to transmit loads in excess of 50,000 root-mean-square kilowatts over a line 200 miles long. The curves clearly show that the

[31] Not printed.

use of 110 kilovolts is limited to loads under 25,000 root-mean-square kilowatts except for distances under 50 miles.

The curves of these figures (theoretically) may be applied throughout the entire range of the figure, but operating practice sets a limit of load for every system as already pointed out in the paragraphs on power limits. This limit determines the maximum load that a given line may carry, and hence fixes a cut-off line for the curves of figures [31] 5 and 6 beyond which it is impractical to use them. Such cut-off lines have been calculated for the several standard operating voltages between 110 kilovolts and 330 kilovolts and have been superimposed on the load curves. The method used to compute these lines will now be described.

Estimation of power limits.—Experience with certain 220-kilovolt 50-cycle lines seems to indicate that approximately 120,000 kilowatts is the practical upper load limit of a 250-mile line operating at the above voltage and frequency; while for a 200-mile line at the same voltage and frequency the corresponding limit is in the neighborhood of 160,000 kilowatts. When corrected to a frequency of 60 cycles this indicates that the angular displacement between the voltage vectors at the two ends of the line should not exceed from 15° to 20°. For the purpose of this report, the limiting angle for the line alone is therefore assumed to be about 18°, or $\sin \theta = 0.31$.

The so-called approximate power limits of lines of various lengths and for the several standard transmission voltages were calculated in conformity with the theory discussed in the earlier pages of this report, using equation (8). The constants a_1, a_2, b_1, and b_2 are found in appendix D of footnote 26, page 457, the ratio $Es/Er = k$ was assumed to be 1.05 and $\sin \theta = 0.31$, as already stated. The values resulting from these calculations are found in figure 7.[31]

One realizes that the values of power limit found in this manner involve certain assumptions as to uniformity in different power systems that can be realized only approximately. Nevertheless, it is believed that the limits found are quite close to those that may be expected in practice and that they may safely be used as a guide in the present investigation.

Relative economies of 154-, 220-, and 330-kilovolt lines.—The question that must next be answered is, "Which of the three voltages—154-, 220-, or 330-kilovolt—is the most economical one to use?"

It has already been shown that extra-high transmission voltages can be economically used only when large amounts of power are to be transmitted over a line of considerable length. When large amounts of power are involved, however, it will usually be impractical to entrust the entire load to a single line.

To guard against the failure of service due to line outage, a minimum of at least two lines would be required for an important market like the Puget Sound region, as soon as the load supplied by the hydroelectric plants on the Columbia River became a considerable percentage of the system load. Thus, before 330-kilovolt lines could be considered on a really favorable basis, the total amount of power to be transmitted to the Puget Sound area would have to be in the neighborhood of 500,000 kilowatts. Studies of the probable growth of power load in this district show that additions of load of this order of magnitude will probably be required in the not-far-distant future.

[31] Not printed.

Assumptions of the order of 250,000 kilowatts per line therefore seem reasonable.

Let it be assumed that in a given plant 500,000 kilowatts of generating machinery is available and that at full load the station power factor is 90 percent. The full-load station kilovolt-ampere is then 555,555. Let the distance of transmission be 200 miles, and assume losses as follows:

	Percent
1. Line loss at full load	10
2. Step-up transformers	1
3. Step-down transformers	1
4. Synchronous condensers [32]	1.5

The full-load receiver input is then $0.865 \times 500{,}000$, or 432,500 kilowatts.

Examination of the power-limit curves of figure 7 [31] shows that the estimated maximum receiver loads that can be delivered by 200-mile lines operating at the several standard voltages above 100 kilovolts are approximately those given in column 4 of table III below. The number of lines required to deliver the output of a 500,000-kilowatt generating station, less losses, for each of the voltages considered, is found in column 3 of the table.

TABLE III

Assumed voltage	Receiver input	Number of lines	Receiver load per line
Kilovolts	*Kilowatts*		*Kilowatts*
110	432,500	16	27,000
132	432,500	14	30,900
154	432,500	8	54,200
220	432,500	4	108,000
330	432,500	2	216,000

From the electrical standpoint the several methods of delivering the assumed amount of power to the load are taken to be equivalent. The lines operating at the lower voltages (110 and 132 kilovolts) are obviously uneconomical in the present instance, but they are included in the table in order to give a better picture of the problem and of the principle underlying its solution. Stated in words, the desired transmission of power may be accomplished in any one of the following ways:

1. By the use of a relatively large number of comparatively inexpensive, low-voltage lines, each carrying a relatively small load.
2. By the use of a minimum number (two) of very expensive, high-voltage lines, each carrying a relatively large load.
3. By the use of an intermediate number of moderately expensive, intermediate-voltage lines, of intermediate carrying capacity.

If it be assumed, for the sake of argument, that the operating advantages are equal for all of the arrangements to be considered (namely, the 154-, 220-, and the 330-kilovolt lines), the choice will fall to that arrangement for which the cost of transporting a kilowatt-hour of energy is minimum. There are certain obvious advantages favoring the use of 220 kilovolt rather than 330 kilovolt for example, but these need not now be considered.

[32] The synchronous condenser capacity required at the end of the line is roughly 50 percent of the receiver input, and the condenser loss is assumed at 3 percent.
[31] Not printed.

To arrive at a solution, cost estimates must now be made for transmission of the assumed amount of power at each of the voltages, 154, 220, and 330 kilovolts. The 110- and 132-kilovolt lines obviously do not need to be considered further.

Itemized estimates of line costs follow. The unit costs used for towers and fittings, insulators, transformers, switches, synchronous condensers, etc., were furnished by manufacturers' representatives. Most of the original data used in making the estimates are found in an appendix to this report. The costs of substation buildings and auxiliary equipment were independently estimated. Costs of conductors are based on an assumed price of 17 cents per pound for copper cable. Present prices (March 1931) are from 15 to 20 percent under this value. Lines are assumed to be operated without the use of any intermediate sectionalizing substations. In case of the longest lines it is probable that the use of such stations would reduce the estimated transmission costs by about 15 percent.

Estimates were first made of the cost of transmitting the output of a 500,000-kilowatt generating plant a distance of 200 miles by each of three methods, namely, over 154-kilovolt lines, over 220-kilovolt lines, and over 330-kilovolt lines. Various load factors from 55 to 85 percent were assumed. The results of these comparative estimates are shown graphically in figure 8.[31] It is seen from this figure that the 220-kilovolt transmission is more economical than is either the 330-kilovolt or the 154-kilovolt transmission. The theoretically most economical transmission voltage is only slightly above 220 kilovolts, and the 154-kilovolt transmission is quite a bit less economical than either of the other two. As the length of line and the amount of power to be handled are increased, the conditions of maximum economy would tend to bring the 330-kilovolt transmission into a more favorable position. It is to be remembered, however, that from an operating standpoint two 330-kilovolt lines carrying the very large loads here assumed are far from being equivalent to the four 220-kilovolt lines, and accordingly they could hardly be considered on an equal basis even though the cost estimates were the same for both. With this in mind, it is difficult to see where there is any likelihood of the need arising for 330-kilovolt transmission.

Since most of the power to be developed on the Columbia River will require transmission of less than the assumed 200 miles, and in view of figure 8,[31] it is clear that the best transmission voltage to use is 220 kilovolts. In order to make it possible to estimate the cost of transmission from any site on the river to the load center, additional cost estimates of 220-kilovolt lines were made for lines varying in length from 100 to 250 miles. For these estimates it was assumed that the lines would always be designed to carry the loads indicated by the 200-kilovolt power-limit curve of figure 7,[31] when fully loaded. The transmission costs resulting from these estimates are shown by the curves of figure 9 [31] for each of a number of load factors and for lines of various lengths.

Finally, it should be emphasized that the cost of transmitting a kilowatt-hour of energy over a given line depends not only upon the load factor and upon the length of line, but is greatly influenced as well by the amount of the transmitted load. The greatest transmission economy is secured when a line is loaded to the limit of its carrying capacity, as determined by conditions of stability.

[31] Not printed.

To illustrate, consider the double-circuit, 220-kilovolt, 100-mile line whose cost estimate begins in column 1 on page 474. This line is assumed to have a capacity of a little over 200,000 kilowatts (fig. 7),[31] and is designed to transmit one half of 375,000 kilowatts, or 187,500 kilowatts per circuit. The cost of transmitting a kilowatt-hour of energy over this line at an assumed load-factor of 55 percent is about 0.5 mill (fig. 9).[31] Had the line been designed to carry only 100,000 kilowatts per circuit, the cost of the line itself, including towers, right of way, conductors, etc., would have been substantially the same as that given for the 187,500-kilowatt circuit, except for some saving in the cost of conductors due to their reduced size. There would have been a considerable saving in the cost of transformers and other terminal equipment, substation structures, etc., but this saving would have been far less than proportional to the reduction in the line output. The cost of transmitting a kilowatt-hour of energy would therefore have been increased from about 0.5 mill to perhaps 0.8 mill. If only 50,000 kilowatts per circuit were transmitted the cost would be further increased to perhaps 1.1 or 1.2 mills per kilowatt-hour. The same principle holds for the longer lines.

When using the curves of figure 9 [31] to estimate transmission costs, therefore, one must bear in mind that the costs there given hold only for the assumed loads and load factors. Assuming the load-limit curves of figure 7 [31] to be correct, the costs given are the minimum transmission costs that may be expected. For loads less than those assumed, the costs are increased in the manner explained above.

COST ESTIMATE

330-kilovolt, 200-mile line

Generator output per line (4×62,500 kilowatts)	kilowatts	250, 000
Full-load losses assumed (see p. 467)	percent	13. 5
Low-tension receiver full-load input per line (1−0.135) 250,000	kilowatts	216, 250
Average full-load power transmitted ((250,000+216,250)÷2)	do	233, 100
Average full-load kilovolt-ampere transmitted (0.90 pf.)	kilovolt-amperes	259, 000
Generator current per terminal	amperes	1, 830

The transformer capacity for both ends of the line is based on the average kilovolt-amperes transmitted. Generators are assumed to be 22,000-volt, three-phase machines, and low-tension oil circuit breakers are rated at 34.5 kilovolts, 3,000 amperes, and 1,500,000 kilovolt-amperes.

1. Transformers, switches, circuit breakers, and synchronous condensers:	
(*a*) 2- by 4-low-tension oil circuit breakers at $7,200	$57, 600. 00
(*b*) 2- by 4-low tension dis. switches at $525	4, 200. 00
(*c*) 2- by 6-transformers (44,000 kilovolt-amperes) at $3 per kilovolt-ampere	1, 584, 000. 00
(*d*) 2- by 2-330-kilovolt oil circuit breakers (2,500,000 kilovolt-amperes) at $113,000	452, 000. 00
(*e*) 2-by 2-three-pole dis. switches at $4,900	19, 600. 00
Subtotal	2, 117, 400. 00
Freight and handling at 7 percent	148, 200. 00
Subtotal	2, 265, 600. 00
Synchronous-condenser capacity (60 percent received kilowatt at $2.50 per kilovolt-ampere)	325, 000. 00
Freight and starting equipment	30, 000. 00
Total electrical items (subtotal 1)	2, 620, 600. 00

[31] Not printed.

2. Right of way:	
75-foot strip per circuit, at $3,000 per mile	$600, 000. 00
Roads and bridges, at $200 per mile	40, 000. 00
Subtotal (2)	640, 000. 00
3. Towers in place + insulators (see curves, fig. 11)[31], at $10,800 per mile. Subtotal (3)	2, 160, 000. 00
4. Conductors:	
600 miles 1,590,000 C.M.A.C.S.R., at $0.30 per foot per 10^6 cir. mils (copper, at 17 cents)	1, 510, 000. 00
Freight and hauling	80, 000. 00
Stringing and placing insulators, at $175 per cond.-mile	105, 000. 00
Two 5/8-inch ground cables, at 8 cents per pound, plus freight	130, 000. 00
Stringing ground wire, at $75 per cond.-mile	30, 000. 00
Subtotal (4)	1, 855, 000. 00
5. Telephone line, at $800 per mile	160, 000. 00
6. Substation and auxiliary equipment (receiver end):	
Site	50, 000. 00
Substation building	300, 000. 00
Warehouse and garage	50, 000. 00
Outdoor structure	50, 000. 00
Storage batteries and charging sets	3, 000. 00
Cooling-water system	5, 000. 00
Transformer oil system	10, 000. 00
Control equipment	20, 000. 00
Miscellaneous equipment	40, 000. 00
Installation and wiring	80, 000. 00
Freight on miscellaneous items	5, 000. 00
Subtotal (6)	613, 000. 00

Summary

1. Transformers, switches, etc	2, 620, 600. 00
2. Right of way	640, 000. 00
3. Towers and insulators	2, 160, 000. 00
4. Conductors, ground wires, and stringing	1, 855, 000. 00
5. Telephone line	160, 000. 00
6. Substation and auxiliary equipment	613, 000. 00
Subtotal	8, 048, 600. 00
7. Contingencies, at 15 percent	1, 207, 300. 00
Subtotal	9, 255, 900. 00
8. Overhead, engineering supervision, etc., at 12½ percent	1, 115, 300. 00
Subtotal	10, 371, 200. 00
9. Interest during construction:	
Private money (8 months, at 6 percent)	414, 800. 00
Public money (8 months, at 4 percent)	276, 500. 00
10. Total cost:	
Private money	10, 786, 000. 00
Public money	10, 647, 700. 00
11. Annual charge on investment:	
Private money, at 8.77 percent	947, 000. 00
Public money, at 6.83 percent	728, 000. 00
12. Operating charge per annum, at $150 per circuit-mile	30, 000. 00
13. Total yearly operating expense:	
Private money	977, 000. 00
Public money	758, 000. 00
14. Cost per kilowatt of generator capacity:	
Private money	43. 10
Public money	42. 60
15. Receiver-kilowatt input per line=250,000 (1.00−0.135) kilowatt	216, 000

[31] Not printed.

16. Receiver kilowatt-hours per year:

55 percent load factor	$1{,}042\times10^6$
65 percent load factor	$1{,}232\times10^6$
75 percent load factor	$1{,}422\times10^6$
85 percent load factor	$1{,}610\times10^6$

17. Cost of transmission per kilowatt-hour.

L.f.	Public money	Private money
Percent	*Mills*	*Mills*
55	0.937	0.737
65	.793	.615
75	.687	.533
85	.607	.471

One double-circuit (200-mile) 220-kilovolt line

Generator output per double-circuit line——kilowatts	250, 000
Receiver input per double-circuit line——do	216, 300
1. Transformers, circuit-breakers, switches, and synchronous condensers:	
(*a*) 2 by 4 oil circuit breaker, at $7,200——ampere	$57, 600. 00
(*b*) 2 by 4, 22-kilovolt, 3,000-ampere disconnecting switches, at $525	4, 200. 00
(*c*) 2 by 6, 220-kilovolt (44,000 kilovolt-amperes) transformers, at $1.95 per kilovolt-ampere	1, 029, 600. 00
(*d*) 2 by 2, 220-kilovolt, oil circuit breaker (1,200 amperes, 2,500,000 kilovolt-amperes), at $45,000	180, 000. 00
(*e*) 2 by 2 disconnecting switches with operating mechanism, at $2,600	10, 400. 00
Subtotal	1, 281, 800. 00
Freight, at 7 percent	89, 700. 00
Subtotal	1, 371, 500. 00
Synchronous condensers 60 percent of recorded kilowatts, at $2.50/kilovolt-ampere	325, 000. 00
Freight and starting equipment for synchronous condensers	30, 000. 00
Total electrical equipment (1)	1, 726, 500. 00
2. Right of way (100-foot strip), at $3,500/mile	700, 000. 00
Roads and bridges, at $200/mile	40, 000. 00
Subtotal (2)	740, 000. 00
3. Towers in place plus insulators, at $9,300/mile (see curve, fig. 11.)[31] Subtotal (3)	1, 860, 000. 00
4. Conductors (1,200 miles, 795,000 circular mils, A.C.S.R.), at $0.30 foot, per 10^6 circular mils (copper, at 17 cents)	1, 512, 000. 00
Freight and hauling	96, 000. 00
Stringing and placing insulators, at $150/conductor-mile	180, 000. 00
Ground cables plus freight	130, 000. 00
Stringing ground cables, at $75 per conductor-mile	30, 000. 00
Subtotal (4)	1, 948, 000. 00
5. Telephone line (same for 330-kilovolts) (5)	160, 000. 00
6. Substation and auxiliary equipment (same as for 330-kilovolts) (6)	613, 000. 00

[31] Not printed.

Summary

1. Transformers, switches, etc	$1, 726, 500. 00
2. Right of way, etc	740, 000. 00
3. Towers and insulators, etc	1, 860, 000. 00
4. Conductors and ground cables in place	1, 948, 000. 00
5. Telephone line	160, 000. 00
6. Substation and auxiliary equipment	613, 000. 00
Subtotal	7, 047, 500. 00
7. Contingencies, at 15 percent	1, 057, 100. 00
Subtotal	8, 104, 600. 00
8. Overhead (engineering, supervision, clerical help, etc.) at 12½ percent	1, 013, 100. 00
Subtotal	9, 117, 700. 00
9. Interest during construction:	
Private money, 8 months, at 6 percent	364, 700. 00
Public money, 8 months, at 4 percent	243, 400. 00
10. Total cost:	
Private money	9, 482, 400. 00
Public money	9, 361, 100. 00
11. Annual charge on investment:	
Private money, at 8.77 percent	831, 600. 00
Public money, at 6.83 percent	647, 600. 00
12. Operating charge per annum, at $150 per circuit-mile	60, 000. 00
13. Total yearly operating expense:	
Private money	891, 600. 00
Public money	707, 600. 00
14. Cost per kilowatt of generator capacity:	
Private money	37. 90
Public money	37. 40
15. Receiver input per line of towers (216,300 kilowatts)	
16. Receiver kilowatt-hours per year:	
55 percent load factor	1042×10^6
65 percent load factor	1232×10^6
75 percent load factor	1422×10^6
85 percent load factor	1610×10^6
17. Cost of transmission per kilowatt-hour (in mills)	

Percent of load factor	Private money	Public money
55	0. 856	0. 679
65	. 724	. 574
75	. 627	. 498
85	. 554	. 440

Two double-circuit (200-mile) 154-kilovolt lines

Generator output per 4 circuits ---kilowatts--	250, 000
Receiver input ---do---	216, 300
1. Transformers oil circuit breaker disconnecting switches and synchronous condensers:	
(*a*) 2 by 4 oil circuit breaker, at $7,200	$57, 600. 00
(*b*) 2 by 4 disc. switches, at $525 each	4, 200. 00
(*c*) 2 by 12, 22,000-kilovolt-ampere transformers, at $1.65 kilovolt-ampere	871, 200. 00
(*d*) 2 by 4, 154-kilovolt disconnecting switches with operating mechanism, at $2,150	17, 200. 00
(*e*) 2 by 4, 154-kilovolt oil circuit breakers, at $20,000	160, 000. 00
Subtotal	1, 110, 200. 00
Freight, at 7 percent	77, 700. 00
Subtotal (1)	1, 187, 900. 00
(*f*) Synchronous condensers, at $2.50 per kilovolt-ampere	325, 000. 00
Freight and starting equipment	30, 000. 00
Subtotal (1)	1, 542, 900. 00

2. Right of way (200-foot strip), at $6,000 per mile	$1, 200, 000. 00
Roads and bridges, at $250 per mile	50, 000. 00
Subtotal (2)	1, 250, 000. 00
3. Towers in place plus insulators (see curve fig. 11),[31] at 2 multiplied by $7,600 per mile	3, 040, 000. 00
4. Conductors (2,400 miles, 500,000 circular mils, A.C.S.R.), at $0.30 per foot, per 10^6 circular mils	1, 900, 800. 00
Freight and hauling	122, 000. 00
Stringing and placing insulators, at $130 per conductor-mile	312, 000. 00
Ground cables plus freight	260, 000. 00
Stringing ground cables	60, 000. 00
Subtotal (4)	2, 654, 800. 00
5. Telephone line (same as for 220-kilovolt)	160, 000. 00
6. Substation and auxiliary equipment	400, 000. 00

Summary

1. Transformers and switches	1, 542, 900. 00
2. Right of way	1, 250, 000. 00
3. Towers and insulators	3, 040, 000. 00
4. Conductors	2, 654, 800. 00
5. Telephone line	160, 000. 00
6. Substation and auxiliary equipment (receiver end)	400, 000. 00
Subtotal	9, 047, 700. 00
7. Contingencies, 15 percent	1, 357, 200. 00
Subtotal	10, 404, 900. 00
8. Overhead (engineering, supervision, clerical help, etc.), 12½ percent	1, 300, 600. 00
Subtotal	11, 705, 500. 00
9. Interest during construction:	
Private money, 8 months, at 6 percent	468, 200. 00
Public money, 8 months, at 4 percent	312, 500. 00
10. Total cost:	
Private money	12, 173, 700. 00
Public money	12, 018, 000. 00
11. Annual charge on investment:	
Private money, at 8.77 percent	1, 067, 600. 00
Public money, at 6.83 percent	820, 800. 00
12. Operating charge per year, $125 per circuit-mile	100, 000. 00
13. Total yearly operating expenses:	
Private money	1, 167, 600. 00
Public money	920, 800. 00
14. Cost per kilowatt of generator capacity:	
Private money	48. 70
Public money	48. 10
15. Receiver input (4 circuits), 216,300 kilowatts	
16. Receiver kilowatt-hours per year:	
55 percent load factor	$1,042\times10^6$
65 percent load factor	$1,232\times10^6$
75 percent load factor	$1,421\times10^6$
85 percent load factor	$1,611\times10^6$
17. Cost of transmission per kilowatt-hour of energy (mills)	

Percent load factor	Private money	Public money
55	1. 12	0. 883
65	. 948	. 747
75	. 821	. 648
85	. 725	. 571

[31] Not printed.

220-kilovolt double-circuit lines of various lengths

[Each line is assumed to be designed for a full load equal (approximately) to that indicated by the power-limit curves]

Item	Circular mils of A.C.S.R.			
	1,113,000	795,000	715,000	715,000
	Length of line (miles)			
	100	150	200	250
Assumed load per double-circuit line	375,000	312,500	250,000	187,000
1. Transmitter switches, oil-circuit breakers and synchronous condensers:				
(*a*) Oil-circuit breakers (line tension)	$86,400	$72,000	$57,600	$43,200
(*b*) Disconnecting switches	6,300	5,250	4,200	3,150
(*c*) Transformers	1,544,400	1,287,000	1,029,600	772,200
(*d*) High-tension oil-circuit breakers	180,000	180,000	180,000	180,000
(*e*) Disconnecting switches with operating mechanism	10,400	10,400	10,400	10,400
Subtotal	1,827,100	1,554,600	1,281,800	1,008,900
Freight 7 percent	127,900	108,800	89,700	70,600
Subtotal	1,955,000	1,663,400	1,371,500	1,079,500
(*f*) Synchronous condensers	487,000	405,000	325,000	245,000
Freight and starting equipment	45,000	37,500	30,000	22,500
Subtotal (1)	2,487,000	2,105,900	1,726,500	1,347,000
2. Right-of-way at 3,500 miles per tower line	350,000	525,000	700,000	875,000
Roads and bridges ($200 per mile)	20,000	30,000	40,000	50,000
Subtotal (2)	370,000	555,000	740,000	925,000
3. Towers in place+insulators at $9,300 per mile. Subtotal (3)	930,000	1,395,000	1,860,000	2,325,000
4. Conductors	1,057,800	1,133,000	1,359,000	1,699,000
Freight and hauling	67,000	72,000	86,000	107,000
Stringing and placing insulators at $150 per circuit-mile	90,000	135,000	180,000	225,000
Ground cables and freight	65,000	97,500	130,000	163,000
Stringing ground cables at $75 per conductor-mile	15,000	22,500	30,000	37,500
Subtotal (4)	1,294,800	1,460,000	1,785,000	2,231,500
5. Telephone line	80,000	120,000	160,000	200,000
6. Substation and auxiliary equipment	920,000	760,000	613,000	450,000
Summary				
1. Transfer switches, etc	2,487,000	2,105,900	1,726,500	1,347,000
2. Right-of-way	370,000	555,000	740,000	925,000
3. Towers, insulators, etc	930,000	1,395,000	1,860,000	2,325,000
4. Conductors and ground cables	1,294,800	1,460,000	1,785,000	2,231,500
5. Telephone line	80,000	120,000	160,000	200,000
6. Substation and auxiliary equipment	920,000	760,000	613,000	450,000
Subtotal	6,081,800	6,395,900	6,884,500	7,478,500
7. Contingencies at 15 percent	912,300	959,400	1,032,700	1,122,000
Subtotal	6,994,100	7,355,300	7,917,200	8,600,500
8. Overhead (engineering, clerical, etc., 12½ percent)	874,300	919,400	989,700	1,075,100
Subtotal	7,868,400	8,274,700	8,906,900	9,675,600
9. Interest during construction:				
Private money	314,700	331,000	356,300	387,000
Public money	209,800	221,000	237,500	258,000
10. Total cost:				
Private money	8,183,100	8,605,700	9,263,200	10,062,600
Public money	8,078,200	8,495,700	9,144,400	9,933,600
11. Annual charge on investment:				
Private money, 8.77 percent	717,700	754,700	812,400	882,500
Public money, 6.83 percent	551,700	580,300	624,600	678,500
12. Annual operating expense at $150 per circular mil	30,000	45,000	60,000	75,000
13. Total annual operating cost:				
Private money	747,700	799,700	872,400	957,500
Public money	581,700	625,300	684,600	753,500

220-kilovolt double-circuit lines of various lengths—Continued

Item	Circular mils of A.C.S.R.			
	1,113,000	795,000	715,000	715,000
	Length of line (miles)			
	100	150	200	250
14. Cost per kilowatt general capitalization:				
Private money	21.80	27.60	37.00	53.70
Public money	21.50	27.20	36.50	53.10
15. Receiver input per tower line	325,000	271,000	216,000	162,000
16. Received kilowatt-hours per year:				
55 percent load factor	$1,566\times10^6$	$1,306\times10^6$	$1,041\times10^6$	780.5×10^6
65 percent load factor	$1,851\times10^6$	$1,543\times10^6$	$1,230\times10^6$	922.4×10^6
75 percent load factor	$2,135\times10^6$	$1,780\times10^6$	$1,419\times10^6$	$1,064\times10^6$
85 percent load factor	$2,420\times10^6$	$2,018\times10^6$	$1,608\times10^6$	$1,206\times10^6$
17. Cost of transmission per kilowatt-hour in mills:				
Private money:				
55 percent load factor	0.477	0.615	0.838	1.225
65 percent load factor	.403	.518	.709	1.037
75 percent load factor	.350	.449	.615	.898
85 percent load factor	.309	.396	.542	.797
Public money:				
55 percent load factor	.372	.479	.657	.965
65 percent load factor	.314	.405	.556	.817
75 percent load factor	.272	.351	.483	.707
85 percent load factor	.241	.310	.426	.625

Unit Prices Used for Estimating

The principal cost data used in making the foregoing estimates are given in this appendix.

Steel towers and insulators.—The weight of steel per mile of tower line is given in the tabulation entitled "Analysis of Tower Cost Per Mile of Line" and in the curves of figure 10.[31]

All suspension towers are designed for the assumption of one conductor broken, ½-inch ice load, an 8-pound wind load, and conductor stressed to a maximum tension equal to 75 percent of the elastic limit. The weights given in the figure are for standard suspension towers, including steel earth anchors. Anchor towers for double-circuit lines are assumed to be 75 percent heavier than the corresponding suspension towers; while for single-circuit lines anchor towers are assumed to be only 20 percent heavier than the suspension towers.

The cost of steel towers is estimated on the basis of $100 per ton of steel f.o.b. cars at the nearest station. Cost of erection of towers is estimated at $50 per ton of steel. Handling and hauling costs are separately estimated as indicated in the tabulation.

Costs of insulators and fittings were estimated, and these costs were added to the appropriate tower costs to obtain the total cost of towers and insulators in place per mile of line for each assumed span length. Total costs per mile of line, including insulators, are shown graphically in figure 11.[31] The most economical spans and the costs appropriate thereto were used in making the final estimates of tower costs.

[31] Not printed.

Analysis of tower cost per mile of line—Continued

Item	Assumed span length			
	700 feet	1,100 feet	1,700 feet	2,100 feet
Number of towers per mile	7.54	4.8	3.1	2.51
Number of suspension towers per mile (suspension towers equal 90 percent of total)	6.78	4.32	2.79	2.26
Number of anchor towers per mile (anchor towers equal 10 percent of total)	.75	.48	.31	.25
Weight [1] of steel per suspension tower (pounds):				
110 kilovolts, 2-circuit	8,200	10,300	16,300	23,200
154 kilovolts, 2-circuit	9,800	12,700	20,700	30,300
220 kilovolts, 2-circuit (average)	12,500	15,500	24,200	34,300
220 kilovolts, 1-circuit	7,500	10,700	17,800	25,000
275 kilovolts, 1-circuit	10,800	14,000	22,200	31,600
330 kilovolts, 1-circuit	15,300	19,300	29,800	41,300
Total weight [1] of steel per mile (in M pounds):				
110 kilovolts, 2-circuit	66.4	53.2	54.4	62.6
154 kilovolts, 2-circuit	79.3	65.6	69.0	81.8
220 kilovolts, 2-circuit	101.0	80.0	80.8	92.8
220 kilovolts, 1-circuit	60.7	55.3	59.4	67.5
275 kilovolts, 1-circuit	87.5	72.3	74.0	85.5
330 kilovolts, 1-circuit	124.0	99.7	99.5	111.7
Cost of erection per mile, at $50 per ton:				
110 kilovolts, 2-circuit	$1,660	$1,330	$1,360	$1,565
154 kilovolts, 2-circuit	1,980	1,640	1,725	2,045
220 kilovolts, 2-circuit	2,530	2,000	2,040	2,320
220 kilovolts, 1-circuit	1,515	1,382	1,485	1,687
275 kilovolts, 1-circuit	2,180	1,807	1,850	2,137
330 kilovolts, 1-circuit	3,110	2,492	2,487	2,792

Item	Assumed line voltage				
	2 circuits 110 kilovolts	2 circuits 154 kilovolts	2 circuits 220 kilovolts	1 circuit 220 kilovolts	1 circuit 330 kilovolts
Insulators per suspension string	7	10	14	14	22
Insulators per suspension tower	42	60	84	42	66
Insulators per anchor-tower string	9	12	16	16	24
Insulators per anchor tower	108	144	384	192	288
700-foot span:					
Disks per mile on suspension towers	286	408	570	286	448
Disks per mile on anchor towers	82	108	288	144	216
Total number disks per mile of line	368	516	858	430	664
1,100-foot span:					
Disks per mile on suspension towers	182	260	364	182	286
Disks per mile on anchor towers	52	70	186	92	140
Total disks per mile of line	234	330	550	274	426
1,700-foot span:					
Disks per mile on suspension towers	118	168	236	118	186
Disks per mile on anchor towers	34	46	120	60	90
Total disks per mile of line	152	214	356	178	276
2,100-foot span:					
Disks per mile on suspension towers	96	136	190	96	150
Disks per mile on anchor towers	28	36	96	48	72
Total disks per mile of line	124	172	286	144	222
700-foot span:					
1. Cost of disks per mile at $2.40	$885	$1,240	$2,060	$1,032	$1,593
2. Suspension clamps per mile at $3.60 per suspension string	147	147	147	74	74
3. Strain clamps per mile at $7.85 per strain string	71	71	71	35	35
4. Arcing horns per mile at $3 per suspension string	122	122	122	61	61
5. Suspension grad. rings per mile at $8 per suspension string	327	327	327	164	164
6. Attachment clevises equal total strings multiplied by 0.50	21	21	21	11	11

[1] Weight of anchor tower is assumed at 1.75 by weight of suspension tower.

Analysis of tower cost per mile of line—Continued

Item	Assumed line voltage				
	2 circuits 110 kilovolts	2 circuits 154 kilovolts	2 circuits 220 kilovolts	1 circuit 220 kilovolts	1 circuit 330 kilovolts
700-foot span—Continued.					
7. Double strain yokes per mile equals $10 multiplied by double strings per mile			90	45	45
8. Double string rings equals double strings multiplied by $12			108	54	54
9. Freight at $0.015 per pound	91	128	213	107	165
10. Hauling and handling at $0.40 per ton-mile	15	21	35	18	27
Total cost per mile	1,679	2,077	3,194	1,601	2,229
1,100-foot span:					
1. Cost of disks per mile at $2.40	562	792	1,320	658	1,022
2. Suspension clamps per mile at $3.60	93	93	93	47	47
3. Strain clamps per mile at $7.85	43	43	43	21	21
4. Arcing horns per mile at $3	93	93	93	47	47
5. Suspension grad. rings at $8	207	207	207	104	104
6. Attachment clevises at 50 cents	15	15	15	8	8
7. Double-strain yokes at $10			54	27	27
8. Double-string rings at $12			65	38	38
9. Freight at $0.015 per pound	58	82	136	68	105
10. Hauling and handling	10	14	23	12	18
Total	1,081	1,339	2,048	1,030	1,437
1,700-foot span:					
1. Cost of disks per mile at $2.40	367	510	860	430	665
2. Suspension clamps per mile at $3.60	61	61	61	30	30
3. Strain clamps per mile at $7.85	30	30	30	15	15
4. Arcing horns per mile at $3	50	50	50	25	25
5. Suspension grad. rings at $8	135	135	135	68	68
6. Attachment clevises per mile at 50 cents	9	9	9	5	5
7. Double strain yokes at $10			38	19	19
8. Double string rings at $12			45	23	23
9. Freight at $0.015 per pound	38	53	88	45	69
10. Hauling and handling	5	7	11	6	9
Total	695	855	1,327	666	928
2,100-foot span:					
1. Cost of disks per mile at $2.40	300	412	686	343	531
2. Suspension clamps per mile at $3.60	49	49	49	25	25
3. Strain clamps per mile at $7.85	44	44	44	22	22
4. Arcing horns per mile at $3	42	42	42	21	21
5. Suspension grad. rings at $8	109	109	109	55	55
6. Attachment clevises per mile at 50 cents	7	7	7	4	4
7. Double-strain yokes at $10			30	15	15
8. Double-string rings at $12			36	18	18
9. Freight at $0.015 per pound	31	43	71	36	55
10. Hauling and handling at $0.40 per ton-mile	4	6	9	5	7
Total	586	712	1,083	542	753

Item	Tower-line items of cost per mile for the several spans noted below			
	700 feet	1,100 feet	1,700 feet	2,100 feet
110-kilovolt, 2-circuit line:				
Cost, steel, f.o.b. nearest station at $100 per ton	$3,320	$2,660	$2,720	$3,130
Hauling and handling average of 10 miles at $0.40 per ton-mile	123	106	109	123
Erection at $50 per ton	1,660	1,330	1,360	1,570
Digging and back filling at average of $3 per yard	1,780	1,360	1,310	1,410
Cost, insulators and fittings at site	1,679	1,081	695	586
Total	8,562	6,537	6,194	6,819
154-kilovolt, 2-circuit line:				
Cost, steel, f.o.b. nearest station, at $100 per ton	3,965	3,280	3,450	4,090
Hauling and handling	159	122	138	164
Erection at $50 per ton	1,980	1,640	1,725	2,045
Digging and back filling at $3 per yard	2,140	1,670	1,660	1,840
Cost, insulators and fittings at site	2,077	1,339	855	712
Total	10,320	8,051	7,828	8,851

Analysis of tower cost per mile of line—Continued

Item	Tower-line items of cost per mile for the several spans noted below			
	700 feet	1,100 feet	1,700 feet	2,100 feet
220-kilovolt, 2-circuit line:				
Cost, steel, f.o.b. nearest station, at $100 per ton	5,050	4,000	4,040	4,640
Hauling and handling	202	160	162	185
Erection at $50 per ton	2,525	2,000	2,020	2,320
Digging and back filling at $3 per yard	2,720	2,040	1,940	2,090
Cost, insulators and fittings at site	3,194	2,048	1,327	1,083
Total	13,691	10,248	9,489	10,318
330-kilovolt, 1-circuit line:				
Cost, steel, f.o.b. nearest station, at $100 per ton	6,200	4,985	4,975	5,585
Hauling and handling	248	200	200	223
Erection at $50 per ton	3,100	2,493	2,488	2,792
Digging and back filling at $3 per yard	3,360	2,520	2,390	2,520
Cost, insulators and fittings at site	2,229	1,437	928	753
Total	15,137	11,635	10,981	11,873

NOTE.—Yards excavation equals k multiplied by weight of steel in pounds; k varies from 0.75 to 0.90 percent.

Right of way.—Experience with right-of-way costs in the areas considered in this report indicates that average costs about as given below may be expected. These costs contemplate the purchase of an easement only, including the right to place and to maintain the necessary towers and fixtures on a 100-foot strip, and to cut all trees that endanger the line. They include the cost of clearing and of burning limbs and brush and of otherwise preparing the right of way for use.

1. Through open, semidesert country east of the Cascade Mountains where little or no clearing is required, $1,000 per mile.

2. Through logged-off land or light second-growth timber, $2,000 per mile.

3. Through light stands of timber, such as one finds in the mountains, $3,500 per mile.

4. Through moderately heavy to heavy stands of virgin timber, $10,000 to $20,000 per mile.

5. Through valuable cultivated lands in regions west of the Cascade Mountains, $3,000 to $7,000 per mile.

Terminal equipment.—The unit costs used in estimating the principal items of terminal equipment are given below. These are exclusive of freight.

Transformers (single-phase):	
154 kilovolts, 22,000 kilovolt-amperes, per kilovolt-ampere	$1.65
220 kilovolts, 44,000 kilovolt-amperes, do	1.95
330 kilovolts, 44,000 kilovolt-amperes, do	3.00
Oil circuit breakers:	
34.5 kilovolts, 3,000 amperes, 1,500,000 kilovolt-amperes	7,200.00
161 kilovolts, 600 amperes, 1,500,000 kilovolt-amperes	20,000.00
230 kilovolts, 1,200 amperes, 2,500,000 kilovolt-amperes	45,000.00
345 kilovolts, 1,200 amperes, 2,500,000 kilovolt-amperes	113,000.00
Disconnecting switches with operating mechanism:	
22 kilovolts, 600 amperes	525.00
161 kilovolts, 600 amperes	2,150.00
230 kilovolts, 600 amperes	2,600.00
330 kilovolts, 600 amperes	4,900.00

Synchronous condensers:	
10,000 kilovolt-amperes	35,000.00
20,000 kilovolt-amperes	58,000.00
30,000 kilovolt-amperes	78,400.00
40,000 kilovolt-amperes	96,750.00

To these costs must be added about 5 percent for freight and from $2,000 to $5,000 per unit for starting equipment.

REPORT BY THE BUREAU OF RECLAMATION, DEPARTMENT OF THE INTERIOR

CONTENTS

	Page
Acknowledgments	481
Summary	481
Conclusions	483
Description of project	485
Previous investigations	485
Irrigable areas	489
Water supply	490
Stream flow	490
Irrigation requirements	492
Grand Coulee Reservoir	493
Columbia River Reservoir	496
Power output	496
Columbia River Dam	497
Scope of investigations	497
Highways	498
Construction railroad	498
Transportation of concrete aggregates	498
Construction power	498
Concrete materials	498
Deposits at dam site	498
Mansfield pit	499
Adrian pit	499
Hartline pit	499
Results of tests on aggregates	500
Foundation conditions	500
Diversion of river during construction	501
Description of dam and appurtenances	502
Power plant	503
Buildings and structures	503
Hydraulic and electrical machinery	503
Annual costs	503
Ultimate irrigation development	504
Columbia River pumping plant	504
Repumping	505
Grand Coulee Reservoir	506
North Grand Coulee Dam	506
South Grand Coulee Dam	506
Canals	507
Tunnels	507
Siphons and penstocks	507
Lateral system	508
Drainage	508
Wasteways	508
Buildings	508
Telephone system	508
Wells	508
Operation and maintenance during construction	509
Summary of estimate of cost of Columbia Basin project for ultimate development	509

CONTENTS—Continued

	Page
First unit irrigation development	509
Feature no. 1	509
Feature no. 2	510
Feature no. 3	510
Feature no. 4	510
Feature no. 5-A	510
Feature no. 6-B	510
Feature no. 6-A	510
Feature no. 7	511
Feature no. 8	511
Feature no. 9	511
Feature no. 10	511
Feature no. 11	511
Main West Canal	511
General items	511
Summary of estimate of cost of first unit of Columbia Basin project	511
Estimates showing comparison of costs of different plans of Grand Coulee Reservoir together with the costs of changes in canals and headgates required for the various plans	512
Annual costs	513
Operation and maintenance cost	513
Annual construction repayments	513
Total annual cost of irrigation	517
Ability of land to pay for irrigation benefits	517
Payments by other benefited interests	517
Power market	517
Market area	517
Municipalities	518
Utility companies	518
Manufacturing companies	518
Future increase in power usage	520
Absorption of Columbia River power	521
Competitive power	522
Value of power as determined by the cost of steam-electric power	523
Transmission of Columbia River power	527
Cost of transmission facilities	527
Cost of transmitting energy	528
Value of energy at power plant	534
Financial results	535

LIST OF TABLES

Table no.	Title	
1.	Run-off of Columbia River at Grand Coulee	491
2.	Net diversion requirements from Grand Coulee Reservoir for fully-developed Columbia Basin project	493
3.	Net irrigation demands on Columbia River for fully-developed Columbia Basin project	495
4.	Various kinds of power available each year	497
5.	Analysis of concrete aggregates	500
6.	Financial operation of irrigation development	514
7.	Power market	520
8.	Estimated cost of steam-generated energy, public development	525
9.	Estimated cost of steam-generated energy, private development	526
10.	Estimated yearly cost of steam stand-by, public and private developments	529
11.	Cost of transmitting energy to load center, public and private developments without steam stand-by	529
12.	Cost of transmitting energy to load center, public development with steam stand-by	530
13.	Cost of transmitting energy to load center, private development with steam stand-by	530
14.	Estimated annual value of energy at the Columbia River power plant with and without steam stand-by	531
15.	Financial operation of power development	536

UNITED STATES DEPARTMENT OF THE INTERIOR,
BUREAU OF RECLAMATION,
Denver, Colo., January 7, 1932.

From: Chief engineer.
To: Commissioner, Washington, D.C.
Subject: Report on proposed Columbia Basin project—Washington.

1. Transmitted herewith is a report prepared in the Denver office on the proposed Columbia Basin project.

2. The report shows that the investment in the dam and power plant will be repaid under the conditions assumed in 50 years, with interest at 4 percent, and leave a substantial surplus for repaying about one half of the investment without interest ultimately required in the entire irrigation development. With this surplus power revenue available for liquidating a portion of the investment in the irrigation development, and on the basis of the estimates and conclusions reached in the report, I believe the Columbia Basin project is physically and financially feasible. With the completion of the power development, the irrigation development may proceed at such time and in units of such size as economic conditions may justify.

3. The postponement of the irrigation development will increase rather than detract from the economic feasibility of the power development, except as such irrigation development affects the power market.

A. F. WALTER.

ACKNOWLEDGMENT

Prior to the preparation of the following report there was made available to the United States Bureau of Reclamation a very comprehensive report and a large amount of supporting data prepared under the immediate direction of Maj. John S. Butler, Corps of Engineers of the United States Army. The investigations by the Corps of Engineers was authorized by the Congress of the United States under section 1 of the Rivers and Harbors Act of January 21, 1927, and in accordance with House Document No. 308, Sixty-ninth Congress, first session.

Full use has been made of the reliable and up-to-date information contained in Major Butler's report. The maps, plans, and calculations contained therein have been of much value, and their availability has saved the expense of surveys and studies which otherwise would have been necessary for the preparation of this report.

Among the other available reports utilized in the preparation of this report, special mention should be made of the comprehensive investigations conducted by the State of Washington and the earlier studies of the Bureau of Reclamation.

SUMMARY

The Columbia Basin project as considered in this report involves the construction of the following principal features.

(*a*) The Columbia River dam, about 450 feet in height above the foundation, which, with appurtenant structures, will contain about 11,266,000 cubic yards of concrete and create a reservoir about 150 miles long, extending to the international boundary, the water sur-

face of which will be about 355 feet above the low-water surface of the Columbia River.

(*b*) The Columbia River power plant containing an installation of turbines and generators of 2,100,000 horsepower capacity.

(*c*) The Columbia River pumping plant, containing an installation of motor-driven pumps of 16,000 c.f.s. total capacity.

(*d*) A dam at each end of the Grand Coulee to form the Grand Coulee Reservoir, about 23 miles long.

(*e*) Pipe lines leading from the Columbia River pumping plant to a supply canal 1.7 miles long which, in turn, leads to the north end of the proposed Grand Coulee Reservoir.

(*f*) An irrigation distribution system consisting of canals, tunnels, siphons, wasteways, bridges, headgates, etc., distributed over the main canal extending from the south end of the proposed Grand Coulee Reservoir, a distance of about 11 miles, from which point it branches into the main west canal and the main east canal. Each of these branch canals supply smaller canals equipped with suitable structures, the final reduction being to the size necessary to supply each 160-acre farm.

(*g*) Power plants and transmission lines at suitable places along the canals of the distribution system for the generation and distribution of about 26,000 kilowatts of seasonal power.

(*h*) Motor-driven pumping plants at suitable places along the canals to repump water a maximum of 100 feet to the various areas adjacent thereto.

(*i*) A drainage system to carry off seepage waters developed with the irrigation of land.

(*j*) Telephones and buildings necessary for the operation of the project and wells for water supply during the construction period.

As a result of the construction of the foregoing items the following uses of power and water are proposed:

(*a*) The production at the power plant at the Columbia River power dam of 800,000 kilowatts of firm continuous power which will be available for commercial sale.

(*b*) The use of the secondary power generated at the Columbia River dam to pump water from the Columbia River Reservoir to the Grand Coulee Reservoir, the maximum difference of elevation between the surfaces of the two reservoirs being about 365 feet.

(*c*) The use of the water pumped into the Grand Coulee Reservoir to furnish an irrigation supply to 1,200,000 acres of land.

(*d*) The seasonal power generated at power plants at various drops on the project canals to be transmitted to pumping plants along the canals to lift water a maximum of 100 feet for irrigating 219,000 acres of the above-mentioned 1,200,000 acres.

The territory considered as the market area for the Columbia River power includes the area within a radius of 300 miles of the dam site embracing all of the State of Washington, the northern part of Oregon, the northern part of Idaho, and the western part of Montana. The present installed capacity of municipal and utility plants within this territory totals about 1,000,000 kilowatts, of which about 28 percent is steam-electric power.

During 1920 to 1930 power requirements in this territory increased at an average rate of 9.5 percent per year, compounded annually. For this report, a gradually decreasing rate of increase has been as-

sumed beginning with 8 percent in 1930 and decreasing to 4 percent in 1960. Practically all of the power of the major hydroelectric developments on which construction has been started by the various power companies and municipalities will have been absorbed by 1940, which is the earliest date that power from the Columbia River development could be made available. The additional generating capacity required during the 15-year period 1940 to 1955 would amount to about 3,000,000 kilowatts, whereas the proposed installation at the Columbia River Dam is 1,500,000 kilowatts or only one half of the expected increase. With proper cooperation on the part of the various power companies and municipalities the proposed Columbia River development should be absorbed in this 15-year period.

Comparative estimates indicate that a price of 2.25 mills per kilowatt-hour should be sufficiently attractive to induce the power companies and municipalities to purchase energy in lieu of constructing additional power plants and to insure that the Columbia River power will be absorbed as rapidly as the growth of load will permit. Based on the absorption of 800,000 kilowatts of continuous power in 15 years, a price of 2.25 mills per kilowatt-hour for firm power, a price of $1 per acre per year for secondary power used for irrigation pumping, which is equivalent to approximately 0.50 mill per kilowatt-hour and land settlement at the rate of 20,000 acres per year, the revenue from power would be sufficient to repay the cost of the Columbia River Dam and power plant with interest at 4 percent per annum in 50 years, in addition to providing for the operation, maintenance, and depreciation of the dam and power plant, and also provide a surplus of approximately $144,000,000 which would be available for repayment of the cost of the irrigation development and other purposes.

With the estimated surplus power earnings available for liquidating a portion of the irrigation investment, the annual construction charges to be paid by the land beginning 4 years after settlement and continuing for 4 years at a rate of $2 per acre and thereafter at $2.50 per acre for 32 years, will repay half of the cost of the investment in the irrigation project within 40 years from the time that water is available for each unit or division.

Investment in project

Columbia River Dam	$125, 750, 000
Columbia River power plant	42, 616, 000
Subtotal	168, 366, 000
Interest during construction on above	17, 524, 000
Subtotal	185, 890, 000
Irrigation development without interest (1,200,000 acres)	208, 265, 000
Total investment	394, 155, 000

The maximum estimated investment in the combined power and irrigation project up to the time when power revenue are sufficient to reduce the investment is $260,000,000.

CONCLUSIONS

1. The market for power in the territory tributary to the proposed Columbia River Dam is sufficient to absorb the total firm power output to be generated at the Columbia River Dam within 15 years after the dam is completed.

2. The time required to absorb the power output is a very important factor in the financial success of the proposed development. The power companies and municipalities operating power systems in the territory will have to cooperate to the fullest extent in the utilization of Columbia River power in order that it may be absorbed as rapidly as possible.

3. The revenue which will be derived from the sale of commercial power at 2.25 mills per kilowatt-hour, combined with the revenue from the sale of power for irrigation pumping at $1 per acre per annum, will be sufficient to return within a period of 50 years the investment in the dam and power plant with interest at 4 percent to pay the cost of operation and maintenance of the dam and power plant and leave a substantial surplus for repayment of a portion of the investment in the irrigation development.

4. The surplus from power revenues is estimated to be sufficient to repay within 40 years about 50 percent of the cost of the irrigation development for the entire acreage of 1,200,000 acres proposed for for the project, or an average of over $85 per acre. The balance of the irrigation investment must be repaid by the lands or from other sources.

5. Assuming the above surplus power revenues to be available, the total annual charge accruing against the land, beginning 4 years after settlement, would have to be $4.59 per acre, of which $2 per acre will be available for repayment of the investment in irrigation works. Beginning with the eighth year after settlement to the end of the fortieth year, the annual charge must be increased to $5.09 per acre, of which $2.59 per acre will be available for repayment of the irrigation investment, without interest.

6. In order to reduce the annual charges for the irrigation benefits accruing against the land, it will be necessary that the State of Washington, municipalities, and all interests benefited within the irrigation district contribute toward the cost in proportion to such benefits.

7. Ultimate irrigation development is proposed for 1,200,000 acres. The slower the irrigation development proceeds the smaller the amount of additional funds that will have to be advanced from the Treasury of the United States.

8. In order to perfect final construction plans, it will be necessary that further information be secured by diamond drilling of the foundation of the Columbia River Dam; that additional field exploration and laboratory tests be made to determine the amount and source of supply of the concrete aggregates for the Columbia River Dam; that a topographic survey and land classification be made of the irrigable area of the project; that test pits and borings be made to determine the classification of material to be excavated in the main canals of the project distribution system for use in final designs and estimates; and that a survey be made to determine the cost of irrigating land by pumping water from the Spokane River and using Columbia River Dam power.

9. No construction on the Columbia River Dam and power plant should be undertaken until contracts are executed for the sale of power which will insure sufficient revenue for annual expenses and the repayment of the investment in the dam and power plant with interest at 4 percent within 50 years.

10. No construction on the irrigation development should be undertaken until the power revenues are assured and a suitable contract for repayment of the investment in irrigation works within 40 years has been executed by the district.

DESCRIPTION OF PROJECT

As considered in this report the proposed Columbia Basin project, located adjacent to and east of the Columbia River in eastern Washington, is a combination of power and irrigation development. The fundamental requisite for either power or irrigation is the construction of a dam in the Columbia River at the so-called Grand Coulee site shown on drawing no. 222-D-14.[31] The Columbia River Dam is to be 4,100 feet long and will raise the water about 355 feet above the low-water surface of the river. It will create an artificial lake 150 miles long extending to the Canadian boundary line. The total height of the dam above the general elevation of the foundation will be about 450 feet.

Hydraulic and electrical machinery is to be installed progressively at the dam for the generation of power. It is contemplated that the firm power will be sold at the dam to responsible agencies engaged in the distribution of electrical energy. Pumping machinery for irrigation requirements is to be installed progressively at the dam and this machinery will utilize the seasonal power available during the high-water season of the Columbia River.

Water for the irrigation project is to be pumped from the Columbia River Reservoir through large discharge pipes to the Grand Coulee Canal, extending a distance of 1.7 miles to Grand Coulee Lake. This lake will be created by the construction of two dams, one at the north end of the Grand Coulee near the Columbia River, and the other near the south end of the Grand Coulee about 4½ miles north of Coulee City. This lake will be about 23 miles long and the difference between the high-water surface in the Grand Coulee Lake and the low-water surface of the Columbia River Reservoir will be about 362 feet.

From the south end of the Grand Coulee Lake, water is conducted through concrete-lined canals, concrete-lined tunnels, steel-pipe siphons, and reinforced concrete pipe siphons to the lateral distribution system which finally delivers water to 981,000 acres of land, including that part of the area considered suitable for irrigation and cultivation. There are a number of places where the larger canals are dropped to lower elevations and the energy of the falling water at such places is to be utilized for repumping to areas lying at a maximum elevation of 100 feet above the canals. This repumping will add an additional irrigable area to the project of 219,000 acres, making the total irrigable area of the project 1,200,000 acres.

PREVIOUS INVESTIGATIONS

The possibilities of irrigating the area along the Columbia River in Grant, Adams, and Franklin Counties in eastern Washington received consideration and investigation by the United States Reclamation Service as early as 1904. Surveys were made for canals using the Columbia, Spokane, and Palouse Rivers as sources of water

[31] Not printed.

supply. A total of $76,400 was spent on these early investigations. The Priest Rapids area was investigated in 1905 at a cost of $6,200.

Again in 1914 and 1915, under a cooperative agreement between the State of Washington and the United States Reclamation Service, an investigation and report was made on a proposed project north and east of Pasco, Wash., using the Palouse River as a source of water supply. This work was in charge of Engineer McCulloch and involved an expenditure by the United States Reclamation Service of $10,200.

Studies by the United States Reclamation Service on the possibilities of power development on the Columbia River at various times prior to 1923 involved an expenditure of $4,000.

The Columbia Basin Commission of the State of Washington of which Marvin Chase, State hydraulic engineer, was chairman, and A. J. Turner, of Spokane, was chief engineer, published a report in 1920 as a result of its surveys and investigations in that year and in 1919. The Commission investigated a number of plans for the project water supply, including several alternatives of a gravity supply diverting from Clark Fork at Albany Falls, a partial water supply from the Wenatchee River and a plan for pumping water from the Columbia River at the Grand Coulee site with a dam in the Columbia River 180 feet in height above low water.

A board of engineers of the United States Reclamation Service, consisting of D. C. Henny, James Munn, and C. T. Pease, reviewed the report of the Columbia Basin Commission of the State of Washington in December 1920. The report of this board suggested a number of changes in unit prices and recommended further investigations.

The State of Washington in 1921 made further investigations at the Columbia River dams site and explored the foundation by diamond drilling. Estimates were made of the costs of developing power, pumping water for irrigation and building transmission lines at the Foster Creek site and also at the Grand Coulee site. The estimates and report of this work were prepared by Willis T. Batchellor, electrical engineer. In the latter part of 1921 the State of Washington employed Gen. George W. Goethals to review existing reports and to make a further report upon the feasibility of the various construction problems of the project. His report dated March 30, 1922, showed considerably lower unit costs than had been used by the Columbia Basin Commission. The cost of work done by the State on completion of this report amounted in round numbers to $150,000.

A board of engineers consisting of J. S. Cavanaugh, colonel, Corps of Engineers, United States Army, D. C. Henny, consulting engineer, United States Reclamation Service; F. F. Henshaw, district engineer, United States Geological Survey; C. S. Heidel, State engineer of Montana; W. G. Swendsen, commissioner, department of reclamation, Idaho; and Marvin Chase, supervisor of hydraulics, State of Washington, made a report to the Federal Power Commission in February 1923. The principal conclusions of this board of engineers as given in the published report were that the Columbia Basin project was the most important single item to be considered in the uses to be made of the Columbia River water above the mouth of the Snake River, that the project could be supplied with water by either a gravity supply diverted from the Clark Fork at Albany Falls or by pumping from the Columbia River at the Grand Coulee dam site, but

that information upon which to base a final decision between a gravity and a pumped supply for the Columbia Basin irrigation project was not complete and should be completed.

The United States Bureau of Reclamation made further investigations of the Columbia Basin project in 1923 and 1924, and the report thereon by Engineer H. J. Gault was published by the Senate of the Sixty-ninth Congress, second session, for the use of the Committee on Irrigation and Reclamation. This report considered four alternatives in each of the two general plans for irrigating the Columbia Basin project. The gravity plan was investigated with high and low lines, each with and without repumping. The pumping plan proposing a dam in the Columbia River at the Grand Coulee site, 280 feet in height above low water, was investigated with and without storage, and with and without repumping. Soils, geology, and water were considered in their relation to the project.

A board of engineers consisting of A. J. Wiley, James Munn, and J. L. Savage, of the United States Bureau of Reclamation, reviewed the above-mentioned Gault report, and on April 6, 1924, submitted a report which was published with the Gault report. The board found that the construction cost of irrigation under the pumping plan of lowest cost would be $246.58 per acre, as against $231.40 per acre under the gravity plan of lowest cost. The board in arriving at the cost of $246.58 per acre for the pumping project considered that the power market in the territory was so fully covered by private and municipal developments that no net income could be relied upon from the sale of power to offset the greater cost of both construction and operation of the pumping over the gravity plan. It was judged that the entire cost of the dam in the Columbia River, that part of the power plant required for irrigation pumping, the pumping plants and transmission lines necessary for repumping on the project, amounting to 47.7 percent of the total cost, would have to be borne by the irrigation project in addition to the construction items for the distribution of water and drainage of the lands.

In 1924 a board of engineers and economists was appointed by the Columbia Basin Commission of the United States Department of the Interior to make a further study of the Gault report and an independent investigation of the project including settlement and farm development problems as well as engineering. The Columbia Basin Commission was appointed by the Secretary of the Interior and its membership consisted of Elwood Mead, Commissioner of the Bureau of Reclamation, and John H. Edwards, Solicitor of the Department of the Interior.

The membership of the board of engineers appointed by the Columbia Basin Commission consisted of Louis C. Hill of California, Charles H. Locher of Maryland, Richard R. Lyman of Utah, Arthur J. Turner, O. L. Waller and Joseph Jacobs of Washington. The report of this board dated February 1925 was published with the Gault report. This board found that economic conditions seemed so definitely to favor the gravity projects that it did not deem it necessary to make an elaborate analysis of the entire Columbia River power problem and consequently limited its examination and report to the analyses and estimates of the various plans of supplying water to the Columbia Basin project by diverting water from the Clark Fork at Albany Falls. The board gave consideration to the carrying capacity

of the canals and in addition to providing for concrete lining in all canals down to 100-c.f.s. capacity, proposed to line with concrete all laterals below 100-c.f.s. capacity and by such construction estimated that the diversion duty would be increased from 80 acres to the second-foot as used in the Gault report to from 112 to 119 acres to the second-foot for the maximum and minimum project respectively. With the above as a basis, the board found the minimum gravity project of 1,224,000 acres could be constructed at a cost of $158 per acre. It concluded that with the construction of the project the State should assume its proper share of the responsibility for collecting payments from the settlers and should also bear its proper share of the losses, if any, incidental to the development of the project.

The Columbia Basin Commission transmitted the above-mentioned report of the board of engineers and economists to the Secretary by letter of August 25, 1925, and this letter was published with the reports above mentioned. The commission concluded that the time had not arrived when local and national interests justified the construction of the project or that the Bureau of Reclamation was possessed of either the information or the experience to formulate a development program as costly and complex as the one outlined and advocated in the report. The cost of all investigations of the Columbia Basin project made by the United States Bureau of Reclamation up to this time, exclusive of those for which the costs have heretofore been mentioned, amounted in round numbers to $97,000.

From 1926 to the early part of 1930, studies of various water-supply and power-development problems relating to the Columbia Basin project were made by the United States Geological Survey at the request of and collaborating with the State of Washington. The principal reports submitted are as follows:

(1) Power Possibilities of Priest River, Idaho, 1926 by G. L. Parker, district engineer, United States Geological Survey, and Eugene Logan, consulting engineer, for the State of Washington.
(2) Preliminary Report Columbia Basin Project, Water Power Analysis 1926, by G. L. Parker, district engineer, United States Geological Survey, and Eugene Logan, consulting engineer for the State department of conservation and development.
(3) Storage Regulation in Flathead Basin for Power and its Effect on the Columbia Basin Project, 1926, by G. L. Parker, district engineer, United States Geological Survey.
(4) Albany Falls Power Project in Connection with Columbia Basin Irrigation Project, 1930, by Eugene Logan, consulting engineer for the State department of conservation and development, Washington.

A very comprehensive investigation of the Columbia River and its tributaries above the mouth of the Snake River was made during 1928, 1929, 1930, and 1931, by the Corps of Engineers of the War Department. The results of this investigation were submitted in 1931 in a report by Maj. John S. Butler, district engineer in charge of the work. This report consists of 2 volumes and 5 appendices. It considers navigation, flood control, irrigation, and power development. In addition to a number of able officers and civilian employees of the War Department, skilled specialists were employed for the study of the problems in economics, geology, dam design, power and irrigation development. A large amount of data were assembled on climate, vital statistics, population trends, markets, lumbering, mineral resources, irrigation economics, and power installations, and a study of

this information was made to determine the probable success of the irrigation project and the future requirement for electrical energy, including that required for the development of the irrigation project.

With particular reference to the irrigation project under the pumping plan, a study and estimate was made of dams of various heights at the Grand Coulee site in the Columbia River. Estimates were made of seven different plans for irrigating the entire project and of two plans for irrigating a part of the project. The following table gives the essential features of the various plans:

Source of water supply, river	Name of area to be irrigated	Acres supplied by gravity only	Acres supplied by pumping 362 feet at Grand Coulee	Acres supplied by repumping 100 feet	Acres supplied by pumping 255 feet	Acres supplied by pumping 635 feet	Acres, total
Wenatchee	Quincy	320,310	0	0	0	0	320,310
Columbia River 10 miles above Priest Rapids.	South of Saddle Mountain.	0	0	0	74,100	66,420	140,520
Clark Fork and Spokane	Maximum project	1,256,940	0	262,950	0	0	1,519,890
Clark Fork	do	1,256,940	0	262,950	0	0	1,519,890
Clark Fork and Wenatchee.	Gravity project only	1,256,940	0	0	0	0	1,256,940
Clark Fork, Spokane, Wenatchee.	Reduced gravity project	1,129,380	0	320,310	0	0	1,449,690
Columbia River at Grand Coulee Dam.	Maximum pumping project.	0	980,340	219,090	0	0	1,199,430
Columbia River at Grand Coulee and at 10 miles above bend.	South of Saddle Mountain and part of pumping project and repumping.	0	834,860	199,250	74,100	66,420	1,174,630
Columbia River at Grand Coulee.	South of Saddle Mountain and part of pumping project.	0	834,860	0	74,100	66,420	975,160

IRRIGABLE AREAS

Irrigable areas as referred to in this report are those lands which are expected to produce good crops when cultivated and irrigated. The irrigation of these areas will require lifting the water from the Columbia River Reservoir to the Grand Coulee Lake through a maximum height or primary lift of 362 feet for 981,000 acres and relifting the pumped water an additional height of 100 feet for 219,000 acres.

All irrigable lands of the project will be served by the main canal which extends southward from the Grand Coulee Lake about 11.7 miles to a point where it branches into two canals, the main west and the main east.

The main west canal extends in a westerly and southerly direction beyond Ephrata and Quincy and with its lateral distributaries supplies water to 371,000 acres, all of which are under the primary lift and no areas along the west main canal are to be irrigated by repumping.

The main east canal extends in a southeasterly direction beyond Hatton and Connell and with its lateral distributaries supplies water to a total of 829,000 acres. Of this area 219,000 acres are to be supplied by repumping and while some high areas lying between the boundaries defined by the main canal lines will be supplied by repumping the greater portion of the area lies adjacent to the east of the east main canals.

Extensive areas within the project boundaries have been eliminated from the irrigable areas for various reasons, such as elevation, probable water-logging, rocks, gravel, etc. These determinations have been made by field inspections using as a guide United States Geological Survey maps on scales of one half and 1 inch to 1 mile where they had been made. In order to make a more dependable determination of the irrigable areas, topographic maps should be made on a scale of 400 feet or 1,000 feet to 1 inch and test pits and borings should be made to determine the character and thickness of the soils and subsoil conditions, particularly as the latter may relate to future waterlogging of the soil.

WATER SUPPLY

Stream flow.—The Columbia River above the proposed Columbia River Dam drains a roughly triangular-shaped area of 74,000 square miles located in parts of British Columbia, Idaho, Montana, and Washington. The main source of water supply for the river is from the melting of the abundant snows accumulated at the higher altitudes on the western slope of the Rocky Mountains and on the Selkirk and Bitterroot Mountains. A number of large lakes located near the headwaters, of which the principal ones are Kootenay Lake in British Columbia, Flathead Lake in Montana, and Pend O'reille, Priest, and Coeur d' Alene Lakes in Idaho, tend to regulate the flow of the river naturally by retarding the flood peaks and storing large volumes of water for release when the river and lake stages recede following the flood run-off. It is possible that at some future date the outflow from these lakes may be controlled artificially for power purposes thus creating a greater regulatory effect than now exists. When and if such regulation should be accomplished the winter flow of the Columbia River and hence the firm power possibilities at the Columbia River Reservoir site would be increased somewhat over that shown herein. Plans for the development of the Columbia Basin project make no allowance for such artificial control of these upstream reservoirs hence for the purposes of this report no allowance is made for such additional regulation.

Discharge records, from which estimates of the flow at Grand Coulee are based are available as follows:

At Trail, British Columbia, May 1913 to March 1931.
At Kettle Falls (or Marcus) Wash., April 1916 to March 1931.
At Grand Coulee, Wash., July to December 1923 and June 1928 to March 1931.
At Vernita (or Wenatchee), Wash., May 1913 to March 1931.

In addition, records are available for the principal tributaries, which enter the main stream in this section. Using these records reliable estimates of flow at Grand Coulee were prepared for the period April 1913 to March 1931. (See table no. 1.)

DEPARTMENT OF THE INTERIOR, BUREAU OF RECLAMATION

TABLE NO. 1.—*Run-off of Columbia River at Grand Coulee*

[Unit 1,000 A.F. Drainage area, 74,100 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Total
1913							4,030	11,700	25,900	17,200	9,590	5,950	74,370
1913-14	3,800	3,080	2,370	2,230	1,930	2,970	5,930	13,500	17,400	15,500	8,120	4,580	81,410
1914-15	3,840	3,910	2,970	2,010	1,600	2,260	5,150	10,800	11,200	11,300	9,590	5,430	70,060
1915-16	3,120	2,920	2,430	1,750	1,820	3,860	6,720	12,400	19,000	25,800	11,600	6,550	97,970
1916-17	3,730	2,750	1,990	1,610	1,440	1,560	3,330	11,300	21,900	19,200	9,160	4,810	82,780
1917-18	3,750	2,400	2,570	5,150	2,890	2,800	5,510	12,900	18,300	15,700	8,360	5,380	85,710
1918-19	3,980	2,830	2,320	2,180	2,410	2,620	5,250	12,500	17,500	13,900	8,480	4,800	78,770
1919-20	2,850	1,800	1,430	1,440	1,460	1,800	2,610	8,610	14,100	19,400	10,900	5,400	71,800
1920-21	5,340	3,830	2,830	2,910	2,580	3,830	5,510	13,600	23,200	15,400	8,480	4,170	91,680
1921-22	3,150	3,180	2,880	2,100	1,520	1,670	3,190	9,650	21,100	13,400	7,810	5,270	74,920
1922-23	3,360	2,330	1,620	2,360	1,460	1,740	4,420	11,600	20,400	15,800	8,360	5,500	78,950
1923-24	2,960	1,950	1,740	1,430	2,290	2,350	2,460	11,200	13,500	10,300	7,060	4,920	62,160
1924-25	2,900	2,750	2,460	2,540	3,490	3,360	8,200	17,000	19,700	15,300	8,520	4,550	90,770
1925-26	2,880	1,930	1,770	1,590	1,680	2,050	3,870	10,300	8,280	8,710	5,550	4,240	52,830
1926-27	3,650	3,690	3,680	2,520	2,170	2,600	3,610	11,400	21,800	18,500	9,950	7,400	90,970
1927-28	6,520	6,400	5,630	3,690	2,940	3,550	5,500	16,800	21,100	16,000	8,850	4,680	101,660
1928-29	3,200	2,460	1,970	1,550	1,180	1,570	2,310	7,130	16,100	10,300	6,820	4,140	58,730
1929-30	2,530	1,740	1,460	1,160	1,280	1,750	4,220	9,840	13,200	12,000	7,620	4,580	61,380
1930-31	2,770	1,940	1,650	1,390	1,350	1,970							11,070

NOTE.—Actual records available at station during periods July to December 1923, and July 1928 to March 1931; balance of time discharges estimated from other records available at Trail, British Columbia, Kettle Falls and Vernita, Wash. Estimated flows for period, April 1913 to January 1924, published in U.S.G.S.W.S. Paper No. 572. Estimated flows for period, February 1924 to June 1928 based on discharges of Columbia River at Kettle Falls and intervening tributaries between Kettle Falls and Grand Coulee.

During this period the flow at Grand Coulee has varied from 17,000 second-feet to 492,000 second-feet, with an average of 109,000 second-feet, corresponding to an average annual run-off of 79,000,000 acre-feet.

There has been very little additional irrigation development on the upper tributaries of the Columbia River during the past 18 years, so that the flow as recorded in table no. 1 represents the flow under present conditions. However, by the time the Columbia Basin project has been fully developed, additional irrigation development may deplete the present flow of the stream by about 1,000,000 acre-feet annually.

In the Gault report of 1924, the amount of such depletion due to future irrigation development above the dam-site was estimated as about 900,000 acre-feet annually.

The irrigable areas and amount of depletion have been estimated by the Army engineers as follows (pt. 2, appendix 2):

Location of irrigable lands	Area in acres	Estimated annual depletion
		Acre-feet
Above Flathead Lake	125,000	160,000
From Priest Lake	20,000	25,000
Between Flathead Lake and Lake Pend O'Reille	290,000	492,000
Between Lake Pend O'Reille and Grand Coulee, exclusive of Spokane River	170,000	272,000
From Spokane River	20,000	28,000
Total	625,000	977,000

In addition to the above lands there is an irrigable area of about 66,000 acres on the Rathdrum Prairie in Idaho which would receive a water supply from either Priest Lake or Lake Pend O'Reille. Making due allowances for this area and also for the areas now under irrigation in the Columbia River watershed, the estimated depletion for additional irrigation and incidental storage development have been taken as 1,000,000 acre-feet annually, as follows (units acre-feet):

January	0	August	160,000
February	10,000	September	70,000
March	20,000	October	10,000
April	90,000	November	−20,000
May	150,000	December	0
June	260,000		
July	250,000	Total	1,000,000

Irrigation requirements.—On account of the variety of soil and climatic conditions on the Columbia Basin project, the crops grown and the water requirements will vary markedly on the different localities. On the whole, however, it is believed that crops and water requirements will be similar to those on the Sunnyside division of the Yakima project.

The physical features of the two projects compare as follows:

Feature	Sunnyside division, Yakima project	Columbia Basin project
Mean annual temperature	51.2° [1]	50.4°.[2]
Mean temperature April to October.	61.6° [1]	62.2°.[2]
Annual precipitation	0.55 foot [1]	0.68 foot.[2]
Precipitation period April to October.	0.24 foot [1]	0.30 foot.[2]
Average frost-free period	157 days [1]	159 days.[2]
Elevation irrigated area	800 feet.	500 to 1,400 feet.
Soil type	Largely deep sandy loam and light volcanic ash. Small areas of decomposed basalt underlain by gravel.	Largely deep soil, varying in texture from fine silty loam to sandy loam. Small areas of shallow sandy soil underlain by gravel.
Annual irrigation requirements delivered to farm.	3.44 acre-feet per acre [3]	Estimated 3.25 acre-feet per acre.

[1] Climatological record at Sunnyside.
[2] Mean of climatological records at Lind, Hatton, Wheeler, Ephrata, and Quincy.
[3] Mean for period 1919 to 1930, inclusive.

From the above tabulation it is noted that while the Columbia Basin project area has slightly higher temperatures in the growing season and a little longer frost-free period than the Sunnyside division, it also receives more precipitation and the soils as a whole are more retentive of moisture than those on the Sunnyside division. In view of these facts the average irrigation requirements on the Columbia Basin project have been estimated at 3.25 acre-feet per acre annually.

Plans for the irrigation of the proposed project contemplate that all main canals and laterals having in excess of 100 second-feet capacity will be lined and also lining laterals below 100 second-feet capacity when indications point to excessive losses, thereby materially saving water that would otherwise be lost by seepage. Some water will still be lost, however, on account of regulatory waste, evaporation loss in the main canals and laterals and seepage losses from the smaller laterals. The total amount of such losses in the

distribution system has been estimated at 25 percent of the water diverted into the main canals.

Opportunities for the reuse of return flow are not so good on this project as would be expected on an area of this size, due to the fact that the coulees which form the natural drainage channels of the project are deep and to recover such return flow would require additional pumping. The Gault report of 1924, estimates that a maximum of 512 second-feet could be reused out of Lind Coulee with the pumping plan fully developed with repumping lifts. For this report it is estimated that an average of 500 second-feet of return flow could be used with the fully developed project.

Based on the foregoing discussion the net diversion requirements from the Grand Coulee Reservoir, for irrigation water for the fully developed area, would be as follows:

TABLE NO. 2.—*Net diversion requirements from Grand Coulee Reservoir for fully developed Columbia Basin project*

Month	Rate of delivery acre-feet per acre	Rate of diversion acre-feet per acre	Total diversions for fully developed area, units 1,000 acre-feet [1]	Less usable return-flow, units 1,000 acre-feet [2]	Net irrigation demand on Grand Coulee Reservoir, units 1,000 acre-feet
April	0.39	0.55	660	27	633
May	.51	.67	805	33	772
June	.58	.74	888	36	852
July	.60	.76	912	37	875
August	.55	.71	852	35	817
September	.39	.55	660	27	633
October	.23	.35	420	17	403
Total	3.25	4.33	5,197	212	4,985

[1] Total irrigable area, 1,199,430.
[2] Average of 500 second-feet, April to October, inclusive, distributed throughout year in same proportions as total diversions.

Grand Coulee Reservoir.—The irrigation plan provides for a reservoir to be created in Grand Coulee by the construction of two dams, which will serve as part of the main conduit and eliminate a very expensive portion of the main canal which would otherwise be necessary to convey the water past that vicinity, and will also provide regulatory storage as hereinafter explained.

At various times during the past 11 years geological examinations have been made to determine the suitability of the Grand Coulee Reservoir site and the probable extent of leakage therefrom. Unpublished geological reports of this site are available as follows:

July 1921 by O. P. Jenkins and H. H. Cooper.
March 1924 by Kirk Bryan.
October 1930 by Henry Landes.
November 1930 by Ira A. Williams.
December 1930 by F. L. Ransome.

That portion of the Grand Coulee proposed to be used as a reservoir site has walls composed largely of basalt. Within the flow line of the proposed reservoir, except for the extreme ends of the coulee and at a few places along the side walls, the basalt is covered by unconsolidated talus slopes, sands, gravels, and silt terraces. The floor of the coulee, except for the southern end where basalt is exposed and

near the northern end where some granite is exposed, is covered by silts which are underlain by sand and gravel.

All of the geologists who reported on this reservoir agree that the most likely place for serious leakage to occur is at the southern end of the reservoir site, where a steep monoclinal fold occurs in the basalt. The inclined flows and the more permeable contacts between the successive flows along which water could percolate are exposed in the sides and bottom of the coulee. There is some disagreement as to the extent of such leakage; Cooper and Jenkins believe that the sharp folding of the basalt was accompanied by faulting along which water could readily escape; Williams believes that, while no general faulting occurred, the folding caused some fractures in the adjacent basalt; Bryan, Landes and Ransome recognize the possibility of leakage along the inclined contacts between the flows and apparently believe that such fractures as may be accompanied by the folding are superficial or will be sealed by the silt which covers the bed of the reservoir.

Ransome and Bryan believe that an underground hydraulic gradient exists from the plateaus toward the reservoir basin so that the pressure thus created would prevent the movement of water from the reservoir toward the sides. Mr. Williams, on the other hand, believes that a general hydraulic gradient exists from the east to west, so that while the raising of the water level would not be sufficient to reverse the gradient to the east, it would cause a steeper gradient to the west. He states that seepage along the west side of the reservoir would be limited by the permeability of the wall; in this connection he points out the possibility of fractures existing, especially at the southern end near the monoclinal fold.

All of the geologists contemplated a maximum flow line elevation of 1,552.5 feet in the reservoir, while present plans contemplate a maximum flow line elevation of 1,570 feet.

In view of the impossibility of determining in advance the extent of the reservoir leakage, such leakage has been very conservatively estimated as 1,000 second-feet (corresponding to about 1-inch loss per day) for the purposes of this report.

With the project fully developed, the water-surface elevation in the Grand Coulee Reservoir will fluctuate between 1,570 and 1,554.8 feet, thereby creating a storage capacity of 329,000 acre-feet which could be utilized to carry the irrigation requirements for short intervals in case it should become necessary to interrupt the pumps during the irrigation season. This storage would be useful in carrying a large part of the irrigation demand during April of each year at a time when the proposed Columbia River Reservoir would be drawn to low levels, during periods of subnormal run-off. The pumping draft and power required for pumping would be reduced as a result of this usable storage in Grand Coulee Reservoir.

A preliminary study of the joint operations of the Columbia River and Grand Coulee Reservoirs during critical periods of low run-off such as occurred during the winters of 1919–20 and 1929–30 shows that a minimum reduction in firm power output at the Columbia River Reservoir would occur if the Grand Coulee Reservoir were maintained at elevation 1,570 throughout the winter until the end of March and then allowed to drop to elevation 1,554.8 during April.

In May and the succeeding months there is always a surplus of water available at the Columbia River Reservoir, so that pumping plants could be run continuously at full capacity and the storage in Grand Coulee Reservoir replenished as rapidly as possible.

While the operation of this reservoir could be varied from year to year to best fit in with the available power and water levels in the Columbia River Reservoir for that year, it has been assumed in these studies that the Grand Coulee Reservoir stages would vary as outlined above for each year. Based on the above discussion and the irrigation demands set forth in table no. 2, the net amount of water to be pumped from the Columbia River Reservoir and the elevations to which such water must be pumped are set out in table no. 3.

TABLE NO. 3.—*Net irrigation demands on Columbia River for fully developed Columbia Basin project*

[Units, 1,000 acre-feet]

Month	Irrigation demand at Grand Coulee Reservoir [1]	Losses from Grand Coulee Reservoir [2]	Storage content of Grand Coulee Reservoir at end of month	Water pumped from Columbia River to Grand Coulee Reservoir	Elevation to which water must be pumped, feet [3]
January	0	61	1,050	61	1,570
February	0	56	1,050	56	1,570
March	0	61	1,050	61	1,570
April	633	60	721	364	[4] 1,563
May	772	61	872	[5] 984	[4] 1,563
June	852	60	912	[5] 952	1,564
July	875	61	960	[5] 984	1,566
August	817	61	1,050	968	1,570
September	633	60	1,050	693	1,570
October	403	61	1,050	464	1,570
November	0	60	1,050	60	1,570
December	0	61	1,050	61	1,570
Total	4,985	723	----------	5,708	----------

[1] From table no. 2.
[2] Estimated at 1,000 second-feet.
[3] Corresponds to elevation of W.S. in Grand Coulee Reservoir, except as noted.
[4] Minimum elevation to which water must be pumped fixed by conditions at outlet of pump discharge pipe.
[5] Pumps operated at full capacity of 16,000 second-feet.

Preliminary studies show that a dam in Grand Coulee, 10 feet higher than contemplated herein, would furnish additional storage which could be used to further reduce the pumping requirements from Columbia River during the winter months and thereby increase the firm power available at that site from 800,000 to 840,000 kilowatts. However, in order to accomplish this, about 1,000 second-feet of additional pumping capacity and a corresponding increase in the power installation would be required at the Columbia River Dam to care for the additional pumping requirements to insure filling the reservoir during the period May to August when a surplus of water is available in the Columbia River. In addition, raising of the water level in the Grand Coulee Reservoir would tend to increase the possibilities for leakage of such reservoir. Before final plans are made for this reservoir more detailed studies should be made to determine the best capacity to which it can be developed safely and economically.

Columbia River Reservoir.—The determination of the economic height for the Columbia River Dam requires the proper balancing of the costs for pumping into the Grand Coulee Reservoir, the costs of power for pumping, the cost and value of power for commercial uses, the value of lands and power sites submerged by the reservoir and other important factors.

Based on preliminary studies of these factors the "high dam" as proposed in the Army report was tentatively adopted and the studies reported herein are based on this dam, which will raise the water level to elevation 1,287.6 feet and create a reservoir in the stream channel about 150 miles long, with a water area of about 120 square miles (77,000 acres). The plan as outlined herein contemplates that in the winter time the reservoir will be drawn down a maximum of 80 feet, thereby making available 5,028,000 acre-feet of storage in years of low run-off for the production of firm power.

Evaporation losses from this reservoir would occur largely in the period from May to September, inclusive, when there is always more than enough water to fully meet irrigation and power requirements, hence no allowance has been made for evaporation losses in the operation studies of this reservoir.

Very little information is available upon which to determine the extent of seepage losses from the Columbia River Reservoir. The fact that the reservoir would occupy the river channel, which is largely cut into indurated rocks, indicates that seepage losses from the reservoir would be negligible and they have been so assumed in this study.

The tailwater elevation below the proposed power plant at the dam has been assumed to vary with the discharge as at present and ranges from about elevation 933.5 feet with a discharge of 19,000 second-feet to about elevation 981 feet with a discharge of 450,000 second-feet.

Power output.—A study of reservoir operations using monthly estimates of inflow and outflow during the critical periods of low run-off such as occurred in the winters of 1919–20 and 1929–30 shows that with the reservoir drawn down 80 feet there would be sufficient flow to maintain a uniform power output of 920,000 kilowatts, if there were no irrigation and pumping demands for the Columbia Basin project. Further study shows that with the irrigation project fully developed, pumping requirements would reduce the firm power output to 800,000 kilowatts. In this study the over-all efficiency of the power plant was taken as 83 percent and that of the pumping plant as 73 percent.

A study was made of the joint operations of the Grand Coulee and Columbia River Reservoirs with stream flows as estimated for the period April 1913 to March 1931, inclusive. The results of this study are shown graphically on drawing 222-D-5.[31] In this study, whenever the Columbia River Reservoir was full, it was assumed that all water, in excess of that pumped to the Grand Coulee Reservoir, to the extent of the power-plant capacity (1,575,000 kilowatts), would be passed through the power plant for the production of secondary energy. When the reservoir was not full the releases through the power plant were limited to the water required for the production of firm power and power required for pumping.

[31] Not printed.

The average amounts of the various kinds of power available each year are as follows:

TABLE NO. 4.—*Various kinds of power available each year*

Year Apr. 1 to Mar. 31	Total power, millions of kilowatt-hours			Months in which secondary power is available [1]
	Firm power	Power required for pumping	Secondary power available for sale [1]	
1913–14	7,008	2,280	1,840	May to March.
1914–15	7,008	2,230	2,460	April to December.
1915–16	7,027	2,240	2,150	April to December and March.
1916–17	7,008	2,230	1,780	April to November.
1917–18	7,008	2,260	2,460	May to March.
1918–19	7,008	2,230	2,280	April to March.
1919–20	7,027	2,260	1,460	April to September.
1920–21	7,008	2,330	2,820	June to March.
1921–22	7,008	2,230	1,890	April to December.
1922–23	7,008	2,250	1,120	May to November.
1923–24	7,027	2,250	1,040	May to September.
1924–25	7,008	2,250	2,210	May to March, except October.
1925–26	7,008	2,230	1,450	April to September.
1926–27	7,008	2,250	2,320	May to March.
1927–28	7,027	2,240	3,850	April to March.
1928–29	7,008	2,230	1,620	April to November.
1929–30	7,008	2,320	700	June to September.
1930–31	7,008	2,330	890	May to September.
Mean	7,013	2,260	1,910	

[1] Available only when reservoir is full. Reservoir spills every year so that if a market should arise for such power in the future more could be generated by providing a larger power-plant capacity.

COLUMBIA RIVER DAM

Scope of investigations.—The geological conditions at the site have been studied by Geologist Kirk Bryan and are covered in his report which is included in the Gault Report of 1924. Between July 9, 1921 and January 9, 1922, 14 diamond-drill holes were put down at this site by the Columbia Basin Survey Commission. Two additional drill holes were put down in 1930 by the Corps of Engineers, United States Army. The geological report and the record and interpretation of drill holes form the basis for present assumptions as to foundation conditions. The foundation area is so extensive and there is such a deep covering over bedrock that there is much uncertainty as to the actual foundation conditions. A large amount of additional testing is necessary to make a reasonably complete exploration of the foundations. The purpose of additional drilling and testing would be to define the surface of the bedrock more completely over the whole area comprising the foundation of the dam and power plant, to determine the depth of unsound rock necessary to remove and to determine the presence of major seams or fault zones within the area. To obtain the necessary additional information, the following program of further diamond drilling and testing has been proposed.

Drilling 48 vertical holes, 8,400 linear feet.
Drilling 10 inclined holes, 8,000 linear feet.
Trenching 550-linear-foot open trench.
Excavating 4 test pits, average 150 feet deep.

Estimated cost of additional foundation exploration necessary is $150,000.

Highways.—The Columbia River dam site can be reached by unimproved roads from Mansfield 35 miles west, from Almira about 20 miles southeast on the Sunset National Highway (U.S. 10); and also by a gravel-surfaced county highway going north through Grand Coulee from Coulee City, located approximately 30 miles southwest of the dam site.

Construction railroad.—No location surveys for a construction railroad have been made. However, there appears to be two feasible routes to the dam site, one connecting with the Great Northern Railroad at Mansfield, 35 miles west, and the other connecting with the Northern Pacific Railroad near Coulee City. A construction cost estimate of a railroad following the latter route was prepared from incomplete United States Geological Survey topography. In addition to providing transportation for the construction of the Columbia River Dam, the Grand Coulee route will also pass near the sites of the proposed North and South Grand Coulee Dams of the proposed Grand Coulee Reservoir. This route will also provide for transportation of concrete aggregates from deposits of this material already accessible by railroad between Coulee City and Hartline, and north of Adrian.

The proposed line, approximately 30 miles in length, will branch from the main line of the Northern Pacific Railroad, near Coulee City junction, and follow the east side of Grand Coulee at an elevation slightly above the flow line of the proposed Grand Coulee Reservoir to a point opposite the North Grand Coulee Dam, from where the line descends to the west end of the Columbia River Dam.

Transportation of concrete aggregates.—For the purpose of estimating the delivered cost of concrete aggregates, it was assumed that the contractor would continue the construction of the railroad down the canyon from the switchback location to a point approximately 2 miles below the dam where the river would be bridged and the railroad constructed upstream to gravel deposits on the east side of the river. It is also practicable to transport concrete aggregates to the mixing plant by an aerial tramway system consisting of several units or lines.

Construction power.—An ample supply of electric power for construction purposes is available from transmission lines of the Washington Water Power Co. which pass through Coulee City. A 60,000-volt branch line to Spokane runs parallel to the tracks of the Northern Pacific Railroad, which at a point west of Almira and directly south of the dam site, is but 16 miles distant across the Hartline Plateau.

Concrete materials.—With the cooperation of the district engineer, Corps of Engineers, United States Army, Seattle, Wash., preliminary field investigations were made of sand and gravel deposits immediately adjacent to the dam site and of several deposits more remotely situated. Approximately 100 material samples of about 100 pounds each, after removal of cobbles larger than 6 inches, were obtained from the various deposits and shipped to the Bureau of Reclamation laboratory at Denver for test. Brief descriptions of the deposits, the work performed, and the general findings are given in the following paragraphs.

Deposits at dam site.—Extensive bench deposits are located on the east side of Columbia River, adjacent to the dam site. Eight test pits from 21 to 41 feet deep and 10 side-hill trenches from 35 to 66

feet in vertical projection, covering an area about 1 mile north and one half mile south of the dam center line, were excavated and logs prepared. The average depth of overburden is about 3½ feet. The aggregate material lies in horizontal strata, differing widely in gradation, and interspersed with layers of clay at depths of 21 feet or more. Lime-coated and discolored material is found in one test pit. The material is fairly well rounded and generally dirty. It is composed largely of basalt (70 to 80 percent), with lesser amounts of granite, shale, quartzite, diorite and andesite. A small percentage of the basalt is vesicular. The aggregate is apparently sound with the exception of the shale. A total of 89 test samples were taken.

The deposit at the dam site may prove to be a practicable source of aggregate for the dam. Accessibility, apparent soundness and freedom from organic impurities of the material, and the satisfactory size range and gradation of the coarse aggregate are characteristics in its favor. Thorough washing would be essential for removing excess silt, disposing of the softer pieces of shale, and avoiding the formation of clay balls. The extreme variations in gradation of the sand, even in the same pit, point to the possible need for division of the same into two or three sizes and recombination in desired proportions. Without such separation, the high average fineness modulus of the washed sand would require correction, by one of a number of possible means. While the tabular values for average pit run proportions show a large excess of sand, it is probable that the actual average percentage of sand is materially less, due to the fact that thick layers of coarse material, especially in the trenches, were not samples and had to be disregarded in arriving at the figures stated. Additional investigations would be required to obtain more reliable data and to definitely establish the sufficiency of the deposits.

Mansfield pit.—This pit is located in Sec. 35, T. 30 N., R. 29 E., about 10 miles in direct line northwest of the Columbia River dam site. It is apparently a small deposit containing relatively fine material only. The material is similar in composition and shape of particles to that at the dam site. Only one sample was taken.

The Mansfield deposit, considered alone, is apparently of little value for the purpose, owing to its limited extent, the large proportion and high fineness modulus of the sand, and a pronounced deficiency in the larger sizes of gravel.

Adrian pit.—This is an extensive deposit located along the Northern Pacific Railroad about 1 mile north of Adrian and 42 miles in direct line southwest of the damsite. The face of the deposit is about 600 feet long and 75 feet high, with the lower half covered by talus. The material is apparently clean, structurally sound, and fairly well rounded. It is composed entirely of basalt with vesicles present in 15 to 25 percent of the coarse aggregate. Four samples were taken from the upper half of the face.

The Adrian deposit is handicapped by its distance from the damsite, its excess of sand, and the relatively high fineness modulus of the sand. The deposit is apparently clean and extensive and, with exception of the deposits at the damsite, shows the most favorable gradation of coarse aggregate.

Hartline pit.—This is an extensive deposit located along the Northern Pacific Railroad and the power line of the Washington Water Power Co. about 21 miles in direct line southwest of the

damsite. It lies about 6 miles east of Coulee City and 3 miles west of Hartline. The exposed face of the deposit is about 500 feet long and 30 feet high, and the pit is covered with an earth overburden about 4 feet deep. The material is apparently clean, structurally sound, and fairly well rounded. It is composed entirely of basalt with vesicles prominent in 30 to 50 percent of the coarse aggregate. The face of the pit was logged and four samples taken. A second deposit with similar material was found about 1½ miles west.

If the data obtained may be taken as representative, the Hartline deposit, although similar in many respects, is much less favorable than the Adrian deposit by reason of the very high proportion of sand, the exceptionally high fineness modulus of the sand and the lower fineness modulus of the gravel.

Results of tests on aggregates.—Sieve analyses, silt determinations, and calorimetric tests were made in the Denver laboratory on all the above-mentioned samples. Some concrete tests are contemplated. The principal results of the completed tests are tabulated below:

TABLE NO. 5.—*Analysis of concrete aggregates*

	At the damsite			Adrian pit	Hartline pit	Mansfield pit
	8 pits	10 trenches	Entire deposit			
Average pit-run proportions:						
Sand to one fourth inch.....percent	36	50.1	42.9	55.6	83.2	70.5
Washed gravel, one fourth inch to 6 inches..do	64	44.3	52.0	41.7	14.0	26.4
Calorimetric tests, unwashed sand	(1)	(1)	(1)	(1)	(1)	(1)
Silt content, by weight of unwashed sand:						
Minimum.....percent	.9	.9	.9	2.3	3.4	1.9
Maximum.....do	72.4	44.6	72.4	2.8	4.4	1.9
Weighted average.....do	6.1	5.3	5.6	2.7	3.7	1.9
Fines removed in washing sand, by weights:						
Weighted average.....percent	11.25	10.05	10.6	3.81	3.84	4.21
Fineness modulus of sand, washed:						
Minimum	1.81	1.64	1.64	3.32	4.12	3.73
Maximum	4.57	4.94	4.94	3.68	4.52	3.73
Weighted average	3.17	3.40	3.30	3.38	4.14	3.73
Fineness modulus of gravel:						
Minimum	7.06	6.0	6.0	7.18	7.11	7.25
Maximum	9.17	8.70	9.17	8.39	8.04	7.25
Weighted average	8.32	8.19	8.26	7.78	7.46	7.25
Grading of gravel, weighted average for entire deposit:						
3-inch seive	13.1	7.5	10.5	48.3	9.8	-------
1½-inch sieve	47.5	47.3	47.4	27.70	25.4	7.6
¾-inch sieve	77.4	72.0	74.9	58.60	42.2	30.8
⅜-inch sieve	94.0	92.4	93.2	86.90	68.6	77.5
No. 4 sieve	100.0	100.0	100.0	100.0	100.0	100.0

[1] Favorable.

NOTE.—Depth of layers and proportions of sand and gravel were taken into account in determining "weighted averages" values.

Foundation conditions.—Knowledge of foundation conditions at the dam site is limited to the information secured by a geological examination and the drilling of 16 diamond drill holes. On the basis of this information it is believed that the surface of bedrock lies at approximately elevation 880 across the valley and rises with side slopes of about 1½ to 1 to the elevation of the crest of the dam. The foundation rock over the whole area is described as a medium gray, fine grained, hard, dense granite, with joints at intervals of 2 to 6 feet. There is no shattering or crushing at joints and the presence of the joints will facilitate quarrying and excavating the rock. Open joints were found to depths of 35 feet, but it is believed that these joints can be success-

fully sealed by grouting. The cores indicated that 5 to 10 feet of rock was unsound and should be removed from the valley floor and that 10 to 15 feet should be removed from the rock surfaces on the slopes. From 20 to 70 feet of fine-grained clay lies above the bedrock. This is believed to be impervious and it should afford a watertight connection between the sheet piling of the cofferdams and the bedrock. A mixture of clay, sand, and gravel is found above this clay stratum, varying from a few feet up to 100 feet. The presence of the clay just above the granite will undoubtedly simplify the foundation work and aid in keeping water out of the excavation, but at the same time the clay may tend to squeeze out under the weight of the overburden and this condition will affect the design of the cofferdams from the standpoint of stability.

Two depressions in the surface of the bedrock were disclosed in the drilling, one at elevation 790 and another at elevation 780. Sufficient drilling has not yet been done to determine the shape and extent of these depressions but they are believed to be potholes in an old stream bed or else depressions eroded by glacial action. There are no surface indications of faults within the area of the site. The large amount of river deposit over the valley floor necessitates enormous quantities of foundation excavation.

Diversion of river during construction.—The care of the Columbia River during construction of the dam presents a difficult problem owing to the large discharges that must be passed. During the period in which there are records giving the flow at the dam site, the maximum daily average flow is found to be 496,000 c.f.s. In the period of record, 17.83 years, the mean daily maximum flow exceeded 450,000 c.f.s. during three different periods and these aggregate only 42 days.

The diversion works will be carried out in two main stages. The first stage includes the excavating of a diversion channel along the east bank of the river; the driving of a cellular sheet pile cofferdam to rock, parallel to and adjacent to the east bank of the river; and the turning of the river into the diversion channel by means of timber cribs sunk in the main channel between the west bank of the river and the ends of the cellular cofferdam. The upstream cribs will be built to elevation 975, which is estimated to pass 600,000 c.f.s. without overtopping the cofferdam. After completing the excavation within this first cofferdam the concrete will be brought up to elevation 1025, except the alternate blocks across the spillway section which will be left at elevation 950 for the passage of flood water. In addition to these low blocks thirty-one 12-foot diameter temporary openings will be left through the dam for the passage of flood water.

The cofferdams of the second stage of the diversion plan will extend from the east bank of the river to the ends of the sheet pile cellular cofferdam. These will be raised to elevation 1,005, which is estimated to divert 450,000 c.f.s. through the openings left in the west portion of the dam. After the excavation is completed the concrete in the east section of the dam will be poured to elevation 1,025. Fourteen additional temporary 12-foot diameter holes will be placed in this section which, together with the 20 permanent 5-foot 8-inch by 10-foot outlets, will provide enough spillway capacity to pass 50,000 c.f.s. after the 15 holes through the power-house section of the dam have been closed, without overtopping the low blocks at

elevation 950. This will give 2 months time at least in the low-water season for raising the low blocks. A number of the low blocks will be kept low at all times until the drum gates are installed.

The temporary 12-foot diameter openings will be utilized until the spillway crest is completed, after which they will be plugged with concrete. A steel bulkhead will be provided for closing each of these openings to facilitate the pouring of the concrete plug.

Description of dam and appurtenances.—The Columbia River Dam is located on the Columbia River near the head of Grand Coulee in section 1, T. 28 N., R. 30 E., and section 6, T. 28 N., R. 31 E. It is a straight concrete gravity dam 450 feet high and 4,100 feet long at the elevation of the roadway on top of the dam.

The spillway consists of an overflow section of the dam, across the river channel, with an over-all length of 1,918 feet. The spillway discharge, assumed to be a maximum of 1,000,000 second-feet, is controlled by fourteen 124- by 28-foot structural steel drum gates. The drum gates will be designed for automatic control, hand-operation, or remote control from the power plant. With 1,000,000 second-feet discharge over the spillway, the water surface in the reservoir will be at elevation 1289.6, causing a 30-foot depth on the crest of the spillway. The energy of the spillway water will be dissipated on a sloping concrete apron. This apron will be designed to create a hydraulic jump at all stages of the tailwater. The final design of this apron will be determined by hydraulic model tests. The spillway will be bridged by 14 concrete arches, providing a 24-foot roadway, these arches being supported on concrete piers 14 feet thick carried up from the overflow crest structure.

Sluiceway openings are placed through the dam on the right side of the spillway at elevations 935, 1050, and 1165 for emergency and diversion purposes. Twenty 5-foot 8-inch by 10-foot 0-inch conduits are shown on the drawing at elevation 935. These conduits have a discharge capacity of 30,000 second-feet with water surface in the reservoir at elevation 965. The drawings also show eight 5-foot 8-inch by 10-foot 0-inch conduits at elevation 1050 and likewise at elevation 1165. All of these sluiceway conduits are controlled by tandem 5-foot 8-inch by 10-foot 0-inch hydraulically operated slide gates.

The Columbia River is the main artery for fish migrations between the tributaries and the Pacific Ocean and for this reason the problem of passing fish through or over the dam is of utmost importance. A mechanical fish elevator, somewhat similar to that used on the Baker Dam, has been tentatively selected as the most practicable type for fish traveling in an upstream direction. This elevator will raise the fish from the head end of a flume, located adjacent to the draft tubes, up to the crest elevation of the dam and will then lower them into the reservoir. The fish elevator consists principally of a flume extending the full width of the tailrace along the downstream side of the power plant together with a fish elevator operating from the head of the flume upward through an inclined shaft to the crest of the dam and downward through a second inclined shaft to the reservoir.

As the possibility of navigation of the Columbia River is very remote, due to the great expense involved in improving the river below the dam, no design or cost for locks has been included in this report.

The meager information available relative to property damage within the reservoir basin does not warrant the preparation of a detailed estimate at this time. This item of cost is included in a general estimate for reservoir right of way.

POWER PLANT

Buildings and structures.—The power house is located on the downstream toe of the dam to the left of the spillway section. The building is a concrete and steel structure 1,028 feet long and 78 feet wide with the 220,000-volt transformer equipment located between the power-house superstructure and the dam. The generator-room floor has been placed at an elevation just above the maximum recorded tailwater elevation, but the entire building is made watertight to an elevation several feet above an assumed maximum flood-water condition.

All low-voltage switching equipment, governor oil-pumping equipment, and the passages for carrying water, oil, and air piping and power busses and cables are located in the substructure of the building. Two house generators are located at the extreme left-hand end of the plant, at which point there is also dismantling space for the units and a machine shop for handling repair work. The building contains two cranes having a combined capacity sufficient to lift the heaviest part of any generating unit.

A control house containing the control equipment for both power house and pumping plant is located apart from the power house adjacent to the left end of the building.

Water is supplied to the turbines through a concrete and steel trash rack structure on the upstream side of the dam. An individual penstock controlled by a stony gate at the upper end is provided for each main generating unit. The penstock openings have their center lines at elevation 1180. The steel penstocks pass through the dam at this elevation and then follow the downstream face of the dam to the turbines in the power house. A Gantry crane is provided on the top of the dam for handling penstock gates and other equipment.

Hydraulic and electrical machinery.—Fifteen main generating units of 105,000-kilowatt capacity each are proposed for the power plant. The turbines are rated at 147,000 horsepower each at 330 feet head and the generators are rated at 120,000 kilovolt-amperes each at 120 revolutions per minute, 22,000 volts, 60 cycles, 87.5 percent power factor. An individual governing system, including actuator, oil pump, and oil tank, is provided for each turbine, and each generator has a direct-connected exciter.

Each generating unit has its own transformer bank for raising the voltage to 220,000, and switching and protection equipment has been included for one outgoing transmission line per generating unit. In addition, five of the generators are equipped with oil circuit breakers, cables, and control equipment for supplying power to the 20 pumps which are proposed for the ultimate installation in the pumping plant.

Annual costs.—The annual cost of operation and maintenance of the power plant has been taken at 50 cents per kilowatt of installed capacity for the ultimate development or $785,000. For the purpose of financial studies it has been assumed that the annual operation and maintenance cost of the initial development consisting of three units will be one third of the cost of the complete development and will

increase uniformly as additional units are installed. The annual operation and maintenance cost for the dam has been taken as $150,000.

Depreciation for both dam and power plant has been taken on an assumed average 30-year life for all items considered depreciable. An annuity has then been set up which when invested at 4 percent will accumulate the required amount for replacement at the end of a 30-year period. On this basis the required annuity is 1.78301 percent of the original cost of the depreciable items.

These annual costs are summarized in the following tabulations:

Complete development:	
Depreciation:	
Cost of depreciable items for dam	$9, 911, 685
Cost of depreciable items for power plant	34, 753, 633
Total in dam and power plant	44, 665, 318
Annuity required, at 1.78301 percent	796, 387
Operation and maintenance:	
Dam	150, 000
Power plant, at $0.50 per kilowatt	787, 500
Total	937, 500
Initial development:	
Depreciation:	
Cost of depreciable items for dam	9, 911, 685
Cost of depreciable items for 3 units in power plant	9, 563, 176
Total in dam and power plant	19, 474, 861
Annuity required, at 1.78301 percent	347, 239
Operation and maintenance:	
Dam	150, 000
Power plant, one third of $787,500	262, 500
Total	412, 500

ULTIMATE IRRIGATION DEVELOPMENT

Columbia River pumping plant.—The pumping-plant building is located along the reservoir shore line just upstream from the left abutment of the dam. It is a reinforced concrete structure about 640 feet long by 100 feet wide, with practically all the buildings below water when the reservoir is at maximum elevation. A Gantry crane will travel the entire length on top of the building and will give access to the machinery through removable hatchways placed over the pumping units. Drainage for the interior of the structure is secured by means of a drainage tunnel leading to a gravity outlet in the tailrace below the power plant. This tunnel will also carry the power cables from the power plant to the pumping plant for the operation of the pump motors. A concrete and steel trash-rack structure occupies the entire reservoir side of the building.

Twenty pumping units are proposed for the ultimate installation, each unit consisting of a single-stage pump having a capacity of 800 second-feet when operating under a total head of 370 feet, direct connected to a 33,000-horsepower, 22,000-volt, synchronous motor operating at 200 revolutions per minute. The motor capacity is such that with a full reservoir 1 main generating unit in the power

plant has sufficient capacity to operate 4 pumping units, and with a minimum reservoir elevation 1 main generating unit has sufficient capacity for operating 3 pumping units. This coordination of generator and pumping unit capacities allows full independent use of each generating unit for operation of the pumping units, and also permits variation in the speed of the units so as to maintain the pump efficiency at the highest possible point throughout a large variation in pumping head.

A separate steel discharge pipe is provided for each pump and these pipes are supported on concrete foundations and located above ground so that they are accessible for inspection, painting, and other maintenance work. All pipes lead to a common outlet structure at the head of the Grand Coulee Canal and each is equipped with a siphon arrangement containing an automatic air valve to prevent reverse flow of water from the canal when the operation of a pump is stopped.

Repumping.—In order to utilize as fully as practicable the power possibilities on the project and to relieve the demand on Columbia River power, it is proposed to develop power for pumping purposes at those favorable places on the irrigation project where on account of the topography and for other reasons it is advisable to drop the canal grades to lower elevations. Power plants are to be constructed at these drops and the seasonal electricity generated is to be transmitted to a number of pumping plants located at various places along the canals where water will be pumped to a total of 219,090 acres lying above the gravity canals. Transmission lines are to be constructed connecting the various power plants and supply lines will be extended to the pumping plants.

Size of installations.—With 3.25 acre-feet of water delivered at the land during the irrigation season and 15 percent loss in distribution in the canals supplying the pumping areas, the pumping duty is 3.82 acre-feet per acre, or a total seasonal requirement of 836,924 acre-feet for 219,090 acres. With an average pumping head of 70 feet, the acre-feet feet pumped during the season is 58,584,680. The installations required for the various heads and canal capacities are as follows:

50 percent, or 29,292,340 acre-feet feet, 1,000-kilowatt installation.
30 percent, or 17,575,404 acre-feet feet, 500-kilowatt installation.
10 percent, or 5,858,468 acre-feet feet, 250-kilowatt installation.
5 percent, or 2,929,234 acre-feet feet, 100-kilowatt installation.
5 percent, or 2,929,234 acre-feet feet, 10–50-kilowatt installation.

Estimated costs of repumping.—The estimated costs of the repumping installations are as follows:

Transmission lines and transformers:	
180 miles of primary line, 66,000-volt copper, treated wood poles, at $2,800 per mile	$504,000
150 miles of secondary line, 11,000-volt copper, treated wood poles, at $1,800 per mile	270,000
26,000 kilowatts in transformer capacity, at $2.50 per kilowatt	65,000
	839,000
Power development:	
26,000 kilowatts, at $60	1,560,000

Pumping plants:	
Buildings, hydraulic equipment pipe lines, and electric equipment, not including step-down transformers:	
29,292,340 acre-feet feet, at $0.065 per acre-foot foot	$1, 904, 002
17,575,505 acre-feet feet, at $0.085 per acre-foot foot	1, 493, 909
5,858,458 acre-feet feet, at $0.10 per acre-foot foot	585, 847
2,929,234 acre-feet feet, at $0.14 per acre-foot foot	410, 093
2,929,234 acre-feet feet, at $0.25 per acre-foot foot	732, 308
	5, 126, 159
Total for repumping	7, 525, 159

Grand Coulee Reservoir.—It is proposed to construct earth dams at the north and south ends of the Grand Coulee. Water pumped from the Columbia River will discharge into the Grand Coulee and be controlled as to elevation and use by the dams and regulating works.

The formation of a lake in the Grand Coulee 23 miles long, having an area of 2,300 acres at the maximum water surface elevation of 1,570, eliminates the necessity for a very expensive canal along the steep walls of the Grand Coulee and saves the loss of about 47 feet in the elevation of the water surface at the south end of the Coulee. It also allows a more efficient use of water for power development and irrigation by providing storage for water which can be pumped when the supply in the river is ample, and in turn decreases the amount of power water required for pumping when the river supply is low.

North Grand Coulee Dam.—The North Grand Coulee Dam, located about 1½ miles from the Columbia River Dam on Grand Coulee, together with the South Grand Coulee Dam, located about 4½ miles north of Coulee City, will be constructed to form the Grand Coulee Reservoir, which is an important link in the main canal system. The site of the North Grand Coulee Dam has been explored with six drill holes and the foundation conditions, as revealed thereby, have determined the selection of an earth-fill dam for this site. The dam section has been designed with unusually flat slopes. The upstream two thirds will be constructed as a sprinkled and rolled earth fill while the downstream one third will consist of a gravel fill with a rock-paved slope and a flat downstream toe. The slope on the water side will be protected with 30 inches of rock riprap laid on 12 inches of gravel. A concrete cut-off wall 10 feet high will extend throughout the length of the dam. On the earth parts of the foundation the concrete cut-off wall is set in a cut-off trench 20 feet deep and is built on top of a row of steel-sheet piling. The rock sections of the foundation, together with the basalt abutment and intake canal section, will be drilled and grouted along the line of the cut-off wall. The maximum height of the dam above the original ground surface will be 92 feet. About 10 feet of foundation excavation over the lower parts of the old stream bed is believed to be necessary. An emergency waste way, controlled by a 50 by 50-foot Stoney gate, provides an outlet to the Columbia River. A 12-foot embankment freeboard is provided for this dam, and an additional 3 feet of freeboard against high waves is provided by means of a concrete parapet wall on the crest of the dam.

South Grand Coulee Dam.—Because of uncertainty in the bearing power and watertightness of the earth foundations at this site, an earth-dam section with flat slopes, similar in most respects to the North Grand Coulee Dam section, has been adopted. A gravel fill will be used instead of a rock fill at the downstream toe because there

will be only small quantities of excavated rock available from required excavations at this site. A cut-off trench, concrete cut-off wall, and steel-sheet piling are provided on the earth foundation as in the North Grand Coulee Dam. It is estimated that 18 inches of stripping will be required over the earth portion of the foundation area. The height of the maximum section of the dam above the original ground surface will be 97 feet and an embankment freeboard of 12 feet is provided together with a 3-foot concrete parapet wall. A Stoney gate 50 feet wide and 36 feet high controls the outflow into the main canal heading at this dam.

Canals.—There are included under this item all canals having a carrying capacity in excess of 100 c.f.s. The maximum amount of water which they will carry is dependent upon the acreage which they serve and is intended to be sufficient for the period of maximum demand after allowing for leakage and waste. With the exception of the canal supplying Grand Coulee Lake, the capacities are computed as follows:

In excess of 100,000 acres, 1 c.f.s. to 80 acres.
Between 100,000 acres and 50,000 acres, 1 c.f.s to 70 acres.
Between 50,000 acres and 25,000 acres, 1 c.f.s. to 65 acres.
Between 25,000 acres and 6,000 acres, 1 c.f.s to 60 acres.

Larger carrying capacities are provided in the smaller canals than in the larger canals in order to provide a more satisfactory rotation system when necessary.

The capacity of the canal supplying Grand Coulee Lake is greater than the canal leading from the lake in order to provide for the estimated rate of leakage from the Grand Coulee Lake and at the same time supply the maximum irrigation demand. During the times of diminished irrigation demand this extra capacity provided will allow an accumulation of storage in the lake. All canals are to be lined with reinforced concrete varying in thickness from a maximum of 12 inches to a minimum of 4 inches. The classification of materials of excavation on all canal lines is based principally on field inspection. Borings and test pits would give a closer estimate of the classification, but the estimate as made is believed to be reasonably close.

Tunnels.—The capacities of all tunnels are determined in the same manner as the canals above mentioned. They are designed of the horseshoe type with a depth of water at 83 percent of the diameter. The tunnels will be lined throughout with concrete. No reinforcing is provided in the tunnel lining except in the closed transition sections at the inlets and outlets. Tunnel excavations will be mainly in basaltic rock, but provision is made in the estimate for some timbering.

Siphons and penstocks.—It is proposed to carry the required water supply across streams and coulees by means of reinforced concrete pipes where the pressure head and capacities required are relatively small. Where greater capacities and larger diameters are required, steel pressure pipes are proposed. Steel pipes are also proposed for the power penstocks and pump-discharge pipes at those places on the project where drops in the canal grades occur and where repumping is contemplated.

The steel pipes are designed to rest on concrete saddles and to have concrete anchors where necessary. Depreciation is calculated as an annuity that would replace the steel pipes in 30 years at 4 percent or providing a reserve fund in the annual operating and maintenance

budget of the irrigation project an amount to be determined by taking 1.78 percent of the original investment in the steel pipes.

Lateral system.—All distributaries of less than 100 c.f.s. capacity are included in the lateral system which is intended to deliver water to each 160-acre farm. Where these ditches are excavated in gravel or other porous material which would allow considerable leakage, it is proposed to line such stretches with reinforced concrete. The lateral system under the Main West Canal is believed to require a relatively small amount of concrete lining and concrete drops and is estimated to cost $21 per acre. Under the Main East Canal the amount of concrete lining will be greater and this portion of the lateral system is estimated at $25 per acre.

Drainage.—There are a number of places on the irrigation project where ditches will have to be constructed to carry off waste and seepage water and to provide outlet channels for wasteways from the canals. Frequently a wasteway channel affords an outlet for drainage ditches. As the wasteways deemed necessary are considered as a separate item and so estimated, although they really act as drainage outlets, the item and estimate of $4 per acre for providing drainage is intended to cover those cases where lateral drains are necessary and to provide additional outlets where necessary.

Wasteways.—Wasteways are necessary on any irrigation project to provide a means of disposing of water during emergencies such as cloudbursts or canal breaks and to afford a means of regulating the water supply close to the land. This allows closer regulation on shorter notice which is important with a long canal system such as the one under consideration. The wasteway channels deemed necessary will, in addition to carrying off waste water occurring by regulation, provide outlets for drainage ditches as mentioned above.

Buildings.—The operation and maintenance of the irrigation project requires a number of permanent buildings such as offices, shops, warehouses, residences for reservoir superintendents and headgate keepers, and the estimate provides an amount to cover their cost. These buildings are in addition to the temporary buildings to be built by the contractors during the construction period. The cost of such temporary buildings are included in the estimates of the various items which necessitate their construction. This item for permanent buildings does not cover the cost of buildings required for the power plant and pumping plant operators as the cost of such buildings are included in the items covering those features.

Telephone system.—The operation and maintenance of the irrigation project will require a great many miles of telephone lines, in order that daily reports of the use and expected demands for water service may be communicated promptly to the employee whose duty is to see that the required amount of water is kept in the canal for prompt and efficient service. The estimate provides for the construction of 400 miles of metallic circuit carried on 25-foot poles with treated butts.

Wells.—A separate estimate is given for this item in order to obviate the necessity for using different prices for the same class of concrete required throughout the project. The cost of the concrete in place is influenced by the availability of the water supply and an estimate is provided for wells in order to make the distance to a water supply practically constant.

Operation and maintenance during construction.—When the water is first turned into the canal there will be items of expense occurring on account of developments which cannot be entirely eliminated beforehand at reasonable expense. After a few years these difficulties are remedied and usually remain so for the life of the project. While these improvements are being made during the operation of the project they are really items of construction and an allowance is made in the construction estimate to cover the cost of such work.

Summary of estimate of cost of Columbia Basin project for ultimate development

Relevant data:	
Power-plant installation.....horsepower..	2, 100, 000
Primary power.....do....	1, 067, 000
Pumping plant installation.....do....	660, 000
Area to be irrigated.....acres..	1, 200, 000
Capacity primary pump installation.....c.f.s....	16, 000
Columbia River Dam.....	$125, 750, 000
Columbia River power plant.....	42, 616, 000
Total cost, dam and power plant.....	168, 366, 000
Primary pumping plant.....	8, 890, 000
Repumping plants.....	7, 525, 000
Grand Coulee Lake.....	8, 703, 000
Canals.....	79, 307, 000
Tunnels.....	22, 778, 000
Siphons.....	37, 595, 000
Lateral system.....	28, 516, 000
Drainage.....	4, 800, 000
Buildings.....	1, 484, 000
Telephones.....	240, 000
Wasteways.....	2, 230, 000
Wells.....	200, 000
Operation and maintenance during construction.....	5, 997, 000
Total cost of irrigation project.....	208, 265, 000
Total per acre cost irrigation project.....	173. 55
Total per acre cost irrigation project per year.....	4. 34
Total cost Columbia Basin project.....	376, 631, 000

First Unit Irrigation Development

The development of the first irrigation unit of 150,000 acres, known as the Quincy area, involves the least investment possible in pumping machinery, pipe lines, dams, canals, and structures necessary to give dependable service to the area, but at the same time includes all of the works required in the beginning so that every part of the initial investment, with the possible exception of the small dam and a short length of canal at Coulee City, will be utilized in the ultimate development of the irrigation project. It is proposed to develop this 150,000-acre unit in blocks of 20,000 acres per year, the first 20,000 acres to be irrigated the year following completion of construction of the Columbia River Dam. The character of the construction proposed is described by features which are shown on drawing no. 222-D-14,[31] as follows:

Feature no. 1.—The Columbia River Dam completed to full dimensions is required.

Feature no. 2.—The initial installation of the pumping plant requires the construction of the entire pump house substructure, the

[31] Not printed.

installation of the Gantry crane for handling the pumping machinery, and the installation of four pumping units. Each pumping unit consists of a vertical shaft, double suction, single stage, centrifugal pump of 800 c.f.s. capacity direct connected to a 35,000 horsepower synchronous motor. Each pump will be connected through a manifold to a steel discharge pipe 8½ feet in diameter and 750 feet in length, the upper end of which will discharge into the Grand Coulee Reservoir supply canal or feature no. 3. No repumping is contemplated for the initial irrigation unit.

Feature no. 3.—The canal leading from the end of the pipe line at the Columbia River Dam to the North Grand Coulee Dam in the Grand Coulee is to be constructed to dimensions required for the ultimate capacity of 16,000 c.f.s. and is to be lined throughout with reinforced concrete.

Feature no. 4.—The North Grand Coulee Dam in the Grand Coulee is to be constructed to the height and dimensions required for ultimate development or of height to store water to elevation 1570.

Feature no. 5-A.—At the south end of the Grand Coulee it is proposed to construct a small dam at what is known as the Coulee City dam site. This dam is to be constructed to the height necessary to supply sufficient water depth in the canal to irrigate the Quincy area. The construction of this dam allows the impounding of water in Grand Coulee to elevation 1542.5, and will provide a relatively inexpensive method of testing the watertightness of the Coulee. In case the leakage is found to be negligible with this test dam at Coulee City, the dam can then be enlarged to allow storage of water to elevation 1570 which is the elevation required for ultimate development. In case the water loss in Grand Coulee Reservoir is found to be excessive with the test dam at Coulee City, this site can be abandoned and a dam (feature no. 5) constructed at a site 4 miles further up the Coulee. In this event there will be a loss of $676,000 in the Coulee City Dam, additional right of way and incidental expenses, and a loss of $224,000 in the temporary canal and headworks described hereafter as feature no. 6-B. However, in case the dam at Coulee City proves successful, there will be no need for the more expensive dam further north (feature no. 5) and there will be a saving of $7,496,000 which is the difference between the cost of the upper dam and the longer canal (feature no. 6) leading to it as compared with the cost of the lower dam and its additional requirement for right of way and a shorter length of canal (feature no. 6-A plus feature no. 6-B).

Feature no. 6-B.—A temporary canal about 3,500 feet long branching from the proposed permanent canal (feature no. 6) which latter extends from the proposed permanent South Coulee Dam to Bacon Siphon, is to be constructed of sufficient dimensions without concrete lining to carry the water required (1,875 c.f.s.) to irrigate 150,000 acres.

Feature no. 6-A.—Only that portion of the canal (feature no. 6) will be constructed which extends from Bacon Siphon on the south to the above-mentioned temporary canal (feature no. 6-B) on the north. Feature no. 6-A is to be constructed of full dimensions required for the ultimate development, but the reinforced concrete lining is to be omitted in the initial development.

Feature no. 7.—The Bacon Siphon as proposed for ultimate development consists of two parallel lines of steel pipes supported upon con-

crete cradles and anchors. It is proposed to construct one line completely. This will give excess carrying capacity for the first unit, but when due consideration is given to the hydraulic properties of the canals required for ultimate development it is not believed that a better arrangement can be provided.

Feature no. 8.—The Bacon Tunnel as proposed for ultimate development consists of two parallel tunnels lined throughout with unreinforced concrete. The route of this tunnel line is through basalt rock. It is proposed to construct one tunnel to full dimensions. No concrete lining is proposed for the first unit and the tunnel will deliver the water required when running about one half full.

Feature no. 9.—The open canal between Bacon Tunnel and Trail Lake Tunnel is to be constructed to dimensions required for ultimate development, but the reinforced concrete lining is to be omitted.

Feature no. 10.—Trail Lake Tunnel as proposed for ultimate development consists of two parallel tunnels. The same plan is proposed for constructing Trail Lake Tunnel for unit development as was mentioned above.

Feature no. 11.—For the ultimate development of the project, a concrete structure is proposed at the point where the main canal branches into two parts, designated the Main West and the Main East Canal. No structure is proposed at this point for the first development as no part of the Main East Canal is to be built and the Main West Canal, which is to be constructed, is merely a continuation of the Main Canal.

Main West Canal.—The Main West Canal is to ultimately serve 371,000 acres. The first unit selected for development lies wholly under the Main West Canal. It is proposed to omit the construction of lateral W-1 and its branches, but lateral W-2 and lateral W-3, and branches of both these laterals, are to be constructed to full dimensions including reinforced concrete lining. The Main West Canal and all tunnels and siphons (features nos. 1 to 7, inclusive) are to be constructed for the ultimate capacity. Construction of the Main West Canal will stop at the point where lateral W-3 branches off the Main West about 7 miles east of Quincy.

As only a part of feature no. 8 is required, that portion which must be constructed to serve the first irrigation unit is designated as feature no. 8-A.

General items.—In the estimate which follows provision is made for the cost of the lateral system, drainage, wasteways, telephones, wells, buildings and operation and maintenance during construction

Summary of estimate of cost of first unit of Columbia Basin project

Relevant date:	
Power-plant installation ..... horsepower	2, 100, 000
Primary power ..... do	1, 067, 000
Pumping-plant installation ..... do	132, 000
Area to be irrigated ..... acres	150, 000
Capacity pump installation ..... cubic foot-seconds	3, 200
Columbia River Dam	$125, 750, 000. 00
Columbia River power plant	42, 616, 000. 00
Total cost, dam and power plant	168, 366, 000. 00

Summary of estimate of cost of first unit of Columbia Basin project—Continued

Primary pumping plant	$4, 004, 000. 00
Grand Coulee Lake	3, 820, 000. 00
Canals	13, 994, 000. 00
Tunnels	4, 338, 000. 00
Siphons	3, 770, 000. 00
Lateral system	3, 150, 000. 00
Drainage	600, 000. 00
Buildings	187, 000. 00
Telephones	30, 000. 00
Wasteways	270, 000. 00
Wells	26, 000. 00
Operation and maintenance during construction	750, 000. 00
Total cost of irrigation project	34, 939, 000. 00
Total per acre cost, irrigation project	232. 92
Total per acre cost, irrigation project per year	5. 82
Total cost, Columbia Basin project	203, 305, 000. 00

Estimates showing comparison of costs of different plans of Grand Coulee Reservoir together with the costs of changes in canals and headgates required for the various plans

Plan no. 1, using test dam at Coulee City:	
North Grand Coulee Dam	[33] $2,070,000
Right of way	[33] 1, 274, 000
Additional right of way required for test dam	[33] 275, 000
Coulee City test dam	[33] 201, 000
Raising Coulee City test dam	1, 634, 000
Temporary canal and headgate, feature no. 6-B	[34] 224, 000
Shorter length of main canal used (feature no. 6-A) with test dam	[34] 1, 926, 000
Concrete lining temporary canal and larger headgate for ultimate capacity if test dam proves satisfactory	436, 000
Total cost	5, 970, 000
Plan no. 2, using dam 4 miles above the test dam without first using test dam:	
North Grand Coulee Dam	2, 070, 000
Right of way	1, 274, 000
Upper south dam in Grand Coulee	4, 683, 000
Canal headgate (feature no. 6) leading to upper south dam	5, 439, 000
Total cost	13, 466, 000
Plan no. 3, using dam 4 miles above the test dam after first building the low-test dam of Coulee City and in case it proves unsatisfactory:	
North Grand Coulee Dam	[33] 2,070,000
Right of way	[33] 1, 274, 000
Additional right of way purchased for Coulee City test dam	[33] 275, 000
Coulee City test dam	[33] 201, 000
Temporary canal and headgate (feature no. 6-B)	[34] 224, 000
Emptying reservoir below elevation 1520 by pumping	[33] 200, 000
Upper South Dam in the Coulee	[33] 4, 683, 000
Canal and headgate (feature no. 6) leading to upper south dam	[34] 5, 439, 000
Total cost	14, 366, 000

[33] These items make up the total Grand Coulee Lake cost for ultimate development.
[34] These items are included in cost of canals for ultimate development.
If test dam and its enlargement is satisfactory, the saving over plan no. 2 is $7,496,000.
If the test dam is unsatisfactory, the extra expense involved is shown by the difference between plan no. 2 and plan no. 3, or $900,000.

Annual costs.—The annual depreciation, operation, and maintenance costs for the primary pumping plant have been set up on the same basis as for the power plant, using a 30-year average life for the depreciable items and 50 cents per kilowatt of capacity installed for operation and maintenance. The costs are summarized in the following tabulations:

FULL DEVELOPMENT

Depreciation:	
Cost of depreciable items	$5,896,597
Annuity required at 1.78301 percent	105,137
Operation and maintenance: 500,000 kilowatts at $0.50	250,000

INITIAL DEVELOPMENT

Depreciation:	
Cost of depreciable items	1,442,639
Annuity required at 1.78301 percent	25,722
Operation and maintenance: One third of ultimate $250,000	83,300

OPERATION AND MAINTENANCE COSTS

The following gives an analysis of the estimated annual operation and maintenance expense of the irrigation project and includes items for depreciation reserves to replace steel pipes, etc.:

Depreciation:	
Primary pumping plant and pipe line,[35] 1.78 percent of $5,896,597	$105,137
Repumping power plants, pumping plants, [35] 1.78 percent of $7,525,159 and transmission lines	133,747
Depreciation on buildings, 5 percent per annum on $1,499,000	74,950
Depreciation on telephones,[35] 1.78 percent of $240,000	4,272
Depreciation on pipe siphons and penstocks, [35] 1.78 percent of $22,538,800	401,190
Total depreciation	719,296
Total depreciation per acre	.60
Operation and maintenance:	
Primary pumping plant at 50 cents per kilowatt	250,000
Secondary power plants at $2 per kilowatt (26,000)	52,000
Secondary pumping plants at $3 per kilowatt (26,000)	78,000
Transmission lines at $50 per mile (330 miles)	16,500
Telephone lines at $25 per mile (330 miles)	10,000
Total operation and maintenance exclusive of irrigation distribution system	406,500
Total operation and maintenance exclusive of irrigation distribution system, per acre	.34
Total of depreciation and operation and maintenance exclusive of irrigation distribution system	1,125,796
Per acre for 1,199,430 acres	.94
Purchase of electricity for primary pumping at $1 per acre per annum	1.00
Operation and maintenance of irrigation distribution system per acre	1.25
Total annual charges exclusive of construction repayment	3.19

[35] Assuming 30-year life and an annuity set aside at 4 percent, requires 1.78 percent per annum on depreciable item.

ANNUAL CONSTRUCTION REPAYMENTS

In the financial study (table no. 6) to determine how the investment is to be repaid it has been estimated that the land, beginning 4 years after the completion of the Columbia River Dam and power plant, and 4 years after the beginning of irrigation of each completed division, will pay $2 per acre per year for 4 years and thereafter pay $2.50 per acre per year for 32 years. In this manner each division or block of

and irrigated will pay out in 40 years an amount which, when added to the estimated proportional power surplus, will liquidate its proportionate share of the irrigation investment.

TABLE No. 6.—*Financial operation of irrigation development*

Year after completion of dam	Acres settled	Repayments from lands		Repayment from power surplus at 2.25 mills per kilowatt-hour	Total repayment for year	Total cost of irrigation construction at beginning of year
		Fifth to eighth year after settlement at $2 per acre	Ninth to fortieth year after settlement at $2.50 per acre			
1	20,000					$33,822,000
2	40,000					34,605,000
3	60,000					35,354,000
4	80,000					36,269,000
5	100,000	$40,000			$40,000	37,244,000
6	120,000	80,000			80,000	38,175,000
7	140,000	120,000			120,000	38,712,000
8	160,000	160,000			160,000	40,018,000
9	180,000	160,000	$50,000		210,000	41,602,000
10	200,000	160,000	100,000		260,000	41,886,000
11	220,000	160,000	150,000		310,000	45,213,000
12	240,000	160,000	200,000	$524,958	884,958	48,540,600
13	260,000	160,000	250,000	1,399,259	1,809,259	51,868,200
14	280,000	160,000	300,000	2,470,009	2,930,009	55,195,800
15	300,000	160,000	350,000	3,540,759	4,050,759	58,523,400
16	320,000	160,000	400,000	3,560,759	4,120,759	61,851,000
17	340,000	160,000	450,000	3,580,759	4,190,759	65,178,600
18	360,000	160,000	500,000	3,600,759	4,260,759	68,506,200
19	380,000	160,000	550,000	3,620,759	4,330,759	71,833,800
20	400,000	160,000	600,000	3,640,759	4,400,759	75,161,400
21	420,000	160,000	650,000	3,660,759	4,470,759	78,489,000
22	440,000	160,000	700,000	3,680,759	4,540,759	81,816,600
23	460,000	160,000	750,000	3,700,759	4,610,759	85,144,200
24	480,000	160,000	800,000	3,720,759	4,680,759	88,471,800
25	500,000	160,000	850,000	3,740,759	4,750,759	91,799,400
26	520,000	160,000	900,000	3,760,759	4,820,759	95,127,000
27	540,000	160,000	950,000	3,780,759	4,890,759	98,454,600
28	560,000	160,000	1,000,000	3,800,759	4,960,759	101,782,200
29	580,000	160,000	1,050,000	3,820,759	5,030,759	105,109,800
30	600,000	160,000	1,100,000	3,840,759	5,100,759	108,437,400
31	620,000	160,000	1,150,000	3,860,759	5,170,759	111,765,000
32	640,000	160,000	1,200,000	3,880,759	5,240,759	115,092,600
33	660,000	160,000	1,250,000	3,900,759	5,310,759	118,420,200
34	680,000	160,000	1,300,000	3,920,759	5,380,759	121,747,800
35	700,000	160,000	1,350,000	3,940,759	5,450,759	125,075,400
36	720,000	160,000	1,400,000	3,960,759	5,520,759	128,403,000
37	740,000	160,000	1,450,000	3,980,759	5,590,759	131,730,600
38	760,000	160,000	1,500,000	4,000,759	5,660,759	135,058,200
39	780,000	160,000	1,550,000	4,020,759	5,730,759	138,385,800
40	800,000	160,000	1,600,000	3,793,990	5,553,990	141,713,400
41	820,000	160,000	1,600,000		1,760,000	145,041,000
42	840,000	160,000	1,600,000		1,760,000	148,368,600
43	860,000	160,000	1,600,000		1,760,000	151,696,200
44	880,000	160,000	1,600,000		1,760,000	155,023,800
45	900,000	160,000	1,600,000		1,760,000	158,351,400
46	920,000	160,000	1,600,000		1,760,000	161,679,000
47	940,000	160,000	1,600,000		1,760,000	165,006,600
48	960,000	160,000	1,600,000		1,760,000	168,334,200
49	980,000	160,000	1,600,000		1,760,000	171,661,800
50	1,000,000	160,000	1,600,000		1,760,000	174,989,400
51	1,020,000	160,000	1,600,000		1,760,000	178,317,000
52	1,040,000	160,000	1,600,000		1,760,000	181,644,600
53	1,060,000	160,000	1,600,000		1,760,000	184,972,200
54	1,080,000	160,000	1,600,000		1,760,000	188,299,800
55	1,100,000	160,000	1,600,000		1,760,000	191,627,400
56	1,120,000	160,000	1,600,000		1,760,000	194,955,000
57	1,140,000	160,000	1,600,000		1,760,000	198,282,600
58	1,160,000	160,000	1,600,000		1,760,000	201,610,200
59	1,180,000	160,000	1,600,000		1,760,000	204,937,800
60	1,199,430	160,000	1,600,000		1,760,000	208,265,400
61	1,199,430	160,000	1,600,000		1,760,000	208,265,400
62	1,199,430	160,000	1,600,000		1,760,000	208,265,400
63	1,199,430	160,000	1,600,000		1,760,000	208,265,400
64	1,199,430	158,860	1,600,000		1,758,860	208,265,400
65	1,199,430	118,860	1,600,000		1,718,860	208,265,400
66	1,199,430	78,860	1,600,000		1,678,860	208,265,400
67	1,199,430	38,860	1,600,000		1,638,860	208,265,400
68	1,199,430		1,598,575		1,598,575	208,265,400
69	1,199,430		1,548,575		1,548,575	208,265,400

TABLE NO. 6.—*Financial operation of irrigation development*—Continued

Year after completion of dam	Acres settled	Repayments from lands		Repayment from power surplus at 2.25 mills per kilowatt-hour	Total repayment for year	Total cost of irrigation construction at beginning of year
		Fifth to eighth year after settlement at $2 per acre	Ninth to fortieth year after settlement at $2.50 per acre			
70	1,199,430		$1,498,575		$1,498,575	$208,265,400
71	1,199,430		1,448,575		1,448,575	208,265,400
72	1,199,430		1,398,575		1,398,575	208,265,400
73	1,199,430		1,348,575		1,348,575	208,265,400
74	1,199,430		1,298,575		1,298,575	208,265,400
75	1,199,430		1,248,575		1,248,575	208,265,400
76	1,199,430		1,198,575		1,198,575	208,265,400
77	1,199,430		1,148,575		1,148,575	208,265,400
78	1,199,430		1,098,575		1,098,575	208,265,400
79	1,199,430		1,048,575		1,048,575	208,265,400
80	1,199,430		998,575		998,575	208,265,400
81	1,199,430		948,575		948,575	208,265,400
82	1,199,430		898,575		898,575	208,265,400
83	1,199,430		848,575		848,575	208,265,400
84	1,199,430		798,575		798,575	208,265,400
85	1,199,430		748,575		748,575	208,265,400
86	1,199,430		698,575		698,575	208,265,400
87	1,199,430		648,575		648,575	208,265,400
88	1,199,430		598,575		598,575	208,265,400
89	1,199,430		548,575		548,575	208,265,400
90	1,199,430		498,575		498,575	208,265,400
91	1,199,430		448,575		448,575	208,265,400
92	1,199,430		398,575		398,575	208,265,400
93	1,199,430		348,575		348,575	208,265,400
94	1,199,430		298,575		298,575	208,265,400
95	1,199,430		248,575		248,575	208,265,400
96	1,199,430		198,575		198,575	208,265,400
97	1,199,430		148,575		148,575	208,265,400
98	1,199,430		98,575		98,575	208,265,400
99	1,199,430		48,575		48,575	208,265,400
100	1,199,430					208,265,400

Year after completion of dam	Cost of irrigation construction during year	Investment remaining in irrigation development at end of year	Return from power surplus available for other purposes	Accumulated return from power surplus used for repayment of irrigation	Accumulated average return per acre from power surplus for 1,199,430 acres	Accumulated return from power surplus available for other purposes
1	$783,000	$34,605,000				
2	749,000	35,354,000				
3	915,000	36,269,000				
4	975,000	37,244,000				
5	931,000	38,135,000				
6	537,000	38,592,000				
7	1,306,000	39,778,000				
8	1,584,000	41,202,000				
9	284,000	41,276,000				
10	3,327,000	44,343,000				
11	3,327,600	47,360,600				
12	3,327,600	49,803,242		$524,958	$0.44	
13	3,327,600	51,321,583		1,924,217	1.60	
14	3,327,600	51,719,174		4,394,226	3.66	
15	3,327,600	50,996,015		7,934,985	6.62	
16	3,327,600	50,202,856		11,495,744	9.58	
17	3,327,600	49,339,697		15,076,503	12.57	
18	3,327,600	48,406,538		18,677,262	15.57	
19	3,327,600	47,403,379		22,298,021	18.59	
20	3,327,600	46,330,220		25,938,780	21.63	
21	3,327,600	45,187,061		29,599,539	24.68	
22	3,327,600	43,973,902		33,280,298	27.75	
23	3,327,600	42,690,743		36,981,057	30.83	
24	3,327,600	41,337,584		40,701,816	33.93	
25	3,327,600	39,914,425		44,442,575	37.05	
26	3,327,600	38,421,266		48,203,334	40.19	
27	3,327,600	36,858,107		51,984,093	43.34	
28	3,327,600	35,224,948		55,784,852	46.51	
29	3,327,600	33,521,789		59,605,611	49.69	
30	3,327,600	31,748,630		63,446,370	52.90	

TABLE NO. 6.—*Financial operation of irrigation development*—Continued

Year after completion of dam	Cost of irrigation construction during year	Investment remaining in irrigation development at end of year	Return from power surplus available for other purposes	Accumulated return from power surplus used for repayment of irrigation	Accumulated average return per acre from power surplus for 1,199,430 acres	Accumulated return from power surplus available for other purposes
31	$3,327,600	$29,905,471		$67,307,129	$56.12	
32	3,327,600	27,992,312		71,187,888	59.35	
33	3,327,600	26,009,153		75,088,647	62.60	
34	3,327,600	23,955,994		79,009,406	65.87	
35	3,327,600	21,832,835		82,950,165	69.16	
36	3,327,600	19,639,676		86,910,924	72.46	
37	3,327,600	17,376,517		90,891,683	75.78	
38	3,327,600	15,043,358		94,892,442	79.11	
39	3,327,600	12,640,199		98,913,201	82.47	
40	3,327,600	10,413,809	$246,769	102,707,191	85.63	$246,769
41	3,327,600	11,981,409	4,060,759	102,707,191	85.63	4,307,528
42	3,327,600	13,549,009	4,080,759	102,707,191	85.63	8,388,287
43	3,327,600	15,116,609	4,100,759	102,707,191	85.63	12,489,046
44	3,327,600	16,684,209	4,120,759	102,707,191	85.63	16,609,805
45	3,327,600	18,251,809	4,140,759	102,707,191	85.63	20,750,564
46	3,327,600	19,819,409	4,160,759	102,707,191	85.63	24,911,323
47	3,327,600	21,387,009	4,180,759	102,707,191	85.63	29,092,082
48	3,327,600	22,954,609	4,200,759	102,707,191	85.63	33,292,841
49	3,327,600	24,522,209	4,220,759	102,707,191	85.63	37,513,600
50	3,327,600	26,089,809	4,240,410	102,707,191	85.63	41,754,359
51	3,327,600	27,657,409	15,054,113	102,707,191	85.63	56,808,472
52	3,327,600	29,225,009	15,074,113	102,707,191	85.63	71,882,585
53	3,327,600	30,792,609	15,094,113	102,707,191	85.63	86,976,698
54	3,327,600	32,360,209	15,114,113	102,707,191	85.63	102,090,811
55	3,327,600	33,927,809	15,134,113	102,707,191	85.63	117,224,924
56	3,327,600	35,495,409	15,154,113	102,707,191	85.63	132,379,037
57	3,327,600	37,063,009	15,174,113	102,707,191	85.63	147,553,150
58	3,327,600	38,630,609	15,194,113	102,707,191	85.63	162,747,263
59	3,327,600	40,198,209	15,214,113	102,707,191	85.63	177,961,376
60		38,438,209	15,233,543	102,707,191	85.63	193,194,919
61		36,678,209	15,233,543	102,707,191	85.63	208,428,462
62		34,918,209	15,233,543	102,707,191	85.63	223,662,005
63		33,158,209	15,233,543	102,707,191	85.63	238,895,548
64		31,399,349	15,233,543	102,707,191	85.63	254,129,091
65		29,680,489	15,233,543	102,707,191	85.63	269,362,634
66		28,001,629	15,233,543	102,707,191	85.63	284,596,177
67		26,362,769	15,233,543	102,707,191	85.63	299,829,720
68		24,764,194	15,233,543	102,707,191	85.63	315,063,263
69		23,215,619	15,233,543	102,707,191	85.63	330,296,806
70		21,717,044	15,233,543	102,707,191	85.63	345,530,349
71		20,268,469	15,233,543	102,707,191	85.63	360,763,892
72		18,869,894	15,233,543	102,707,191	85.63	375,997,435
73		17,521,319	15,233,543	102,707,191	85.63	391,230,978
74		16,222,744	15,233,543	102,707,191	85.63	406,464,521
75		14,974,169	15,233,543	102,707,191	85.63	421,698,064
76		13,775,594	15,233,543	102,707,191	85.63	436,931,607
77		12,627,019	15,233,543	102,707,191	85.63	452,165,150
78		11,528,444	15,233,543	102,707,191	85.63	467,398,693
79		10,479,869	15,233,543	102,707,191	85.63	482,632,236
80		9,481,294	15,233,543	102,707,191	85.63	497,865,779
81		8,532,719	15,233,543	102,707,191	85.63	513,099,322
82		7,634,144	15,233,543	102,707,191	85.63	528,332,865
83		6,785,569	15,233,543	102,707,191	85.63	543,566,408
84		5,986,994	15,233,543	102,707,191	85.63	558,799,951
85		5,238,419	15,233,543	102,707,191	85.63	574,033,494
86		4,539,844	15,233,543	102,707,191	85.63	589,267,037
87		3,891,269	15,233,543	102,707,191	85.63	604,500,580
88		3,292,694	15,233,543	102,707,191	85.63	619,734,123
89		2,744,119	15,233,543	102,707,191	85.63	634,967,666
90		2,245,544	15,233,543	102,707,191	85.63	650,201,209
91		1,796,969	15,233,543	102,707,191	85.63	665,434,752
92		1,398,394	15,233,543	102,707,191	85.63	680,668,295
93		1,049,819	15,233,543	102,707,191	85.63	695,901,838
94		751,244	15,233,543	102,707,191	85.63	711,135,381
95		502,669	15,233,543	102,707,191	85.63	726,368,924
96		304,094	15,233,543	102,707,191	85.63	741,602,467
97		155,519	15,233,543	102,707,191	85.63	756,836,010
98		56,944	15,233,543	102,707,191	85.63	772,069,553
99		8,369	15,233,543	102,707,191	85.63	787,303,096
100			15,233,543	102,707,191	85.63	802,536,639

TOTAL ANNUAL COST OF IRRIGATION

The total annual cost of irrigation benefits are estimated at $3.19 for the first 4 years, if a depreciation reserve is provided. If no depreciation reserve is provided, the cost is $2.59 per acre.

With $2 per acre for construction beginning the fifth year and continuing to and including the eighth year, the total annual cost for irrigation excluding depreciation will be $4.59 per acre. Continuing thereafter for 32 years the annual cost will be $5.09 per acre.

When the construction payments from the land are added to the proportionate share of the estimated surplus power revenue, the combined receipts from irrigation and power will not only liquidate the investment for each division or block of land irrigated within the 40-year period from the time each division is first irrigated, but there will be sufficient surplus power revenue accruing during the 40 years subsequent to the completion of the Columbia River Dam to liquidate about one half of the entire irrigation investment required for the ultimate project of 1,199,430 acres.

ABILITY OF LAND TO PAY FOR IRRIGATION BENEFITS

The lands to be irrigated on the project are well adapted to the production of alfalfa, sweetclover, potatoes, corn, and small grains. It is expected that the farm production will be largely fed to livestock and converted into beef, pork, and mutton. Dairying and poultry raising will also find a place in the farm program. With a proper rotation program and with a normal price relation between products of the farm marketed and those purchased, it is expected that the land will be able to meet an annual charge of not to exceed $5.25 per acre for irrigation benefits.

PAYMENTS BY OTHER BENEFITED INTERESTS

While the foregoing charges are assumed to be borne entirely by the land and can only be realized by providing interest-free money for the entire irrigation investment and by assuming that about one half of the irrigation investment is repaid from surplus power revenues, there are other interests than irrigation which will be greatly benefited by the proposed development and the charges accruing against the land might be reduced by applying an ad valorem tax to all property benefited within the irrigation district as provided by Washington State law.

POWER MARKET

Market area.—The market area in which the power from the proposed Columbia River development would have to be absorbed includes the area within a radius of approximately 300 miles of the dam site, which includes all of the State of Washington, the northern part of Oregon, the northern part of Idaho, and the western part of Montana. Drawing no. 222-D-23[31] is a map of this area showing the principal power systems operating therein. The most important power market in this territory is the Puget Sound district in western Washington, which is the logical market for a large part of the Colum-

[31] Not printed.

bia River power. Following is a list of the principal power systems serving this territory:

Municipalities:
- City of Seattle.
- City of Tacoma.
- City of Centralia.

Utility companies:
- Puget Sound Power & Light Co.
- The Washington Water Power Co.
- Pacific Power & Light Co.
- Mountain States Power Co.
- Grays Harbor Railway & Light Co.
- Willapa Electric Co.
- Western Washington Electric Light & Power Co.
- Olympic Public Service Co.
- Washington Gas & Electric Co.
- The Montana Power Co.

Manufacturing Companies:
- Crown-Zellerbach Corporation.
- Weyerhaeuser Timber Co.

The city of Seattle has been operating a municipal power system since 1905 and now supplies about 75 percent of the consumers in the city. The city has 4 hydroelectric plants with a total installed capacity of 98,300 kilowatts and 1 steam-electric plant of 30,000 kilowatts capacity, making a total combined capacity of 128,300 kilowatts. The systems of Seattle and Tacoma are interconnected through a 66,000-volt transmission line which has a capacity of approximately 15,000 kilowatts. Power from the city's hydroelectric development on the Skagit River is transmitted to the city over a 165,000-volt transmission line 100 miles in length.

The city of Tacoma has a municipal power system which has been in service since 1893, and this system now serves the entire city. The city's generating facilities consist of 3 hydroelectric plants having a combined installation of 116,000 kilowatts and 2 steam-electric plants having a combined capacity of 34,000 kilowatts, making a total capacity of 150,000 kilowatts. The city's system is interconnected with the city of Seattle and with the Puget Sound Power & Light Co. Power from the city's Lake Cushman hydroelectric development is transmitted at 110,000 volts over a line about 35 miles in length.

The city of Centralia completed the initial installation of 4,000 kilowatts in a hydroelectric power plant in 1930. The ultimate capacity of this development is 11,000 kilowatts. Power is transmitted to the city over a 66,000-volt transmission line 25 miles in length.

The Puget Sound Power & Light Co., which operates under the supervision of Stone & Webster, Inc., serves the western part of Washington, including the cities of Seattle, Bellingham, Everett, Olympia, Chehalis, Bremerton, and Wenatchee. The power system includes 15 hydroelectric plants having a combined installed capacity of 156,735 kilowatts and 7 steam-electric plants having a combined installed capacity of 112,000 kilowatts, making a total installed capacity of 268,735 kilowatts. This system is interconnected with the Washington Water Power Co. on the east and also with the city of Tacoma, the Washington Pulp & Paper Corporation, the Northwestern Electric Co., Western Canada Power Co., Great Northern Railway, Weyerhaeuser Timber Co., and with the United States

navy yard at Bremerton. In 1931 the initial installation, consisting of two units of 15,000 kilowatts capacity each, in the new hydroelectric development at Rock Island on the Columbia River was placed in service. This development is planned for an ultimate installation of 150,000 kilowatts. Power is transmitted from this plant to the Puget Sound district over 110,000-volt lines.

The Washington Water Power Co. is controlled by the American Power & Light Co., which in turn belongs to the Electric Bond & Share Co. group of properties. This company operates in eastern Washington and northern Idaho and has 13 hydroelectric power plants with a combined generating capacity of 205,584 kilowatts. The company is interconnected with the Pacific Power & Light Co., the Montana Power Co., Puget Sound Power & Light Co., Mountain States Power Co., Stevens County Power & Light Co., and the Chicago, Milwaukee & St. Paul Railroad. The company has a large hydroelectric plant at Chelan Falls, where two units of 24,000 kilowatts' capacity each are now installed and where an additional 72,000 kilowatts can be developed by the installation of additional units as may be required to meet the growth in load.

The Pacific Power & Light Co. operates in southern Washington, northern Oregon, and northern Idaho. It is controlled by the American Power & Light Co. and belongs to the Electric Bond & Share Co. group of properties. The system comprises 5 hydroelectric plants having a combined installed capacity of 13,500 kilowatts and 2 steam-electric plants having a combined capacity of 3,000 kilowatts, making a total capacity of 16,500 kilowatts. The system is interconnected with the Washington Water Power Co. and with the Northwestern Electric Co.

The Mountain States Power Co. operates in northwestern Washington, western Oregon, and northern Idaho. It is controlled by the Standard Gas & Electric Co., which in turn belongs to the H. M. Byllesby & Co. group of properties. The company has a small power plant at Sandpoint, Idaho, with an installed capacity of 500 kilowatts and obtains most of the energy required on this system from the Washington Water Power Co. over a 66,000-volt interconnection.

The Federal Light & Traction Co., a subsidiary of the Cities Service Co., owns and operates a number of small power systems along the west coast of Washington. These properties include the Grays Harbor Railway & Light Co., the Willapa Electric Co., the Western Washington Electric Light & Power Co., and the Olympic Public Service Co. They have a total generating capacity of 13,186 kilowatts, of which 12,900 kilowatts is steam-electric and 286 kilowatts is Diesel-electric. Additional power is obtained from lumber mills in the immediate vicinity and from the Puget Sound Power & Light Co.

The Washington Gas & Electric Co. operates in the vicinity of Longview, Wash. The company is controlled by the North American Gas & Electric Co. It has a steam-electric plant at Longview having a capacity of 24,000 kilowatts.

The Montana Power Co. is controlled by the American Power & Light Co. and belongs to the Electric Bond & Share group of properties. The western part of the Montana Power Co. system in the extreme western part of the State of Montana is in the territory considered as the market area for the Columbia River power. The Thompson Falls hydroelectric plant, which is located in this territory, has an installed capacity of 35,000 kilowatts. This plant is intercon-

nected with the Washington Water Power Co. on the west and with the main system of the Montana Power Co. on the east through the Chicago, Milwaukee & St. Paul Railway Co.'s lines.

The Crown-Zellerbach Corporation, which is engaged in the paper industry, has 2 hydroelectric plants having a combined capacity of 25,000 kilowatts and 6 steam-electric plants having a combined capacity of 30,150 kilowatts, making a total installed capacity of 55,150 kilowatts. This company has interconnections with the Puget Sound Power & Light Co. The Washington Pulp & Paper Corporation is the largest subsidiary of the Crown-Zellerbach group in Washington.

The Weyerhaeuser Timber Co. is engaged in the lumber industry in the Northwest. It has three important steam-electric generating stations having a total installed capacity of 29,000 kilowatts.

Future increase in power usage.—During the 10-year period ending with 1930 the requirements for power, as shown in table no. 7, in the territory within a radius of 300 miles of the proposed Columbia River development have been increasing at an average rate of 9.5 percent per year, compounded annually. The population of this territory is approximately 3,000,000, or about the same as the northern portion of California, and the energy generated during 1930 was approximately 85 percent of the amount required to supply the Northern California market. A study was made of the Northern California power market in 1928 by Mr. Lester S. Ready, consulting engineer of San Francisco, Calif., in connection with the proposed Kennett Reservoir development on the Sacramento River, a report on which was published as Bulletin No. 20 of Department of Public Works of the State of California. In that report it was estimated that the future growth in load in Northern California would be at a reducing percentage, ranging from approximately 7 percent in 1928 to as low as 4 percent about 1950.

TABLE NO. 7.—*Power market*

Data for power market, which includes the area within a 300-mile radius of the proposed damsite, and all of Oregon]

Year	Power output in millions of kilowatt-hours			Average load in kilowatts	Peak load in kilowatts	Installed capacity in kilowatts
	Market area excluding Oregon	Total for Oregon	Total for market area			
1	2	3	4	5	6	7
1917	[2] 964	[3] 325	[4] 1,289	[5] 147,146	[6] 294,292	[7] 364,987
1920	1,309	476	1,785	203,767	407,534	432,145
1921	1,175	469	1,644	187,671	375,342	437,645
1922	1,294	513	1,807	206,279	412,558	486,245
1923	1,548	594	2,142	244,520	489,040	517,660
1924	1,633	678	2,311	263,813	527,626	535,458
1925	1,701	730	2,431	277,511	555,022	643,868
1926	2,020	831	2,851	325,457	650,914	717,022
1927	2,278	845	3,123	356,507	713,014	768,082
1928	2,569	1,041	3,610	412,100	824,200	829,215
1929	2,705	1,161	3,866	441,324	882,648	921,025
1930	2,811	1,219	4,030	460,046	920,092	974,860

[2] Figures in column 2 were compiled from reports of the Puget Sound Power & Light Co., City of Seattle, City of Tacoma, Washington Pulp & Paper Corporation, Gray's Harbor Railway & Light Co., Pacific Power & Light Co., (the Thompson Falls plant of the Montana Power Co., the Washington Water Power Co. which includes the Lewiston and Grangeville plants in northern Idaho, all associated companies and their predecessor companies).

[3] Figures in column 3 were taken directly from the reports of the U.S. Geological Survey.

[4] Figures in column 4 are the total of those in columns 2 and 3.

[5] Figures in column 5 were derived from those in column 4.

[6] Figures in column 6 were derived from those in column 5 by assuming a 50-percent load factor.

[7] Figures in column 7 were compiled from reports of the companies mentioned in footnote 2, together with data obtained from reports of the U.S. Geological Survey for the State of Oregon.

The Seattle district engineer, Corps of Engineers, United States Army, made a very comprehensive investigation of the power-market situation in the Northwest and in a report on the Columbia River dated July 31, 1931, estimated that the future increase in power requirements would be at a gradually reduced rate of increase starting with a rate of increase of 9.5 percent in 1930, decreasing to 4.75 percent in 1960 and finally reaching zero in 1990. This estimate of load growth is shown graphically by curves A on drawing no. 222-D-6.[31]

For the purposes of this study a somewhat more conservative assumption has been used in regard to future increase in power requirements. A gradually decreasing rate of increase has been assumed beginning with 8 percent in 1930 and decreasing to 4 percent in 1960. This is shown graphically by curves B on drawing no. 222-D-6.[31]

Absorption of Columbia River power.—The installed-generator capacity in the territory in which the power from the proposed Columbia River development would have to be absorbed now amounts to a little over 1,000,000 kilowatts, and if the load continues to increase in the next decade as it has in the past, but at a gradually reduced rate of increase as suggested above, the installed capacity will have to be doubled by 1940 in order to supply the demand. Practically all of the major hydroelectric developments on which construction has been started by the various power companies and municipalities will have been absorbed by 1940, which is the earliest date that power from the Columbia River development could be made available.

Assuming that the power load continues to increase after 1940 in accordance with curves B on drawing no. 222-D-6,[31] there would be required a total of 5,000,000 kilowatts of generating capacity by 1955. The additional generating capacity that would have to be provided during the 15-year period 1940 to 1955 would amount to about 3,000,000 kilowatts, whereas the proposed installation at the Columbia River power plant is 1,500,000 kilowatts. In other words, the proposed installation of 1,500,000 kilowatts would take care of approximately half of the expected increase in power requirements during the 15-year absorption period. The other half of the expected increase would have to be supplied by other hydro or steam development.

The total amount of energy generated in the territory in which the output of the proposed power plant would have to be utilized amounted to 4,030,000,000 kilowatt-hours in 1930. If the energy requirements continue to increase in the future as they have in the past 10 years, but at a gradually reducing rate of increase, as indicated by curves B on drawing no. 222-D-6,[31] the total amount of energy generated will be approximately 8,000,000,000 kilowatt-hours in 1940, and this will have increased to over 20,000,000,000 kilowatt-hours in 1955. The annual energy requirements will have increased 12,000,000,000 kilowatt-hours in the 15-year period from 1940 to 1955, during which it is assumed that the energy output of the Columbia River power plant will be absorbed. The total amount of firm energy which this plant will make available will be 7,000,000,000 kilowatt-hours per year, which amount will be sufficient to meet

[31] Not printed.

more than half the expected increase in the 15-year absorption period. The remainder would have to be supplied from other sources.

With proper cooperation on the part of the various power companies and municipalities which will have to absorb the power output of the proposed Columbia River development, no serious difficulty should arise in connection with the absorption of this large block of power within 15 years after the initial installation is completed, and it might be possible that the full output could be absorbed in a shorter time. The economic feasibility of the project is dependent to a very large degree on the rapidity of absorption of the power, particularly during the early years of operation, when the revenues from power will be insufficient to meet the annual expense and deficits will be inevitable.

COMPETITIVE POWER

The economic limitations of transmission of electric power over high-voltage transmission lines make it necessary that the power to be developed at the proposed Columbia River Dam be utilized within a radius of approximately 300 miles. Under certain special conditions surplus power available at the Columbia River Dam might be used in lieu of power from other sources and thereby release the latter for use elsewhere in more distant markets, but such an arrangement would be used only as a means of utilizing surplus energy and would have little effect on the price of firm power.

The Pacific Northwest is estimated to have 38 percent of the total potential water power in the United States, and quite naturally the present power requirements are supplied largely from hydro sources. The installed generator capacity in this territory is now a little over 1,000,000 kilowatts, of which about 28 percent is in steam plants and the remainder, or about 72 percent, in hydro plants. Previous to 1929 the steam plants produced about 5 percent of the total energy while in 1929, due to low stream flow, the output of the steam plants increased to 14.5 percent, and in 1930 it was about 10.4 percent of the total power generated.

It is probable that a large part of the additional power installations in the Northwest during the next decade will be hydro rather than steam, as all of the large power companies and the municipalities which have power systems have hydro developments planned and partially developed. The Puget Sound Power & Light Co. has the Rock Island development on the Columbia River, where an additional 120,000 kilowatts can be installed; the capacity of the Lake Chelan development of the Washington Water Power Co. can be increased by 70,000 kilowatts by the installation of additional generating units; the Inland Power & Light Co. has a development on the Lewis River where 160,000 kilowatts will be developed ultimately.

The city of Seattle has its Skagit River development under way where some 780,000 kilowatts can be developed ultimately, which is expected to meet the needs of the city during the next 15 years. The city of Tacoma has its Cushman development, the capacity of which can be increased by 100,000 kilowatts. The proposed hydroelectric development which the Montana Power Co. has planned at the outlet of Flathead Lake will add about 100,000 kilowatts to the generating facilities of that system.

Naturally the smaller hydro developments located close to the load centers and which were easy and cheap to construct were undertaken first and up to the present time the tremendous potential resources of the larger rivers have offered blocks of power so large compared to the needs of the systems as to be unfeasible economically. The rapid growth of power demands has now reached a point where the larger developments are economically feasible with the result that such projects as the Rock Island on the Columbia River, the Ariel on the Lewis River, and Diablo on the Skagit River are being undertaken.

By the time the initial installation at the proposed Columbia River Dam is placed in service most of the hydro developments which are now being constructed by the various power companies and municipalities will be completed and the Columbia River power will have to compete in price with power from additional developments which will be more costly than those now under construction and which are located farther from the market and consequently will involve more costly transmission facilities and also with power produced in large modern steam-generating stations located near the load centers and using the cheapest fuel obtainable.

Under present conditions in the Northwest, hydro power can be delivered at load centers at somewhat less cost than steam power as evidenced by the fact that the new developments planned for the immediate future are all hydro, but as the distances that the hydro power must be transmitted become greater and as the cost of construction of the hydro plants becomes greater due to the more difficult and expensive projects being left for later development, coupled with the downward trend of steam-plant costs and the steady improvement in steam-plant efficiencies, the present narrow margin between the cost of hydro and steam power is constantly becoming smaller and it seems probable that by the time power from the proposed development on the Columbia River at the head of Grand Coulee becomes available the cost of steam power rather than the cost of hydro power from other sources will determine the value of the Columbia River power.

Value of power as determined by the cost of steam-electric power.—During recent years there has been a very marked improvement in the efficiency of steam-generating stations and it is to be expected that this trend will continue in the future. Large modern steam plants are now capable of producing 480 kilowatt-hours per barrel of fuel oil when operating at 60 percent load factor which corresponds to a thermal efficiency of about 13,000 B.t.u. per kilowatt-hour. It seems probable that the thermal efficiency may be improved in the near future so that a kilowatt-hour will require not more than 12,000 B.t.u.

There is an ample supply of coal available in the Northwest and several of the smaller steam plants are operating on refuse from the lumber industry. The available supply of natural gas is too limited to make this fuel a factor in determining the cost of steam power. The Shuffleton steam plant of the Puget Sound Power & Light Co. located on Lake Washington, which is the largest and most modern plant in the Northwest, and which is designed so that it can be readily converted to utilize hogged fuel (lumber refuse) or pulverized coal, is now burning fuel oil which, under present conditions, is the

cheapest fuel obtainable in sufficient quantities for large central-station use.

The price of fuel is the most important single factor affecting the cost of steam power and the question of future price of fuel oil is impossible of determination for any period of time. At present the average price of fuel oil in southern California fields is 70 to 80 cents per barrel. The cost of transporting fuel oil in tankers from southern California to Puget Sound ports amounts to about 25 cents per barrel and the cost delivered is about $1 per barrel or slightly less. This is less than the present cost of the equivalent quantity of coal.

The California conservation law which went into effect during the summer of 1929 requires the beneficial use of natural gas as a condition to the production of oil and this has resulted in marked reductions in the price of gas, in some instances down to the equivalent of oil at about 50 cents per barrel. Naturally, this low price for natural gas has had considerable effect on the price of fuel oil. It seems fair to assume that the condition of over-production and consequent low price of fuel oil will prove to be temporary and it is the general consensus of opinion that over a long period of time the price of fuel oil will increase rather than decrease. The depletion of nearby oil fields and natural-gas supplies, improvements in the processes for obtaining gasoline from fuel oil which will have a tendency to decrease the fuel-oil residue, together with the general governmental policy of conservation and restriction of production, will all tend toward this end.

Considering the present price of fuel oil and that as noted above, these prices are more likely to increase rather than decrease; a price of $1 per barrel delivered at Puget Sound ports has been used as a basis for determining the cost of steam power.

The largest and most efficient steam-power plant on the West coast is the Long Beach no. 3 plant of the Southern California Edison Co. which is designed for an ultimate installation of four units of 100,000-kilowatt capacity each. This plant is equipped for using either natural gas or fuel oil and is arranged so that coal-burning equipment can be installed later if it should develop that such fuel is more economical. The steam pressure is 400 pounds and the temperature of the steam is 700° F. At 100 percent load factor this plant produces a little better than 490 kilowatt-hours net per barrel of fuel oil, corresponding to a fuel economy of 12,674 B.t.u. per kilowatt-hour. The cost of this power plant will be $77.50 per kilowatt of installed capacity when the ultimate installation of four units is completed. The Los Angeles Gas & Electric Corporation has a smaller steam plant located at Seal Beach near Los Angeles which is reported to have cost $78.20 per kilowatt of installed capacity. The Shuffleton steam plant recently constructed by the Puget Sound Power & Light Co. is reported to have cost $105 per horsepower or $140 per kilowatt of installed capacity.

For the purposes of this study the following assumptions have been used to determine the cost of competitive steam power based on the cost and performance of the Long Beach no. 3 plant of the Southern California Edison Co.

Steam generating station data

Capital cost—$77.50 per kilowatt of installed capacity.
Fuel consumption—0.002 barrel per kilowatt-hour generated, plus 0.55 barrel per kilowatt of installed capacity per year.
Operation and maintenance—$2.25 per kilowatt of required capacity.
Required capacity = peak load.
Installed capacity = 110 percent of required capacity.

	Public development	Private development
	Percent	*Percent*
Rate of return on investment	0	7.0
Rate of interest	4.75	0
Amortization	.88	0
Depreciation	2.25	2.25
Taxes	0	1.50
General expense (percent of total cost other than fuel and taxes)	3.0	3.0

Tables 8 and 9 show the cost of steam-generated energy under the above assumptions for public and privately owned steam plants, with the price of fuel oil varying from 75 cents to $1.50 per barrel delivered and for various load factors from 40 to 80 percent.

Drawing no. 222-D-7 [31] shows graphically the cost of steam-generated energy for both public and privately owned and operated steam plants with various prices of fuel oil and various load factors.

TABLE NO. 8.—*Estimated cost of steam-generated energy—public development*

Cost of fuel oil per barrel	$0.75	$1.00	$1.25	$1.50
Load factor, 40 percent				
Kilowatt-hours generated per year per kilowatt capacity, 3,504.				
Barrels of fuel oil per year per kilowatt capacity, 7.613.				
Kilowatt-hours per barrel of fuel oil, 460.				
Interest, depreciation, amortization, and operation and maintenance	$8.968	$8.968	$8.968	$8.968
General expenses, 3 percent of above	.269	.269	.269	.269
Cost of fuel oil per year per kilowatt capacity	5.710	7.613	9.516	11.419
Total annual cost per kilowatt required	14.947	16.850	18.753	20.656
Cost per kilowatt-hour, mills	4.266	4.809	5.352	5.895
Load factor, 50 percent				
Kilowatt-hours generated per year per kilowatt capacity, 4,380.				
Barrels of fuel oil per year per kilowatt capacity, 9.365.				
Kilowatt-hours per barrel of fuel oil, 468.				
Interest, depreciation, amortization, and operation and maintenance	8.968	8.968	8.968	8.968
General expenses, 3 percent of above	.269	.269	.269	.269
Cost of fuel oil per year per kilowatt capacity	7.024	9.365	11.706	14.047
Total annual cost per kilowatt required	16.261	18.602	20.943	23.284
Cost per kilowatt-hour, mills	3.712	4.247	4.781	5.316
Load factor, 60 percent				
Kilowatt-hours generated per year per kilowatt capacity, 5,256.				
Barrels of fuel oil per year per kilowatt capacity, 11.117.				
Kilowatt-hours per barrel of fuel oil, 473.				
Interest, depreciation, amortization, and operation and maintenance	8.968	8.968	8.968	8.968
General expenses, 3 percent of above	.269	.269	.269	.269
Cost of fuel oil per year per kilowatt capacity	8.338	11.117	13.896	16.675
Total annual cost per kilowatt required	17.575	20.354	23.133	25.912
Cost per kilowatt-hour, mills	3.344	3.872	4.401	4.930

[31] Not printed.

TABLE NO 8.—*Estimated cost of steam-generated energy—public development*—Continued

Cost of fuel oil per barrel	$0.75	$1.00	$1.25	$1.50
Load factor, 70 percent				
Kilowatt-hours generated per year per kilowatt capacity, 6,132.				
Barrels of fuel oil per year per kilowatt capacity, 12.869.				
Kilowatt-hours per barrel of fuel oil, 476.				
Interest, depreciation, amortization, and operation and maintenance	$8.968	$8.968	$8.968	$8.968
General expenses, 3 percent of above	.269	.269	.269	.269
Cost of fuel oil per year per kilowatt capacity	9.652	12.869	16.086	19.303
Total annual cost per kilowatt required	18.889	22.106	25.323	28.540
Cost per kilowatt-hour, mills	3.080	3.605	4.130	4.654
Load factor, 80 percent				
Kilowatt-hours generated per year per kilowatt capacity, 7,008.				
Barrels of fuel oil per year per kilowatt capacity, 14.621.				
Kilowatt-hours per barrel of fuel oil, 479.				
Interest, depreciation, amortization, and operation and maintenance	8.968	8.968	8.968	8.968
General expenses, 3 percent of above	.269	.269	.269	.269
Cost of fuel oil per year per kilowatt capacity	10.966	14.621	18.276	21.931
Total annual cost per kilowatt required	20.203	23.858	27.513	31.168
Cost per kilowatt-hour, mills	2.883	3.404	3.926	4.447

TABLE NO. 9.—*Estimated cost of steam generated energy—Private development*

Cost of fuel oil per barrel	$0.75	$1.00	$1.25	$1.50
Load factor, 40 percent				
Kilowatt-hours generated per year per kilowatt capacity, 3,504.				
Barrels of fuel oil per year per kilowatt capacity, 7.613.				
Kilowatt-hours per barrel of fuel oil, 460.				
Depreciation, return on investment, and operation and maintenance	$10.136	$10.136	$10.136	$10.136
General expenses, 3 percent of above	.304	.304	.304	.304
Taxes	1.279	1.279	1.279	1.279
Cost of fuel oil per year per kilowatt capacity	5.710	7.613	9.516	11.419
Total annual cost per kilowatt required	17.429	19.332	21.235	23.138
Cost per kilowatt-hour, mills	4.974	5.517	6.060	6.603
Load factor, 50 percent				
Kilowatt-hours generated per year per kilowatt capacity, 4,380.				
Barrels of fuel oil per year per kilowatt capacity, 9.365.				
Kilowatt-hours per barrel of fuel oil, 468.				
Depreciation, return on investment, and operation and maintenance	10.136	10.136	10.136	10.136
General expenses, 3 percent of above	.304	.304	.304	.304
Taxes	1.279	1.279	1.279	1.279
Cost of fuel oil per year per kilowatt capacity	7.024	9.365	11.706	14.047
Total annual cost per kilowatt required	18.743	21.084	23.425	25.766
Cost per kilowatt-hour, mills	4.279	4.814	5.348	5.883
Load factor, 60 percent				
Kilowatt-hours generated per year per kilowatt capacity, 5,256.				
Barrels of fuel oil per year per kilowatt capacity, 11.117.				
Kilowatt-hours per barrel of fuel oil, 473.				
Depreciation, return on investment, and operation and maintenance	10.136	10.136	10.136	10.136
General expenses, 3 percent of above	.304	.304	.304	.304
Taxes	1.279	1.279	1.279	1.279
Cost of fuel oil per year per kilowatt capacity	8.338	11.117	13.896	16.675
Total annual cost per kilowatt required	20.057	22.836	25.615	28.394
Cost per kilowatt-hour, mills	3.816	4.345	4.873	5.402

TABLE NO. 9.—*Estimated cost of steam generated energy—Private development*—Continued

Cost of fuel oil per barrel	$0.75	$1.00	$1.25	$1.50
Load factor, 70 percent				
Kilowatt-hours generated per year per kilowatt capacity, 6,132.				
Barrels of fuel oil per year per kilowatt capacity, 12.869.				
Kilowatt-hours per barrel of fuel oil, 476.				
Depreciation, return on investment, and operation and maintenance	$10.136	$10.136	$10.136	$10.136
General expenses, 3 percent of above	.304	.304	.304	.304
Taxes	1.279	1.279	1.279	1.279
Cost of fuel oil per year per kilowatt capacity	9.652	12.869	16.086	19.303
Total annual cost per kilowatt required	21.371	24.588	27.805	31.022
Cost per kilowatt-hour, mills	3.485	4.010	4.534	5.059
Load factor, 80 percent				
Kilowatt-hours generated per year per kilowatt capacity, 7,008.				
Barrels of fuel oil per year per kilowatt capacity, 14.621.				
Kilowatt-hours per barrel of fuel oil, 479.				
Depreciation, return on investment, and operation and maintenance	10.136	10.136	10.136	10.136
General expenses, 3 percent of above	.304	.304	.304	.304
Taxes	1.279	1.279	1.279	1.279
Cost of fuel oil per year per kilowatt capacity	10.966	14.621	18.276	21.931
Total annual cost per kilowatt required	22.865	26.340	29.995	33.650
Cost per kilowatt-hour, mills	3.263	3.758	4.280	4.802

TRANSMISSION OF COLUMBIA RIVER POWER

Cost of transmission facilities.—At present, 220,000 volts is the practical limit for high-voltage, high-power, long-distance transmission. Higher voltages are being investigated, but considering the greater first cost of transmission lines designed and built for such higher voltages, it seems doubtful if any marked reduction in the cost of transmitting energy would be affected and at the present state of the art it would not be conservative to assume that power from the proposed Columbia River development would be transmitted at a voltage of more than 220,000.

The area in the vicinity of Puget Sound offers the largest market for Columbia River power within economic transmission distance, and it is assumed that a large part of the power will be utilized in that territory ultimately. The distance that the power would have to be transmitted to reach this market would be approximately 170 miles.

As a basis for determining the cost of transmitting electrical energy to this market, it is assumed that four 220,000-volt circuits would be provided, each capable of delivering 127,000 kilowatts under normal operating conditions with a reasonable factor of safety against instability at times of system disturbances. Each circuit would be capable of carrying up to 146,000 kilowatts under emergency conditions when one of the other circuits is out of service. Synchronous condensers would be provided as part of the terminal substation equipment in the ratio of 0.59 kilovolt-ampere of condenser capacity per kilowatt of delivered power, for regulation of power factor and voltage.

The cost of the transmission lines including terminal substations and right of way is estimated as follows:

340 miles double circuit 220-kilovolt line	$8,950,000
Terminal substations, including synchronous condenser equipment	5,458,000
Right of way	1,510,000
Total	15,918,000

Estimated annual cost of transmission lines including terminal substations is as follows:

	Public development	Private development
Fixed charges:		
Interest, 4.75 percent	$756,000	
Return on investment, 7 percent		$1,114,000
Amortization, 0.88 percent	140,000	
Taxes, 1.5 percent		239,000
Depreciation exclusive of right of way, 2.25 percent	324,000	324,000
Operation and maintenance:		
Line, $125 per circuit mile	85,000	85,000
Terminal substation, 2 percent of cost	109,000	109,000
Subtotal	1,414,000	1,871,000
General expense, 2 percent of above	28,000	37,000
Total annual cost	1,442,000	1,908,000

In order to provide reliable and satisfactory service over long-distance power-transmission circuits, it is generally considered necessary to provide sufficient steam-standby generating capacity at the terminal end which, together with the overload capacity of the circuits remaining in service, will carry the full load with one of the circuits out of service. On this basis there would be required 70,000 kilowatts of steam-standby capacity to supplement the delivery of power over the four 220,000-volt circuits contemplated for delivering power to the Puget Sound area, at times when one of the four circuits is out of service.

The assumptions used and the estimated annual cost of providing steam stand-by are shown in table 10 and the annual cost of steam stand-by in dollars per kilowatt of capacity for various prices of fuel oil and for both public and private developments are shown graphically on drawing no. 222-D-8.[31]

Cost of transmitting energy.—The total cost in mills per kilowatt hour for transmitting energy from the Columbia River power plant to the load center for various load factors and prices of fuel oil, and for both public and private developments, are shown by tables nos. 11, 12, and 13, and by graphs on drawings[31] nos. 222-D-9 and 222-D-10.

These costs were determined by the following formulas:

$$C = \frac{T}{1{,}000K}$$

and

$$C_s = \frac{T+S}{1{,}000K}$$

where

C = Cost in mills per kilowatt-hour for transmitting energy from the Columbia River power plant to the load center, without steam stand-by.

C_s = Same as C except with steam stand-by.

T = Annual cost, in dollars, of transmission from the Columbia River power plant to the load center (for the various load factors and for public and private developments as show in item b of table no. 14).

S = Annual cost, in dollars, of steam stand-by (for the corresponding load factors, for public and private developments, and for the various fuel costs, as shown in item d of table no. 14).

K = Total energy generated at the Columbia River power plant in millions of kilowatt-hours (for the corresponding load factors as shown in table no. 14).

[31] Not printed.

TABLE NO. 10.—*Estimated yearly cost of steam stand-by, public and private developments*

Assumptions:	
Capital cost per kilowatt of installed capacity	$77.50
Depreciation (percent)	2.25
Operation and maintenance per kilowatt	$1.75
Fuel oil—barrels per kilowatt	1.00
General expenses—3 percent of costs other than oil and taxes:	
Return on investment for private development (percent)	7.0
Taxes on investment for private development do	1.5
Rate of interest for public development do	4.75
Amortization for public development (40-year sinking fund, at 4¾ percent) (percent)	0.88

ANNUAL COST PER KILOWATT

Cost of fuel oil per barrel	$0.75	$1.00	$1.25	$1.50
Private development:				
Depreciation, return on investment, and operation and maintenance	$8.919	$8.919	$8.919	$8.919
General expenses	.267	.267	.267	.267
Fuel oil	.75	1.00	1.25	1.50
Taxes	1.162	1.162	1.162	1.162
Cost per kilowatt per annum	11.098	11.348	11.598	11.848
Public development:				
Interest, depreciation, amortization, and operation and maintenance	7.857	7.857	7.857	7.857
General expenses	.235	.235	.235	.235
Fuel oil	.75	1.00	1.25	1.50
Cost per kilowatt per annum	8.842	9.092	9.342	9.592

TABLE NO. 11.—*Cost of transmitting energy to load center public and private developments without steam stand-by*

	Public development	Private development
Load factor, 40 percent:		
T	1,442,800	1,908,800
K	1,967	1,967
C	0.734	0.970
Load factor, 50 percent:		
T	1,442,800	1,908,800
K	2,459	2,459
C	0.587	0.776
Load factor, 60 percent:		
T	1,442,800	1,908,800
K	2,950	2,950
C	0.489	0.647
Load factor, 70 percent:		
T	1,442,800	1,908,800
K	3,442	3,442
C	0.419	0.555
Load factor, 80 percent:		
T	1,442,800	1,908,800
K	3,934	3,934
C	0.367	0.485

T=Annual cost, in dollars, of transmission from Columbia River to load center.
K=Total energy generated at Columbia River in millions of kilowatt-hours.
C=Cost in mills per kilowatt-hour for transmitting energy from Columbia River to load center, without steam stand-by.

TABLE NO. 12.—*Cost of transmitting energy to load center public development with steam stand-by*

Cost of fuel oil per barrel	$0.75	$1.00	$1.25	$1.50
Load factor, 40 percent:				
T	1,442,800	1,442,800	1,442,800	1,442,800
S	618,900	636,400	653,900	671,400
T+S	2,061,700	2,079,200	2,096,700	2,114,200
K (millions of kilowatt-hours)	1,967	1,967	1,967	1,967
Cs	1.048	1.057	1.066	1.075
Load factor, 50 percent:				
T	1,442,800	1,442,800	1,442,800	1,442,800
S	618,900	636,400	653,900	671,400
T+S	2,061,700	2,079,200	2,096,700	2,114,200
K (millions of kilowatt-hours)	2,459	2,459	2,459	2,459
Cs	.838	.846	.853	.860
Load factor, 60 percent:				
T	1,442,800	1,442,800	1,442,800	1,442,800
S	618,900	636,400	653,900	671,400
T+S	2,061,700	2,079,200	2,096,700	2,114,200
K (millions of kilowatt-hours)	2,950	2,950	2,950	2,950
Cs	.699	.705	.711	.717
Load factor, 70 percent:				
T	1,442,800	1,442,800	1,442,800	1,442,800
S	618,900	636,400	653,900	671,400
T+S	2,061,700	2,079,200	2,096,700	2,114,200
K (millions of kilowatt-hours)	3,442	3,442	3,442	3,442
Cs	.599	.604	.609	.614
Load factor, 80 percent:				
T	1,442,800	1,442,800	1,442,800	1,442,800
S	618,900	636,400	653,900	671,400
T+S	2,061,700	2,079,200	2,096,700	2,114,200
K (millions of kilowatt-hours)	3,934	3,934	3,934	3,934
Cs	.524	.529	.533	.537

T=annual cost, in dollars, of transmission from Columbia River to load center.
S=annual cost, in dollars, of steam stand-by.
K=total energy generated at Columbia River in millions of kilowatt-hours.
Cs=cost, in mills per kilowatt-hour, of transmitting energy from Columbia River to load center, with steam stand-by.

TABLE NO. 13.—*Cost of transmitting energy to load center private development with steam stand-by*

Cost of fuel oil per barrel	$0.75	$1.00	$1.25	$1.50
Load factor, 40 percent:				
T	1,908,800	1,908,800	1,908,800	1,908,800
S	776,900	794,400	811,900	829,400
T+S	2,685,700	2,703,200	2,720,700	2,738,200
K (millions of kilowatt-hours)	1,967	1,967	1,967	1,967
Cs	1.365	1.374	1.383	1.392
Load factor, 50 percent:				
T	1,908,800	1,908,800	1,908,800	1,908,800
S	776,900	794,400	811,900	829,400
T+S	2,685,700	2,703,200	2,720,700	2,738,200
K (millions of kilowatt-hours)	2,459	2,459	2,459	2,459
Cs	1.092	1.099	1.106	1.114
Load factor, 60 percent:				
T	1,908,800	1,908,800	1,908,800	1,908,800
S	776,900	794,400	811,900	829,400
T+S	2,685,700	2,703,200	2,720,700	2,738,200
K (millions of kilowatt-hours)	2,950	2,950	2,950	2,950
Cs	.910	.916	.922	.928
Load factor, 70 percent:				
T	1,908,800	1,908,800	1,908,800	1,908,800
S	776,900	794,400	811,900	829,400
T+S	2,685,700	2,703,200	2,720,700	2,738,200
K millions of kilowatt-hours)	3,442	3,442	3,442	3,442
Cs	.780	.785	.790	.796
Load factor, 80 percent:				
T	1,908,800	1,908,800	1,908,800	1,908,800
S	776,900	794,400	811,900	829,400
T+S	2,685,700	2,703,200	2,720,700	2,738,200
K (millions of kilowatt-hours)	3,934	3,934	3,934	3,934
Cs	.683	.687	.692	.696

T=annual cost, in dollars, of transmission from Columbia River to load center.
S=annual cost, in dollars, of steam stand-by.
K=total energy generated at Columbia River in millions of kilowatt-hours.
Cs=cost, in mills per kilowatt-hour, of transmitting energy from Columbia River to load center, with steam stand-by.

TABLE NO. 14.—*Estimated annual value of energy at the Columbia River power plant with and without steam stand-by, assuming load center 170 miles transmission distance*

Assumptions: Peak kilowatts generated at Columbia River hydro plant, 561,300.
Peak kilowatts delivered from terminal substation, 508,000.
Number of 220-kilovolt, 3-phase, double circuit lines, 2.

	Public development				Private development			
Cost of fuel oil per barrel, dollars	$0.75	$1.00	$1.25	$1.50	$0.75	$1.00	$1.25	$1.50
Load factor, 40 percent								
Millions of kilowatt-hours generated annually at Columbia River power plant, 1,967.								
(a) Annual cost of equivalent steam plant at load center (508,000 kilowatts required, 558,800 kilowatts installed)	7,593,100	8,559,800	9,526,500	10,493,200	8,853,900	9,820,700	10,787,400	11,754,100
(b) Annual cost of transmission from power plant to load center (2 double circuit lines)	1,442,800	1,442,800	1,442,800	1,442,800	1,908,800	1,908,800	1,908,800	1,908,800
(c) Annual value of power at Columbia River power plant without steam stand-by	6,150,300	7,117,000	8,083,700	9,050,400	6,945,100	7,911,900	8,878,600	9,845,300
(d) Annual cost of steam stand-by (70,000 kilowatts)	618,900	636,400	653,900	671,400	776,900	794,400	811,900	829,400
(e) Annual value of power at Columbia River power plant with steam stand-by	5,531,400	6,480,600	7,429,800	8,379,000	6,168,200	7,117,500	8,066,700	9,015,900
(f) Value of power at Columbia River power plant in mills per kilowatt-hour without steam stand-by	3.127	3.618	4.110	4.601	3.531	4.022	4.514	5.005
(g) Value of power at Columbia River power plant in mills per kilowatt-hour with steam stand-by	2.812	3.294	3.777	4.260	3.136	3.618	4.101	4.584
Load factor, 50 percent								
Millions of kilowatt-hours generated annually at Columbia River power plant, 2,459.								
(a) Annual cost of equivalent steam plant at load center (508,000 kilowatts required, 558,800 kilowatts installed)	8,260,600	9,449,800	10,639,000	11,828,300	9,521,400	10,710,700	11,899,900	13,089,100
(b) Annual cost of transmission from power plant to load center (2 double circuit lines)	1,442,800	1,442,800	1,442,800	1,442,800	1,908,800	1,908,800	1,908,800	1,908,800
(c) Annual value of power at Columbia River power plant without steam stand-by	6,817,800	8,007,000	9,196,200	10,385,500	7,612,600	8,801,900	9,991,100	11,180,300
(d) Annual cost of steam stand-by (70,000 kilowatts)	618,900	636,400	653,900	671,400	776,900	794,400	811,900	829,400
(e) Annual value of power at Columbia River power plant with steam stand-by	6,198,900	7,370,600	8,542,300	9,714,100	6,835,700	8,007,500	9,179,200	10,350,900
(f) Value of power at Columbia River power plant in mills per kilowatt-hour without steam stand-by	2.773	3.256	3.740	4.224	3.096	3.579	4.063	4.547
(g) Value of power at Columbia River power plant in mills per kilowatt-hour with steam stand-by	2.521	2.997	3.474	3.950	2.780	3.256	3.733	4.209

TABLE NO. 14.—*Estimated annual value of energy at the Columbia River power plant with and without steam stand-by, assuming load center 170 miles transmission distance*—Continued

	Public development				Private development			
Cost of fuel oil per barrel, dollars	$0.75	$1.00	$1.25	$1.50	$0.75	$1.00	$1.25	$1.50
Load factor, 60 percent								
Millions of kilowatt-hours generated annually at Columbia River power plant, 2,950.								
(a) Annual cost of equivalent steam plant at load center (508,000 kilowatts required, 558,800 kilowatts installed)	8,928,100	10,339,800	11,751,600	13,163,300	10,189,000	11,600,700	13,012,400	14,424,200
(b) Annual cost of transmission from power plant to load center (2 double circuit lines)	1,442,800	1,442,800	1,442,800	1,442,800	1,908,800	1,908,800	1,908,800	1,908,800
(c) Annual value of power at Columbia River power plant without steam stand-by	7,485,300	8,897,000	10,308,800	11,720,500	8,280,200	9,691,900	11,103,600	12,515,400
(d) Annual cost of steam stand-by (70,000 kilowatts)	618,900	636,400	653,900	671,400	776,900	794,400	811,900	829,400
(e) Annual value of power at Columbia River power plant with steam stand-by	6,866,400	8,260,600	9,654,900	11,049,100	7,503,300	8,897,500	10,291,700	11,686,000
(f) Value of power at Columbia River power plant in mills per kilowatt-hour without steam stand-by	2.537	3.016	3.495	3.973	2.807	3.285	3.764	4.243
(g) Value of power at Columbia River power plant in mills per kilowatt-hour with steam stand-by	2.328	2.800	3.273	3.745	2.543	3.016	3.489	3.961
Load factor, 70 percent								
Millions of kilowatt-hours generated annually at Columbia River power plant, 3,442.								
(a) Annual cost of equivalent steam plant at load center (508,000 kilowatts required, 558,800 kilowatts installed)	9,595,600	11,229,800	12,864,100	14,498,300	10,856,500	12,490,700	14,124,900	15,759,200
(b) Annual cost of transmission from power plant to load center (2 double circuit lines)	1,442,800	1,442,800	1,442,800	1,442,800	1,908,800	1,908,800	1,908,800	1,908,800
(c) Annual value of power at Columbia River power plant without steam stand-by	8,152,800	9,787,000	11,421,300	13,055,500	8,947,700	10,581,900	12,216,100	13,850,400
(d) Annual cost of steam stand-by (70,000 kilowatts)	618,900	636,400	653,900	671,400	776,900	794,400	811,900	829,400
(e) Annual value of power at Columbia River power plant with steam stand-by	7,533,900	9,150,600	10,767,400	12,384,100	8,170,800	9,787,500	11,404,200	13,021,000
(f) Value of power at Columbia River power plant in mills per kilowatt-hour without steam stand-by	2.369	2.843	3.318	3.793	2.600	3.074	3.549	4.024
(g) Value of power at Columbia River power plant in mills per kilowatt-hour with steam stand-by	2.189	2.659	3.128	3.598	2.374	2.844	3.313	3.783

Load factor, 80 percent								
Millions of kilowatt-hours generated annually at Columbia River power plant, 3,934.								
(*a*) Annual cost of equivalent steam plant at load center (508,000 kilowatts required, 558,800 kilowatts installed)	10,263,100	12,119,900	13,976,600	15,833,300	11,615,400	13,380,700	15,237,500	17,094,200
(*b*) Annual cost of transmission from power plant to load center (2 double circuit lines)	1,442,800	1,442,800	1,442,800	1,442,800	1,908,800	1,908,800	1,908,800	1,908,800
(*c*) Annual value of power at Columbia River power plant without steam stand-by	8,820,300	10,677,100	12,533,800	14,390,500	9,706,600	11,471,900	13,328,700	15,185,400
(*d*) Annual cost of steam stand-by (70,000 kilowatts)	618,900	636,400	653,900	671,400	776,900	794,400	811,900	829,400
(*e*) Annual value of power at Columbia River power plant with steam stand-by	8,201,400	10,040,700	11,879,900	13,719,100	8,929,700	10,677,500	12,516,800	14,356,000
(*f*) Value of power at Columbia River power plant in mills per kilowatt-hour without steam stand-by	2.242	2.714	3.186	3.658	2.467	2.916	3.388	3.860
(*g*) Value of power at Columbia River power plant in mills per kilowatt-hour with steam stand-by	2.085	2.552	3.020	3.487	2.270	2.714	3.182	3.649

VALUE OF ENERGY AT POWER PLANT

It is assumed that the Columbia River power plant will be constructed and operated by the Government; that the energy generated will be sold at the high-voltage side of the transformers at the power plant; and that the transmission lines will be constructed and operated by the agencies which purchase the energy. Under these conditions the value of energy at the power plant will be determined by the cost of an equivalent amount of substitute energy delivered at the terminal substations located at the load centers, less the cost of transmitting energy from the Columbia River power plant to the same load centers.

Drawing no. 222-D-7[31] shows graphically the estimated cost in mills per kilowatt-hour of energy generated by a steam-electric plant for various load factors and prices of fuel oil and for both public and private steam plants. Drawings nos. 222-D-9 [31] and 222-D-10 [31] show the estimated cost of transmitting energy from the Columbia River power plant to the load center for various load factors and for both public and private transmission.

Table 14 shows the value of energy at the Columbia River power plant for various load factors, various prices of fuel oil and for both publicly and privately owned and operated substitute steam plants and transmission lines, both with and without steam stand-by to supplement delivery of power over long-distance transmission lines. The value of energy at the Columbia River power plant under the same conditions is shown graphically by the curves on drawings nos. 222-D-11 [31] and 222-D-12.[31]

These curves indicate that with fuel oil costing $1 per barrel delivered, the value of energy at the Columbia River power plant would vary from 2.55 mills per kilowatt-hour for public ownership and operation of a substitute steam-electric plant and transmission facilities to 2.92 mills per kilowatt-hour for a privately owned and operated substitute steam-electric plant and transmission lines, both on the assumption that steam stand-by is included and that the load factor is 80 percent.

Some margin should be allowed between the cost of substitute power from other sources and the price of Columbia River power so as to induce the various power companies and municipalities to utilize the Columbia River power in preference to power from other sources and to expedite the absorption of the Columbia River power as rapidly as possible which is a very important factor in the financial success of the proposed power development. Based on the cost of equivalent substitute power obtained from steam-electric generating stations located at load centers and with fuel oil at $1 per barrel, the value of energy at the Columbia River power plant would be somewhere between 2.5 and 3.6 mills per kilowatt-hour, depending on load factor and whether public or private agencies purchase the power. A price of 2.25 mills per kilowatt-hour should be sufficiently attractive to induce the power companies and municipalities to purchase energy in lieu of constructing additional power plants, either steam or hydroelectric, of their own and to insure that the Columbia River power will be absorbed as rapidly as the growth of load will permit.

[31] Not printed.

FINANCIAL RESULTS

Studies have been made of the financial operation of the proposed Columbia River development based on the following assumptions:

(*a*) The firm power amounting to 800,000 kilowatts of continuous power is absorbed in 15 years which corresponds to a rate of 53,300 kilowatts, or 467,000,000 kilowatt-hours per year.

(*b*) The firm energy is sold at 2.25 mills per kilowatt-hour.

(*c*) Irrigation development and settlement proceeds at the rates of 20,000 acres per year.

(*d*) Secondary power for pumping purposes is paid for at the rate of $1 per acre per year, which is equivalent to approximately 0.5 mill per kilowatt-hour.

(*e*) Operation of the power plant by Government forces in order to take full advantage of secondary power for irrigation pumping and thus secure the maximum returns from the installation.

Based on the above assumptions, the revenue would be sufficient to repay the cost of the Columbia River Dam and power plant with interest at 4 percent per annum within 50 years, in addition to providing for the operation, maintenance, and depreciation of the dam and power plant and also provide a surplus of approximately $144,000,000 which would be available for repayment of the cost of the irrigation development and other purposes. This financial operation is shown by table 15 and graphically by drawing no. 13.[31]

The absorption of the 800,000 kilowatts of continuous firm power should be accomplished within a period of 15 years without serious difficulty provided the power companies and municipalities will all cooperate to the fullest possible extent and if the requirement for power in the Pacific Northwest continues to increase in the future.

[31] Not printed.

TABLE No. 15.—*Financial operation*

[Power sold at 2¼ mills per kilowatt-hour—Land settled at rate of 20,000 acres per year. Power absorption period, 15 years]

Year after completion of dam	Number units installed at beginning of year	Millions of kilowatt-hours sold, exclusive of pumping uses	Cost, including interest during construction at beginning of year	Investment, including interest during construction and accumulated deficit at beginning of year	Revenue from power for pumping at $1 per acre	Revenue from sale of commercial power at 2.25 mills per kilowatt-hour	Total gross revenue	Operation and maintenance	Depreciation reserve funded at 4 percent	Interest on investment	Payment for retirement of investment	Total annual expense	Deficit	Surplus available for irrigation repayment or other purposes
1	3	467	$158, 577, 792	$158, 577, 792	$20, 000	$1, 050, 750	$1, 070, 750	$412, 500	$347, 239	$6, 343, 112		$7, 102, 851	$6, 032, 101	
2	4	934	160, 853, 863	166, 885, 964	40, 000	2, 101, 500	2, 141, 500	456, 250	384, 668	6, 675, 439		7, 516, 357	5, 374, 857	
3	5	1, 402	163, 129, 934	174, 536, 892	60, 000	3, 154, 500	3, 214, 500	500, 000	422, 097	6, 981, 476		7, 903, 573	4, 689, 073	
4	6	1, 869	165, 406, 005	181, 502, 036	80, 000	4, 205, 250	4, 285, 250	543, 750	459, 526	7, 260, 081		8, 263, 357	3, 978, 107	
5	7	2, 336	167, 682, 076	187, 756, 214	100, 000	5, 256, 000	5, 356, 000	587, 500	496, 955	7, 510, 249		8, 594, 704	3, 238, 704	
6	8	2, 803	169, 958, 147	193, 270, 989	120, 000	6, 306, 750	6, 426, 750	631, 250	534, 384	7, 730, 840		8, 896, 474	2, 469, 724	
7	9	3, 270	172, 234, 218	198, 016, 784	140, 000	7, 357, 500	7, 497, 500	675, 000	571, 813	7, 920, 671		9, 167, 484	1, 669, 984	
8	10	3, 738	174, 510, 289	201, 962, 839	160, 000	8, 410, 500	8, 570, 500	718, 750	609, 242	8, 078, 514		9, 406, 506	836, 006	
9	11	4, 205	176, 786, 360	205, 074, 916	180, 000	9, 461, 250	9, 641, 250	762, 500	646, 671	8, 202, 997	$29, 082	9, 641, 250		
10	12	4, 672	179, 062, 431	207, 321, 905	200, 000	10, 512, 000	10, 712, 000	806, 250	684, 100	8, 292, 876	928, 774	10, 712, 000		
11	13	5, 139	181, 338, 502	208, 689, 202	220, 000	11, 562, 750	11, 782, 750	850, 000	721, 529	8, 346, 768	1, 864, 453	11, 782, 750		
12	14	5, 606	183, 614, 573	209, 080, 820	240, 000	12, 613, 500	12, 853, 500	893, 750	758, 958	8, 363, 233	2, 312, 601	12, 328, 542		$524, 958
13	15	6, 074	185, 890, 644	209, 044, 290	260, 000	13, 666, 500	13, 926, 500	937, 500	796, 387	8, 361, 772	2, 431, 582	12, 527, 241		1, 399, 259
14	15	6, 541	185, 890, 644	206, 612, 708	280, 000	14, 717, 250	14, 997, 250	937, 500	796, 387	8, 264, 508	2, 528, 846	12, 527, 241		2, 470, 009
15	15	7, 008	185, 890, 644	204, 083, 862	300, 000	15, 768, 000	16, 068, 000	937, 500	796, 387	8, 163, 354	2, 630, 000	12, 527, 241		3, 540, 759
16	15	7, 008	185, 890, 644	201, 453, 862	320, 000	15, 768, 000	16, 088, 000	937, 500	796, 387	8, 058, 154	2, 735, 200	12, 527, 241		3, 560, 759
17	15	7, 008	185, 890, 644	198, 718, 662	340, 000	15, 768, 000	16, 108, 000	937, 500	796, 387	7, 948, 746	2, 844, 608	12, 527, 241		3, 580, 759
18	15	7, 008	185, 890, 644	195, 874, 054	360, 000	15, 768, 000	16, 128, 000	937, 500	796, 387	7, 834, 962	2, 958, 392	12, 527, 241		3, 600, 759
19	15	7, 008	185, 890, 644	192, 915, 662	380, 000	15, 768, 000	16, 148, 000	937, 500	796, 387	7, 716, 626	3, 076, 728	12, 527, 241		3, 620, 759
20	15	7, 008	185, 890, 644	189, 835, 934	400, 000	15, 768, 000	16, 168, 000	937, 500	796, 387	7, 593, 557	3, 199, 797	12, 527, 241		3, 640, 759
21	15	7, 008	185, 890, 644	186, 639, 137	420, 000	15, 768, 000	16, 188, 000	937, 500	796, 387	7, 465, 565	3, 327, 789	12, 527, 241		3, 660, 759
22	15	7, 008	185, 890, 644	183, 311, 348	440, 000	15, 768, 000	16, 208, 000	937, 500	796, 387	7, 332, 454	3, 460, 900	12, 527, 241		3, 680, 759
23	15	7, 008	185, 890, 644	179, 850, 448	460, 000	15, 768, 000	16, 228, 000	937, 500	796, 387	7, 194, 018	3, 599, 336	12, 527, 241		3, 700, 759
24	15	7, 008	185, 890, 644	176, 251, 112	480, 000	15, 768, 000	16, 248, 000	937, 500	796, 387	7, 050, 044	3, 743, 310	12, 527, 241		3, 720, 759
25	15	7, 008	185, 890, 644	172, 507, 902	500, 000	15, 768, 000	16, 268, 000	937, 500	796, 387	6, 900, 312	3, 893, 042	12, 527, 241		3, 740, 759
26	15	7, 008	185, 890, 644	168, 614, 760	520, 000	15, 768, 000	16, 288, 000	937, 500	796, 387	6, 744, 590	4, 048, 764	12, 527, 241		3, 760, 759
27	15	7, 008	185, 890, 644	164, 565, 996	540, 000	15, 768, 000	16, 308, 000	937, 500	796, 387	6, 582, 640	4, 210, 714	12, 527, 241		3, 780, 759
28	15	7, 008	185, 890, 644	160, 365, 282	560, 000	15, 768, 000	16, 328, 000	937, 500	796, 387	6, 414, 211	4, 379, 143	12, 527, 241		3, 800, 759
29	15	7, 008	185, 890, 644	155, 976, 139	580, 000	15, 768, 000	16, 348, 000	937, 500	796, 387	6, 239, 046	4, 554, 308	12, 527, 241		3, 820, 759
30	15	7, 008	185, 890, 644	151, 421, 831	600, 000	15, 768, 000	16, 368, 000	937, 500	796, 387	6, 056, 873	4, 736, 481	12, 527, 241		3, 840, 759
31	15	7, 008	185, 890, 644	146, 685, 350	620, 000	15, 768, 000	16, 388, 000	937, 500	796, 387	5, 867, 414	4, 925, 940	12, 527, 241		3, 860, 759
32	15	7, 008	185, 890, 644	141, 759, 410	640, 000	15, 768, 000	16, 408, 000	937, 500	796, 387	5, 670, 376	5, 122, 978	12, 527, 241		3, 880, 759

33	15	7,008	185,890,644	136,636,432	660,000	15,768,000	16,428,000	937,500	796,387	5,465,457	5,327,897	12,527,241		3,900,759
34	15	7,008	185,890,644	131,308,535	680,000	15,768,000	16,448,000	937,500	796,387	5,252,341	5,541,013	12,527,241		3,920,759
35	15	7,008	185,890,644	125,767,522	700,000	15,768,000	16,468,000	937,500	796,387	5,030,701	5,762,653	12,527,241		3,940,759
36	15	7,008	185,890,644	120,004,869	720,000	15,768,000	16,488,000	937,500	796,387	4,800,195	5,993,159	12,527,241		3,960,759
37	15	7,008	185,890,644	114,011,710	740,000	15,768,000	16,508,000	937,500	796,387	4,560,468	6,232,886	12,527,241		3,980,759
38	15	7,008	185,890,644	107,778,824	760,000	15,768,000	16,528,000	937,500	796,387	4,311,153	6,482,201	12,527,241		4,000,759
39	15	7,008	185,890,644	101,296,623	780,000	15,768,000	16,548,000	937,500	796,387	4,051,865	6,741,489	12,527,241		4,020,759
40	15	7,008	185,890,644	94,555,134	800,000	15,768,000	16,568,000	937,500	796,387	3,782,205	7,011,149	12,527,241		4,040,759
41	15	7,008	185,890,644	87,543,985	820,000	15,768,000	16,588,000	937,500	796,387	3,501,759	7,291,595	12,527,241		4,060,759
42	15	7,008	185,890,644	80,252,390	840,000	15,768,000	16,608,000	937,500	796,387	3,210,096	7,583,258	12,527,241		4,080,759
43	15	7,008	185,890,644	72,669,132	860,000	15,768,000	16,628,000	937,500	796,387	2,906,765	7,886,589	12,527,241		4,100,759
44	15	7,008	185,890,644	64,782,543	880,000	15,768,000	16,648,000	937,500	796,387	2,591,302	8,202,052	12,527,241		4,120,759
45	15	7,008	185,890,644	56,580,491	900,000	15,768,000	16,668,000	937,500	796,387	2,263,220	8,530,134	12,527,241		4,140,759
46	15	7,008	185,890,644	48,050,357	920,000	15,768,000	16,688,000	937,500	796,387	1,922,014	8,871,340	12,527,241		4,160,759
47	15	7,008	185,890,644	39,179,017	940,000	15,768,000	16,708,000	937,500	796,387	1,567,161	9,226,193	12,527,241		4,180,759
48	15	7,008	185,890,644	29,952,824	960,000	15,768,000	16,728,000	937,500	796,387	1,198,113	9,595,241	12,527,241		4,200,759
49	15	7,008	185,890,644	20,357,583	980,000	15,768,000	16,748,000	937,500	796,387	814,303	9,979,051	12,527,241		4,220,759
50	15	7,008	185,890,644	10,378,532	1,000,000	15,768,000	16,768,000	937,500	796,387	415,141	10,378,532	12,527,560		4,240,440
51	15	7,008	185,890,644		1,020,000	15,768,000	16,788,000	937,500	796,387			1,733,887		15,054,113
52	15	7,008	185,890,644		1,040,000	15,768,000	16,808,000	937,500	796,387			1,733,887		15,074,113
53	15	7,008	185,890,644		1,060,000	15,768,000	16,828,000	937,500	796,387			1,733,887		15,094,113
54	15	7,008	185,890,644		1,080,000	15,768,000	16,848,000	937,500	796,387			1,733,887		15,114,113
55	15	7,008	185,890,644		1,100,000	15,768,000	16,868,000	937,500	796,387			1,733,887		15,134,113
56	15	7,008	185,890,644		1,120,000	15,768,000	16,888,000	937,500	796,387			1,733,887		15,154,113
57	15	7,008	185,890,644		1,140,000	15,768,000	16,908,000	937,500	796,387			1,733,887		15,174,113
58	15	7,008	185,890,644		1,160,000	15,768,000	16,928,000	937,500	796,387			1,733,887		15,194,113
59	15	7,008	185,890,644		1,180,000	15,768,000	16,948,000	937,500	796,387			1,733,887		15,214,113
60	15	7,008	185,890,644		1,199,430	15,768,000	16,967,430	937,500	796,387			1,733,887		15,233,543

REPORT SUBMITTED BY ARTHUR M. HYDE, SECRETARY OF AGRICULTURE, TO THE BOARD OF ENGINEERS FOR RIVERS AND HARBORS

WAR DEPARTMENT,
January 30, 1932.

THE BOARD OF ENGINEERS FOR RIVERS AND HARBORS,
War Department.

GENTLEMEN: In response to your public notice of December 19, 1931, dealing with the proposed development of the Columbia River and in particular the Columbia Basin irrigation project, we desire to submit the following statement.

The Department of Agriculture does not here attempt to report on the economic feasibility of the Columbia Basin project. We want to present some facts which bear upon the relationship between this project and the long-time outlook for the agriculture of the region and of the Nation.

The irrigation project would bring into production 1,200,000 acres. Your engineers have estimated that the combined power and irrigation development would cost more than $400,000,000. This discussion is based on the demand that the United States Government should provide the money, repayable at 4 percent over a long period of years.

I take it that your opinion thus far is summarized in the following sentences from the public notice:

> From the information presented the Board is not convinced of the advisability of the United States participating in the construction of this project at the present time. * * *
>
> It has been estimated that a period of 25 years might elapse after the completion of construction before the entire power could be disposed of. The cost of irrigation by this project is high and it would be impossible to finance the project on the basis of returns from the sale of irrigation water even if no interest charges were considered. The financing of the entire combined project by the combined receipts from the sale of water and the sale of power might be possible under certain conditions. Such financing would require the use of the profits of the power development to provide irrigation. Whether or not such profits would be sufficient would be dependent on the growth of the demand for electric power over a period in the comparatively distant future. The total investment required would be in the neighborhood of $400,000,000. Agriculture in the United States has been suffering from overproduction for a considerable period of years. It does not appear that large expenditures by the Federal Government for the purpose of bringing new land under cultivation are justified at the present time.

We share your skepticism of the economic desirability of the project. Our agricultural plant is already too large. We already have a productive agricultural capacity far beyond our needs. We have 964,000,000 acres classed as land in farms. On about a third of this acreage we are already producing enough products to feed and clothe our population and send vast surpluses abroad. These surpluses are at once the cause of low prices and our farm problem. If we are to have a profitable agriculture, we need to prevent these surpluses. To do so we need to reduce our present cultivated acreage by probably 30 or 40 million acres.

In large part because we have had a decade of overproduction and overexpansion there are these further facts to hurdle: (1) The farmer's purchasing power is 42 percent below the pre-war level (1910–14); (2) taxes on farm property are two and a half times what they were in the pre-war period; (3) farm land values the country

over are virtually back to pre-war levels; (4) the total farm mortgage debt is now almost three times as much as it was in 1910; and (5) forced sales of farms for the 5 years 1926–31 totaled 134 per thousand.

As the farmers of the State of Washington are painfully aware, in their State during the past 5 years more than 147 farms per thousand went under forced sale—a third of them because of delinquent taxes, two thirds of them by foreclosure of mortgage or bankruptcy. Of the Federal land bank loans outstanding on November 30, 1931, Washington reported 18.3 percent of its loans delinquent, a majority of these for more than 90 days.

The market is glutted with farm lands at depressed prices. There are no takers. It is plainly and indisputably against the interests of the farmers of Washington and of the adjoining States to undertake a project that would bring into production 12,000 more farms. Private enterprise would not think of attempting it. For the Government to attempt it would be indefensible.

Those 12,000 additional farms would compete directly with the 71,000 farms already established in the State of Washington, and with the 144,000 farms in the adjoining States of Oregon, Idaho, and Montana, for every new farm competes with every established farm just as surely as every new steel mill, or oil well, or grocery store competes with every established unit.

The men on the 215,000 farms in those 4 Northwestern States have not been lying down on the job. They have produced—until it hurt. The consumers of the Northwest need have no fear of famine. Washington produces 48 percent more per capita than it consumes per capita; Oregon, 61.7 percent more; Montana, 247.9 percent more; and Idaho, 252.8 percent more, according to the figures for 1924–28. The 11 States of the far West represent 9.3 percent of the population of the United States, but they produce 51 percent of all the alfalfa, 22 percent of all the hay, 23 percent of the wheat, 43 percent of the apples, 90 percent of the grapes, 100 percent of the lemons, and 70 percent of the oranges. Therein is enough bread and fruit, milk, and meat for many millions of people.

The hard fact is that because of climatic limitations the Columbia Basin cannot grow a crop of which the Nation does not now produce huge surpluses.

The farmers of the Northwest must look askance at the project for another reason. It is proposed to have the Federal Government spend $400,000,000 to bring 1,200,000 acres into production. That figures down to a construction cost of more than $333 per acre.

To that basic cost of $333 per acre the settler must add the cost of the land (90 percent of the land in the project is privately owned), the cost of leveling, ditching, and draining, and of buildings, equipment, and livestock. If, before he tries to add all that up, he looks around him, he will see an average valuation for farm land and buildings of $57.17 per acre in the States of Washington, $38.12 in Oregon, $11.81 in Montana, and $44.64 in Idaho, according to the 1930 census. Even if the average valuation per acre for Washington were double the present figure the per acre cost on the Columbia Basin project, however, it may be figured, must remain grotesquely uneconomic.

We fail to see how the project can possibly constitute a sound opportunity for any prospective settler. The competition afforded

compared with older agricultural countries, the United States has hardly scratched the surface of the possibilities in the use of fertilizer.

All these factors combined will probably make it possible for the United States to provide for domestic consumption with little or no increase of crop acreage. And if the trend in our exports of farm products continues downward, we may need less land under cultivation 30 years from now. As it is, American agriculture is cruelly out of balance. It will require a good many years to achieve a balance, even if no acreage by homesteading or reclamation is added.

Even if, contrary to our expectations, we should have a sudden and considerable national need for more land in crops, we have more than 500,000,000 unplowed acres to fall back on. Our present crop acreage could be more than doubled. Some 300,000,000 acres would require only plowing to bring them into cultivation.

There are 170,000,000 acres in forest and cut-over land physically capable of crop production after clearing and, in some cases, draining. Of the 113,000,000 acres of wet lands in the United States, some 91,000,000 acres—22 percent of our present crop acreage—would be suitable for crops after drainage and, in some cases, clearing.

Of the 84,000,000 acres in organized drainage enterprises in the United States in 1929, only 65 percent of the total area was planted to crops. Our studies show that there are large areas of productive land in these districts awaiting only the economic need to bring them under cultivation by private enterprise.

Similarly, the 1930 census shows 30,599,470 irrigable acres in irrigation enterprises, Federal and private, but only 63.9 percent of the total actually irrigated. Engineering works were capable of providing water, however, for 84.7 percent of the total irrigable area. The irrigated acreage in 1930 could thus have been a third greater than it actually was, so far as availability of water was concerned. This situation has obtained for many years. It is approximately as true of our Federal reclamation projects as of private irrigation enterprises.

In both drainage and irrigation districts, Federal as well as private, the economic successes to date have not been so numerous as to call for more. Many districts are in desperate financial straits now, as evidence presented to congressional committees will testify. In all too many cases the trouble traces back to the fact that the district was organized without proper analysis of the probable demand for the crops to be grown.

With respect to Federal projects, Congress has passed a series of relief acts during the past decade, among them the Omnibus Reclamation Act of May 25, 1926. This act increased the period of repayment of construction charges, at the discretion of the Secretary of the Interior, to 40 years. It formerly was 20 years. This has permitted the reduction, in effect, of delinquent payments due on construction charges. Another section of the act permitted direct charge offs for a variety of reasons outside the control of the settler. Up to June 30, 1930, a total of $15,578,855.60 was charged off or accounted for as loss.

Our experience thus far, both in private and in Federal reclamation attempts, suggests that the dramatic appeal of turning a desert into a garden spot has too often outweighed considerations of economic feasibility. Fertile soil is not the only factor in cost of production

or in the happiness of the settler. The vision of high yields without regard to cost has led to misfortune for too many settlers.

Discussion of the project, however, cannot be confined to economic facts. Broad matters of national policy are involved.

Let it be noted that the Columbia Basin project has been considered an irrigation project from the start. Dozens of boards and commissions passed judgment on it as such. The proponents for the project considered it as such. For more than a decade they argued for it as such.

That argument failed. Now it appears as a combination power and irrigation project. Nevertheless, its purpose still is to bring more land into production.

To this, American farmers have a right to protest. Obviously as a pure irrigation project it would never be built. As a pure power project it would never be considered by private capital. Combined, it adds power as a further subsidy to irrigation, and is therefore the more dangerous to agriculture. The Government has not yet gone into the power business. The speedy divorce of reclamation and power would be better for both.

The reclamation revolving fund has always been in large part a subsidy from the United States Treasury. Proponents of governmental reclamation usually attempt to justify the expenditure of public funds for such projects on the ground that the source of the reclamation fund is the proceeds of sale of public lands and the income from mineral rights. These public revenues belong to the States, it is argued, in which they originate. It is pertinent to reply that public lands are public property; that they do not now and never have belonged to the States in which they are located; and that the State in which they are located is no more entitled to influence the expenditure arising from their sale or lease than the port of New York is entitled to dictate the expenditure of customs duties collected there or the State of North Carolina to determine the objects upon which tobacco taxes are to be expended.

Since the Coulee Dam and irrigation project would cost upward of $400,000,000, and since the reclamation fund amounts to only $100,000,000 (commitments already having been made in excess of any possible additions to that fund), it is difficult to escape the conclusion that this expenditure must come directly out of public revenues derived from taxation.

Interest-free funds for Federal reclamation have constituted a subsidy for a quarter of a century. The extent of that subsidy has been estimated at more than $200,000,000. Is still another form of subsidy necessary? If necessary, is it sound national policy? It seems manifestly unfair to established American farmers—in the Northwest as well as in the East—who have invested some 50 billions of dollars in the agricultural plant, to complicate their economic difficulties by subsidizing the expansion of new acreage.

The existing Federal reclamation policy has brought into production around 2½ million acres, if Warren Act lands be included. Production from this area is only a small percentage of the total agricultural production of the United States, but is a large and highly important percentage of the surplus production of the United States.

We are not opponents of reclamation nor of the development of the resources of any State whenever such resources are capable of profit-

able development. Generally, private capital is a better judge of the profitableness of any development, and a much better administrator than the Government ever will be. Only when important national interests are involved which private capital cannot or will not serve, should the Government invade this field.

We have already embarked upon a large number of reclamation projects. Few of them, in spite of vast subsidies in the form of write-off charges or forgiven interest, are successful. They need much in the way of betterments before they can support suitably the settlers already there. New projects increase the competition and the problems of such established projects and delay the achievement of any real success. It is our view that the proper field of reclamation service lies not in expansion to new fields, but in the development of the projects we have.

The question here is not one of helping the people of the area involved in the Columbia Basin project, unless it be the landholders. Twenty or more years ago dry-land farmers settled there to grow wheat, under the stimulus of a few wet years. The abnormal rainfall did not long continue. The attempt to farm there was a gamble, with the odds against success. Farms and communities were before long abandoned. At present the area is for the most part unsettled. No one will be displaced or disturbed if we refrain from the development. To build this project with Government funds means that we shall be setting up competition for the millions of farmers already established who are struggling desperately to retain their homes. To increase their problems, in any degree no matter how small or how remote, could be justified only on the ground of urgent national needs which do not, at this time, exist.

Finally, the future of our national-land policy is involved. The day of settlement in this country is about over; the day of resettlement, of regrouping, of adjustment to new economic conditions is here. The farmer of the past, often a pioneer, spent his substance struggling with physical forces. The farmer of today faces a struggle with economic forces.

We have graduated, I hope, from the day when people were lured to the land by means of brass bands and perfervid promises. We may not be able to prevent some private-land agencies from continuing unwise blandishments, but we should at least keep governmental agencies aware of our changed national needs.

The proper size of our agricultural plant cannot be too definitely fixed. Conditions change, and national demands upon agriculture change with them. Nevertheless, one great benefit from a proper land policy would be the approximation of the size of our land plant in the light of economic conditions. We ask the farmer to adjust his acreage. His is an impossible task if the Federal Government is constantly enlarging the total acreage to which he must adjust his own. The Nation, as well as the individual, must do its share to prevent the ruinous blight of overproduction.

Sincerely yours,

(Signed) ARTHUR M. HYDE,
Secretary.

over are virtually back to pre-war levels; (4) the total farm mortgage debt is now almost three times as much as it was in 1910; and (5) forced sales of farms for the 5 years 1926–31 totaled 134 per thousand.

As the farmers of the State of Washington are painfully aware, in their State during the past 5 years more than 147 farms per thousand went under forced sale—a third of them because of delinquent taxes, two thirds of them by foreclosure of mortgage or bankruptcy. Of the Federal land bank loans outstanding on November 30, 1931, Washington reported 18.3 percent of its loans delinquent, a majority of these for more than 90 days.

The market is glutted with farm lands at depressed prices. There are no takers. It is plainly and indisputably against the interests of the farmers of Washington and of the adjoining States to undertake a project that would bring into production 12,000 more farms. Private enterprise would not think of attempting it. For the Government to attempt it would be indefensible.

Those 12,000 additional farms would compete directly with the 71,000 farms already established in the State of Washington, and with the 144,000 farms in the adjoining States of Oregon, Idaho, and Montana, for every new farm competes with every established farm just as surely as every new steel mill, or oil well, or grocery store competes with every established unit.

The men on the 215,000 farms in those 4 Northwestern States have not been lying down on the job. They have produced—until it hurt. The consumers of the Northwest need have no fear of famine. Washington produces 48 percent more per capita than it consumes per capita; Oregon, 61.7 percent more; Montana, 247.9 percent more; and Idaho, 252.8 percent more, according to the figures for 1924–28. The 11 States of the far West represent 9.3 percent of the population of the United States, but they produce 51 percent of all the alfalfa, 22 percent of all the hay, 23 percent of the wheat, 43 percent of the apples, 90 percent of the grapes, 100 percent of the lemons, and 70 percent of the oranges. Therein is enough bread and fruit, milk, and meat for many millions of people.

The hard fact is that because of climatic limitations the Columbia Basin cannot grow a crop of which the Nation does not now produce huge surpluses.

The farmers of the Northwest must look askance at the project for another reason. It is proposed to have the Federal Government spend $400,000,000 to bring 1,200,000 acres into production. That figures down to a construction cost of more than $333 per acre.

To that basic cost of $333 per acre the settler must add the cost of the land (90 percent of the land in the project is privately owned), the cost of leveling, ditching, and draining, and of buildings, equipment, and livestock. If, before he tries to add all that up, he looks around him, he will see an average valuation for farm land and buildings of $57.17 per acre in the States of Washington, $38.12 in Oregon, $11.81 in Montana, and $44.64 in Idaho, according to the 1930 census. Even if the average valuation per acre for Washington were double the present figure the per acre cost on the Columbia Basin project, however, it may be figured, must remain grotesquely uneconomic.

We fail to see how the project can possibly constitute a sound opportunity for any prospective settler. The competition afforded

by the project will, on the other hand, inevitably make the lot of farmers now established in the Northwestern States more difficult than it already is. Nobody will be disturbed or displaced if the project is not undertaken until it is needed; many thousands of established farm families, particularly in Washington and adjoining States, will have to face sharp competition and greater depression if it is constructed.

The proponents of this project are not farmers. Farmers have not beseiged the Congress with demands that the Columbia Basin irrigation project be undertaken. No farmer of the Northwest would, in his right mind, urge the Nation to undertake something that would add to already burdensome surpluses, depress prices of his products, reduce the value of his land, threaten his economic security, and lift huge sums out of the United States Treasury for the avowed purpose of agricultural expansion in an era when precisely the opposite policy is called for.

If the project is not needed for the agricultural development of the Northwestern States, the question arises, Is it needed for the agricultural development of the Nation? The fact that it is to be built with national funds makes that inquiry pertinent. It must be judged largely upon its economic value to the Nation. Unless the Nation as a whole needs the project, it has no economic justification.

The fact that the four Northwestern States already produce 110.7 percent more than they consume proves that the excess must compete for sale in world markets or in the markets of the United States. This competition, as well as the fact that national funds are to be used, reveals the project as a national problem.

We have already mentioned some of the elements in the Nation-wide agricultural situation. We do not expect the present extreme depression to continue. Nevertheless, for agriculture it has been a 10-year, not a 2-year depression. The evidence is by now fairly conclusive that we face a change in the long-time market prospects for agricultural products.

We are witnessing a desperate struggle for self-sufficiency on the part of European nations; increased competition for world agricultural markets from the vastly increased acreage and production of such countries as Canada, Argentina, Australia, and Russia; the significant change in our status from a debtor to a creditor nation; and the distinct slowing up in the rate of population increase in the United States. These factors bear directly on the prospect for consumption of farm products, the prospective demand for crop acreage, and the direction our national agricultural policies should take.

We have to base our plans for the future on the prospect of a stationary population of less than 145,000,000 by about 1960. As late as 1923 population was increasing at the rate of nearly 2,000,000 a year. Now the annual increase is less than a million. Barring a radical change in our immigration laws, we can expect during the next 10 years a population increase of only half of that of the last 10 years.

In the State of Washington population increased during the past decade at the rate of 15.2 percent. The average for the United States was 16.1 percent.

The population trends further suggest that the consumption of farm products in Washington, as in all the far Western States except California, will not increase as rapidly as in the United States as a

whole. To supply the California market with the needed meat and dairy products all the Western States are already in competition with one another. Dry lands compete with irrigated lands; irrigated lands compete with other irrigated land. Hundreds of millions of acres of cheap grazing lands, not to mention irrigable lands—even in Federal projects—are not yet fully utilized.

Nor does there appear to be much prospect for a change in the diet that will materially increase the per capita requirements for farm land. Since the turn of the century the increased consumption of milk and pork has been largely counterbalanced by decreased consumption of beef; the decreased consumption of cereals has been counterbalanced by the increased consumption of sugar and vegetables. The net result has been a total per capita consumption of farm products in the maximum years (1926 and 1928), when urban prosperity was highest, only 6 percent above the average of the pre-war period, 1909–13. For over 30 years the total per capita consumption of farm products has not varied more than 10 percent. It has now (1931) fallen slightly below the average for 30 years ago. It therefore seems probable that for at least several decades to come the domestic demand for farm products will vary almost directly with the Nation's population growth.

Since the domestic demand is hitched snugly to population growth, hopes for any considerable expansion turn next to the export market. The prospects here are least encouraging of all. American agriculture can no longer look to the export market to absorb large surplusses. Even if economic forces turned sharply in our favor, there would still be the fact that in our best market—northwestern Europe—population rates of increase have shown a marked tendency to decline.

There may ultimately be possibilities for expansion of our trade with the Orient. No marked possibilities are visible to the naked eye as yet. Meanwhile, American agriculture has to adjust itself to the outlook which stubborn facts indicate, not to the outlook which our hopes would fashion for us.

How much land, then, will we need in crops in the next few decades?

Recall that since the World War the agricultural production of the United States has increased about 20 percent, whereas total crop acreage has remained more or less stationary, and population has increased only 16 percent. In fact, crop acreage was lower in 1931 than in the peak year, 1919, even though population had increased about 20,000,000 between 1919 and 1931.

Recall also that four factors account for most of this increase in production: (1) Substitution of tractors and automobiles for horses and mules, which between 1918 and 1931 released 30,000,000 acres of crop land for other than horse and mule feed: (2) increased production of meat and milk per unit of feed consumed, which has added the equivalent of 25,000,000 acres to the crop area; (3) a shift from the less productive to the more productive crops per acre; and (4) a shift from beef cattle toward dairy cattle, hogs, and chickens, which produce more food than beef cattle per unit of feed consumed.

The first two and most influential factors are likely to continue. Another factor, increased production per acre, through wider use of cheap fertilizer, seems destined during the next few decades to increase crop yields notably, and probably much faster than population. As

compared with older agricultural countries, the United States has hardly scratched the surface of the possibilities in the use of fertilizer.

All these factors combined will probably make it possible for the United States to provide for domestic consumption with little or no increase of crop acreage. And if the trend in our exports of farm products continues downward, we may need less land under cultivation 30 years from now. As it is, American agriculture is cruelly out of balance. It will require a good many years to achieve a balance, even if no acreage by homesteading or reclamation is added.

Even if, contrary to our expectations, we should have a sudden and considerable national need for more land in crops, we have more than 500,000,000 unplowed acres to fall back on. Our present crop acreage could be more than doubled. Some 300,000,000 acres would require only plowing to bring them into cultivation.

There are 170,000,000 acres in forest and cut-over land physically capable of crop production after clearing and, in some cases, draining. Of the 113,000,000 acres of wet lands in the United States, some 91,000,000 acres—22 percent of our present crop acreage—would be suitable for crops after drainage and, in some cases, clearing.

Of the 84,000,000 acres in organized drainage enterprises in the United States in 1929, only 65 percent of the total area was planted to crops. Our studies show that there are large areas of productive land in these districts awaiting only the economic need to bring them under cultivation by private enterprise.

Similarly, the 1930 census shows 30,599,470 irrigable acres in irrigation enterprises, Federal and private, but only 63.9 percent of the total actually irrigated. Engineering works were capable of providing water, however, for 84.7 percent of the total irrigable area. The irrigated acreage in 1930 could thus have been a third greater than it actually was, so far as availability of water was concerned. This situation has obtained for many years. It is approximately as true of our Federal reclamation projects as of private irrigation enterprises.

In both drainage and irrigation districts, Federal as well as private, the economic successes to date have not been so numerous as to call for more. Many districts are in desperate financial straits now, as evidence presented to congressional committees will testify. In all too many cases the trouble traces back to the fact that the district was organized without proper analysis of the probable demand for the crops to be grown.

With respect to Federal projects, Congress has passed a series of relief acts during the past decade, among them the Omnibus Reclamation Act of May 25, 1926. This act increased the period of repayment of construction charges, at the discretion of the Secretary of the Interior, to 40 years. It formerly was 20 years. This has permitted the reduction, in effect, of delinquent payments due on construction charges. Another section of the act permitted direct charge offs for a variety of reasons outside the control of the settler. Up to June 30, 1930, a total of $15,578,855.60 was charged off or accounted for as loss.

Our experience thus far, both in private and in Federal reclamation attempts, suggests that the dramatic appeal of turning a desert into a garden spot has too often outweighed considerations of economic feasibility. Fertile soil is not the only factor in cost of production

or in the happiness of the settler. The vision of high yields without regard to cost has led to misfortune for too many settlers.

Discussion of the project, however, cannot be confined to economic facts. Broad matters of national policy are involved.

Let it be noted that the Columbia Basin project has been considered an irrigation project from the start. Dozens of boards and commissions passed judgment on it as such. The proponents for the project considered it as such. For more than a decade they argued for it as such.

That argument failed. Now it appears as a combination power and irrigation project. Nevertheless, its purpose still is to bring more land into production.

To this, American farmers have a right to protest. Obviously as a pure irrigation project it would never be built. As a pure power project it would never be considered by private capital. Combined, it adds power as a further subsidy to irrigation, and is therefore the more dangerous to agriculture. The Government has not yet gone into the power business. The speedy divorce of reclamation and power would be better for both.

The reclamation revolving fund has always been in large part a subsidy from the United States Treasury. Proponents of governmental reclamation usually attempt to justify the expenditure of public funds for such projects on the ground that the source of the reclamation fund is the proceeds of sale of public lands and the income from mineral rights. These public revenues belong to the States, it is argued, in which they originate. It is pertinent to reply that public lands are public property; that they do not now and never have belonged to the States in which they are located; and that the State in which they are located is no more entitled to influence the expenditure arising from their sale or lease than the port of New York is entitled to dictate the expenditure of customs duties collected there or the State of North Carolina to determine the objects upon which tobacco taxes are to be expended.

Since the Coulee Dam and irrigation project would cost upward of $400,000,000, and since the reclamation fund amounts to only $100,000,000 (commitments already having been made in excess of any possible additions to that fund), it is difficult to escape the conclusion that this expenditure must come directly out of public revenues derived from taxation.

Interest-free funds for Federal reclamation have constituted a subsidy for a quarter of a century. The extent of that subsidy has been estimated at more than $200,000,000. Is still another form of subsidy necessary? If necessary, is it sound national policy? It seems manifestly unfair to established American farmers—in the Northwest as well as in the East—who have invested some 50 billions of dollars in the agricultural plant, to complicate their economic difficulties by subsidizing the expansion of new acreage.

The existing Federal reclamation policy has brought into production around 2½ million acres, if Warren Act lands be included. Production from this area is only a small percentage of the total agricultural production of the United States, but is a large and highly important percentage of the surplus production of the United States.

We are not opponents of reclamation nor of the development of the resources of any State whenever such resources are capable of profit-

able development. Generally, private capital is a better judge of the profitableness of any development, and a much better administrator than the Government ever will be. Only when important national interests are involved which private capital cannot or will not serve, should the Government invade this field.

We have already embarked upon a large number of reclamation projects. Few of them, in spite of vast subsidies in the form of write-off charges or forgiven interest, are successful. They need much in the way of betterments before they can support suitably the settlers already there. New projects increase the competition and the problems of such established projects and delay the achievement of any real success. It is our view that the proper field of reclamation service lies not in expansion to new fields, but in the development of the projects we have.

The question here is not one of helping the people of the area involved in the Columbia Basin project, unless it be the landholders. Twenty or more years ago dry-land farmers settled there to grow wheat, under the stimulus of a few wet years. The abnormal rainfall did not long continue. The attempt to farm there was a gamble, with the odds against success. Farms and communities were before long abandoned. At present the area is for the most part unsettled. No one will be displaced or disturbed if we refrain from the development. To build this project with Government funds means that we shall be setting up competition for the millions of farmers already established who are struggling desperately to retain their homes. To increase their problems, in any degree no matter how small or how remote, could be justified only on the ground of urgent national needs which do not, at this time, exist.

Finally, the future of our national-land policy is involved. The day of settlement in this country is about over; the day of resettlement, of regrouping, of adjustment to new economic conditions is here. The farmer of the past, often a pioneer, spent his substance struggling with physical forces. The farmer of today faces a struggle with economic forces.

We have graduated, I hope, from the day when people were lured to the land by means of brass bands and perfervid promises. We may not be able to prevent some private-land agencies from continuing unwise blandishments, but we should at least keep governmental agencies aware of our changed national needs.

The proper size of our agricultural plant cannot be too definitely fixed. Conditions change, and national demands upon agriculture change with them. Nevertheless, one great benefit from a proper land policy would be the approximation of the size of our land plant in the light of economic conditions. We ask the farmer to adjust his acreage. His is an impossible task if the Federal Government is constantly enlarging the total acreage to which he must adjust his own. The Nation, as well as the individual, must do its share to prevent the ruinous blight of overproduction.

Sincerely yours,

(Signed) ARTHUR M. HYDE,
Secretary.

APPENDIX TO STATEMENT SUBMITTED BY THE SECRETARY OF AGRICULTURE

Prepared by Division of Land Economics, Bureau of Agricultural Economics, United States Department of Agriculture

THE PROSPECT FOR CONSUMPTION OF FARM PRODUCTS

The future need for farm products from central Washington can be considered with reference to—

(1) The adjacent area of Washington, Oregon, and Idaho.
(2) The 11 Western States.
(3) The United States.
(4) Foreign countries.

The need for farm products in each of these regions will depend upon population growth and changes in consumption per capita.

THE PROSPECT FOR POPULATION GROWTH

It is more hazardous to estimate population growth in a State than in the entire United States, because of unrestricted migration within the United States. It is best, perhaps, to start with the prospect for population growth in the United States, since, assuming no relaxation of the restrictions on immigration, this can be estimated for several decades ahead with considerable assurance.

Population prospect for the United States.—The following table (I), compiled by P. K. Whelpton, of the Scripps Institute for Population Research, Miami University, from census data, but with allowances for incomplete reports of both births and deaths, shows the approximate net increase in population each year 1920 to 1930. In 1931 the returns to the Census Bureau during the first 10 months indicate that the year's births will be about 2,370,000 and the deaths about 1,440,000, leaving a natural increase of 930,000. The net emigration for 1931, as estimated on the basis of 11 months' returns, will be about 90,000 (emigrants exceeding immigrants), leaving a net increase of population during the year of about 840,000.

TABLE I.—*Population increase in the United States, 1920 to 1930*

[Thousands]

Year	Population Jan. 1 [1]	Births [1]	Deaths [1]	Natural increase	Net immigration [2]	Increase in population [3]
1920	[4] 105,711	2,848	1,390	1,458	495	1,948
1921	107,659	2,946	1,255	1,691	280	1,966
1922	109,625	2,772	1,291	1,481	277	1,753
1923	111,378	2,795	1,361	1,434	707	2,133
1924	113,511	2,851	1,326	1,525	295	1,815
1925	115,326	2,790	1,364	1,426	252	1,672
1926	117,008	2,725	1,432	1,293	304	1,592
1927	118,590	2,625	1,355	1,270	252	1,519
1928	120,119	2,491	1,445	1,046	216	1,258
1929	121,377	[5] 2,399	[5] 1,449	950	222	1,168
1930	[6] 122,535	[6] 2,410	[6] 1,390	1,020	90	1,110

[1] Calculated by Scripps Foundation for Population Research, mainly from data in annual numbers of the census reports Birth Statistics and Mortality Statistics.
[2] U.S. Department of Labor: Annual Report of the Commissioner General of Immigration. Washington. Government Printing Office. 1920 to date.
[3] Natural increase plus net immigration, decreased by 0.3 percent each year so the total gain for 10 years and 3 months agrees with that shown by the 1920 and 1930 censuses.
[4] Fourteenth Census, vol. I.
[5] Preliminary.
[6] Census enumeration for 1930, minus gain in population during January–March 1930.

It will be noted that 10 years ago, indeed as late as 1923, the population of the Nation was increasing nearly 2,000,000 a year. Now the increase is less than 1,000,000. (See fig. 1.)[31] Between 1921 and 1931 the number of children born in the United States dropped from about 2,940,000 to about 2,370,000. Immigration declined from nearly 300,000 to a net loss of about 90,000 in 1931, and the number of deaths increased over 100,000. The increase in deaths was not because people were dying younger, but because there is an increasing number of old people. The number of people over 65 years of age increased 34 percent between 1920 and 1930, according to the census, whereas the number of children under 5 years of age decreased 1 percent. Enrollment in the first grade of the public schools has been declining irregularly since 1918, in the second grade since 1922, and in the third grade since 1924. The rapid decline in the birth rate since 1924 has not had time to be reflected in the school-enrollment statistics.

On the basis of these trends in births and deaths, and assuming only as large immigration as is allowed by the quota law, Mr. Whelpton estimates an increase in the Nation's population during the next 10 years about half that during the last 10 years, and a stationary population of less than 145,000,000 people about 1960. This estimate accords with that of Dublin and Lotka, of the Metropolitan Life Insurance Co., and is accepted by all population statisticians of the Nation. A few years after 1960, as the young and middle-aged people of today attain old age and die, a slow decline in the Nation's population may set in. The present birth rate, after allowance is made for the larger proportion of women of child-bearing age, than there will be in the future, is scarcely sufficient to maintain permanently even the present population of about 125,000,000.

WILL THE TREND IN BIRTHS AND DEATHS PERSIST?

But it is fitting to ask, May there not develop a decline in the death rate or a rise in the birth rate? With reference to the death rate, physicians and statisticians of the insurance companies agree that there can be little further extension in the United States of the average span of life. At present a new-born child, it is expected, will live to be nearly 60 years old on the average, whereas in New Zealand, a pastoral country whose record an industrial nation like the United States can scarcely hope to equal, the new-born child will live to be 64 on the average. This is the highest in the world. Although the expectation of life in the United States may increase slightly, a rise in the death rate is inevitable, as the young and middle-aged people, the heritage of a higher birth rate and a heavier immigration in the past, grow older. Only 1 person in 85 to 90 of the Nation's population is dying each year at present, and it is obvious that every new-born child does not live to be 85 to 90 years old. In a few years the death rate will rise, unless a great increase in immigration occurs, simply because there will be more old people to die. There is no hope, therefore, for an increase of population through a decline in the death rate. Let us consider, therefore, the prospect for the birth rate.

[31] Not printed.

The major immediate causes of the rapid decline in the birth rate since the World War are the reduction in European immigration and the increase in migration from farm to city. The immigrants from Europe were mostly young people, recently married or of marriageable age. Moreover, many of these immigrants, perhaps most of them, came from peasant farms where the tradition of large families persisted. The recent rapid decline in the ratio of children to women of child-bearing age in the cities has been confined to the population of foreign birth or parentage. The foreign-born mothers are growing older and, therefore, having fewer children, while the native-born mothers of foreign parentage are adopting urban American ways. For many years native-born mothers in the large cities have not been having enough children to maintain even a stationary population.

When foreign immigration was restricted during and after the World War, a greatly increased movement set in from the farms to the cities, which has persisted until recently. For the first time in the Nation's history (except possibly between 1910 and 1920) the farm population diminished during the past decade. This migration also has been mostly of young people—middle-aged and old people cannot well learn a new occupation and make the many other adjustments necessary. Since farm people have a much higher birth rate than city people (almost twice as high as in cities of 100,000 population and over), this migration of the young to the cities, where they will have fewer children than on the farm, is reducing the Nation's birth rate.

Moreover, the flow has been so great that it has depleted the farm population and diminished the number of people who can migrate from the farms to the cities in the future. There were in 1930 over 650,000 fewer children under 5 years of age on farms than in 1920, a decrease of one sixth; and 350,000 fewer children 5 to 9 years old, a decrease of nearly one tenth. On the other hand, there were nearly 300,000 more people over 55 years old on farms in 1930 than in 1920, an increase of 9 percent. The human population on farms, like the horse population, is growing older.

But the scarcity of children in the cities is much more serious than on the farms. In 1920 there were just about enough children in cities of over 100,000 population to maintain population stationary. In 1930 there was a 20 percent deficit. In the smaller cities (over 2,500 population) the deficit averaged only 7 percent. On the other hand, in the farm population there was still a surplus of children in 1930 of 50 percent above the number necessary to maintain a stationary population and in the rural nonfarm (mostly village) population a surplus of nearly 30 percent. So long as immigration from abroad remains rigidly restricted, not only will the cities be dependent on the rural and principally the farming people for any increase of population, but they will be dependent on movement of people from rural districts to prevent a gradual decline.

A large factor, therefore, in the population prospect is the proportion of the people who live under rural conditions. What is the outlook for change in the farm population particularly? Apparently there are two major forces working in opposite directions. The mechanization of agriculture, which must continue for a few years at least, since there are not half enough colts on farms to replace

those that die or become incapacitated yearly, tends to reduce the number of workers needed on farms. Between 1910 and 1930, in both of which years the census was taken in April, the number of males engaged in agriculture declined over 1,000,000, but practically all this decline occurred in laborers working on "home farm," mostly children over 15 years of age. Number of farmers and of hired laborers remained almost stationary. Agricultural production increased nearly a third, but this increase was not owing to mechanization alone.

On the other hand, there is a notable movement of urban factory workers, professional, and business men to small farms or suburban places where they can have a garden and keep a cow and a few chickens, producing vegetables, milk, and eggs for home use, but sometimes also for sale. Between 1920 and 1925 the census recorded an increase of 35 percent in farms of 3 to 10 acres in size and of 16 percent in farms of 10 to 20 acres, whereas the number of farms in all the larger size groups decreased. Between 1925 and 1930 the farms in the middle-size groups decreased, while the number of large farms increased. The prospect at present is for an increase of this movement of city workers to suburban places and small part-time farms. Although this is likely to raise the birth rate among these people and is a most salutary trend, it will doubtless diminish rather than increase the quantity of farm products purchased. Since it is likely that urban industries in the next decade will not expand their need for labor as rapidly as in the past decade, it is probable that the safest assumption with reference to farm population is that it will remain about stationary, perhaps decline slightly. But it will almost certainly continue to constitute a decreasing proportion of the national population.

Let us consider, therefore, the fundamental forces affecting the birth rate, both urban and rural. Why should the ratio of children to women of child-bearing age be nearly twice as high among the farming people as among the people living in large cities? And why should the trend everywhere in the Occident, not only in the United States but in Europe also, be downward? Clearly the decline is associated with industrial development and city life, and probably the major cause is the cost of raising children, particularly in the cities, and the competition of other desires. A recent investigation made by the Metropolitan Life Insurance Co. indicates that it costs in the cities about $9,000 to raise a child to the age of 18 for a family having an income of $2,500 a year. Since it requires about three children per family to maintain even a stationary population, it appears that for a typical urban American family to raise three children will cost $25,000 to $30,000. This necessarily reduces the standard of living, and fewer parents, evidently, are willing to make the sacrifice.

Quite often, too, urban conditions of living are not favorable to family life. In the modern urban industrial system there is little place for the child and almost no place for the aged, while the wife tends to become either a factory or an office worker, and the home is more and more in an apartment house or a hotel. In many, perhaps most, cases the individual, not the family, is the economic unit. On the farm, not only can the child be raised more cheaply than in the city, but also in most cases he is an economic asset from 10 years of age onward, while the wife is an economic necessity and a coworker,

and even the aged find plenty that they can do. Moreover, the farm is the home and the factory, and the family is both the economic and social unit. However, the cost of raising children is felt on the farms as well as in the cities, and there is increasing rural imitation of the fashions and standards of urban life.

Whether the suburban movement will decentralize the city population, and partially restore the former family ideals, only the future can reveal; but as yet the influence is inappreciable. The farmers of the United States can count on only a slow increase in population, and, as will be shown later, in the domestic demand for farm products, with a more or less stationary consumption only a few decades in the future.

All this assumes, of course, that the restrictions on immigration will not be relaxed. If such an immigration as occurred in 1923, for example, should be maintained while the birth rate declined, the entire picture would be altered. One hundred thousand more immigrants next year, 200,000 more the year after, followed by accretions of 100,000 a year until the 700,000 of 1923 is reached, would result in a rate of population increase during the next decade probably as large as that at present or, roughly, 1,000,000 a year. For the population of the Nation to increase nearly 2,000,000 a year, however, as it was increasing a decade ago, would require a larger immigration than has ever occurred in our national history. Whether such an increase in immigration will develop is a matter also which only the future can reveal. At present it appears no more likely than that the trend of the birth rate will be reversed.

This prospect for population growth in the United States as a whole has been considered at such length because Washington and the entire West, for that matter, is a surlpus producing area for most farm products, and the price of these farm products in Washington, or in the West, will depend upon and tend to be lower than the average price for the Nation.[36]

The prospect for population in the West.—The following table (II) shows that the increase of population in Washington, also in Washington, Oregon, and Idaho taken as a whole, from 1920 to 1930 averaged 15.2 percent, and in the 11 Western States over 33 percent as compared with 16 percent for the United States as a whole. But if California be excluded, the gain in these 10 Western States was only 13.6 percent. In the preceding decade (1910–20) the rate of population increase was 18.8 in Washington, 20.2 percent in Washington, Oregon, and Idaho as a whole, and 30 percent in the 11 Western States, as compared with about 15 percent for the United States as a whole. Excluding California the gain in the 10 Western States was 23 percent. The increase of population in the West, therefore, excluding California, also in the three States of Idaho, Oregon, and Washington taken as a whole, and in Washington alone, was smaller during the decade 1920–30 than in the United States as a whole, also the rate of increase diminished, as compared with the preceding decade.

[36] It is probable that the per-capita consumption of farm products in Washington is not far from the average for the United States. Washington in 1930 had 1.3 percent of the population of the United States and produced during the preceding 5 years 5.2 percent of the Nation's wheat, 25 percent of the apples, and 2 percent of the hay, which is fed mostly to meat and milk animals. The animal products of Washington constituted 1.23 percent of the Nation's production in the 5-year period 1924–28 (beef and veal 0.9 percent, milk 1.73 percent, poultry and eggs 2 percent, and wool 1.73 percent). Totaling all agricultural products, including animal products (and excluding feed consumed by farm animals), it appears that Washington produced over 1.6 percent of the Nation's net agricultural production, which may be compared with 1.3 percent of the Nation's population.

TABLE II.—*Rate of increase of population, Western States, by decades, 1870–1930*

State	Percent of increase					
	1920–30	1910–20	1900–10	1890–1900	1880–90	1870–80
United States	16.1	14.9	21.0	20.7	25.5	30.1
Montana	−2.1	46.0	54.5	70.3	265.0	90.1
Wyoming	16.0	33.2	57.7	47.9	200.9	128.0
Colorado	10.2	17.6	48.0	30.6	112.7	387.5
New Mexico	17.5	10.1	67.6	21.9	34.1	30.1
Arizona	30.3	63.5	66.2	39.3	118.2	318.7
Utah	13.0	20.4	34.9	31.3	46.4	65.9
Nevada	17.6	−5.5	93.4	−10.6	−23.9	46.5
Idaho	3.0	32.6	101.3	82.7	171.5	117.4
Washington	15.2	18.8	120.4	45.0	375.6	213.6
Oregon	21.8	16.4	62.7	30.2	81.8	92.2
California	65.7	44.1	60.1	22.4	40.3	54.3
11 Western States	33.6	30.4	66.8	31.9	75.5	78.5
10 Western States (California excluded)	13.6	23.1	70.7	38.0	109.2	109.9
Washington, Oregon, and Idaho	15.2	20.2	95.7	43.2	170.3	117.5

These trends in population suggest that the consumption of farm products in Washington, or in Washington, Oregon, and Idaho taken as a whole, or in the West, excluding California, will not increase as rapidly as in the United States as a whole. In California, however, the trend of population is rapidly upward, and that State is importing meat and dairy products. Central Washington, however, in supplying the California market would be in competition with all the other Western States, where there are hundreds of millions of acres of grazing land and where the value of irrigated land has been pretty thoroughly deflated.

CHANGES IN PER CAPITA CONSUMPTION OF FARM PRODUCTS

But changes in diet, particularly from cereals toward more meat and milk, might increase the per capita consumption of farm products in the United States. Such changes have occurred since the World War, and are of greater extent than any since the beginning of the century, at least. But the increased consumption of milk and pork has been largely counterbalanced by decreased consumption of beef, and the decreased consumption of the cereals by increased consumption of sugar and vegetables. (See fig. 2.[31]) The net result has been a total per capita consumption of farm products in the maximum years (1926 and 1928, when urban prosperity was at its height), only 6 percent above the average of the base period (1897–1901), or above the pre-war period 1909–13. The minimum per capita consumption was in 1917 and 1918, when it fell 4 percent below the 1897–1901 average. For over 30 years [37] the total per capita consumption of farm products has not varied more than 10 percent, and it has now (1931) fallen slightly below the average of 30 years ago. The domestic demand for farm products for at least several decades to come seems very likely, therefore, to vary almost directly with the Nation's population.

Nor is per capita consumption in the State of Washington or the West likely to diverge much from its present relation to the national average. Regional advances in income, with consequent improve-

[31] Not printed.
[37] Previous to 1897 the data were not adequate to construct indices of production and consumption.

ment in standards of living, attact people of appropriate training or experience from other regions and the difference is soon equalized.

THE PROSPECT FOR EXPORTS

Several of the principal agricultural products of Washington—notably wheat, fruit, condensed and evaporated milk—are exported to foreign markets. It is worth while, therefore, to note the prospect for exports of these products.

With reference to wheat the farmers of Washington are in competition with all the world in supplying the deficit countries of western Europe and eastern Asia. In northwestern Europe the birth rates are trending downward even more rapidly than in the United States, except in France, where population has remained practically stationary for 60 years. (See fig. 3.) [31] In every country from Sweden to Scotland and Switzerland the number of births have fallen to that point where they are scarcely sufficient to maintain the present population; and in England and Germany only about 9 daughters are being born to replace 10 mothers of the present day.

Moreover, vigorous efforts are being made to stimulate food production within each European country, not only in order that the food supply may be assured in case of war, but also to avoid sending gold abroad in payment for foodstuffs. Practically prohibitive tariffs have been placed on wheat by Germany ($1.62 a bushel), France (86 cents), Italy (over $1), and now Great Britain seems likely to place a tariff duty on wheat.

American apples, likewise, are facing the prospect of tariff duties in Europe as well as sanitary regulations (affects only grades below "fancy" grade in England), and exports of practically all farm products, except cotton possibly, are likely to be seriously retarded by the fact that not only Europe but the entire world also is in debt, principally to the United States, and interest payments need to be met before consumption goods can be purchased. Luxury products, like apples, dairy products, meat (to many peoples), are likely to feel this situation even more keenly than wheat. This is as true of the Orient as of Europe.

The trend of exports of farm products has been downward for a decade. (See fig. 4.)[31] In the fiscal year 1930–31 it was lower than in any year during the twentieth century. The world situation affords little evidence of improvement in the near future. The distant future cannot be forecast except to note that the Orient, owing to the trend of its poplation, appears to afford more hope than Europe.

THE PROSPECTIVE DEMAND FOR CROP ACREAGE

Despite an increase in agricultural production since the World War of about 20 percent, total crop acreage has remained more or less stationary. (See fig. 5.)[31] It was lower in 1931 than in 1919. Moreover, crop yields per acre have not increased and were lower in 1929 and 1930, owing to the weather conditions than for many years. The great increase in agricultural production during the decade after the war was owing almost wholly to four factors of minor

[31] Not printed.

consequence before the war which suddenly became of major importance.

1. First in importance is the substitution of gasoline for horse and mule feed. The decline of about 8,400,000 horses and mules on farms, and of probably over a million more in cities, between 1918 and 1931 has released nearly 30,000,000 acres of crop land, which has been used mostly to feed meat and milk animals and to produce cotton. This is equivalent to an increase of fully 10 percent in the effective crop acreage of the Nation. As there are less than half enough colts on farms to replace the horses and mules that die or become disabled yearly, substitution of tractors and automobiles for horses and mules probably will continue for several years at least.

2. Almost as important as the mechanization of crop production has been the increasing production of meat and milk per unit of feed consumed. The increase in animal products (other than power) since the World War has been about 23 percent, whereas crop feed available has increased not more than 10 percent, while the feed from pasturage probably has declined slightly (fig. 6).[31] This increased production of milk and meat per unit of feed consumed, assignable to culling of cows, slaughter of cattle, sheep, and swine at an earlier age (young animals make greater gains on the same amount of feed than older animals), reduction in death losses by better sanitation, particularly among hogs, a vast shift in pork production from the South to the Northwest, where the stock is better, and more efficient in transforming feed into pork and lard, the use of minerals in feeding, and many other causes have added the equivalent of 25,000,000 acres, probably, to the crop area.

Looking to the future, this factor undoubtedly will continue to be of great importance in the economizing of farm land, for culling of dairy cows and reduction of losses of pigs through sanitation and better feeding, can and probably will continue for many years. However, gains through slaughter at an earlier age and through shifts in production from south to north will be less important, undoubtedly, than during the past decade, because such shifts are probably nearly completed.

3. Less important, yet a significant factor, particularly from the standpoint of crop-land requirements of the Nation, has been the shift from the less productive crops per acre to the more productive; notably, from corn toward cotton in the South, a crop which is worth much more per acre, from wheat toward corn in the North, and from grain and hay toward fruit and vegetables in several areas, notably in California. Looking to the future, there is no assurance that these shifts from less productive to more productive crops will continue.

4. Likewise, there has been a shift from beef cattle toward dairy cattle, hogs, and chickens, which produce much more food than beef cattle per unit of feed consumed (fig. 7).[31] During the next decade this factor may sink into insignificance or disappear, owing to the probable upward trend of the beef-cattle cycle; but later, when the number of beef cattle decline, this factor is again likely to become of some importance.

Nearly all the increase in agricultural production per acre since the war, therefore, can be assigned to the decline in horses and mules and improvements in animal husbandry. These two factors alone have

[31] Not printed.

added the equivalent of, roughly, 55,000,000 acres to the effective crop area since the World War, which is an increase of about 18 percent. It is these two new factors, principally, which have enabled the total crop acreage to remain almost stationary while agricultural production increased about 20 percent.

SUMMARY OF PROSPECTIVE NEED FOR CROP LAND

Since the World War, therefore, the population of the Nation has increased over 20 percent, and agricultural production also is about 20 percent greater, while total crop acreage has remained stationary. The maximum population of the Nation, which will occur about 30 years hence, perhaps sooner, will be less than 20 percent greater than the population today, unless the trend of the birth rate is reversed or restrictions on immigration are relaxed. It is probable that the factors just described which have held crop acreage stationary while production increased may diminish somewhat in influence in the future, but the cheap price of fertilizers and the universal testimony of agronomic experiments and cost of production studies, as to the profitability of their greater use, suggests that crop yields per acre may increase notably during the next few decades. That all these factors which tend to increase production per acre will continue to hold crop acreage stationary appears probable, in view of the rapid decline in the annual increase of the Nation's population.

The future need for any expansion in the crop area appears dependent primarily upon the export demand for farm products, which at the present requires only about 10 percent of the total crop acreage. The outlook for any great increase in exports is not bright.

It may be noted, in this connection that, according to the census, about 32,000,000 acres which were in crops in 1919 were used for pasture, lay idle, or had reverted to brush or forest in 1929. A decrease in crop acreage was revealed in about two thirds of the counties of the Nation. This decrease occurred in irrigated land in the West as well as humid land in the East. But in nearly one third of the counties of the Nation, located mostly in the subhumid to semiarid Great Plains region, an increase in crop area of about 33,000,000 acres occurred. This increase was the result largely of advances in the mechanization of agriculture and in agronomic technique. These advances were facilitated by the large size of the farms in the Great Plains region, and seem likely to extend gradually into more humid areas, particularly where the farms are large and the soil fertile. They are likely to lower the cost of production, and make competition increasingly difficult in the production of grain, hay, and livestock in areas where the farms are small, as is the case in most irrigated districts.

LAND AVAILABLE FOR CROP PRODUCTION

In 1930 about half (51.9 percent) of the total land area of the United States (1,903,216,640 acres) was in farms and only slightly more than one fifth (21.7 percent) of all land was classed as crop land.[38]

The large area of land not being used for crops is further emphasized by noting that crop land represents less than half (41.9 percent)

[38] U.S. census, 1930 (preliminary figures).

of the land area in farms. Figure 8 [31] shows the percentage distribution of all farms land according to use and also pictures the percentage relation of land in farms and land not in farms. It will be noted that crop land plus plowable pasture land represent only 27.6 percent of our land surface. Of the remaining 72.4 percent of our land surface (1,377,594,000 acres) it has been variously estimated that 600,000,000 acres are physically capable of producing crops, but are not now so employed.

Although physical characteristics of unoccupied lands are unfavorable for the agricultural use of a larger acreage than is capable of being used for crops, it is evident that there is no lack of acreage for the prospective farmer who wishes to acquire undeveloped land. Such land is available in every part of the United States.

CLASSES OF UNDEVELOPED LAND

For purposes of distinguishing between the general type of reclamation necessary to bring land under cultivation, undeveloped land is divided into four more or less overlapping classes: Forest and cut-over land, drainable land, irrigable land, and dry-farming and grazing lands.

FOREST AND CUT-OVER LAND

In 1923 it was estimated that there were approximately 170,000,000 acres [39] of forest and cut-over land physically capable of being used for crop production after clearing and draining where necessary. Changes which have taken place in these acreages since 1923 have not been estimated. The approximate location of forest, cut-over land, and woodland in farms is pictured in figure 9.[31]

Although there are scattered areas of forest and cut-over lands in the United States, it will be noted that the lands are concentrated in three general regions. One large region lies in the northern parts of Michigan, Wisconsin, and Minnesota, and is known as the Great Lakes region; another extends south and west from Virginia into eastern Texas and Oklahoma, and is known as the Southern Pine region; and the third lies in central and northwestern California, western Oregon, western and northern Washington, northern Idaho and western Montana, and is known as the Pacific Northwest.

Large areas of cut-over land, particularly in the southern region, must be artificially drained, as well as cleared, before crops can be produced. To determine whether or not it is economically sound to bring such land, or in fact any other raw land, under cultivation calls for a careful analysis of the productive capacity of the land after reclamation, the cost of reclaiming the land, the demand for crops best adapted to the region in question, and the comparative advantages of producing such crops in different undeveloped areas.

DRAINABLE LAND

Of the approximate total area of land in the United States that is too wet for cultivation (113,537,000 acres), it has been estimated that 91,543,000 acres, which amount to 22.1 percent of the area of the present crop acreage, will be suitable for crops after reclamation. Most of the undrained land lies east of the one hundredth meridian

[31] Not printed.
[39] Yearbook of the U.S. Department of Agriculture, 1923, p. 427.

(fig. 10).[31] The largest areas will be found in the cut-over regions of Michigan, Wisconsin, and Minnesota, and along the Atlantic coast and Gulf of Mexico from Virginia to south Texas and up the Mississippi River to southeast Missouri.

The area may be roughly classified as tidal flats located along the sea and Gulf coasts; river flood plains located principally in the valley bottoms of the rivers flowing across the Atlantic Coastal Plain and along the Mississippi and its tributaries; the Everglades in Florida; and the glacial marshes, muck and peat bogs in the Great Lake States. With the exception of the Florida Everglades, the wet prairie lands of southern Louisiana, and the lands along the Gulf Coast in Texas, nearly all of the large tracts of unsettled, unreclaimed lands needing drainage are timbered lands. Clearing land of stumps, brush, down logs and other debris is an expensive operation which often costs more than the cost of engineering works to drain the land. The fact that the costs of these two operations generally aggregate more than the value of the land after it has been reclaimed accounts in large part for the large areas of undeveloped land within organized drainage districts. Of the total area of land in drainage enterprises in 1929,[39] 81 percent (68,263,831 acres) was in occupied farms and 35 percent (29,490,275 acres) was unimproved (table III).

TABLE III.—*Area in occupied farms, area planted and total area in drainage enterprises in 1929, by States*

[1930 Census]

State	Total area in drainage enterprises, acres		Area in occupied farms, 1930		Area planted, 1929	
	1930	1920	Acres	Percent	Acres	Percent
Arizona	318,931	39,640	304,802	95.6	278,066	87.2
Arkansas	4,631,155	3,479,591	2,940,035	63.5	2,425,632	52.4
California [1]	2,288,479	1,108,319	2,078,720	90.8	1,851,061	80.9
Colorado	366,719	171,656	305,966	83.4	274,922	75.0
Florida [1]	5,961,470	1,637,073	443,230	7.4	217,136	3.6
Georgia	84,255	65,452	63,865	75.8	37,097	44.0
Idaho	375,464	64,642	362,303	96.5	334,546	89.1
Illinois [1]	5,034,122	3,909,049	5,002,880	99.4	4,265,524	84.7
Indiana [1]	10,210,604	9,087,183	10,095,944	98.9	8,528,179	83.5
Iowa [1]	6,248,189	5,224,478	6,195,281	99.2	5,684,899	91.0
Kansas	257,169	93,856	253,845	98.7	219,736	85.4
Kentucky	585,625	358,480	515,101	88.0	320,084	54.7
Louisiana [1]	3,568,443	2,266,328	2,502,397	70.1	1,917,185	53.7
Michigan [1]	9,119,668	9,729,171	8,655,636	94.9	6,475,839	71.0
Minnesota [1]	11,357,883	9,232,709	8,560,555	75.4	5,788,537	51.0
Mississippi [1]	2,967,838	1,601,444	2,198,283	74.1	1,782,174	60.0
Missouri	3,150,022	2,596,204	2,427,599	77.1	2,067,727	65.6
Montana	167,629	168,682	150,844	90.0	114,266	68.2
Nebraska [1]	863,559	607,730	848,329	98.2	734,618	85.1
Nevada	162,980	15,940	155,491	95.4	111,512	68.4
New Mexico	176,292	140,219	151,516	85.9	137,570	78.0
North Carolina [1]	686,486	542,828	331,481	48.3	269,074	39.2
North Dakota	1,094,142	1,240,328	1,094,114	100.0	908,979	83.1
Ohio [1]	8,147,508	8,107,204	7,992,228	98.1	6,748,152	82.8
Oklahoma	170,158	12,150	163,936	96.3	135,956	79.9
Oregon	211,182	4,000	146,576	69.4	116,987	55.4
South Carolina	208,249	140,031	94,744	45.5	61,606	29.6
South Dakota	697,758	222,062	684,746	98.1	567,285	81.3
Tennessee	593,560	363,671	413,791	69.7	212,690	35.8
Texas [1]	2,886,356	2,166,128	1,899,254	65.8	1,272,762	44.1
Utah	156,052	113,823	109,518	70.2	90,368	57.9
Virginia	15,042	----------	5,704	37.9	4,748	31.6
Washington	367,242	94,924	351,898	95.8	309,818	84.4
Wisconsin	892,713	794,569	574,892	64.4	350,522	39.3
Wyoming	245,703	95,474	188,327	76.6	163,015	66.3
Total	84,268,547	65,495,038	68,263,831	81.0	54,778,272	65.0

[1] Preliminary.
[31] Not printed.
[39] Figures given for 1929 were obtained from the 1930 United States Census (preliminary).

A large area of land assessed for drainage benefits which is not improved and is not yet yeilding an income for other purposes in any drainage district or other improvement districts creates problems which are more than likely to result in financially embarrassed and defunct enterprises. In a study of drainage districts in the South [40] it was found that an average of 40 years would be required to bring under cultivation all undeveloped land in organized districts on the basis of the rate of development which took place between the years 1920 and 1926. Many of these districts were found to be in financial difficulties, and the results of the study led to the concludion that an agriculture more profitable than obtains at present is necessary to enable these districts to maintain their existing capitalization. Evidence presented by drainage experts representing various parts of the country before the House Committee on Irrigation and Reclamation point out emphatically that these conditions still prevail in a large number of districts in the United States.[41] The mere evidence that large areas of land in organized districts have not been in demand for agricultural purposes suggests the need for a careful planning of the agricultural possibilities of undeveloped and developed lands in organized districts and proposed districts in the light of the probable demand for land for agricultural purposes. In order to insure as much as is possible the sound development of land in districts only partly developed and the rehabilitation of financially embarrassed and defunct districts which have agricultural possibilities, it is necessary to determine the capacity of the land to meet obligation and to adjust existing bonded indebtedness accordingly. Until such procedure has been consummated, the establishment of profitable farms will be seriously handicapped.

IRRIGABLE LAND

Generally speaking, the land lying west of about the one hundredth meridian, which passes through the west central portions of the Dakotas, Nebraska, Kansas, Oklahoma, and Texas, receives a rainfall too light for ordinary production of crops. Although the major portion of this area is mountainous and desert waste in so far as intensive crop production is concerned, there are many broad and fertile river valleys, level plateaus among the mountains, lake beds or lake margins, and other places that are or can be irrigated. Of the 30,599,470 irrigable acres in irrigation enterprises in 1930, only 19,547,544 acres, or 63.9 percent, were irrigated, although engineering works were capable of providing water for 26,101,890 acres or 84.7 percent of the total.[42] In other words, in addition to 4,578,993 acres for which engineering works were not ready to supply water in 1930, there were 6,554,346 nonirrigated acres which engineering works were prepared to irrigate but which were not demanded for irrigatied farming purposes. The distribution of these acreages among the different States is presented in table IV.

[40] Marsden, Roger D. and Teele, R. P., "Economic Status of Drainage Districts in the South", U.S. Dept. of Agriculture, Technical Bulletin No. 194, October 1926, p. 48.
[41] "Loans for Relief of Drainage Districts", hearings before the Committee on Irrigation and Reclamation, House of Representatives, 71st Cong., 2d and 3d sess. on H.R. 11718 and S. 4123, April, May, and December 1930.
[42] 1930 Census.

TABLE IV.—*Number of enterprises and irrigable and irrigated land in these enterprises by States for 1920 and 1930*

[1930 census]

State	Area [1] in enterprises				Area enterprises were capable of supplying water				Area irrigated						Number of enterprises	
	1930	1920	Increase or decrease		1930	1920	Increase or decrease		1929	1919	Increase or decrease		Proportion of area, 1929	Proportion of area capable of supplying water, 1929	1930	1920
			Acres	Per-cent			Acres	Per-cent			Acres	Per-cent				
Arizona	1,085,627	813,153	272,474	33.5	824,152	627,303	196,849	31.4	575,590	467,565	108,025	23.1	53.0	69.8	1,270	1,388
Arkansas	225,992	246,480	−20,488	−8.3	209,942	179,013	30,929	17.3	151,787	143,946	7,841	5.4	67.2	72.3	1,043	944
California	8,075,895	7,805,207	270,688	3.5	6,815,250	5,894,466	920,784	15.6	4,746,632	4,219,040	527,592	12.5	58.8	69.6	38,117	24,115
Colorado	4,528,251	5,220,588	−692,337	−13.3	4,078,712	3,855,348	223,364	5.8	3,393,619	3,348,385	45,234	1.4	74.9	83.2	6,509	6,634
Idaho	2,814,048	3,780,048	−966,000	−25.6	2,617,021	3,092,810	−475,789	−15.4	2,181,250	2,488,806	−307,556	−12.4	77.5	83.3	3,222	3,629
Kansas	95,719	102,562	−6,843	−6.7	83,583	67,853	15,730	23.2	71,290	47,312	23,978	50.7	74.5	85.3	300	209
Louisiana	850,401	851,211	−810	−.1	795,165	728,742	66,423	9.1	450,901	454,882	−3,981	−.9	53.0	56.7	2,352	1,373
Montana	2,622,423	4,329,148	−1,706,725	−39.4	2,276,000	2,753,498	−477,498	−17.3	1,594,912	1,681,729	−86,817	−5.2	60.8	70.1	4,461	6,035
Nebraska	763,039	766,768	−3,729	−.5	703,641	562,468	141,173	25.1	532,617	442,690	89,927	20.3	69.8	75.7	721	470
Nevada	983,717	1,382,036	−398,319	−28.8	736,249	704,708	31,541	4.5	486,648	561,447	−74,799	−13.3	49.5	66.1	1,245	1,015
New Mexico	741,245	961,879	−220,634	−22.9	656,669	696,119	−39,450	−5.7	527,033	538,377	−11,344	−2.1	71.1	80.3	1,965	2,391
North Dakota	24,860	57,476	−32,616	−56.7	24,006	34,235	−10,229	−29.9	9,392	12,072	−2,680	−22.2	37.8	39.1	23	30
Oklahoma	7,344	11,742	−4,398	−37.5	7,331	9,672	−2,341	−24.2	1,573	2,969	−1,396	−47.0	21.4	21.5	77	33
Oregon	1,478,128	1,925,987	−447,859	−23.3	1,158,210	1,344,046	−185,836	−13.8	898,713	986,162	−87,449	−8.9	60.8	77.6	4,066	4,710
South Dakota	122,510	188,382	−65,872	−35.0	109,550	150,914	−41,364	−27.4	67,107	100,682	−33,575	−33.3	54.8	61.3	121	292
Texas	1,566,876	1,687,447	−120,571	−7.1	1,177,415	1,150,542	26,873	2.3	798,917	586,120	212,797	36.3	51.0	67.9	1,728	1,371
Utah	1,739,869	2,359,244	−619,375	−26.3	1,542,475	1,700,550	−158,075	−9.3	1,324,125	1,371,651	−47,526	−3.5	76.1	85.8	2,714	2,403
Washington	915,379	836,795	78,584	9.4	631,511	637,151	−5,640	−.9	499,283	529,899	−30,616	−5.8	54.5	79.1	2,986	2,692
Wyoming	1,958,147	2,564,668	−606,521	−23.6	1,655,008	1,831,039	−176,031	−9.6	1,236,155	1,207,982	28,173	2.3	63.1	74.7	2,631	3,564
Total	30,599,470	35,890,821	−5,291,351	−14.7	26,101,890	26,020,477	81,413	.3	19,547,544	19,191,716	355,828	1.9	63.9	74.9	[2]75,551	63,298
Total for Idaho, Washington, and Oregon	5,207,555	6,542,830	−1,335,275	−20.4	4,406,742	5,074,007	−667,265	−13.2	3,579,246	4,004,867	−425,621	−10.6	68.7	81.2	10,274	11,031
Total for Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming	26,942,729	31,978,753	−5,036,024	−15.7	22,991,257	23,137,038	−145,781	−.6	17,463,960	17,401,043	62,917	.4	64.8	76.0	60,186	58,576

[1] Irrigable area, 1930; total area, 1920.
[2] Net, when duplications are taken into account is 75,517.

It will be noted that of the 915,379 acres in enterprises in the State of Washington only slightly more than half (54.5 percent or 499,283 acres) were irrigated in 1929. Of the 416,096 acres in the enterprises which were not irrigated, water was available for 132,228 acres. With the exception of the States of Washington, California, and Arizona, there were decreases between 1920–30 ranging as high as 39.4 percent of the area in irrigation enterprises in each of the remaining 16 States in which lands were irrigated. In Oregon and Idaho the decrease was 23.2 and 25.6 percent, respectively.

Even when one considers Federal irrigation enterprises, it is difficult to avoid the conclusion that there is far more land in organized districts than will be economically demanded for crop production for many years to come.

According to the Annual Report of the Commissioner of Reclamation for the year ended June 30, 1931, the Bureau was prepared to supply water to 1,993,393 acres on projects proper, but almost a fourth (24.5 percent or 488,580 acres) of this acreage was not irrigated in 1929. By adding to these totals the land in the so-called Warren Act projects, the Bureau was prepared to supply water to 3,634,112 acres in 1930, but more than a fifth (23.2 percent or 843,256 acres) of this acreage was not irrigated.

The prospective irrigation farmer is confronted with problems somewhat similar to those described for drainage districts. Financially embarrassed and defunct irrigation districts are not uncommon. The organization of many districts was promoted before they were justified on the basis of demand for crops to be grown. The inclusion of unproductive land in addition to more land than could be adequately irrigated with available water, poor engineering works, excessive costs, and many less important factors contribute toward the failure of enterprises. Recapitalization of the enterprise on the basis of a conservative estimate of the earning capacity of productive land is essential on many projects to insure the establishment of profitable farming enterprises. Officials in several States have taken steps to facilitate refinancing programs and the discouragement of the organization of new districts or the extension of existing districts. With respect to Federal projects, Congress passed a series of relief Acts, particularly during the past decade, and among them the "Omnibus Reclamation Act" (act of May 25, 1926) is the most important. Among other feature of this act the period of repayment of construction charges was, at the discretion of the Secretary of the Interior, increased to 40 years. Rapidly mounting delinquent payments due on construction charges were in this way reduced or wiped out. The following quotation from the act (subsection k) provides for relief to irrigation farmers in still another way:

> That on any existing project where, in the opinion of the Secretary, it appears that on account of lack of fertility in the soil, an inadequate water supply, or other physical causes settlers are unable to pay construction costs, or wherever it appears that the cost of any reclamation project, by reason of error or mistake or for any cause, has been apportioned or charged upon a smaller area of land than the total area of land under said project, the Secretary is authorized to undertake a survey and make recommendations to Congress.

Up to June 30, 1930, a total of $15,578,855.60 [43] was charged off or accounted for as loss. These charge-offs were found necessary in spite of the fact that no interest was required in cost of construction. In general, the policy of charging off or writing down construction charges is commendable. In fact, until the overcapitalization in each project is eliminated by some method or other, the projects will not be sound financially. Prospective irrigation farmers cannot afford to purchase land in any irrigation enterprise that is not economically sound. This is particularly true on those projects where farmers are jointly responsible for meeting the construction and other costs without regard to default in payment of charges against any individual farm unit or tract of irrigable land.

The climate, crop possibilities, and cost of irrigating land are important factors which are often discounted. The dramatic appeal of turning desert or other barren waste land into a garden spot often overshadows the economic advisability of doing so. In one extreme represented by the Southwest, there are hot, dry valleys with a semitropical temperature the entire year, and in the other extreme represented by the high mountain valleys and plateaus of the Northwest the winters are cold and dry, and frosts occur even in summer. The soil is usually very fertile. A fertile soil, the application of water to growing crops at just the right time and in the quantity needed, and the preponderance of clear days and even temperature are a combination of factors which usually results in higher yields per acre than yields from fields depending upon rainfall.

The vision of high yields without regard to cost, however, has led to misfortune for many prospective irrigation farmers. Cost of construction of reservoirs and main canals per acre of land range as high as $176 and more on the proposed Columbia River Basin project. In addition to this cost, there is the cost of clearing and leveling the land, constructing lateral ditches, preparing the land for irrigated crop culture, erecting farm buildings, and food, clothing, and other living expenses. Economic surveys of reclamation projects made by a committee which included "practical irrigators, economic experts from agricultural colleges, and representatives of the Bureau of Reclamation" led to the conclusion that from $5,000 to $10,000 must be spent to provide the permanent improvements and equipment necessary for an 80-acre farm.[44]

DRY-FARMING AND GRAZING LAND

Irrigation farming, dry farming, and grazing are intermingled in the western half of the United States, beginning at about the one hundredth meridian. In a large part of this area river valleys are or can be irrigated, the higher benches and terraces are usable for dry-farming purposes, and the remainder of the land suitable for any agricultural purpose is usable for grazing purposes.

No inventory of the existing and potential dry-farming area has been made. Although the Federal and State governments own large

[43] Report of Commissioner of Reclamation for fiscal year ending June 30, 1930, p. 57.
[44] Extract from speech by Dr. Elwood Mead before the American Society of Civil Engineers in May 1929, p. 1208, Proceedings American Society of Civil Engineers.

areas of these lands, no Federal or State policy based on an understanding of the economic potentialities of these land resources has been formulated.

Other things being equal, the grazing value of this territory depends upon the supply of drinking water for the stock, the carrying capacity of the range, the length of the grazing season, and the possibility of growing hay and forage.

CROPS TO BE GROWN ON PROPOSED COLUMBIA RIVER BASIN PROJECT

Before any proposed reclamation project can be considered to be economically feasible and socially justified, particularly when the Federal Government is to be responsible for forwarding funds for the development of the project, it is essential, among other things, to prove conclusively; first, that crops to be grown can be grown more economically on the land to be reclaimed than on available land suitable for growing the same crops in existing organized projects and communities in other parts of the United States; second, that markets will absorb the crops to be grown at a profit to the producers; and, third, that the Federal Government will not be promoting and (or) subsidizing the production of crops in one section of the country when such crops enter into competition with the same or substitute crops produced in other sections of the country.

The Department of Agriculture has not had an opportunity to study and determine the economic feasibility of the agricultural aspects of the proposed Columbia River Basin project. Consequently no attempt has been made in the following statement to present more than a few of the many aspects of the questions involved which should not be overlooked or discounted.

NET FARM PRODUCTION

The average annual value of net farm production per capita [45] is much higher in every State in which farm crops are produced under irrigation than the average for the United States (table V). In fact, for the three States immediately concerned with the proposed Columbia River Basin project Idaho, Oregon, and Washington, the percentages above the average for the United States are 206.3, 40.5, and 28.6, respectively. For the 11 Mountain and Pacific States combined the average per capita production above the average per capita production for the United States as a whole is 42.4 percent. These figures do not suggest, as many proponents of the development of the project in question seem to believe, that the West is a deficit area for farm products, or that the development of the Western States has been stagnant.

[45] Crops consumed on the farm plus crops sold plus crops held for sale plus livestock products corrected for crops fed to livestock.

TABLE V.—*Average annual value net farm production* [1] *for several selected States, 1924–28, based on average farm prices over a 10-year period, 1917–26*

	Net farm production			
	Total	Per capita production	Amount per capita + or − U.S. average	Percent + or − U.S. average
	Dollars	*Dollars*	*Dollars*	*Percent*
United States	12, 687, 142, 404	108. 9	0. 0	0. 0
North Dakota	335, 091, 689	501. 3	+392. 4	+360. 3
South Dakota	276, 549, 044	411. 4	+302. 5	+277. 8
Nebraska	487, 662, 589	361. 7	+252. 8	+232. 1
Kansas	533, 770, 637	290. 1	+181. 2	+166. 4
Oklahoma	438, 880, 452	194. 1	+85. 2	+78. 2
Texas	999, 154, 543	185. 0	+76. 1	+69. 9
Montana	178, 209, 330	329. 0	+220. 1	+202. 1
Idaho	146, 851, 902	333. 6	+224. 7	+206. 3
Wyoming	62, 572, 913	292. 2	+183. 3	+168. 3
Colorado	182, 198, 650	182. 1	+73. 2	+67. 2
New Mexico	61, 297, 689	153. 1	+44. 2	+40. 6
Arizona	53, 299, 097	133. 8	+24. 9	+22. 9
Utah	72, 598, 045	149. 2	+40. 3	+37. 0
Nevada	21, 293, 102	247. 4	+138. 5	+127. 2
Washington	208, 282, 859	140. 0	+31. 1	+28. 6
Oregon	136, 367, 913	153. 0	+44. 1	+40. 5
California	551, 936, 208	113. 7	+4. 8	+4. 4
11 Mountain and Pacific States	1, 674, 907, 708	155. 1	+46. 2	+42. 4

[1] Crops consumed on the farm plus crops sold plus crops held for sale plus livestock products corrected for crops fed to livestock.

CONSUMPTION OF FARM CROPS

The average annual per capita consumption of farm crops in the United States for the 5-year period 1924–28, expressed in terms of average prices for farm crops over a 10-year period (1917–26), was $94.55 (table VI). If we assume that the per capita consumption of farm crops in the Mountain and Pacific States was the same as the average for the United States, these 11 States combined produce 64 percent more farm products than they consume. On this basis Idaho, Oregon, and Washington produce 252.8, 61.7, and 48.0 percent, respectively, more than they consume. Even assuming that the average per capita consumption in these States is a third more than the average for the United States, a large percentage of the farm crops they produce must be disposed of on markets in other parts of the country.

TABLE VI.—*Average annual per capita consumption of farm crops* [1] *compared with average annual per capita net farm production* [2] *1924–28, for all States and selected States* [3]

States	Average per capita net farm production, dollars	Average per capita consumption		
		Total, dollars	Increase or decrease of production over consumption	
			Dollars	Percent
United States	108.9	94.55	+14.3	+15.1
North Dakota	501.3	(4)	+406.7	+430.1
South Dakota	411.4	(4)	+316.8	+335.0
Nebraska	361.7	(4)	+267.1	+282.5
Kansas	290.1	(4)	+195.5	+206.8
Oklahoma	194.1	(4)	+99.5	+105.2
Texas	185.0	(4)	+90.4	+95.6
Montana	320.0	(4)	+234.4	+247.9
Idaho	333.6	(4)	+239.0	+252.8
Wyoming	292.2	(4)	+197.6	+209.0
Colorado	182.1	(4)	+87.5	+92.5
New Mexico	153.1	(4)	+58.5	+61.9
Arizona	133.8	(4)	+39.2	+41.5
Utah	149.2	(4)	+54.6	+57.7
Nevada	247.4	(4)	+152.8	+161.6
Washington	140.0	(4)	+45.4	+48.0
Oregon	153.0	(4)	+58.4	+61.7
California	113.7	(4)	+19.1	+20.2
11 Mountain and Pacific States	155.1	(4)	+60.5	+64.0

[1] Plant foodstuffs, industrial crops, and animal products.
[2] Crops consumed on the farm plus crops sold plus crops held for sale plus livestock products corrected for crops fed to livestock.
[3] Based on average prices for farms crops over the 10-year period, 1917–26.
[4] Assumed to be approximately same as United States average.

Without giving adequate weight to the relationships between existing production and consumption schedules for farm crops in the determination of the economic feasibility of the proposed development of new farm land, the determination of marketability of crops to be grown is bound to result in misleading conclusions. With a possible, but not probable, exception of certain specialty crops which might be grown, crops grown on land in new developments come in direct competition with the same or substitute crops produced on other lands which are sold on the same or competing markets. In deficit areas for particular crops or groups of crops this competitive element may be largely local. To argue, however, that production of additional crops does not adversely affect, either directly or indirectly, the market for the same crops produced by other farmers amounts to saying that supply has nothing to do with price in an open market.

Even if the contention were true that all products of Federal reclamation projects are consumed in the State which produced them, surely the farmers of the numerous non-Federal reclamation projects which have been in distress, as well as those of existing Federal projects

that have had to have special financial relief from time to time during the past decade, would find their market affected adversely by the reclamation of additional acreage.

The results of a careful analysis of elasticity of demand for and supply of the crops which would de produced on the proposed Columbia River Basin project is essential to support any statement that the crops which would be grown on the project will be marketable at a profit to the producer and without a depressing effect on prices which existing producers of the same crops receive. Unless a careful analysis of this kind proves market conditions to be otherwise, it is difficult to avoid the conclusions that the areas in question are already surplus and not deficit areas, and that any additional crops thrown on the market will depress prices for the same and/or substitute crops grown by established farmers. Furthermore, without carefully weighing these factors, any estimates as to prices which might be received for crops to be grown are more than likely to be seriously inflated.

PRODUCTION OF FARM CROPS

A brief consideration of the production of a few of the main crops which would be produced on the proposed Columbia River Basin project in the light of total population in the same areas emphasizes certain competitive aspects of the proposed project which seem to have been overlooked by the proponents of the project.

The population of the 11 Mountain and Pacific States combined represented only 9.3 percent of the total population of the United States between 1924 and 1928. Attention is directed to the fact that this 9.3 percent of the total United States population produced a much higher proportion of the total United States production of certain crops, many of which would also be grown on the proposed Columbia River Basin project. These 11 States produced between 1924 and 1928:

51.3 percent of the total alfalfa crop.
22.2 percent of the total hay crop.
22.8 percent of the total wheat crop.
4.5 percent of the total oats crop.
2.0 percent of the total cotton crop.
43.3 percent of the total apple crop.
90.0 percent of the total grape crop.
100.0 percent of the total lemon crop.
70.1 percent of the total orange crop.
8.3 percent of the total grapefruit crop.

A distribution of the production of these crops, by States, is presented in table VII.

Average annual production and percent of total production in the United States of several selected farm crops between 1924–28 in the 11 Mountain and Pacific States

State	Average annual U.S. population between 1924–28, percent	Alfalfa		Total hay		Wheat		Barley		Oats	
		1,000 tons	Percent	1,000 tons	Percent	1,000 bushels	Percent	1,000 bushels	Percent	1,000 bushels	Percent
United States	100.0	28,752	100.0	107,109	100.0	833,165	100.0	240,742	100.0	1,371,786	100.0
Montana	0.5	1,414	4.9	2,904	2.7	57,954	7.0	4,348	1.9	18,113	1.3
Idaho	.4	2,216	7.7	2,982	2.8	25,580	3.1	5,025	2.1	6,366	.5
Wyoming	.2	834	2.9	1,640	1.5	3,332	.4	1,580	.7	4,158	.3
Colorado	.9	2,029	7.1	3,519	3.3	18,328	2.2	8,676	3.6	5,544	.4
New Mexico	.3	317	1.1	441	.4	2,364	.3	151	.1	946	.1
Arizona	.3	569	2.0	635	.6	1,015	.1	704	.3	462	.03
Utah	.4	1,393	4.8	1,611	1.5	5,490	.7	1,010	.4	2,280	.2
Nevada	.1	422	1.5	680	.6	424	.1	338	.1	73	.01
Washington	1.3	828	2.9	2,103	2.0	42,922	5.2	2,248	.9	9,272	.7
Oregon	.8	714	2.5	2,073	1.9	20,478	2.5	2,751	1.1	9,740	.7
California	4.2	4,013	14.0	5,223	4.9	11,830	1.4	28,176	11.7	4,276	.3
11 Mountain and Pacific States	9.3	14,749	51.3	23,811	22.2	189,717	22.8	55,007	22.8	61,230	4.5

State	Apples (commercial)		Grapes		Lemons		Oranges		Grapefruit	
	1,000 bushels	Percent	1,000 tons	Percent	1,000 boxes	Percent	1,000 boxes	Percent	1,000 boxes	Percent
United States	97,119	100.0	2,338,907	100.0	6,811	100.0	37,785	100.0	9,472	100.0
Montana	233	0.2								
Idaho	4,021	4.1	282	0.01						
Colorado	2,626	2.7	306	.01						
New Mexico	563	.6	517	.02						
Arizona	28	.03	1,071	.05			75	0.2	124	1.3
Utah	552	.6	1,228	.05						
Nevada			235	.01						
Washington	24,617	25.3	2,966	.1						
Oregon	4,333	4.5	1,737	.1						
California	5,084	5.2	[1] 2,097,200	89.7	6,811	100.0	26,435	70.0	666	7.0
11 Mountain and Pacific States	42,057	43.3	2,105,542	90.0	6,811	100.0	26,510	70.1	790	8.3

[1] Includes 15,000 tons not harvested in 1926, 142,000 tons not harvested in 1927, and 153,000 tons not harvested in 1928.

×