

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

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

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

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

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

POWER IN ALUMINUM PRODUCTION

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

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

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

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

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

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

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

DEVELOPMENT OF THE ALUMINUM INDUSTRY

HISTORICAL SETTING

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

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

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

GROWTH OF THE INDUSTRY IN THE UNITED STATES

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

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

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

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

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

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

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

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

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

Year	New production in short tons ¹	Secondary production in short tons ²	Imports in short tons ³	Exports in short tons ³	Available supply
1930.....	114, 517	.....	12, 273	5, 957	.....
1929.....	112, 500	50, 000	24, 208	9, 749	176, 959
1928.....	90, 000	47, 500	18, 961	8, 366	148, 395
1927.....	80, 000	40, 200	36, 366	8, 026	154, 540
1926.....	75, 000	44, 200	37, 611	4, 875	151, 936
1925.....	73, 000	44, 000	20, 999	6, 321	131, 678
1924.....	75, 000	27, 700	15, 905	3, 172	115, 433
1923.....	70, 000	21, 300	21, 238	2, 770	109, 768
1922.....	40, 000	16, 290	21, 946	2, 171	76, 062
1921.....	30, 000	8, 900	16, 280	1, 098	54, 082
1920.....	70, 000	15, 500	19, 649	4, 701	100, 445
1919 ⁴	64, 000	18, 691	8, 822	2, 510	91, 513
1915 ⁴	49, 500	8, 500	4, 267	.....	.....
1913 ⁴	23, 000	4, 654	11, 380	.....	.....

¹ Figures estimated by "The Mineral Industry".

² Figures for 1920-30 from U. S. Department of Commerce, Bureau of Mines: "Bauxite and Aluminum."

³ Figures for 1920-29 from U. S. Department of Commerce, Bureau of Foreign and Domestic Commerce, "Foreign Commerce and Navigation of the United States in 1929," and preliminary figures for 1930, U. S. Bureau of Mines.

⁴ Figures for 1913, 1915, 1919 from U. S. Senate Hearings Before Committee on the Judiciary, Pursuant to Resolution 109, Sixty-ninth Congress, 1 sess.

ALUMINUM MANUFACTURING PROCESSES

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

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

EXTRACTION OF ALUMINA

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Cost item	Bayer process		Haglund process			
			At prices in Germany		At prices in United States	
Power consumption...	268 kw.-hr. at \$0.004.	\$1.07	4,082 kw.-hr. at \$0.0017.	\$6.94	At \$0.002.....	\$3.16
Bauxite	2.2 tons at \$5.00....	12.32	2 tons at \$5.62....	11.24	At \$5.00.....	11.20
Bituminous coal.....	2.64 tons at \$2.....	5.28	800 pounds at \$4.32.	1.72	At \$4.09.....	1.64
Coke and coke breeze.....	0.25 ton at \$7.30 ¹	4.19	666 pounds at \$6.48.	2.15	At \$2.60.....	.86
Lime.....	0.125 ton at \$98.90.....		70 pounds at \$75.62.	2.64	At \$90.....	2.10
Soda ash.....	.....	.....	16.5 man-hours at \$0.21.	3.46	11 man-hours at \$0.50.	5.50
Pyrolite.....	.....	.....	.....	.....	.....	.....
Electrodes.....	.....	.....	.....	.....	.....	.....
Labor.....	24 man-hours at \$0.50.	12.00	.....	.....	.....	.....
Miscellaneous supplies, repairs, and general expense.	.....	10.00	.....	5.62	.....	5.62
Total operating cost.	.....	44.86	.....	33.77	.....	35.08

¹ Figured on a recovery of one half sodium hydroxide.

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

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

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

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

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

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

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

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

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

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

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

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

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

INGOT PRODUCTION

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

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

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

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

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

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

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

COST OF PRODUCING ALUMINUM

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

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

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

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

¹ Estimated cost of Bayer process alumina plus freight.

² Estimated cost by an electrochemical process carried on at aluminum plant.

WORKING OF ALUMINUM

HOT WORKING

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

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

COLD WORKING

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

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

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

SOURCES OF RAW MATERIALS

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

¹¹ Bakker, H. E., and Edwards, Junius D. Working of Aluminum, in The Aluminum Industry.

¹² General Electric Review, January 1930.

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

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

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

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

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

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

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

BAUXITE DEPOSITS IN SOUTH AMERICA

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

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

BAUXITE DEPOSITS IN EUROPE

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

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

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

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

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

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

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

¹³ Powlowski. Les Bauxite Francaises. Paris. 1925.

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

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

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

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

BAUXITE DEPOSITS IN OTHER COUNTRIES

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

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

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

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

FLUORSPAR AND CRYOLITE

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

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

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

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

¹⁴ Kitson Gold Coast Geological Survey Mining Magazine, 33. 1925.

region has been limited to the few steel plants. Fluorspar has been mined at Jamestown in Boulder County; at Rosita in Custer County; at Duffields in El Paso County; at Evergreen in Jefferson County; and at Wagon Wheel Gap, Mineral County, Colorado. It occurs also in a number of other counties in this State. The quality of fluorspar is said to be excellent. In New Mexico mining has occurred in Dona Ana, Sierra, Luna, and Grant Counties, and deposits are reported in other counties. The lack of an abundant water supply has not been conducive to fluorspar mining at some locations, water being necessary to wash the ore. Fluorspar mined in Nevada in 1929 came from Nye County and Mineral County. While most of this ore was shipped to steel plants, some fluorspar from Mineral County was used in the manufacture of hydrofluoric acid.

77. A survey of the Nation's fluorspar deposits has not been made, principally because present known resources have been regarded as adequate to meet the country's needs. And yet, while 146,439 tons were produced in this country in 1929, 54,345 tons were imported. France and Germany were the chief sources of imported fluorspar. Other countries which shipped fluorspar, chiefly to our steel mills, were Spain, Italy, the United Kingdom, and Africa. Canada produced fluorspar mainly in British Columbia.

78. The successful operation of a flotation mill on mill tailings in 1929 marks the beginning of the use of lower-grade ores for aluminum industry fluorspar.

79. The sources of the third material essential for aluminum reduction, petroleum coke, have been discussed fully in the Original and Some New Electric Furnace Products, page 440.

ORGANIZATION AND LOCATION OF ALUMINUM PRODUCING UNITS

80. The Aluminum Co. of America is the sole producer of aluminum in the United States. In May 1928 its properties in Canada and in Europe were transferred to a newly incorporated company called Aluminum Limited. As, however, a large part of Canadian production is shipped into the United States and, therefore, materially affects production in the United States, operations in Canada will be considered along with those in this country.

SHIPMENT OF BAUXITE

81. *Mines.*—Less than half of the bauxite now manufactured into aluminum in the United States is secured from deposits in this country. Although the Aluminum Co. of America, through its subsidiary American Bauxite Co., owns extensive mines at Bauxite, Ark., and through a subsidiary, the Republic Mining & Manufacturing Co., owns bauxite properties in Georgia, Alabama, and Arkansas, the bauxite drawn from these properties for aluminum production is decreasing. In its stead, large quantities are being imported from Dutch Guiana and British Guiana. In Dutch Guiana the Aluminum Co. of America operates mines through its subsidiary, Surinaamsche Bauxite Maatschappij. In British Guiana its subsidiary, Demerara Bauxite Co., Ltd., owns extensive private properties and also has a concession from the British Government. The Aluminum Co. of America also owns deposits of low-grade ore in Minas Geraes, Brazil, which are not mined at present.

82. The ore consumed at the Canadian plants of the company came chiefly from the South American operations, even though a part of this was exported to American ports and then reshipped to Canada.

83. *Steamship lines.*—The Aluminum Co. of America owns two steamship lines. One, the Aluminum Line, which plies between the Guianas and New Orleans, Mobile, and Tampa; the other, the Ocean Dominion Steamship Corporation, which plies between the Guianas and Halifax, Montreal, and New York. As these are not common carriers, the Merchant Fleet Corporation reports that all rates are closed rates.

84. *Railroads.*—The Aluminum Co. of America also owns the Bauxite & Northern Railway Co., which carries bauxite and other freight from Bauxite, Ark., to the Iron Mountain Railroad. Bauxite from the Mississippi River port near St. Louis to East St. Louis is handled by a second company railroad, the Alton & Southern Railroad. A third railroad, the St. Louis & Ohio River Railroad, carries coal from the coal mines to East St. Louis. A fourth short line, the Massena Terminal Railroad Co., hauls freight from the main lines of the New York Central and Grand Trunk Railway to the company's plant at Massena and to the town of Massena. All these railroads not only carry the freight for the plants but also act as common carriers.

85. *Freight rates.*—According to the Inland Waterways Corporation, the shipping charge on bauxite from New Orleans to East St. Louis is \$3 per gross ton without handling charges. The Interstate Commerce Commission quotes an all-rail rate from Bauxite, Ark., to East St. Louis, at \$3.65 per gross ton.

86. The Aluminum Co. supplies its European plants in part from its own European mines. In France it owns two deposits outright and through the Norsk Aluminum Co. has half ownership in a third deposit. It also has one-half interest in Societa Anonima Mineraria Triestina, Istria, Italy. About two thirds of the stock interest of Primorski Bauxit Dioni' Co. Drustvo, in Dalmatia, Yugoslavia, is owned by the Aluminum Co. Small quantities of ore have been shipped into this country from Yugoslavia and from France.

87. *Fluorspar mining.*—The Fluorspar necessary for the manufacture of artificial cryolite is mined by the Franklin Fluorspar Co., which has a flotation mill at Rosiclare, Ill. This, too, is an Aluminum Co. subsidiary.

88. *Alumina works.*—The only alumina works in the United States is located at East St. Louis, Ill. It is operated by the subsidiary, the Aluminum Ore Co. This plant location was chosen because the process employed in alumina extraction required coal, limestone, and soda ash as well as bauxite. As required tonnage of these minerals was greater than bauxite tonnage, the plant was located near a source of these minerals. The company owns the coal mines which furnish all coal for operations of the alumina plant.

89. The East St. Louis plant has a capacity of approximately 400,000 tons alumina and supplies all reduction works in the United States and one Canadian plant with alumina. Freight rates on alumina from East St. Louis to Massena are quoted at \$0.69 per hundredweight. Until the development of the Frary process of electrothermal ore reduction, it also furnished alumina to the Arvida plant. At the present time the Arvida plant is reducing alumina

from bauxite which is shipped to it directly or indirectly from South America in small ocean steamers coming through the St. Lawrence River and up the Saguenay River.

90. A second alkali alumina extraction works was started on the Chesapeake Bay in 1916, but it was not completed.

ALUMINUM REDUCTION PLANTS AND POWER DEVELOPMENTS

91. *Massena.*—The largest reduction works of the Aluminum Co. is at Massena, N.Y., where production in a single year has exceeded 50,000 tons aluminum. This plant's supply of power is partly purchased from the Cedar Rapids Manufacturing & Power Co., and partly generated by the Aluminum Co.'s own hydroelectric plant at Massena. This power plant is situated about 600 feet from the aluminum reduction room and transmits 60,000 kilowatts at 600 volts on aluminum transmission lines supported by aluminum frame structures. The water power is developed by deflecting water from the St. Lawrence River through a 3-mile canal to the Grasse River. Several smaller plants are located at points on the Raquette River. These smaller plants make available an additional 45,000 kilowatts to Massena.

92. Just recently, a blooming mill has been completed at Massena which is reported to have a capacity of 500 tons a day. It is said to be the largest structural aluminum plant in the world. In this plant all operations from the remelting of the aluminum pig to final heat treatment are carried on electrically and all mechanical equipment, temperature controls, and regulators are operated electrically.

93. *Alcoa.*—The second largest reduction plant in this country is located at Alcoa, adjoining Marysville in Blount County, Tenn. The reduction plant was built in 1914 and has been increased in size until it now has 10 pot rooms. In 1919 a plant was built to supply the carbon electrodes. In 1920 a sheet mill was added. A new rolling mill has been built which has an initial capacity of 500 tons per month with provisions for increasing this capacity to 1,500 tons per month. In 1929, an aluminum bronze powder plant was built to manufacture pigments for use in aluminum paint. The power is transmitted to Alcoa from two power houses of the Tallassee Power Co. located above Alcoa on the Tennessee River. A third source of power has just been completed further up the Little Tennessee at Calderwood. This power plant is equipped with two 56,000-horsepower units operating on 213 foot head. Provision has been made for addition of a third unit.

94. *Badin.*—The third reduction works of the Aluminum Co. of America is located at Badin in Stanly County, N.C. This has six pot rooms, and a carbon plant which supplies the necessary electrodes and pot lining material. It is served by 3 power houses, 1 at Badin, 1 at Yadkin Falls, and the third at High Falls—all on the Yadkin River.

95. *Niagara Falls.*—The fourth reduction plant is at Niagara Falls. This was the location of the company's original plant but only a small part of the entire development at this location is now operating. Power is purchased for this operation. Electrodes are made by the Republic Carbon Co., owned in part by the Aluminum Co. of America.

96. *Canada.*—The original Canadian plant of the Aluminum Co. was established at Shawinigan Falls, Province of Quebec. By far the larger plant, however, has been located recently at Arvida. Small ocean steamers can come up the Saguenay River to the plant while larger ones land their cargo at Port Alfred on the St. Lawrence River. This plant gets its cryolite from Greenland and its bauxite from Dutch Guiana and British Guiana. All processes in the manufacture of alumina, aluminum ingots, as well as electrodes and cell linings are carried on electrically at this factory. Power is secured from the Chute a Caron Power Co., Ltd., through which Aluminum Limited owns riparian rights on the Saguenay River. About 500,000 horsepower has been or is being developed at Isle Maligne and additional construction is under way that will bring the total horsepower available at Arvida operations to 1,000,000 horsepower.¹⁵

97. *Europe.*—The Aluminum Co. of America, through affiliations with the Societa dell' Aluminio Italiano, operates a reduction plant in Italy having a capacity of 5,000 to 6,000 tons per annum. Through affiliations with the Norsk Aluminum Co. and Det Norske Nitridaktieselskab it operates plants in Norway. Its relationship in Det Norske Aktiesselskat for Elektrokewski Industri gives it partial rights to land for the development of two water power sites in Norway, and valuable electrode patent rights.

98. *Other power sites.*—In addition to the power plants owned at or near Massena, N.Y., in the Great Smoky Mountains of Tennessee, on the Yadkin River in North Carolina, and on the Saguenay River, Canada, the Aluminum Co. of America acquired property as early as 1906 near Long Sault Rapids in the St. Lawrence. This has never been developed due to the lack of coordinate legislation on the part of the United States Government, the State of New York, the Canadian Dominion's Government, and the Province of Ontario. It also has undeveloped power sites in the Great Smoky Mountains of Tennessee.

ROLLING MILLS

99. The following rolling mills are operated by the Aluminum Co. of America. Their estimated capacity is given.

Location	Annual capacity
United States:	
New Jersey:	
Edgewater, Bergen County.....	10,500 short tons.
New York:	
Niagara Falls.....	10,500 short tons.
Massena.....	175,000 short tons (reported).
Ohio:	
Cleveland.....	6,600 short tons. Forging capacity to be tripled.
Pennsylvania:	
Arnold, Westmoreland County . . .	6,000 short tons. New tube mill to be added.
New Kensington, Westmoreland County.	7,500 short tons.
Tennessee:	
Alcoa, Blount County.....	16,500 short tons. (Provision for increase to 28,500 tons.)
Wisconsin:	
Manitowoc.....	} Sheets for own utensil production, only.
Two Rivers.....	
Canada: Toronto.....	1,650 short tons.

¹⁵ Edwards, Junius D., Assistant Director of Research, Aluminum Co. of America. Aluminum and its Production.

OTHER FABRICATING PLANTS

100. The company also owns plants manufacturing castings, forgings, or other aluminum articles.

Plant location	Subsidiary	Product manufactured
California: Oakland.....	Modern Foundry and Pattern Works.	Aluminum castings.
Connecticut: Fairfield.....	Aluminum Manufactures, Inc.....	Sand castings.
Michigan:		
Detroit.....	do.....	Sand castings for automobile parts.
Do.....	Aluminum Co. of Michigan.....	Aluminum fabrications for automobiles.
New Jersey:		
Edgewater.....	Aluminum Index Co.....	Aluminum index cards.
Do.....	Aluminum Screw Machine Products Co.	Screw-machine products.
Garwood.....	Aluminum Die-Castings Co.....	Die castings.
New York:		
Buffalo.....	Aluminum Body Co.....	Aluminum automobile bodies.
Do.....	Aluminum Manufactures, Inc.....	Castings.
Ohio: Cleveland.....	do.....	Sand castings for automobile parts.
Pennsylvania:		
Arnold.....	Aluminum Seal Co.....	Bottle closures.
New Kensington.....	Aluminum Cooking Utensils Co.....	Cooking utensils.
Do.....	United States Aluminum Co.....	Fabricating sheets, wire, tubing, rods, and other semifinished products.
Do.....		Aluminum-bronze powder and foil.
Wisconsin: Manitowac and Two Rivers.....	Aluminum Goods Manufacturing Co.....	Cooking utensils and novelties.

European fabricating plants

Plant location	Subsidiary	Product manufactured
England.....	Birmingham Aluminum Castings Company, Ltd.	Castings.
France.....	Fondrie De Precision	Die castings.
Germany.....	Aluminum Spritzgriss Werke, G.M.B.H.	Do.
Italy: Milan.....	Anonima Italiana Conduttori Alluminio.	Transmission wire and cable.
Norway.....	Norsk Aluminum Company.....	Crude and fabricated aluminum.
Switzerland.....	Arbon and Rorschach, through Societa Anonyme d' Aluminum Coire.	Castings.

ALUMINUM CONSUMPTION

101. *Grades.*—Virgin aluminum is sold in ingot form in three grades. Grade A, 99 percent or more aluminum, is used for sheet and other wrought products. Grade B, 98 to 99 percent aluminum, is used largely for alloy castings. Grade C, or 94 to 98 percent aluminum, in grain or granulated form is used principally for deoxidation in steel manufacture. Grade A and an alloy containing about 1.25 percent manganese, known as "3S", are produced in all forms in which aluminum is used.

102. Grade A was quoted at \$0.243 throughout 1929 and until June 26, 1930; on that date a new price, \$0.233, was announced which still pertained in April 1931. Grade B dropped during the same period from \$0.239 to \$0.229.

103. *Domestic markets.*—Continuous research has brought about an expanding market for aluminum. As new uses for the metal have been found, its relative importance in older markets has shifted. In the early days of the industry the largest amount of aluminum was consumed in cooking utensil manufacture. As aluminum alloy castings found a market in the automotive industry this became the largest single consumer of aluminum. In 1925 cooking utensil manufacture took but 10 percent of the total aluminum produced and automo-

biles approximately 60 percent. However, with the falling off in automobile sales in 1930 and with the expansion of the aluminum market into structural and other fields, the automotive industry consumed less than 36 percent of the total 1930 production while our cooking utensils consumption increased to 14 percent.

104. The United States Bureau of Mines quotes the 1930 consumption of virgin domestic aluminum in the several industries as follows:

	Percent
Transportation (land, air, and water)-----	38
Electrical conductor-----	16
Cooking utensil-----	14
Machinery (electrical appliances, etc.)-----	9
Iron and steel metallurgy-----	8
Building-----	4
Miscellaneous foundry and metal working-----	4
Chemical-----	2
Food products-----	1
General miscellaneous-----	4

CONSUMPTION IN TRANSPORTATION INDUSTRIES

105. *Automobiles*.—As has been stated, the automotive industry consumes large quantities of aluminum-copper alloy castings as well as some aluminum-zinc and some aluminum-silicon alloy castings. These are fashioned in pistons, crank cases, cylinder heads, transmission cases, and into a number of small parts. Strong alloys are entering into truck and bus body frames, while tops and sides are also made of aluminum.

106. *Aircraft*.—Aluminum castings are also entering into aircraft construction. Not only are castings used for aluminum pistons and other aircraft engine parts, but they are also employed for aileron levers, control levers, shock absorbers, fuselage, and landing gears. Duraluminum, containing copper and small amounts of manganese and magnesium, has been used for aircraft structures. Unalloyed aluminum is used for gasoline and oil tanks. Aluminum propellers are also in use. In aircraft construction aluminum alloys must compete with magnesium alloys, for magnesium alloys not only possess equal tensile strength and ductility but also save 40 percent in weight. Some of the magnesium alloys do, of course, contain aluminum, but the amount is relatively small. (See p. 307 of *Power in the Manufacture of Chemicals and Metals from Brine*.)

107. In the lighter-than-air craft strong aluminum alloys have also become accepted materials. The Zeppelins have employed it as their principal construction metal not only in the internal framework but also in the covering. Duraluminum is used in the framework, whereas alclad, an alloy core covered with a layer of pure aluminum integral with the core, is used for the outer covering.

108. *Railroads*.—Strong aluminum alloys are entering also into railroad-car construction largely because of their lightness which permits a saving in power required for operation. Aluminum-tank cars resistant to certain acids have become the method of transporting such acids. Aluminum is also being applied to steam and electric locomotive reciprocating parts.

109. *Marine construction*.—Aluminum has been used in the construction of yachts and other small water craft, and it is entering into larger marine craft. The Naval Limitation of Armaments Confer-

ence which fixed the displacement limit has turned attention to aluminum alloys as metals of value in the construction of much battleship furniture and equipment.

CONSUMPTION IN THE ELECTRICAL INDUSTRY

110. Weight for weight, aluminum has twice the conductivity of copper. It has been used, therefore, for the transmission of current since 1898. It is the practice today to provide aluminum transmission lines with a steel-wire core to carry the suspended conductor. Effort is being made to introduce an aluminum alloy cable which will not require the steel core; this is marketed as "Aldrey" by a German company and as "Almelec" by a French company. Aluminum insulated cables for underground network systems as well as for automobile wiring systems were also marketed in 1930.

111. Aluminum is used for busbars in power stations and in industrial plants handling heavy currents. Outdoor busbar systems employ stranded cable, while tubing is used for rigid systems and flat strips when large currents are handled indoors. Aluminum is applied also to other electrical equipment in small quantities.

CONSUMPTION IN COOKING UTENSILS AND MACHINES

112. Not only has aluminum held its place as a material for household cooking utensils, but it is employed in restaurants, in canneries, and in packing houses, and in various food factories either because of its lightness, its heat retentivity, or its resistance to acids. Aluminum mason jar cap manufacturing is reported as a market for 10,000,000 pounds of aluminum.¹⁶ The Norsk Aluminum Co. (affiliated with the Aluminum Co. of America) is making aluminum cans especially for use in the fish-canning industry. The major problem is one of cost. By embossing the cans the expense of labeling is saved which, it is claimed, will make aluminum cans as cheap as tin cans.

113. Aluminum is also used in machines that are handled extensively. Vacuum cleaners, typewriters, washing machines, are among the articles that are being constructed of aluminum alloy. Equipment that handles heavy weights such as cranes are also being made of aluminum.

CONSUMPTION IN METAL INDUSTRIES

114. As has been stated, grade C aluminum is applied to steel for deoxidation. It may be added as aluminum or in the form of a silicon-aluminum-iron alloy, but is usually the final deoxidizer employed.

115. Where carbon-free metals are desired, aluminum may be used as the reducing agent. This so-called Goldschmit or thermit process is employed in vanadium, chromium, cobalt, manganese, and certain alloy production. Barium peroxide and aluminum powder in capsule form and having a fuse of magnesium are employed to start the aluminum grain or shot to burning the oxide from the other metals. The same process is used in welding and repairing iron and steel, the aluminum being mixed with iron.

¹⁶ Engineering and Mining Journal. February 1927.

STRUCTURAL USES

116. The development of a casting technique for large aluminum alloy ingots and the design of heat-treating equipment for large structural shapes made possible the completion of an aluminum structural mill in 1929 and the entrance of aluminum alloys into the structural field. The research laboratory of the Aluminum Co. of America at New Kensington was a practical demonstration of the use of aluminum alloys not only for angles, I-bars, channels, and other usual structural shapes, but also for exterior cornices, spandrels, window frames and sills, copings, and roofing accessories. Furniture and equipment as well as cranes are of aluminum alloys. Already building construction in 1930 is credited with the consumption of approximately 5,000 tons of aluminum alloying. The Empire State Building in New York City alone consumed 4,250 tons during its erection. Manufacture has begun on aluminum window screening and on woven and barbed wire for fencing.

OTHER FIELDS

117. The resistance of aluminum to corrosion by certain acids under given conditions has led to its use in construction of storage or transportation tanks for acetic and nitric acid and dilute sulphuric acid. It is also employed for roofing and tubing in plants handling acetic acid such as rayon plants. Aluminum powder is mixed with lacquer, varnishes, bodied oils, or bronzing liquids to make aluminum paint. This is regarded as an excellent priming coat for wood and for painting dark shops. It is applied to exterior steel construction, to oil tanks, and other exposed steel. As foil, aluminum replaces tin and tin-lead foil, in the confectionery, yeast, and tobacco industries.

COMPETITION

118. Aluminum competes with basic metals in each of its major consumption fields. In the electrical industry, it is a substitute for copper; in cooking utensils for iron and tin; in the structural, transportation, and machinery fields for iron and steel; in corrosion resistance equipment, in paint; and as a rubber filler, for zinc; and in foil, paint, and chemical apparatus, for lead. In aircraft it comes into direct competition with magnesium and with steel in tubing for aircraft.

119. The present advantage of the industry lies in the use of aluminum in many diverse fields of industrial activity so that depression in any one industry may not materially affect the prosperity of the entire industry.

LOCATION OF DOMESTIC MARKETS

120. Automobile castings are manufactured close to their largest consuming markets located in Michigan, Ohio, and New York. In these States and in Illinois, New Jersey, Pennsylvania, Wisconsin, Indiana, Missouri, Tennessee, Connecticut, Massachusetts, California, and Washington, alloy castings are made for this and other industries.

121. The largest plants manufacturing cooking utensils are in Pennsylvania and Wisconsin with smaller plants in Illinois and Ohio. The machinery industries which consume aluminum are located chiefly in Ohio, New York, Illinois, Connecticut, Massachusetts, and Iowa. Metallurgical consumers are located in Pennsylvania, Ohio, and New Jersey.

EXPORTS

122. Although aluminum is purchased in ingot form in the domestic market to a large extent, exports of ingot aluminum from the United States were almost negligible in 1929. Plates, sheets, bars, strips, and rods were the largest item of export, amounting to 8,209 tons. More than a third of this went to British India and another third to the United Kingdom.

123. Canada, on the other hand, exported 36,485 tons of aluminum of which 14,181 tons reached the United States, 8,758 tons were shipped to Japan, 6,100 tons to the United Kingdom, 3,443 tons to Germany, 1,596 tons to Switzerland, and less than 1,000 tons to a number of other countries.

124. Japan is dependent on imported aluminum. Although research is underway to make aluminum from clays available in the country, processes to date have been too expensive. The amount which she imports is increasing. It is fabricated at Kobe and Osaka into kitchen and other utensils, into transmission cable, into alloys and about 10 percent into automotive engine castings. The Asia Co., Ltd., of Tokio is the principal aluminum importing company. The Aluminum Co. of America has an interest in this company.

TABLE IV.—Exports of aluminum products from the United States in 1929 by country of destination ^{1 2}

Country	Bauxite and other aluminum ores (long tons)	Ingot, scrap, and alloys (short tons)	Plates, sheets, bars, strips, and rods (short tons)	Tubes, moldings, castings, and other shapes (short tons)
Total.....	133,551	307	8,209	1,233
Argentina.....		6	196	24
Belgium.....	200	22	272	24
Brazil.....		1	247	38
British India.....		29	2,923	581
Canada.....	125,545	47	283	395
Chile.....		1	27	2
China.....		2	305	1
Germany.....		35	76	
Italy.....		10	433	48
Japan.....		97	47	22
United Kingdom.....	227	52	2,917	74
All others.....	7,579	5	483	24

¹ Compiled from: U.S. Department of Commerce, Bureau of Foreign and Domestic Commerce, Foreign Commerce and Navigation of the United States for 1929.

² Exclusive of kitchenware and miscellaneous fabricated materials.

WORLD PRODUCTION OF ALUMINUM

THE EUROPEAN CARTEL

125. The world's aluminum production is controlled by two groups, the Aluminum Co. of America with Aluminum Limited, and the International Aluminum Cartel. The latter organization is made up of the principal producing companies of France, Germany, Great Britain, and Switzerland. The European cartel was formed in 1926 to regulate production, stabilize prices, expand markets, and exchange technical information for 2 years. In 1928 the cartel was renewed for a 3-year period.

126. *French producing companies.*—L'Aluminium Francais is the selling and fabricating agent for the two French producing companies,

QUANTITIES PRODUCED

129. The foregoing table compares the bauxite production of each country with its aluminum production. The United States produced 48 percent of the world's aluminum in 1929. Including the production of its Canadian works, the Aluminum Co. of America manufactured more than half of the entire amount of aluminum in the world. Only 18 percent of the world's bauxite was mined in the United States while mines in British and Dutch Guiana produced 20 percent of the entire supply. (Bauxite mining includes bauxite for industries other than the aluminum industry.)

130. Germany had risen to second place in the production of aluminum in 1929, while France ranked third, Norway fourth, and Switzerland fifth. The only other producing countries were Great Britain, Austria, and Italy.

131. Canada and Norway export a large part of the aluminum they produce. Both countries count on Japan, Great Britain, and the United States for their principal consuming markets, although Canada ships in largest quantities to the United States, and Norway sends the largest amount of her aluminum to Great Britain. France, Hungary, Italy, and the Guianas are bauxite exporting countries, while Germany, Great Britain, and the United States are bauxite importing countries.

132. Plant expansion is going on in all European countries as well as in the United States and in Canada. Unquestionably, world aluminum producers believe the aluminum market is an expanding market.

Bibliography

Year	Author	Title
1924	Anderson, R. J.	Metallurgy of Aluminum and Aluminum Alloys.
1929	Bossert, T. W.	Aluminum and Its Alloys in Aircraft. In American Electrochemical Society Proceedings, Sept. 19, 1929.
1927	Edwards, J. D.	Aluminum from Oersted to Arvida, in American Electrochemical Society Proceedings.
1929	do	Alumina Production in Its Present Day Aspects.
1929	Edwards, J. D., and Taylor, Cyril S.	Nominal Composition of Strong Alloys, in Transactions of the American Electrochemical Society, 1929. Vol. LVI.
1927	Edwards, J. D.	Aluminum Paint, in Aluminum Catalogue.
1930	Edwards, Frary, and Jeffries.	The Aluminum Industry.
1930		Massena Mill Relies Largely on Electrical Application, Apr. 12, 1930. Electrical World.
1927		Engineering and Mining Journal. Price quotations.
1929		
1930		
1927	Faragher, P. V.	
1930	Frary, Francis C.	Commercial Forms and Applications of Aluminum and Aluminum Alloys. American Institute of Mining Metallurgy. Eng. Tech. Pub. 33.
		Present Day Aspects of the Aluminum Industry, an address before the New York section of the American Electrochemical Society, Feb. 14, 1930.
1924	Guillet, L.	History of Light Alloys of Aluminum and the Present Position of Their Manufacture. J. Inst. Met. 33.
1926	Haglund, J. R.	The Haglund Process.
1930	Hobbs, Douglas B.	Aluminum in 1929, in Engineering and Mining Journal.
1928		Journal du four "Electrique", no. 4.
1928	Knibbs, N. V. S.	The Industrial Uses of Bauxite.
1929	Lowdon, D. S.	The Aluminum Industry, in Harvard Business Review, October.
1928	Mantel, C. L.	Aluminum, in Chemical and Metallurgical Engineering. August.
1927	McBride, R. S.	Modern Technology in Producing Pig Aluminum, in Chemical and Metallurgical Engineering, vol. 34, no. 2. February.
1928		The Development of the Aluminum Industry, in Metal Industry, vol. 26, no. 3.

Bibliography—Continued

Year	Author	Title
1929	Roush, G. A.	The Mineral Industry During 1928, vol. XXXVII.
1930	Porter, J. D.	Aluminum in the South, Journal of Chemical Education, October 1930.
1927	Rheinboldt.	Hundred Years—Aluminum, Metallwirtschaft 6: J. Inst. Met. 37.
1925	Thompson, Maurice D.	Theoretical and Applied Electrochemistry.
	U.S. Department of Commerce:	
1928	} Bureau of Mines.	Bauxite and Aluminum.
1929		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.
1926do.	Hearings Before the Committee on the Judiciary Pursuant to S.Res. 109.

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