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THE ORIGINAL AND SOME NEW ELECTRIC FURNACE PRODUCTS

CONTENTS

	Page
Power requirements of original electric-furnace products	427
Calcium carbide	428
Development of industry	428
Originally a source of illuminating gas	428
Use in metal and organic chemical industries	428
Position as a basic raw material threatened	429
Present production in United States	429
Manufacturing processes	430
Power consumption	430
Costs of production	430
Organization of industry	431
Plants manufacturing calcium carbide	431
Subsidiary plants producing acetylene, oxygen, and welding equipment	431
Subsidiary plants producing organic chemicals and gases	432
Competitive conditions	432
European developments	432
Excess capacity in United States	433
Electric furnace abrasives and refractories	433
Demand for hard abrasives and superrefractories	433
Production	435
Silicon carbide and fused alumina	435
Mullite refractory producers	436
Manufacturing processes and power consumption	436
Silicon carbide	436
Fused alumina abrasives and refractories	437
Mullite	439
Sources of raw materials	439
Sand	439
Petroleum coke	440
Bauxite	440
Mullite minerals	441

CONTENTS—Continued

	Page
Fused quartz	441
Silicon and calcium	442
Graphite	442
Production	442
Markets	443
Manufacturing processes and power consumption	443
Bibliography	444

When hydroelectric service was made available at Niagara Falls in 1895, the manufacture of products requiring such high temperatures as to be commercially practical only in electric furnaces, began on a commercial scale. Silicon carbide for abrasives, calcium carbide for acetylene lighting, and crystalline graphite for electrodes were among the first industries to become established at the Falls. Fused alumina and other electrometallurgical industries located there in the early years of the twentieth century.

While new plants have been established at other locations, these industries still center about Niagara Falls consuming from 2,000 kilowatt-hours to 8,000 kilowatt-hours of energy per ton of electric-furnace product.

The demand for silicon carbide and fused alumina is growing, not only because of the increased need for hard abrasives in machining alloy steel, but also because both materials make excellent high-temperature refractories. The electrical energy consumed in crude silicon-carbide production in the United States and Canada in 1929 was approximately 227,000,000 kilowatt-hours. Crude fused alumina production in the two countries required in excess of 150,000,000 kilowatt-hours. While almost all crude abrasives are made into abrasive wheels and papers or into refractory shapes in the United States only one third of the crude alumina is fused in the United States and less than one seventh of crude silicon carbide is formed in United States plants. The remainder is made on the Canadian side of Niagara Falls and at Shawinigan Falls, Canada, by American companies.

Calcium carbide production in the United States consumed approximately 720,000,000 kilowatt-hours in 1929. The present capacity of calcium carbide plants in the United States and in foreign countries exceeds the demand for the material which finds sharp competition in every market in which its finished products enter. The position of calcium carbide as a commercial source of acetylene is also threatened by the production of acetylene from methane. American firms manufacturing calcium carbide have entered upon the manufacture of organic chemicals, gases, ferro-alloys and other products.

Crystalline graphite production requires approximately 7,600 kilowatt-hours per ton. As only one company was engaged in its commercial production prior to 1929, total production figures are not available. Plants consuming a large number of graphite electrodes in electric furnace production are beginning to manufacture their own electrodes from petroleum coke.

Silicon and metallic calcium find small commercial application. Fused quartz, however, is finding extended demand not only as equipment for acid manufacture but also in optical and photographic lenses and in ultra-violet and infra-red ray transmission glass. A ton of transparent quartz would require over 10,000 kilowatt-hours of electricity for fusion; it is still manufactured by the pound.

Calcium Carbide

DEVELOPMENT OF THE INDUSTRY

1. Calcium carbide, although a manufactured product itself, serves as the raw material for a number of chemicals. The development of the calcium carbide industry is inextricably tied up with the changes in demand for compounds af which it is the basic material. Only recently has its position as an essential raw material been threatened.

2. *Source of light.*—When in contact with water, calcium carbide gives off an illuminating gas, acetylene. Although calcium carbide was discovered as early as 1862, it gained commercial significance as a source of this gas only after its accidental rediscovery by Thomas L. Willson at Spray, N.C., in 1892. As gas was being used for lighting at this time, the discovery was immediately seized upon and patents were sold to a company which licensed their use.

3. By 1896, the first calcium carbide manufacturing plant began operations at Niagara Falls. The carbide was shipped to Philadelphia to the Acetylene Light, Heat & Power Co. to augment the city's gas supply. A second carbide plant was built by another company at Sault Ste. Marie, Mich. Both plants and licenses were taken over by the Union Carbide Co. which enlarged the plants to meet the great demand for lighting acetylene. This company was protected by the original patents until the time of their expiration in 1912.

4. The increased use of electricity for lighting, not only in cities but also in rural regions, has greatly decreased the value of acetylene as an illuminating gas. Today, only where electricity is not available and where abundant light must be generated quickly does acetylene find a market because of its portability and the speed and ease with which it produces a bright light.

5. *Source of heat.*—A second use of acetylene was developed, however. When acetylene is burned with oxygen instead of air, an intensely hot flame is generated which is used to weld and cut metals. As firms using acetylene for this purpose also required a supply of oxygen, many oxygen-producing firms became subsidiaries of corporations controlling calcium-carbide production, acetylene production and distribution, and manufacture of oxy-acetylene welding equipment.

6. But in this field, too, acetylene has come in competition not only with other gases but also with electricity. While it gives the hottest of chemical flames (7,878° F.), hydrogen with or without oxygen is used for some purposes and electric welding is gaining in importance in the nonpressure field.

7. *Base for organic chemicals.*—However, a new use for acetylene was discovered during the war. At that time there was a heavy demand for acetone, necessary for the manufacture of cordite, the type of smokeless powder used by the British fighting forces. The existing production of acetone by the distillation of wood could not meet the demand. A plant was erected at Shawinigan Falls, Canada, for the

production of acetone from acetylene. As a new need had arisen for pure acetic acid in airplane dope, this plant produced the acetic acid from acetylene instead of carrying the process to the acetone stage. (Acetone was produced from corn and rice in other plants.) While production ceased, temporarily, with the signing of the armistice, the production of synthetic glacial acetic acid from acetylene began again in the latter part of 1928 at Niagara Falls, N.Y., as well as at Shawinigan Falls, Canada.

8. With acetylene as a base, a series of combinations are possible that result in some of the most complicated compounds of organic chemistry. As a consequence, carbide companies have erected organic chemical factories. The extent to which these may be able to compete with similar products derived from other sources will determine the position of acetylene in the years to come. At present not more than 10 percent of the calcium carbide produced in the United States enters into the production of synthetic organic chemicals.

9. *Fixation of nitrogen.*—The use of calcium carbide for the fixation of nitrogen began at Niagara Falls, Canada, in 1909. As only one Canadian firm produced calcium carbide for the sole purpose of manufacturing calcium cyanamide and fertilizers, the details of this manufacture are reported in the section "Power in the Fertilizer Industry."

10. *Position as a basic material threatened.*—The position of calcium carbide as the sole commercial source of acetylene is threatened by experiments under way at the Kaiser-Wilhelm Institute fur Kohlenforschung. German chemists have succeeded in producing acetylene from methane in low-pressure-discharge apparatus. While no commercial production has, as yet, taken place, commercial success of the methanol acetylene would challenge the position of calcium carbide seriously.

11. Recently, the Union Carbide Co. of Niagara Falls has been collecting carbon monoxide gas produced in the manufacture of calcium carbide and has been turning it into synthetic methanol.

12. *Production in the United States.*—The production of calcium carbide in the United States totaled 201,955 tons in 1927, the latest year for which official figures are available. A little less than 2,000 tons were imported from Canada in 1929. Exports, chiefly to the Philippine Islands, Mexico, Panama, Cuba, and other Central and South American countries exceeded 2,000 tons.

TABLE I.—*Calcium-carbide production in the United States* [1]

Year	Short tons produced
1923	90, 750
1925	170, 773
1927	201, 955
1929	225, 000

[1] Figures reported by the U.S. Bureau of the Census. Calcium-carbide production figures for 1929 and years prior to 1923 are not separable from figures for other calcium compounds. 1929 quotations are estimates made by "Industrial and Engineering Chemistry."

Manufacture of Calcium Carbide

13. *The charge.*—Limestone, containing 96 percent or more of calcium carbonate, is partially crushed and heated in a rotary or vertical kiln. The calcium carbonate is decomposed forming calcium oxide or burnt lime. About 1,800 pounds of burnt lime and dry carbon in the form of foundry or petroleum coke, or anthracite coal, are coarsely ground, mixed, and fused in an electric furnace producing calcium carbide and waste carbon monoxide. Soft-burned coke containing not more than 6 percent ash and not more than 0.5 percent moisture is the carbon chiefly used in this country. Petroleum coke, either by itself or mixed with byproduct coke, is employed to a limited extent. In Europe, anthracite coal is extensively applied. While the low electrical conductivity of charcoal and its small ash content facilitate furnace operation and give good output the expense involved in charcoal handling has practically eliminated it from commercial carbide furnace use. The life of the electrode is dependent upon the carbon employed; its consumption is lowest with coke. Furnace voltage and energy supplied is also determined by type of furnace charge.

14. *The electric furnace.*—The early small electric carbide furnaces were of the block type wherein the solidified calcium carbide was drawn off from underneath the working zone of the furnace. Tapping furnaces have superseded these. They may be single-phase or three-phase furnaces. Units double the latter size are constructed by including 2 three-phase electrode systems in 1 furnace jacket. This gives an 18,000-kilowatt furnace with 6 electrodes, each carrying up to 45,000 amperes. For such a loading, the contact must be kept cool by circulating cold water through hollow bolts and contact plates. Consequently, electrodes of coarse anthracite that will withstand water cooling at a furnace temperature of about 3,000° C. are preferred.

15. Large furnaces can work continuously without shutting down for serious repairs. Because they can be operated with load variations, night current is used in some European plants. As the molten carbide is tapped from the electric furnace, at hourly or longer intervals, it goes to cooling floors and then to breakers and mills. It is crushed and graded in the sizes required for particular purposes and is then packed in airtight metal drums for shipment.

16. *Energy consumption.*—The amount of energy consumed by the carbide electric furnace varies with the size and type of furnace and the kind of carbonaceous material employed. The largest furnaces in this country require approximately 2,600 kilowatt-hours of energy to produce 1 ton calcium carbide. A 5,000-kilowatt furnace requires approximately 3,200 kilowatt-hours per ton of carbide. Tapping furnaces of but 1,400-kilowatt capacity take as much as 4,000 kilowatt-hours per ton produced.

17. *Costs of production.*—The raw materials required for the manufacture of calcium carbide are abundant and are secured from the sources nearest to the operating plant. Power is purchased at Niagara Falls under contract for $20 per horsepower-year. The Union Carbide & Carbon Co. operates the Michigan Northern Power Co. which supplies power to the carbide plant at Sault Ste. Marie. Other companies purchase their power. A subsidiary of the Union

Carbide & Carbon Corporation, the National Carbon Co., manufactures the electrodes for carbide furnaces.

18. While details concerning operating costs are not disclosed by individual companies, the following estimates apply current market prices to quantities of material and labor required in the production:

Capital costs: 15 percent on $60 per ton-year	$9.00
Production costs:	
Limestone, 2,880 pounds at $1.50 per ton	2.22
Bituminous coal, 540 pounds at $4 per ton	1.08
Coke, 1,200 pounds at $5.83 (New York)	3.50
Electrodes, 20 pounds at $0.05 pound	1.00
Power, 3,200 kilowatts at $0.003	9.60
Labor and other operating expenses	5.50
Total estimated cost	31.90

Organization of the Industry

PLANTS MANUFACTURING CALCIUM CARBIDE

19. The manufacture of calcium carbide is carried on at 6 plants in the United States by 3 companies. These plants have combined capacities in excess of 350,000 tons calcium carbide, while production is but 220,000 tons. The largest producer is the Union Carbide & Carbon Co. whose subsidiary, the Union Carbide Co., operates plants at Niagara Falls, N.Y., and Sault Ste. Marie, Mich., while a second subsidiary, the American Carbolite Co., produces calcium carbide at Duluth, Minn. This corporation also manufactures calcium carbide at Welland, Ontario.

20. The Air Reduction Co. operates carbide plants at Keokuk, Iowa, and at Ivanhoe, Va. The third producer is the Federal Carbide Co., a Swann Corporation subsidiary, with plant at Anniston, Ala.

SUBSIDIARY PLANTS PRODUCING ACETYLENE, OXYGEN, AND ACETYLENE WELDING EQUIPMENT

21. Calcium carbide for lighting or organic-chemical production may be shipped in drums directly from carbide factories to points of consumption. If, however, it is to produce acetylene for welding and cutting, the acetylene must be compressed and dissolved in acetone, as acetylene in itself is explosive.

22. The carbide manufactured by the Union Carbide & Carbon Corporation plants is turned into dissolved and compressed acetylene by its subsidiary, the Prest-O-Lite Co., with main plant at Indianapolis and 50 other plants. This company also markets the dissolved acetylene in returnable steel cylinders. As users of acetylene for welding of metals require a supply of oxygen to produce the welding flame, a third subsidiary, the Linde Air Products Co. with 68 plants scattered about the country, produces oxygen and delivers it to users in steel cylinders. The apparatus essential for welding is manufactured by a fourth subsidiary, the Oxweld Acetylene Co.

23. The Air Reduction Co., incorporated in 1915, has been acquiring, through lease or purchase, a number of plants that produce dissolved acetylene and oxygen. Its oxy-acetylene welding equipment is produced by a subsidiary, the Davis-Bournonville Co., of New Jersey. The Air Reduction Sales Co. operates about 100 oxygen

plants located in Oregon, California, Texas, Louisiana, Kentucky, West Virginia, North Carolina, Virginia, as well as in Middle Western and eastern industrial States. Acetylene plants are located in a number of these States. The company acquired a group of French patents (including the "Claude" patents) covering basic processes for the separation of air by liquefaction, together with the exclusive rights for their development in the United States.

24. A number of independent companies buy their carbide and produce acetylene for welding purposes.

SUBSIDIARY PLANTS PRODUCING ORGANIC CHEMICALS AND GASES

25. The Carbide & Carbon Chemicals Corporation of West Virginia is the organic chemical branch of the Union Carbide & Carbon Co. It is not only using calcium carbide as a raw material but is working with natural gas and other hydrocarbons. When off-grade calcium carbide is converted to acetylene and acetylene added to water in the presence of sulphuric acid and a mercury salt, a transitional chemical, acetaldehyde, is obtained. This may be oxidized to acetic acid as is being done by the Niacet Chemical Corporation at Niagara Falls. Acetic acid plus heated lime results in acetone which is manufactured by the Carbide & Carbon Chemicals Corporation. It is estimated that the rayon industry alone consumed 11,000 tons of acetic acid, 11,000 tons of acetic anhydride, and 5,600 tons of acetone in 1929.

26. The Niacet Chemical Corporation produces not only acetic acid and acetaldehyde but also acetaldol, crotonaldehyde, paroldelhyde, and paraldol—chemicals having varying uses in medicine and in industry. The Carbide & Carbon Chemicals Corporation also produces a long list of organic chemicals.

27. The Air Reduction Co. not only separates oxygen and nitrogen by liquefaction and subsequent fractionation of air, but also secures other constituent gases of the air. Isolated argon is used as a filler in electric-light bulbs. Neon fills vacuum tubes when a brilliant red light is desired for harbor lights or in advertising display. Helium, krypton, and xenon are very rare elements obtained. A subsidiary of this company also produces carbon dioxide for soda water, fire extinguishing, and refrigeration.

Competitive Conditions

EUROPEAN PRODUCTION

28. Calcium carbide is manufactured in Canada, Norway, Sweden, Switzerland, France, and Germany. Plans for the increased development of the large power plant in Dalmatia by the French company, Phosphates Tunisiens, include the establishment of a calcium carbide plant as well as of other types of electrochemical and electrometallurgical factories. European trade articles indicate that there is fear lest this lead to an overproduction of calcium carbide, which is avoided only with difficulty at this time.[22]

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[22] Chemical Age (London), Sept. 7, 1929. The Carbide Industry.

UNITED STATES PLANT CAPACITY EXCEEDS MARKET DEMANDS

29. While the larger part of European calcium carbide is applied to the fixation of nitrogen, and our producers are protected by a 1 cent per pound tariff on carbide, United States calcium carbide plant capacity also exceeds present productive demands. Calcium carbide meets competition in every market in which its finished products are consumed.

30. The census reports the production of 989,228,000 cubic feet of acetylene in 1929. This required approximately 99,000 tons of carbide. The larger part of this acetylene was used in oxyacetylene welding and cutting. Such welding and cutting is done on pipe lines, for repairing railway trackage, and other metal equipment; and has become a unit manufacturing process in the production and assembling of railway cars, automobiles, storage tanks, and metal furniture. It can be used also for applying bronze and abrasive resisting materials to worn surfaces.

31. While it has been recognized that oxyacetylene welding and cutting were essential for emergency work because more heat units could be supplied to scattered points at lessened cost, and that it was more effective on light metals and on destructive work due to its greater cutting speed, the atomic hydrogen flame using no oxygen as well as electric arc welding are being applied extensively. The reduced cost of hydrogen made possible by dissociation of ammonia or of any methane gas by means of electrically heated equipment is responsible for the increased use of atomic hydrogen.

32. Calcium carbide as a source of acetic acid and acetone is meeting increasing competition from the acid made by fermentation of farm waste as well as from synthetic acetone obtained from natural gas.

Electric Furnace Abrasives and Refractories

DEMAND FOR HARD ABRASIVES AND SUPERREFRACTORIES

33. *Manufactured abrasives.*—The production of the manufactured abrasives, silicon carbide and fused alumina, made possible precision grinding and extended the scope of grinding operations into the field of hard-alloy and high-carbon steels. Although commercial production of silicon carbide (SiC), a material second only to the diamond in hardness, was begun in 1891 with the idea of substituting this material for diamond dust in polishing of precious stones, it was soon found to be superior to the natural abrasive, emery, in valve grinding. Its use in grinding and cutting metals has increased rapidly with the demand for precision tools, for carefully machined parts, and for alloy steels. Silicon carbide grit can successfully grind the next hardest known substance, cobalt-tungsten carbide alloy, which is beginning to find use in tool steels.

34. As silicon carbide is brittle, it is applied successfully only to metals of low tensile strength and to nonmetals. Fused alumina, ranking fourth in hardness, has been employed chiefly to grind metals of high tensile strength. It has an advantage over silicon carbide in that its hardness and toughness are controllable by the addition or extraction of several substances. Consequently, fused alumina finds

more varied application than silicon carbide. Not only is it used in metal working, but it is also replacing garnet in abrasive belts in wood-working industries. These two manufactured abrasives offer severe competition to such natural abrasives as corundum, emery, and garnet.[23]

35. *Superrefractories.*—Demand for materials reduced only at high temperatures and employment of higher pressures in the chemical industries has necessitated the production of refractory materials which can withstand much higher temperatures than the ordinary fire-clay refractories. The high-fusion point of silica and alumina makes these minerals inherently excellent refractory materials.

36. *Amorphous silicon carbide or silicon oxycarbide.*—In commercial practice an amorphous silicon carbide is formed during the process of manufacturing the crystalline silicon carbide abrasive, although it may also be made in a specially constructed furnace. This by-product has high heat-resisting characteristics and is an excellent heat conductor. As it can carry severe loads and is acid resistant, it is rapidly finding its place among refractory materials. When made into brick, this silicon carbide is used in furnaces and kilns where high temperatures, rapid change of temperatures, flame impingment, or heat transmission are essential. It is made into muffles for porcelain-enameling and pigment-calcining furnaces, and into electric heating elements for heat-treating furnaces and ceramic kilns, and into terminal mountings and accessories.

37. *Diaspore refractories.*—Alumina is also an excellent refractory material, neither strongly acidic nor strongly basic. Dehydrated bauxite and diaspore refractories have been made for some time, but because they have not been heated sufficiently during their manufacture they have shrunk at high temperatures during use. Studies of the shrinking characteristics of specific alumina clays under varying temperatures and heat-treatment periods are under way. It is not yet ascertainable to what extent electric furnace heat will be essential for shrinking diaspore, bauxite, or other alumina materials in order that refractories made up of these materials will be stable under high-temperature range.

38. *Fused alumina refractories.*—Fused alumina, such as is employed as an abrasive, is resistant to extremely high temperatures; it has been used, however, only where severe conditions that cannot be met by cheaper refractories are encountered. The enamel industry and ceramic industries are employing it either as linings of enameling furnaces or for saggers. In powdered form, fused alumina mixed with a bonding material is used as a furnace cement.

39. *Mullite refractories.*—While mullite is present in fire-clay refractories, only recently have efforts been made to manufacture mullite refractories. Mullite shapes made in the electric furnace have given excellent results in glass-melting tanks, in forging furnaces, and in brass-melting and special alloy-melting furnaces. Made from special mullite minerals, mullite has been used in oil refineries for lining sludge oil incinerators.

40. Other superrefractories that are being tried out are electrically sintered magnesite, giving the highest-grade magnesia refractory for basic open-hearth furnaces and electric-furnace linings; a combination

[23] Metallic abrasives such as steel wool, steel shot, and the metallic oxides, rouge and crocus, are not included in this report, as they are not electric furnace products.

of chromium oxide and silica, and zirconium. Electric-furnace graphite has long been recognized as an excellent high-temperature refractory under nonoxidizing conditions.

Production

SILICON CARBIDE AND FUSED ALUMINA

41. *Companies.*—The Carborundum Co. began the manufacture of silicon carbide in 1891 at Monongahela, Pa. In 1895 it erected a plant at Niagara Falls, N.Y.; a subsidiary was established on the Canadian side of the Falls. Later, its largest factory for manufacturing silicon carbide was located at Shawinigan Falls, Quebec. Fused alumina is produced at the Niagara Falls plants. The crude materials are converted into marketable abrasives at Niagara Falls; into refractories at Perth Amboy, N.J.; and into furnace heating elements and other furnace accessories by a subsidiary, the Globar Corporation, at Niagara Falls. The Carborundum Co. remains the world's largest producer of silicon carbide, even though basic patents have expired.

42. The Norton Emery Wheel Co., of Worcester, Mass., took over the original patents for the manufacture of fused alumina abrasives and began commercial production at Niagara Falls, N.Y., in 1901. Its New York plant was sold in 1930 and all production of fused alumina and silicon carbide transferred to its factory at Chippewa, Ontario, just south of the Falls. Here it produces more fused alumina abrasive than any other company. This, together with silicon carbide, is shipped to its Worcester (Mass.) plant for cleaning and grading and manufacturing into grinding wheels, abrasive papers, and refractories.

43. In addition to the Carborundum Co. and the Norton Co., silicon carbide is manufactured by the Federal Abrasive Co., at Anniston, Ala., and by the Exolon Co. at Thorold, Ontario, with cleaning and grading plant at Blasdell, N.Y. Fused alumina abrasives are produced by the Norton Co. in Canada, by the Carborundum Co., at Niagara Falls, by the Federal Abrasive Co. at Anniston, Ala., by the General Abrasive Co. of Niagara Falls, N.Y., by the Exolon Co. at Thorold, Ontario, and by the Abrasive Co. at Hamilton, Ontario. As all basic patents have expired, each company markets its products under trade names, such as carborundum, crystolon, carbolon, alundum, aloxite, exolon, and carbofrax.

44. *Quantities manufactured.*—Because of the relation between United States producing plants and Canadian plants, production figures for both countries are given together. Out of a total production of 126,712 short tons of crude artificial abrasives manufactured in the two countries, 72,614 tons, or 57.3 percent, were fused alumina, 30,309 tons, or 24 per cent, silicon carbide, and the remainder, metallic abrasives. The silicon carbide and fused alumina accounted was manufactured not only into abrasives but also into refractories. As both applications are made by the same companies, separate figures are not available as to the amount entering into each marketed product.

45. While 1929 Canadian figures have not been secured, in 1928, 39,413 tons of fused alumina and 19,008 tons of silicon carbide were

manufactured on the Canadian side of Niagara Falls or at Shawinigan Falls, Quebec, or about two thirds the combined production of fused alumina in the United States and Canada and 86 percent of the combined production of silicon carbide is produced in Canadian plants. Although Canadian factories ship their output of crude abrasive refractory material to the parent plants in the United States to be crushed, cleaned, graded, and manufactured into grinding wheels, abrasive papers, furnace and kiln brick, tile, muffles, and saggers, the United States is really dependent upon Canada for the major part of its manufactured abrasives and high-grade super-refractory materials.

TABLE II.—*Production of artificial abrasives and refractory materials in the United States and Canada* [1]

Year	Total manufactured abrasives (short tons) [2]	Crude silicon carbide		Crude fused alumina	
		Short tons	Percent of total	Short tons	Percent of total
1929	126,712	30,309	23.9	72,614	57.3
1928	99,731	22,162	22.2	59,103	59.3
1927	90,626	26,289	29.0	50,973	56.2
1926	73,603	17,026	23.1	43,967	59.7
1925	88,530	24,112	27.2	53,253	60.2
1924	60,097	17,792	29.6	33,708	56.1
1923	80,769	21,149	26.2	51,391	63.6
1922	53,935	16,233	30.1	31,898	59.1
1921	13,199	2,707	20.5	7,325	55.5
1920	42,437	6,887	16.2	32,891	77.5
1919	50,518	28,435	56.3	19,723	39.0
1915	57,911	(3)		(3)	
1913	16,745	(3)		(3)	

[1] Compiled from U.S. Bureau of Mines: Abrasive Materials in 1929, and Mineral Resources of the United States, 1926.
[2] Includes metallic abrasives, silicon carbide, and fused alumina applied to refractories.
[3] Separate figures not available for 1913 and 1915.

46. *European production.*—Imports of silicon carbide and fused alumina from Europe are small, coming principally from France. There are five plants manufacturing silicon carbide in Europe, the largest being located at Eydeham, Norway. The Electro-Chimique de Mercus of France has the heaviest production of fused alumina of the seven European manufacturers.

47. *Mullite-refractory producers.*—The Corning Glass Works developed the process of manufacturing mullite in the electric furnace. This is now being produced for the general market by the Corhart Refractories Co. of Louisville, Ky. It is marketed under the trade name of Electrocast. Mullite refractories from special ores are produced in Los Angeles, Calif., by the Vitrefrax Co. and are marketed as brick called Durox.

MANUFACTURING PROCESSES

SILICON CARBON

48. *The furnace.*—Open electric furnaces supported on piers are employed in the manufacture of silicon carbide. Water-cooled graphite electrodes are introduced through permanent brick furnace ends. The furnace sides are taken down after each run.

49. *The charge.*—The charge is made up of approximately 53 to 56 parts of silicon, from 28 to 34 parts of coke, 7.5 parts of sawdust, and sometimes 1.5 parts of salt. Silicon is secured from good-quality glass sand containing 99 percent or more silica and almost free of iron, lime, phosphorus, and magnesium. Salt is added to eliminate any iron or oxides that may be present; it combines with these, forming volatile chlorides which escape into the air. Highest-grade silicon carbide is made from petroleum coke; bituminous coal coke is employed only for lower grades. Sawdust produces a porous mass which is easily broken up and permits accumulated gases to escape.

50. *The core.*—The mixed charge is loaded into the furnace to the level of the electrodes. From electrode to electrode a trench is made which is filled with a graphite and granular coke core. This core offers high resistance to the passage of current, thereby creating intense heat. After the core is complete, the remainder of the charge is added.

51. *Power consumption.*—The starting voltage varies with the core resistance, but usually is from 300 to 330 volts. At a temperature of 1,460° C. the carbon and silica begin to combine, forming an amorphous carbide. From 1,840° C. to 2,220° C. crystalline carbide is formed. If the charge is heated above 2,220° C. the silicon carbide decomposes into amorphous graphitic carbon and volatile silicon. After 36 hours the current is turned off, the furnace is cooled, and the sides are taken down. An outer crust of impurities is first removed. Beneath this is a layer of unconverted charge which is used in the next batch. From 2 to 4 inches of amorphous silicon carbide is then found, which is used for refractories. The fourth layer is the crystalline silicon carbide abrasive. The central core has become amorphous graphite. From a 22-ton charge approximately 6 tons of crystalline carbide of good abrasive grain is obtained, while 2 tons of refractory amorphous carbide has been produced as a byproduct. The run of 36 hours requires from 40,000 to 50,000 kilowatt-hours, or each ton of abrasive produced demands from 6,666 to 8,333 kilowatt-hours of electricity.

52. The silicon carbide lump removed from the electric furnace is crushed and screened. It is then washed with steam and water, caustic soda, and hydrochloric acid to remove any silicon, graphite, or iron present. After drying, silicon carbide is graded according to the size of the individual grain.

53. When amorphous silicon carbide is made in a separate furnace less carbon is used, so that the silica will not be completely reduced. More than one core is built up in the furnace for a more even distribution of heat, or it may be made in a closed arc furnace.

FUSED ALUMINA ABRASIVES

54. Alumina abrasives are made from bauxite, corundum, or pure alumina. By combination with other substances, a series of special abrasives are obtained. The larger tonnage, however, is made from bauxite according to the following methods.

55. *The charge.*—Bauxite, containing at least 50 percent alumina, and water, silica, iron, and titanium oxide, is crushed to ½-inch pieces. It is then calcined to remove its water content. A careful analysis determines the quantity of remaining substances and the consequent

amounts of coke and iron essential for the reduction and elimination of impurities. Bituminous coal coke is used to reduce the impurities to metallic form. Iron added unites with the silicon, forming a button of ferro-silicon, and also renders magnetic other impurities for later removal by means of an electromagnet. Mr. Eardley-Wilmot states that a typical charge might be made up of 80 percent calcined bauxite, 16 percent iron borings, and 4 percent coke. Actually, for every ton fused alumina produced in 1928, 1.09 tons bauxite, 0.08 ton coke, and 0.11 ton iron were consumed.

56. *The furnace.*—Open-bucket or cone-shaped electric furnaces are used for the fusion. The bucket—or the hearth in the case of cone furnaces—is on a truck, so it can be wheeled under the electrodes. These are of carbon and are raised or lowered mechanically into the charge to give a fixed current. The hearth is built up of bauxite dust and old carbon electrodes cemented together with pitch, or of pitch and coke, after each run. The cone-shaped, water-cooled shell is lowered onto the hearth after it has been wheeled beneath the electrodes, when a bucket furnace is not used. Only part of the charge is added at a time. After this has fused, more is dumped in and fused, and this continues until the entire furnace is filled, a process requiring 24 to 36 hours, depending upon the power used. The electrodes are lifted to a new level after each charge.

57. *Power consumption.*—Fusion requires an internal heat of approximately 3,500° F. Furnaces are of varying size. Alternating current is used. Approximately 2,000 to 2,540 kilowatt-hours of energy are required per ton of crude aluminous abrasive produced.

58. After the current is turned off, cooling is given careful attention. Water is circulated on the outside of the furnace walls for several hours. When the furnace is cooled, it is wheeled out from under the electrodes; the shell is removed in the cone furnace, or the ingot dumped out of the bucket furnace. After the ingot has cooled for about a week, it is broken up. The ferro-silicon button, weighing 2 to 3 tons, is removed and the alumina crushed and screened. An electromagnet takes out the magnetized impurities after which a further roasting renders the nonmagnetic iron content magnetic for further magnetic separation of impurities. The clear alumina is graded according to size.

59. *Special alumina abrasives.*—The titanium content of bauxite is not eliminated by this process of manufacture. As this mineral renders the abrasive tough and resistant to fracture, it cannot be used successfully for all purposes. Consequently, for some abrasives, either high-grade corundum or a pure amorphous alumina powder is employed. As the pure alumina is almost free of impurities, it requires little reduction and is charged and fused rapidly. Graphite electrodes are used. After cooling, it is roasted to remove any traces of aluminum carbide.

60. As natural corundum contains some silicon and iron, as well as water, it is mixed with sufficient iron borings to make the ferro-silicon produced magnetic. Coke also must be added to reduce these impurities.

61. The abrasive temper is not only affected by the degree of purity of the raw material, but also by the addition of minor amounts of several oxides. While all types are fused in the electric furnace, details of reduction and cooling vary.

62. *Grinding wheels and coated abrasives.*—The graded abrasives are bonded together by various means in the form of grinding wheels or abrasive paper. The larger number of grinding wheels are still made by the vitrified process. Ball clays, fireclays, kaolin, other clays, and feldspar are used as bonding materials. These are combined with the abrasive grain, mixed with water, and poured into molds or pressed into shape by hydraulic pressure. The green wheel is shaped and then fired in kilns, heated by coal or producer gas. The bakelite wheel, which is now much advertised, is replacing the vitrified wheel to some extent. Bakelite, a synthetic phenol plastic, is mixed with the abrasive and a special solution added to make the mixture plastic. After the mixture has been forced through a sieve, it is pressed into shape by hydraulic pressure either in electrically or steam heated presses or in a cold press. The wheels are baked to about 300° F.

63. In the manufacture of coated abrasives, a heavy kraft paper, manila fiber paper, cotton drill, or a combination of drill and paper is employed. The roll of backing is run through a heated aperture over a roller which revolves in a heated hide-glue trough. After the glue deposit has been evened up by a vibrating brush, the heated abrasive grain falls through a regulated aperture upon the glue-covered paper. A steel roll forces the grain into the glue. After the paper is dried a regluing operation takes place.

64. *Refractories.*—The graded, ground electric-furnace products are bonded with a small amount of ceramic bonding material, are pressed into desired shapes, and kiln baked.

65. *Mullite.*—In the manufacture of mullite refractories, a mineral containing more than 68 percent alumina and silica are melted in an electric furnace. The mobile mass is poured into sand molds to form the finished shapes or into ingot molds. Ingots are crushed, mixed with a binder, and formed into desired shapes. All shapes are annealed slowly under regulated temperatures and after this refiring are ready for shipment. Details of this process are not disclosed by the company applying it.

66. Several minerals, namely, sillimanite, dumortierite, cyanite, and andalusite, upon being subjected to high temperatures, develop the mullite crystallization. These are formed into brick of 72 percent or more mullite ($3Al_2O_32SiO_2$) composition. This method of obtaining a mullite refractory is being used in California, where andalusite, dumortierite, and cyanite are found.

Sources of Raw Materials

FOR SILICON-CARBIDE MANUFACTURE

67. A ton of silicon carbide requires approximately 1.9 tons silica mineral, 1.3 tons petroleum coke, 0.02 ton salt, and 0.4 ton sawdust.

68. *Sand.*—Finely crushed quartz or sand containing not less than 99 percent silica is the source of silica for these manufactured abrasives. It must be almost free of magnesia, phosphorus, and lime, and low in iron. These sands are obtained, at present, chiefly from Pennsylvania and Illinois, and from a sandstone quarry at St. Canute, Quebec. However, as this quality is similar to a good type of glass sand, it occurs in a number of States. While production of glass sand is heaviest in Illinois, West Virginia, and Pennsylvania, it

has occurred also in California. Because sand deposits are abundant, no data has been assembled as to the purity of deposits in different sections of States. But as quartz is so often found with feldspar, the Intermountain Experimental Station of the United States Bureau of Mines in cooperation with the department of mining and metallurgical research of the University of Utah, has devised a method whereby feldspar particles are floated off. The reagents used are easily obtained.

69. *Petroleum coke.*—Petroleum coke is the solid residue from the destructive distillation of petroleum. It is produced either as a byproduct of the coking still or of the cracking process. In 1927, over 1,000,000 tons was produced in the United States. Texas marketed the largest amount while California, Wyoming, Colorado, and Montana produced 123,000 short tons. The following table gives production by States and average value per ton. The value is determined in large measure by the market for this byproduct. Silicon carbide, as well as calcium carbide and graphite, afford high priced markets, while pulverized coke for industrial fuel brings a low price.

70. The extensive adoption of the hydrogenation process by the petroleum industry may affect the production of petroleum coke. For, by this process, motor fuels and lubricants are obtained without simultaneous formation of coke.

TABLE III.—*Production of petroleum-coke by States in 1927* [1]

State	Number plants	Quantity produced (short tons)	Average value per ton
Total	92	1,243,510	$5.76
Arkansas, Kentucky	3	8,516	3.98
California	3	61,641	2.00
Colorado, Montana	3	3,237	4.25
Georgia, South Carolina, West Virginia	3	10,354	5.81
Illinois	5	100,964	5.34
Indiana, Missouri	4	171,697	6.90
Kansas	7	103,150	3.83
Louisiana	5	134,348	10.54
Maryland, New York, Rhode Island	5	37,007	8.29
New Jersey	5	51,461	9.58
Ohio	6	61,691	7.02
Oklahoma	11	119,797	2.36
Pennsylvania	8	76,766	7.99
Texas	19	244,768	4.07
Wyoming	5	58,113	4.71

[1] U.S. Department of Commerce, Bureau of the Census.

71. Common salt in powdered form is used in the manufacture of silicon carbide. While hardwood sawdust is preferred, any coarse, granular sawdust is effective.

72. *For fused alumina manufacture.*—Bauxite is the important mineral essential to fused-alumina production. It should contain at least 50 percent alumina, less than 3 percent iron, and less than 6 percent silica. In 1929, 113,015 tons were consumed by the abrasive and refractory industries. This was shipped from Alabama and Arkansas deposits. The Norton Co. of Worcester, Mass., largest manufacturer of fused alumina, owns and operate its own mines near Bauxite, Ark.

73. Utah ships a small tonnage of by-product alumina from Marysvale potash developments to California for use in the manufacture of high alumina refractories. From Missouri comes most of the diaspore manufactured into such refractories. A detailed description of bauxite deposits will be found in "Power in Aluminum Production", pages 119-121.

Iron borings or any convenient source of iron is used to create proper iron content.

74. *For mullite production.*—Andalusite, one of the minerals which invert to mullite upon heating, occurs in commercial quantities in Nevada and California. Cyanite is found in the Inyo range of California, in other Pacific Coast and Rocky Mountain States, and along the Appalachian Plateau. The only known deposits of sillimanite are in India.

Fused Quartz

75. Fused quartz, produced in the electric furnace, was first manufactured on a commercial scale in England in 1906. Although its production is too small to be recorded separately in official reports, characteristics of fused quartz are such that it will probably play an increasing part in present industrial developments.

76. *Uses.*—As it resists sudden heating and the action of acids, fused quartz was first used for laboratory basins, beakers, pipes, and other vessels, but now enters into commercial chemical manufacturing equipment. In some fire-extinguishing apparatus, it is the frangible link in sprinkler jets. The electrical industry employs it in apparatus in which high vacuum and high insulating properties are essential. Transparent fused quartz is made into telescope lenses, photographic lenses, and into window glass which transmits ultraviolet rays and infrared rays.

77. *Sources of raw materials.*—Transparent fused quartz is made of rock crystal, which is free of all discoloration and water clear. This material comes from Brazil and Madagascar. Opaque quartz is made of the best quality glass sand or other pure quartz. (See pp. 439 and 440.)

78. *Manufacturing processes.*—In transparent-quartz manufacture, the lumps of rock crystal are carefully sorted and cleaned. Perfect pieces are used for lenses and prisms for optical and photographic instruments and slightly inferior crystal for quartz glass. For lenses, pieces are packed as closely as possible into graphite crucibles which are placed in a vacuum furnace. For window panes, the crystal is fused on flat graphite disks between squared graphite slabs. Quartz fuses at 3,200° F. After fusion, nitrogen is introduced into the furnace at a pressure of 150 pounds per square inch and causes any bubbles which have formed to collapse. When tubes or other shapes are to be made, the molten quartz is forced into shape by a graphite plunger. Quartz fusion requires from 5 to 8 kilowatt-hours per pound.[24]

79. The opaque form of fused quartz is made about a carbon rod. Quartz sand is heated by the carbon rod until it has fused. While silicon carbide is formed nearest the rod, this adheres to the carbon, while the fused quartz in tube form is removed and remelted for various apparatus.

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[24] Berry, E. R., Clear Fused Quartz Made in the Electric Furnace.

80. The General Electric Co. is manufacturing fused quartz in the United States. The Thermal Syndicate, an English company, is marketing it as "Vitreosil" in the United States.

SILICON

81. Silicon in a free state is made by The Carborundum Co. High-grade silica and petroleum coke are reduced in an arc furnace with a consumption of electricity approximately 12,000 kilowatt-hours per ton of silicon. While it will unite with a number of metals to form compounds named silicides, and is a reducing agent as well as a substitute for carbon in such organic compounds as silicon methyl and silicon ethyl, it has only small commercial application.

CALCIUM

Calcium can be obtained in a metallic state by the electrolysis of fused calcium chloride, employing a carbon anode. It is a hydrogenation catalyst. When alloyed with lead by use of a lead cathode, a bearing metal is secured.

Electric Furnace Graphite

PRODUCTION

82. The manufacture of graphite was begun in 1897 at Niagara Falls under patents obtained by Dr. A. G. Acheson, the discoverer of silicon carbide. The same company, now known as the Acheson Graphite Co., remained the sole manufacturer of graphite for sale until 1929 when the Exolon Co. of Blasdell, N.Y., and Thorold, Ontario, manufacturers of electric-furnace abrasives, and the American Cyanamid Co., manufacturers of calcium cyanamide and nitrogen fertilizers, announced they were producing graphite for sale. Other companies, however, have begun manufacturing graphite electrodes for their own consumption. The Acheson Graphite Co. is now a subsidiary of the Union Carbide & Carbon Corporation, and operates plants at Niagara Falls, Ontario, as well as at Niagara Falls, N.Y., and at Buffalo, N.Y.

83. The production figures quoted by the United States Bureau of Mines are figures of Acheson graphite production, only.

TABLE IV.—*Production of manufactured graphite in United States and Canada* [1]

Year	United States (short tons)	Canada (short tons)	Year	United States (short tons)	Canada (short tons)
1913	6,817	1,092	1921	[2] 2,944	[2] 188
1914	5,228	617	1922	[2] 6,516	[2] 362
1915	[2] 2,542	[2] 249	1923	[2] 13,381	[2] 777
1916	[2] 4,199	[2] 263	1924	[2] 5,493	[2] 408
1917	[2] 5,237	[2] 548	1925	[2] 6,068	(3)
1918	[2] 4,591	[2] 904	1926	[2] 10,582	(3)
1919	[2] 4,082	[2] 179	1927	[2] 6,129	(3)
1920	[2] 3,700	[2] 103			

[1] Compiled from U.S. Department of Commerce, Bureau of Mines, Graphite in 1928.
[2] Powdered graphite only; electrode material not included.
[3] Not reported.

MARKETS FOR MANUFACTURED GRAPHITE

84. The largest demand for manufactured graphite is as electrodes to convey current in electric furnaces. In this field it encounters competition from amorphous carbon electrodes which are gas or electric furnace baked at lower temperatures. The manufactured graphite electrode is preferred in a number of processes because of its higher conductivity and ease with which it may be machined. The extended application of the Söderberg continuous electrode, which is baked by current passing through the electrode casing and by heat from the furnace as the electrode's lower end is consumed in the furnace itself, may affect the use of graphitic electrodes.

85. Manufactured graphite is also used in dry batteries where it gives conductivity to the manganese dioxide. It is considered superior to natural flake graphite and amorphous carbon for this purpose, although its higher cost permits the employment of these less expensive forms. It is also made into brushes for direct current motors while both carbon and natural graphite find extensive use as brushes for turbogenerators, battery charging and other machines where quietness of operation is desirable and low mechanical strength permissable.

86. Powdered manufactured graphite, mixed with water, oil, or grease adheres to metallic surfaces thus reducing their friction, or while in suspension, keeps bearings from rubbing against each other. It is used, therefore, as a very effective lubricant. It is also a boiler scale preventative. All types of graphite enter into paint manufacture, opinion varying as to the relative merits of manufactured graphite.

87. *Manufacturing processes.*—Graphite is made of petroleum coke or anthracite coke. It is manufactured in powdered form or as electrodes. A furnace similar to the silicon carbide furnace is employed. The electrodes enter at either end of the furnace and the current is conducted through a central core of carbon rods, or other carbon conductor.

88. *Powdered graphite.*—When powdered graphite is produced, lumps of coke and some iron oxide are imbedded in coke dust. The charge is covered with silica and coke to exclude air. As the iron oxide is reduced, the iron sinks to the furnace bottom; as the temperature rises, it is vaporized and combines with the carbon to form a carbide. Carbide is volatilized at higher temperatures leaving carbon in the form of graphite. The temperature and length of the heating period depend upon the quality of graphite to be produced, the amorphous carbon being gradually converted into graphite. When the current is cut off, the coke and silica cover is removed, the furnaces cooled, and a layer of carbide taken off before graphite is found. The graphite is ground into condition for the special purposes it is to serve.

89. *Graphite electrodes.*—Because purity is essential in most processes which employ graphite electrodes to lead electric current, petroleum coke or specially prepared anthracite coke forms the basis of these electrodes. Petroleum coke is often preferred because of its low ash content and high fixed carbon. This coke as it comes from oil refineries is crushed, screened, and calcined in gas-heated or electric-heated calciners to drive off volatile constituents. The

electric calciner has a series of suspended carbon electrodes which form arcs with an electrode imbedded in the bottom of the furnace shell. The coke is fed in around the electrodes and as it becomes conductive, the electrodes are raised. The calcined coke is mixed with binding materials such as tar and pitch and with a small amount of carbide-forming substance such as oxide of iron. When large electrodes are made, the mixture is compressed by automatic rams into molds. For small rods it is extruded under high pressure in a hydraulic press into desired form and size.

90. *Electric consumption.*—The floor of the electric furnace is covered with pulverized carbon. When rectangular electrodes are graphitized they are packed in heaps separated by pulverized coke. Rounded electrodes are surrounded by an inner shell of ground coke; coke and sand form the outer covering. This carbon dust acts as a resistor and carries the current. Initial voltage is from 200 to 210; as the resistance of the coke is lowered, voltage is reduced to maintain a constant heat. Graphite for electrodes is 99.5 percent pure while for dry battery fillers and other uses 92 percent purity is sufficient. The higher the purity, the longer the heat treatment required. Theoretically, but 3,580 kilowatt-hours of energy are necessary to convert 1 ton of coke into graphitic electrodes; the low efficiency of the open graphite furnaces is such, however, that actual consumption of current is close to 7,600 kilowatt-hours. In Germany, electrical consumption is placed at over 9,000 kilowatt-hours per ton of graphite produced.

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ELECTRIC REDUCTION OF GOLD AND SILVER AND RARE OR MINOR METALS

CONTENTS

	Page
Gold and silver	445
Sources of metals	446
Occurrence of gold and silver in United States	446
Gold mining in the several States	447
Silver mining in the several States	448
World production of gold and silver	448
Extracting and refining of gold and silver	449
Electrolytic refining of silver	450
Electrolytic refining of gold	450
Production and refinement of gold and silver	450
Quantities refined at mints and by private refineries	450
Private refineries	450
World consumption	451
Gold	451
Silver	452
Rare or minor metals	453
Tungsten and molybdenum	453
Cobalt alloys	454
Tantalum	454
Barium	455
Cerium	455
Lithium	455
Beryllium	455
Bismuth	456
Metals refined electrolytically in countries other than the United States	456
Nickel	456
Tin	456

Gold and Silver

The production of gold and silver is affected vitally by the fact that monetary uses constitute so important a market. Particularly is this true of gold, for while certain populous countries like China make silver the money standard of half the people of the world, yet gold is the standard of the majority of all important nations, measured by political influence and by financial and commercial importance. Furthermore, the price of gold in the United States is fixed