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2016 Minerals Yearbook

GRAPHITE [ADVANCE RELEASE]

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Graphite

By Donald W. Olson

Domestic survey data and tables were prepared by Chanda C. Williams, statistical assistant.

In 2016, no domestic production of natural graphite was reported, but U.S. production of synthetic graphite was estimated to be 207,000 metric tons (t) valued at about $658 million. U.S. exports and imports of natural graphite were estimated to be 14,300 t and 38,900 t, respectively. U.S. exports and imports of synthetic graphite were estimated to be 30,100 t and 75,000 t, respectively. U.S. apparent consumption of natural and synthetic graphite was estimated to be 24,600 t and 252,000 t, respectively. World production of natural graphite was estimated to be 1.15 million metric tons (Mt) (table 1).

Graphite is one of four forms of crystalline carbon; the others are carbon nanotubes, diamonds, and fullerenes. In graphite, the carbon atoms are densely arranged in parallel-stacked, planar honeycomb-lattice sheets. When a graphite structure is a one-atom-thick planar sheet, it is called graphene, which is an extremely light and strong material produced from graphite. Graphite is gray to black in color, opaque, and usually has a metallic luster; sometimes it exhibits a dull earthy luster. Graphite occurs naturally in metamorphic rocks, is a soft mineral with a Mohs hardness of 1–2, and exhibits perfect basal (one-plane) cleavage. Flexible but not elastic, graphite has a melting point of 3,927 °C (7,101 °F) and is highly refractory. Possessing a low specific gravity, graphite is the most electrically and thermally conductive of the nonmetals and is chemically inert. In total, these properties make natural and synthetic graphite desirable for many industrial applications.

Natural graphite is classified into three types: amorphous, flake or crystalline flake, and vein or lump. Amorphous graphite is the lowest quality and most abundant. The descriptor “amorphous” refers to its small crystal size and not to a lack of crystal structure. Amorphous graphite is used for lower value graphite products and is the lowest priced graphite. Large amorphous graphite deposits are found in Europe, China, Mexico, and the United States. The flake or crystalline form of graphite consists of many graphene sheets stacked together. Flake or crystalline flake graphite is less common and of higher quality than amorphous graphite. Flake graphite occurs as separate flakes crystallized in metamorphic rock, and high-quality flake graphite can be four times the price of amorphous graphite. High-purity graphite flakes can be processed into expandable graphite for many uses, such as flame retardants. The foremost deposits are found in Austria, Brazil, Canada, China, Germany, Madagascar, Mozambique, Tanzania, and the United States. Vein or lump graphite is the rarest, most valuable, and highest quality type of natural graphite, and it occurs in veins along intrusive contacts in solid lumps. Vein or lump graphite is only mined commercially in Sri Lanka.

Natural graphite is mined from open pits and underground mines. Production from open pit operations is preferred and is less expensive in settings where the overburden can be removed economically. Mines in Madagascar are mostly of this type. In the Republic of Korea, Mexico, and Sri Lanka, where the deposits are deep, underground mining techniques are required.

Beneficiation processes for graphite can vary from complex four-stage flotation at mills in Europe and the United States to simple hand sorting and screening of high-grade ore at operations in Sri Lanka. Certain soft graphite ores, such as those found in Madagascar, need no primary crushing and grinding. Typically, such ores contain the highest proportion of coarse flakes. Ore is sluiced to the field washing plant, where it undergoes desliming to remove the clay fraction and is subjected to a rough flotation to produce a concentrate with 60% to 70% carbon. This concentrate is transported to the refining mill for further grinding and flotation to reach 85% carbon and is then screened to produce a variety of products marketed as flake graphite that contains 85% to 90% carbon.

Production

The U.S. Geological Survey (USGS) obtained the production data in this report through a voluntary survey of U.S. synthetic graphite producers. Data were estimated for nonrespondents based on responses received in previous years, industry production trends, reports from other industry sources, and discussions with consultants within the graphite industry.

No natural graphite was mined in the United States in 2016, but 207,000 t of synthetic graphite with an estimated value of $658 million was produced and shipped (tables 1, 3). Synthetic graphite underwent a 75% increase in the quantity produced and a 19% decrease in value compared with that of the previous year.

The first method used to produce synthetic graphite was invented in the mid-1890s by Edward Goodrich Acheson. He discovered that by heating carborundum (silicon carbide) to high temperatures, the silicon vaporizes at about 4,150 °C (7,500 °F), leaving behind almost pure graphitic carbon. Synthetic graphite electrodes that conduct electricity to melt scrap iron and steel or direct-reduced iron in electric arc furnaces are made from petroleum coke mixed with coal tar pitch. The mixture is extruded and shaped, then baked to carbonize the pitch, and finally graphitized by heating it to temperatures approaching 3,000 °C to convert the carbon to graphite. Synthetic graphite powder is made by heating powdered petroleum coke above the temperature of graphitization (3,000 °C), sometimes with minor modifications (Kopeliovich, 2013).

Exploration and Development

During 2016, two companies from Canada were developing and evaluating graphite deposit projects in the United States. Alabama Graphite Corp. was developing the Coosa Graphite project in Alabama, and Graphite One Resources Inc. was developing the Graphite Creek project in Alaska (Westwater Resources, Inc., 2017a, b; Graphite One Resources Inc., undated).

During 2016, Alabama Graphite Corp. continued exploring, evaluating, and developing its Bama Mine project, which it acquired in September 2014. The Bama Mine project is more than 520 hectares (1,300 acres) in Chilton County, AL, which includes the Bama Mine. The Bama Mine is the southernmost mine in the Alabama Graphite Belt, which is a geologic trend of high-quality graphite deposits, and it had produced larger quantities and higher quality flake graphite than any other graphite mine in Alabama. The Bama Mine stopped production in the 1930s because a fire destroyed the mill. In the area of the Bama Mine, widespread occurrence of weathered graphitic schist is found at the surface. The Bama Mine project site has power, water, road, and rail infrastructure established and is located about 14 kilometers (9 miles) from an interstate highway and less than 1.5 kilometers (1 mile) from a major railroad (Westwater Resources, Inc., 2017a). During 2016, Alabama Graphite Corp. also continued to explore and develop its 100%-owned Coosa Graphite project in Coosa County, AL. The Coosa Graphite project consists of 17,000 hectares (42,000 acres) in an area that was a significant source of high-grade crystal flake graphite in the past. Alabama Graphite evaluated the deposit and stated that the property has an indicated resource reported as 71.2 Mt grading 2.39% graphite and an inferred resource reported as 72.1 Mt grading 2.56% graphite (Westwater Resources, Inc., 2017b). The Bama Mine project and the Coosa Graphite project are located within the Alabama Graphite Belt, from which significant quantities of graphite were produced from the late 1800s through the 1950s (Westwater Resources, Inc., 2017a).

During 2016, Graphite One was delineating, evaluating, and developing the Graphite Creek project, which is a massive, near-surface deposit that included 165 mineral claims in a known graphite mineralization region of 7,317 hectares on the Seward Peninsula in western Alaska, about 55 kilometers (37 miles) north of Nome. The Graphite Creek deposit consists of large-flake, high-grade graphite that was delineated by a 2013 drilling program. The original resource estimate stated that the project contained inferred resources reported as 284.7 Mt grading 4.5% graphite (including 37.7 Mt grading 9.2% graphite and 8.6 Mt grading 12.8% graphite). Based on these inferred resources, Graphite Creek may be the largest and highest grade of all identified graphite deposits in the United States (Graphite One Resources Inc., undated). In March 2016, Graphite One released an updated mineral resource estimate based on the analyses of a 2014 drilling program. The estimate, using a 3% graphite cutoff grade, was 17.95 Mt indicated, grading 6.3% graphite, and 154.36 Mt inferred, with 5.7% graphite. The drilling results moved a portion of the previously released resource estimate from inferred to indicated resource status (Graphite One Resources Inc., 2016).

Consumption

The USGS obtained the consumption data in this report through a survey of the companies that import and use natural graphite in the United States. Data were estimated for nonrespondents based on responses received in previous years, industry consumption trends, reports from other industry sources, and discussions with consultants within the graphite industry. This end-use survey represented most of the graphite industry in the United States.

U.S. apparent consumption of natural graphite decreased by 30% to 24,600 t in 2016 from 35,100 t in 2015, whereas U.S. apparent consumption of synthetic graphite increased by 51% to 252,000 t in 2016 from 167,000 t in 2015. Total U.S. graphite apparent consumption, including natural and synthetic, increased by 37% to 277,000 t in 2016 from 202,000 t in 2015 (table 1).

U.S. consumption of natural graphite increased by 3% to 42,900 t in 2016 from 41,800 t in 2015 (table 2). The reported natural graphite consumption data in table 2 include a small amount of mixed natural and synthetic graphite in the amorphous graphite category. Apparent consumption in table 1 does not include unreported changes in company stocks and therefore differs from reported consumption in table 2. Reported consumption of crystalline graphite increased by 3% in 2016 to 21,600 t from 20,900 t in 2015. Consumption of amorphous graphite increased slightly in 2016 to 21,300 t from 20,900 t in 2015. The primary uses of graphite during 2016 were batteries; brake linings; carbon products, such as bearings and brushes, crucibles, moderator rods in nuclear reactors, nozzles, retorts, stoppers, and sleeves; chemically resistant materials; drilling-mud additives; electrical conductors; foundries; fuel cells; graphene; high-strength composites; lubricants; pencils; powdered metals; refractories; rubber; and steelmaking. Brake linings and refractories, combined, accounted for 42% of all forms of natural graphite consumption. Foundries and lubricants accounted for another 8% of all forms of natural graphite consumption. The refractories industrial sector was the leading graphite consumer, accounting for 43% of crystalline flake graphite use in 2016. Automobile manufacturing and construction influenced steelmaking activity, which in turn influenced refractories demand. Although graphite is an essential component of many types of batteries, battery applications accounted for slightly more than 2% of natural graphite consumption during 2016, remaining the same as that of 2015.

An important and potentially increasing portion of graphite use was related to high-technology applications that use graphite as an anode material in batteries. The batteries end-use category was predicted to become the fastest growing graphite market with a growth of 15% to 25% per year, owing to increased demand for electric and hybrid vehicles and portable electronic devices, such as mobile telephones, smartphones, and tablet-sized computers (Moores and others, 2012, p. 11). However, during 2016, data for U.S. natural graphite consumption did not yet demonstrate this predicted growth rate.

Tesla Motors, Inc. was building a large plant, in Sparks, NV, to manufacture lithium-ion electric vehicle batteries. The plant's completion was initially projected for 2020, but the project was about 2 years ahead of schedule. During July 2016, 14% of the plant was completed, and the first batteries were expected to be produced by the end of the year. Tesla partnered with battery maker Panasonic Corp., with both companies operating parts of the factory. Panasonic agreed to make the battery cells, while Tesla would assemble the cells into battery packs (Valdes-Dapena, 2016). When complete, the plant would require 95,000 metric tons per year (t/yr) of flake graphite to produce

35,000 t/yr of spherical graphite for use as anode material for lithium-ion batteries.

Graphite has metallic and nonmetallic properties that make it suitable for many industrial applications. The metallic properties include electrical and thermal conductivity. The nonmetallic properties include high thermal resistance, inertness, and lubricity. The combination of conductivity and high thermal stability allows graphite to be used in many applications, such as batteries, fuel cells, and refractories. Graphite's lubricity and thermal conductivity make it an excellent material for high-temperature applications because it provides effective lubrication at a friction interface while furnishing a thermally conductive matrix to remove heat from the same interface. Electrical conductivity and lubricity allow its use as the primary material in the manufacture of brushes for electric motors. A graphite brush effectively transfers electric current to a rotating armature while the natural lubricity of the brush minimizes frictional wear. Advanced technology products, such as friction materials and battery and fuel cells, require high-purity graphite. Natural graphite is purified to 99.9% carbon content for use in battery applications.

Graphite is made up of flat, parallel sheets of carbon atoms in a hexagonal arrangement; it is possible to insert other atoms between the sheets, a process called intercalation. The insertion of other atoms makes dramatic changes in the properties of graphite. Graphite can be intercalated with sulfuric and nitric acids to produce expanded graphite, from which foils are formed and used in seals, gaskets, and fuel cells.

Refractory applications of graphite include carbon-bonded brick, castable ramming, and gunning mixtures. Carbon-magnesite brick has applications in high-temperature corrosive environments, such as iron blast furnaces, ladles, and steel furnaces. Carbon-alumina linings are principally used in continuous casting steel operations. Alumina- and magnesite-carbon brick requires graphite with a particle size of 100 mesh and a purity of 95% to 99%.

Crystalline flake graphite accounted for just over 50% of natural graphite use in the United States in 2016 and was consumed mainly in the manufacture of batteries, brake linings, lubricants, powdered metals, refractories, and rubber. Amorphous graphite accounted for slightly less than 50% of natural graphite use and was mainly used in brake linings, foundries, lubricants, powdered metals, refractories, steelmaking, and other applications where the addition of graphite improves the process or the end product (table 2). Lump graphite is used in many applications, including steelmaking, depending on purity and particle size.

Synthetic graphite is used in more applications in the United States than natural graphite and accounts for a 91% share by quantity and a 96% share, by value, of the graphite consumption (table 1). The primary market for high-purity synthetic graphite is as an additive to increase carbon content in iron and steel. This market consumes a substantial portion of the synthetic graphite. Other important uses of all graphite types are in the manufacture of catalyst supports; low-current, long-life batteries; porosity-enhancing inert fillers; powder metallurgy; rubber; solid carbon shapes; static and dynamic seals; steel; and valve and stem packing. The use of graphite in low-current batteries is gradually giving way to carbon black, which is more economical. High-purity natural and synthetic graphite are used to manufacture antistatic plastics, conductive plastics and rubbers, electromagnetic interference shielding, electrostatic paint and powder coatings, high-voltage power cable conductive shields, membrane switches and resistors, semiconductive cable compounds, and electrostatic paint and powder coatings.

High-purity natural and synthetic graphite play an essential role in the emerging nonhydrocarbon energy sector and are used in several new energy applications. In energy production applications, graphite pebbles are used for modular nuclear reactors; graphite is also used in high-strength composites for wind, tide, and wave turbines. In energy storage applications, graphite is used in bipolar plates for fuel cells and flow batteries, anodes for lithium-ion batteries, electrodes for supercapacitors, high-strength composites for flywheels, phase-change heat storage, and solar boilers. For energy management applications, graphite is used in high-performance polystyrene thermal insulation and silicon chip heat dissipation. These new energy applications use value-added graphite products such as high-carbon-purity, small-particle, potato-shaped material called spherical graphite; expanded graphite; and graphene. Current graphite capacity may not be adequate for the increasing demands of these new energy applications, which may require doubling the current graphite supply when fully implemented (O'Driscoll, 2010).

Graphene has been referred to as "the world's next wonder material." This material consists of a single atomic layer of carbon atoms arranged in a flat honeycomb pattern. Within a 1-millimeter-thick graphite flake are approximately 3 million stacked sheets of graphene. Crystalline flake graphite can be processed into graphene, which has unique properties. Graphene can be used to make inexpensive solar panels, powerful transistors, and wafer-thin tablet computers that could be the next-generation tablets (Topf, 2012). The unique properties of graphene afford the potential to make high-tech products thinner, transparent, flexible, and more powerful. Graphene has 1,000 times the current capacity of copper wire, is 200 times stronger than structural steel, has 10 times greater heat conductivity than copper and 20% more flexibility, without sustained damage, than copper (Desjardins, 2012).

Prices

During 2016, prices for all mesh sizes of natural crystalline flake graphite decreased from those of 2015, with median yearend prices decreasing between 32% and 48%. Prices for natural amorphous powder graphite also decreased compared with those of 2015, with median yearend prices decreasing by 7%. Prices for synthetic graphite remained constant compared with those of 2015 (table 4).

Prices for crystalline and crystalline flake graphite concentrates ranged from $400 to $850 per metric ton; prices for amorphous powder ranged from $400 to $450 per ton (table 4). The average unit value of all U.S. natural graphite exports decreased by 20% to $1,480 per ton in 2016 from $1,860 per ton in 2015 (tables 1, 5). The average unit value of all U.S. natural graphite imports decreased slightly to $1,220 per ton in 2016 from $1,250 per ton in 2015 (tables 1, 6). Ash and carbon content, crystal and flake size, and size distribution affect the price of graphite. Prices for fine synthetic powder, 97% to 99% carbon, ranged from $950 to $1,500 per ton (table 4). The average unit value of U.S. synthetic graphite exports decreased by 13% to $4,820 per ton in 2016 from $5,520 per ton in 2015 (tables 1, 5). The average unit value of all U.S. synthetic graphite imports increased by 7% to $1,700 per ton in 2016 from $1,580 per ton in 2015 (tables 1, 8).

Foreign Trade

Total graphite exports increased slightly in tonnage to 44,400 t valued at $166 million in 2016 from 43,700 t valued at $198 million in 2015. Total graphite export tonnage was 32% natural graphite and 68% synthetic graphite (table 5). Total natural graphite imports decreased by 17% in tonnage to 38,900 t in 2016 from 46,700 t in 2015, and the value decreased by 19% to $47.6 million in 2016 from $58.6 million in 2015 (table 6). These decreases in natural graphite imports resulted from substantial decreases in the quantity and value of the "other natural crude; high-purity; expandable" graphite category during 2016 and from a substantial decrease in the quantity of the "amorphous" graphite category during 2016. The principal import sources of natural graphite were, in descending order of tonnage, China, Mexico, Canada, Brazil, and Madagascar, which collectively accounted for 97% of the tonnage and 86% of the value of total natural graphite imports. Mexico, China, and Madagascar were the leading suppliers of amorphous graphite, and Sri Lanka provided all the lump and chippy dust and "high-purity, expandable" varieties. Canada, China, Brazil, and Madagascar were, in descending order of tonnage, the leading suppliers of crystalline flake and flake dust graphite.

Total synthetic graphite imports decreased by 7% in tonnage to 75,000 t in 2016 from 80,600 t in 2015, and the value decreased slightly to $127 million in 2016 from $128 million in 2015 (table 8). Principal import sources of synthetic graphite were, in descending order of tonnage, China, Mexico, France, Switzerland, Japan, Brazil, Hong Kong, and Russia, which collectively accounted for 90% of the tonnage and 78% of the value of total synthetic graphite imports.

World Review

World production of natural graphite decreased slightly in 2016 to an estimated 1.15 Mt from 1.17 Mt in 2015. China maintained its position as the world's leading graphite producer, with an estimated 780,000 t, or 68% of total global production. India ranked second with 149,000 t, or 13% of the total, followed by Brazil, Canada, Russia, Ukraine, Pakistan, and Madagascar, in decreasing order of tonnage. These eight countries accounted for 97% of world production (table 9).

Brazil.—In 2016, Brazil produced 95,000 t of marketable natural graphite. Nacional de Grafite Ltda. was thought to be the only producer of natural flake graphite in Brazil during 2016. The company operated mines and plants at three sites in Minas Gerais. High-grade crystalline flake graphite projects were being developed in Brazil, with at least two companies conducting or considering graphite exploration and development (Roskill Information Services Ltd., 2017, p. 144–146).

Canada.—In 2016, Canada had two active open pit mines with combined production of about 30,000 t of natural flake graphite: about 80% from the Lac des Iles flake graphite mine in Quebec, owned by Timcal Ltd., operated under the control of Imerys Graphite & Carbon and approximately 20% from the Black Crystal flake graphite quarry in British Columbia, owned by Eagle Graphite Corp. The Kearney graphite mine in Ontario, owned by Ontario Graphite Ltd., was expected to come online by 2018.

During 2016, graphite mining companies in Canada were actively pursuing more than 24 graphite exploration and development projects in Canada. Exploration was primarily focused on properties in Ontario and Quebec, but other graphite exploration projects were underway in British Columbia, New Brunswick, Newfoundland and Labrador, Nova Scotia, and Saskatchewan (Roskill Information Services Ltd., 2017, p. 146–150).

China.—In 2016, China was the world's leading producer and exporter of natural and synthetic graphite. China may also have the most extensive natural graphite resources in the world. China produced approximately 780,000 t of natural graphite, of which 480,000 t was flake graphite, and the remainder was amorphous graphite. More than 60% of the flake graphite was produced in the Heilongjiang Province, and most of the amorphous graphite was produced from the Hunan Province (Roskill Information Services Ltd., 2017, p. 151–178). China was also the world's leading consumer of graphite; its iron and steel industry is the leading consuming market of natural and synthetic graphite (Roskill Information Services Ltd., 2017, p. 151).

Beginning in 2011 and continuing through 2016, owing to environmental and resource protection concerns, the Government of China ordered a majority of amorphous graphite mines under its control, in Hunan Province, to close or consolidate and further ordered an upgrade of the processing plants. These changes caused a decline in amorphous graphite production. Flake graphite production in China remained stable until 2013, when the Government began closing and consolidating crystalline flake graphite mines for environmental and resource protection concerns. By the beginning of 2015, more than 200 crystalline flake graphite mines had closed. These mine closings and consolidations took place primarily in Heilongjiang Province, which produced 43% of the world's flake graphite (Razoumova, 2014). China closed more than 20% of its crystalline flake capacity during the past 3 years (Paradigm Metals Ltd., 2014). Dust emissions from the mining of crystalline flake graphite were a major issue, and although graphite is inert and not harmful, the air pollution from dust was a problem for local residents and farmers. The air pollution problem became known as "graphite rain." The Government of China issued stricter regulations and required producers to upgrade their equipment to control dust emissions (Moores, 2011; Lazenby, 2014; Roskill Information Services Ltd., 2017, p. 151–178).

In 2016, China produced approximately 697,000 t of synthetic graphite from at least 29 plants. This production accounted for approximately 46% of global synthetic graphite production. Synthetic graphite production increased about 3.7% per year during the past 10 years. Most of this output was in the form of synthetic graphite electrodes for export (Roskill Information Services Ltd., 2017, p. 151–178).

Mozambique.—No natural graphite mining took place during 2016, but the country was the focus of several natural flake graphite development projects. The planned production capacity for the country far exceeded that of any operation currently producing worldwide, and projections for Mozambique's emerging graphite mining sector continued to increase. Triton Minerals Ltd. (Australia) announced exploration success at its Balama North project in the northern Cabo Delgado Province. According to Triton Minerals, exploration results confirmed Balama North's potential to become a major high-grade graphite project. The largest graphite deposit in the world is the nearby Balama deposit owned by Syrah Resources Ltd. (Australia), which has estimated resources of 1.1 billion metric tons, thereby containing more natural graphite than all other identified global deposits combined. Metals of Africa Ltd. obtained three exploration licenses for the same area. Syrah Resources expected to begin commissioning activities of its graphite mine during 2016; Triton Minerals had not yet announced a timeline for production. Graphite mining in the Balama district of Mozambique was projected to be relatively low cost because ores are easily accessible by open pit mining, of high quality, and located 240 kilometers from the deepwater port of Pemba (Economist Intelligence Unit, Ltd., The, 2014; Roskill Information Services Ltd., 2017, p. 199; Syrah Resources Ltd., undated).

Tanzania.—During 2016, several natural flake graphite deposits were being explored, but no graphite was produced. Discovery Africa Ltd. (Australia), through its Tanzania Graphite project, discovered a very large, high-grade, flake graphite deposit in southern Tanzania. The company executed a memorandum of agreement for the acquisition of up to 80% of Hatua Resources (T) Ltd., which held four exploration licenses in the region. Assessment and sampling of graphitic schist outcrops in all four locations graded up to 49.9% total graphitic carbon. The average samples within the licenses exhibited 15.3% total graphitic carbon (Discovery Africa Ltd., 2014; Roskill Information Services Ltd., 2017, p. 210).

Outlook

Worldwide demand for natural and synthetic graphite is expected to increase as more nonhydrocarbon energy applications that use graphite are developed. Steel production and other types of metallurgical activity, which are important consumers of graphite, are expected to increase as well. Global graphite consumption is expected to increase, owing to new technologically advanced applications, such as aerospace applications, fuel cells, graphene, lithium-ion batteries, pebble-bed nuclear reactors, and solar power. Most notable for graphite among these applications are fuel cells, lithium-ion batteries, and pebble-bed nuclear reactors. Batteries are predicted to increase and become the leading graphite market by 2026, surpassing the traditional leading graphite markets of electrodes and refractories. Electrodes and refractories are expected to decline whenever steelmaking declines (Desjardins, 2012; Freedonia Group, Inc., The, 2014; Roskill Information Services Ltd., 2017, p. 43).

Batteries are expected to be the end-use sector with the most significant increase in graphite use, owing to growth in the portable electronics and electric vehicle industries. These applications require larger, more powerful, and more graphite-intensive lithium-ion batteries. The share of graphite consumption by the battery end-use sector is expected to increase to between 8% and 10% by 2017. Production of spherical graphite-feedstock material needs to increase to meet additional battery demand. Graphite is not dependent on the success of the lithium-ion battery, however, because natural graphite anodes are preferred in current battery technologies. Consumption for all types of graphite used in battery applications may increase and account for about 26% of total graphite consumption by 2026 (Moores and others, 2012, p. 12–13; Roskill Information Services Ltd., 2017, p. 43).

The ability to refine and modify graphite is expected to be the key to future growth in the graphite industry. Refining techniques have enabled the use of improved graphite in electronics, foils, friction materials, and lubrication applications. Products available through advanced refining technology could increase profitability in the U.S. graphite industry in the next few years.

The demand for graphite used in rubber and plastics (including Styrofoam® coatings) are increasing, and continued growth is expected. The United States market for graphite in pencils has almost disappeared; most pencil "leads" now are imported directly from China. These markets, however, use little graphite and are not expected to have a significant impact on future consumption.

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TABLE 1
SALIENT NATURAL AND SYNTHETIC GRAPHITE STATISTICS[1]

(Metric tons and thousand dollars)

	2012	2013	2014	2015	2016
United States:					
Natural:					
Exports:					
Quantity	7,980	10,000	12,200	11,600	14,300
Value	19,100	18,300	19,300	21,700	21,200
Imports for consumption:					
Quantity	56,700	61,300	69,600	46,700	38,900
Value	68,400	70,500	72,300	58,600	47,600
Apparent consumption:[2]					
Quantity	48,700	51,300	57,400	35,100	24,600
Value	49,300	52,200	52,900	36,900	26,400
Synthetic:					
Production:					
Quantity	141,000	129,000	135,000	119,000	207,000
Value	946,000	976,000	939,000	816,000	658,000
Exports:					
Quantity	48,900	29,700	32,500	32,000	30,100
Value	171,000	210,000	221,000	177,000	145,000
Imports for consumption:					
Quantity	122,000	59,100	60,700	80,600	75,000
Value	191,000	130,000	135,000	128,000	127,000
Apparent consumption:[2]					
Quantity	214,000	158,000	163,000	167,000	252,000
Value	966,000	895,000	852,000	767,000	640,000
World production, natural	1,030,000 r	1,100,000 r	987,000 r	1,170,000 r	1,150,000

[r]Revised.
[1]Table includes data available through August 28, 2018. Data are rounded to no more than three significant digits.
[2]Domestic production plus imports minus exports.

TABLE 2
U.S. CONSUMPTION OF NATURAL GRAPHITE, BY END USE[1]

End use	Crystalline Quantity (metric tons)	Crystalline Value (thousands)	Amorphous[2] Quantity (metric tons)	Amorphous[2] Value (thousands)
2015:				
Brake lining	1,010	W	W	W
Carbon products[3]	372 r	$1,200 r	571	$743
Foundries[4]	W	W	W	W
Lubricants[5]	1,330	2,890	W	W
Powdered metals	W	W	W	W
Refractories	9,950	8,970	W	W
Rubber	W	W	623	1,310
Other[6]	4,240	13,200	8,980	9,480
Total	20,900	37,100	20,900	26,000
2016:				
Brake lining	719	2,050	3,380	3,660
Carbon products[3]	331	1,100	637	776
Foundries[4]	W	86	W	W
Lubricants[5]	W	W	1,420	1,910
Powdered metals	W	W	W	W
Refractories	9,380	7,940	4,600	W
Rubber	W	W	702	1,470
Other[6]	6,450	19,600	8,070	8,700
Total	21,600	41,900	21,300	26,400

[r]Revised. W Withheld to avoid disclosing company proprietary data; included in "Total."
[1]Table includes data available through August 28, 2018. Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Includes mixtures of natural and manufactured graphite.
[3]Includes bearings and carbon brushes.
[4]Includes foundries (other) and foundry facings.
[5]Includes ammunition packings.
[6]Includes antiknock gasoline additives and other compounds, batteries, crucibles, drilling mud, electrical and electronic devices, industrial diamond, magnetic tape, mechanical products, nozzles, paints and polishes, pencils, retorts, sleeves, small packages, soldering and welding, steelmaking, stoppers, and other end-use categories.

TABLE 3
SHIPMENTS OF SYNTHETIC GRAPHITE BY U.S. COMPANIES, BY END USE[1]

End use	Quantity (metric tons)	Value (thousands)
2015:		
Cloth and fibers (low modulus)	W	W
Electrodes	86,600	$303,000
Unmachined graphite shapes	12,900	85,300
Other[2]	19,300	428,000
Total	119,000	816,000
2016:		
Cloth and fibers (low modulus)	W	W
Electrodes	84,900	227,000
Unmachined graphite shapes	15,300	47,000
Other[2]	107,000	384,000
Total	207,000	658,000

W Withheld to avoid disclosing company proprietary data; included in “Other.”
[1]Table includes data available through August 28, 2018. Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Includes anodes, crucibles and vessels, electric motor brushes and machined shapes, graphite articles, high-modulus fibers, lubricants (solid or semisolid), refractories, steelmaking carbon raisers, additives in metallurgy, and other powder data.

TABLE 4
REPRESENTATIVE YEAREND GRAPHITE PRICES[1]

(Dollars per metric ton)

Type	2015	2016
Crystalline medium, 85% to 87% carbon, +100-80 mesh	700–800	400–500
Crystalline fine, 90% carbon, -100 mesh	750–800	500–550
Crystalline medium, 90% carbon, +100-80 mesh	950–1,050	550–620
Crystalline large, 90% carbon, +80 mesh	1,150–1,250	600–650
Crystalline fine, 94% to 97% carbon, -100 mesh	1,000–1,100	620–650
Crystalline medium, 94% to 97% carbon, +100-80 mesh	1,200–1,300	700–750
Crystalline large, 94% to 97% carbon, +80 mesh	1,400–1,500	700–850
Amorphous powder, 80% to 85% carbon	430–480	400–450
Synthetic fine, 97% to 98% carbon[2]	950–1,450	950–1,450
Synthetic fine, 98% to 99% carbon[2]	1,000–1,500	1,000–1,500

[1]Prices are cost, insurance, and freight main European port, unless otherwise specified.
[2]Prices are cost, insurance, and freight Asian port.

Sources: Industrial Minerals, no. 578, December 2015, p. 67; Industrial Minerals, no. 589, December 2016−January 2017, p. 66.

TABLE 5
U.S. EXPORTS OF NATURAL AND SYNTHETIC GRAPHITE, BY COUNTRY OR LOCALITY[1, 2]

	Natural[3]		Synthetic[4]		Total	
Country or locality	Quantity (metric tons)	Value[5] (thousands)	Quantity (metric tons)	Value[5] (thousands)	Quantity (metric tons)	Value[5] (thousands)
2015:						
Brazil	96	$222	5,970	$24,000	6,070	$24,200
Canada	5,900	3,620	3,770	11,200	9,670	14,900
China	252	712	2,010	18,400	2,260	19,100
France	21	79	1,710	8,770	1,730	8,850
Germany	79	161	1,120	6,680	1,200	6,840
Hong Kong	8	35	11	804	19	838
India	822	1,540	551	994	1,370	2,530
Italy	58	207	1,200	6,600	1,250	6,810
Japan	1,020	2,930	996	5,510	2,020	8,440
Korea, Republic of	355	1,010	1,370	37,900	1,720	38,900
Mexico	1,420	5,380	7,820	13,300	9,240	18,700
Netherlands	192	1,480	188	471	380	1,950
Poland	78	266	250	1,110	328	1,370
Saudi Arabia	165	87	964	4,470	1,130	4,550
Taiwan	87	352	445	4,560	532	4,910
United Kingdom	46	122	1,150	1,890	1,200	2,010
Venezuela	189	1,260	169	443	358	1,700
Vietnam	38	95	258	20,500	296	20,600
Other	807	2,110	2,080	9,200	2,890	11,300
Total	11,600	21,700	32,000	177,000	43,700	198,000
2016:						
Brazil	132	353	953	4,900	1,090	5,250
Canada	8,620	4,280	4,510	11,000	13,100	15,300
China	176	401	2,060	21,200	2,230	21,600
France	25	85	1,550	8,910	1,580	9,000
Germany	61	194	684	6,420	745	6,620
Hong Kong	9	36	6	581	16	617
India	520	1,230	389	1,120	909	2,350
Italy	51	93	1,370	7,600	1,420	7,690
Japan	904	2,840	1,290	6,980	2,190	9,830
Korea, Republic of	116	365	1,970	24,900	2,090	25,200
Mexico	2,580	7,800	9,710	11,000	12,300	18,800
Netherlands	86	758	61	378	147	1,140
Poland	109	356	439	2,330	548	2,690
Saudi Arabia	136	111	1,570	5,770	1,700	5,880
Taiwan	80	337	440	4,560	520	4,890
United Kingdom	29	129	1,020	1,540	1,050	1,670
Venezuela	55	161	--	--	55	161
Vietnam	64	173	195	16,400	259	16,500
Other	548	1,520	1,890	9,510	2,440	11,000
Total	14,300	21,200	30,100	145,000	44,400	166,000

-- Zero.

[1]Table includes data available through August 28, 2018. Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Numerous countries for which data were reported have been combined in "Other."

[3]Amorphous, crystalline flake, lump and chip, and natural, not elsewhere classified. The applicable Harmonized Tariff Schedule of the United States (HTS) nomenclatures are "Natural graphite in powder or in flakes" and "Other," codes 2504.10.0000 and 2504.90.0000.

[4]Includes data from applicable HTS nomenclatures "Artificial graphite" and "Colloidal or semicolloidal graphite," codes 3801.10.0000 and 3801.20.0000.

[5]Values are free alongside ship.

Source: U.S. Census Bureau.

TABLE 6

U.S. IMPORTS FOR CONSUMPTION OF NATURAL GRAPHITE, BY COUNTRY OR LOCALITY[1]

	Crystalline flake and flake dust		Lump and chippy dust		Other natural crude, high-purity, expandable		Amorphous		Total	
Country or locality	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)
2015:										
Brazil	3,980 r	$8,920 r	--	--	--	--	709 r	$1,020 r	4,690	$9,940
Canada	5,090 r	7,520 r	--	--	2,530 r	$3,550 r	--	--	7,620	11,100
China	16,600 r	21,800 r	--	--	1,030 r	2,450 r	19 r	23 r	17,700	24,300
Czechia	20 r	83 r	--	--	--	--	--	--	20	83
France	--	--	--	--	(3) r	4 r	36 r	39 r	36	43
Germany	67 r	293 r	--	--	32 r	739 r	4 r	5 r	103	1,040
Japan	4 r	11 r	--	--	709 r	4,060 r	--	--	713	4,070
Madagascar	829 r	1,060 r	--	--	--	--	998 r	590 r	1,830	1,650
Mexico	--	--	--	--	--	--	13,500	5,320	13,500	5,320
South Africa	--	--	--	--	33 r	78 r	--	--	33	78
Sri Lanka	--	--	480	$861	--	--	--	--	480	861
Sweden	--	--	--	--	1 r	48 r	--	--	1	48 r
Switzerland	2 r	9 r	--	--	--	--	--	--	2	9 r
Taiwan	--	--	--	--	(3) r	8 r	--	--	(3)	8 r
United Kingdom	4 r	12 r	--	--	14 r	59 r	--	--	18	71
Other	(3) r	4 r	--	--	-- r	-- r	--	--	(3)	4 r
Total	26,600 r	39,700 r	480	861	4,350 r	11,000 r	15,300 r	7,000 r	46,700	58,600 r
2016:										
Brazil	3,450	6,750	--	--	--	--	595	673	4,040	7,430
Canada	7,840	9,830	--	--	(3)	5	--	--	7,840	9,840
China	4,020	8,480	--	--	2,040	4,130	7,360	4,910	13,400	17,500
France	--	--	--	--	--	--	74	77	74	77
Germany	--	--	--	--	154	688	--	--	154	688
Japan	3	21	--	--	277	3,780	--	--	280	3,800
Madagascar	435	539	--	--	--	--	1,800	1,740	2,240	2,280
Mexico	--	--	--	--	--	--	10,300	4,060	10,300	4,060
Sri Lanka	--	--	447	840	--	--	--	--	447	840
Sweden	--	--	--	--	2	41	--	--	2	41
Switzerland	1	6	--	--	--	--	--	--	1	6
Taiwan	--	--	--	--	1	7	--	--	1	7
United Kingdom	44	119	--	--	2	644	18	23	20	786
Other	95	201	--	--	2	51	18	13	115	265
Total	15,800	25,900	447	840	2,480	9,340	20,100	11,500	38,900	47,600

[r]Revised. -- Zero.

[1]Table includes data available through August 28, 2018. Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Customs values.

[3]Less than ½ unit.

Source: U.S. Census Bureau; data adjusted by the U.S. Geological Survey.

TABLE 7
U.S. IMPORTS FOR CONSUMPTION
OF GRAPHITE ELECTRODES, BY COUNTRY OR LOCALITY[1, 2]

Country or locality	Quantity (metric tons)	Value[3] (thousands)
2015:		
Austria	1,560	$6,190
Canada	98	235
China	8,230	28,200
Germany	3,280	15,800
India	12,200	30,500
Japan	19,200	76,300
Malaysia	361	1,250
Mexico	9,350	27,400
Poland	2,140	7,100
Russia	12,000	28,300
Spain	963	3,620
Ukraine	571	1,430
United Kingdom	860	3,310
Venezuela	263	580
Other	151	594
Total	71,200	231,000
2016:		
Austria	2,550	6,000
Canada	70	29
China	4,520	11,300
Germany	3,480	10,800
India	4,150	9,030
Japan	11,000	29,100
Malaysia	1,040	2,390
Mexico	13,500	28,300
Poland	1,840	6,620
Russia	13,600	29,700
Spain	1,010	2,570
Ukraine	327	663
United Kingdom	1,670	5,080
Other	140	1,300
Total	58,900	143,000

[1]Table includes data available through August 28, 2018. Data are rounded to no more than three significant digits; may not add to totals shown.
[2]The applicable Harmonized Tariff Schedule of the United States (HTS) nomenclature is "Graphite electrodes, exceeding 425 mm in diameter, of a kind used for furnaces," and "Carbon electrodes of a kind used for furnaces, excluding graphite," codes 8545.11.0010, 8545.11.0020, and 8545.11.0050.
[3]Customs values.

Source: U.S. Census Bureau.

TABLE 8
U.S. IMPORTS FOR CONSUMPTION OF SYNTHETIC GRAPHITE, BY COUNTRY OR LOCALITY[1, 2]

	2015		2016	
Country or locality	Quantity (metric tons)	Value[3] (thousands)	Quantity (metric tons)	Value[3] (thousands)
Belgium	126	$671	171	$1,370
Brazil	339	999	2,280	1,540
Canada	2,400	2,860	1,080	2,700
China	53,000	43,900	42,500	32,800
Egypt	110	183	--	--
France	1,350	6,090	4,540	11,600
Germany	2,470	13,300	1,770	11,000
Hong Kong	729	724	2,070	3,210
India	1,840	2,380	797	2,160
Italy	89	1,050	37	703
Japan	3,860	25,100	3,210	24,100
Korea, Republic of	252	2,270	615	2,410
Malaysia	1,610	1,830	1,560	1,620
Mexico	6,400	7,910	6,860	11,100
Norway	201	262	664	436
Poland	2,070	5,100	90	164
Russia	177	119	1,950	1,130
South Africa	60	48	1	8
Spain	255	318	494	656
Switzerland	2,420	8,360	3,770	13,700
Taiwan	72	243	112	338
United Kingdom	631	2,520	179	1,490
Other	105 r	1,390 r	165	3,230
Total	80,600	128,000	75,000	127,000

[r]Revised. -- Zero.
[1]Table includes data available through August 28, 2018. Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Synthetic graphite data is for Harmonized Tariff Schedule of the United States codes 3801.10.1000, 3801.10.5000, 3801.20.0000, 3801.90.0000, and 6903.10.0000.
[3]Customs values.

Sources: U.S. Census Bureau and the U.S. International Trade Commission.

TABLE 9
NATURAL GRAPHITE: WORLD PRODUCTION BY COUNTRY OR LOCALITY[1]

(Metric tons)

Country or locality[2]	2012	2013	2014	2015	2016
Austria	219	200 r, e	150 r, e	500 e	500 e
Brazil	88,110	91,908	87,000 r	90,000 r, e	95,000 e
Canada[e]	24,000	20,000	20,000 r	30,000 r	30,000
China:[e]					
Amorphous	200,000	200,000	250,000	275,000	300,000
Flake	450,000	500,000	400,000	505,000	480,000
India, run-of-mine[3]	139,742 r	157,999 r	107,688 r	170,000 e	149,019
Korea, North[e]	30,000	30,000	30,000	30,000	5,500
Madagascar[e]	3,500 r, 4	6,100 r	5,700 r	5,000	8,000
Mexico, amorphous	19,730 r	21,163 r	22,018 r	6,520 r	3,839
Norway	6,992	6,207 r	8,308 r	8,000 e	8,000 e
Pakistan[e]	900	6,200	13,800	14,000	14,000
Russia	14,000	15,000 r	17,600 r	15,900 r	19,000
Sri Lanka	4,173 r	3,143 r	4,000 e	4,000 e	4,000 e
Turkey, run-of-mine[5]	31,500	28,740	3,850	3,850 e	3,850 e
Ukraine[e]	5,800	5,500 r	5,000	5,000	15,000
Vietnam[e]	5,000	5,000	5,000	5,000	5,000
Zimbabwe[e]	7,000 r	6,900 r	6,900 r	7,000	6,000
Total	1,030,000 r	1,100,000 r	987,000 r	1,170,000 r	1,150,000

[e]Estimated. [r]Revised.

[1]Table includes data available through November 23, 2017. All data are reported unless otherwise noted. Totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

[2]In addition to the countries and (or) localities listed, Uzbekistan may have produced graphite, but information was inadequate to make reliable estimates of output.

[3]Indian marketable production is 10% to 20% of run-of-mine production.

[4]Reported exports.

[5]Turkish marketable production averaged approximately 5% of run-of-mine production. Almost all was for domestic consumption.