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.
	U.S. Department of Commerce:	
1928 1929	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

NITROGEN AND ITS COMPOUNDS

PHOSPHORIC ACID AND PHOSPHATIC COMPOUNDS

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 available 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, G. 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 percent 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	[2] 55.00	[2] 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 Ellise 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	[7] 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	[2] 72, 631	[2] 37, 577	45, 260	37, 477	35, 899
Value	$319, 498	$162, 020	$259, 405	$147, 908	$141, 931
Montana: Western rock:					
Long ton			---	---	40
Value			---	---	$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 witn 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	Percent
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	Percent
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, 750, 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		$50
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. I. 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