2017 Minerals Yearbook

GRAPHITE [ADVANCE RELEASE]

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Graphite

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In 2017, no domestic production of natural graphite was reported, but U.S. production of synthetic graphite was 220,000 metric tons (t) valued at about $682 million. U.S. exports and imports of natural graphite were 13,900 t and 51,900 t, respectively. U.S. exports and imports of synthetic graphite were 36,000 t and 111,000 t, respectively. U.S. apparent consumption of natural and synthetic graphite was 38,000 t and 294,000 t, respectively. World production of natural graphite was estimated to be 897,000 t (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 the graphite structure is only a one-atom-thick planar sheet, it is called graphene. Graphite is used to produce graphene. Graphene is extremely light and strong. 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. It is a soft mineral with a Mohs hardness of 1 to 2, and it exhibits perfect basal (one-plane) cleavage. Graphite is flexible but not elastic, has a melting point of 3,927 degrees Celsius (°C), and is highly refractory. It has a low specific gravity. Graphite is the most electrically and thermally conductive of the nonmetals and is chemically inert. All these properties combined make both 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. Amorphous refers to its very small crystal size and not to a lack of crystal structure. Amorphous 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 higher quality than amorphous graphite. Flake graphite occurs as separate flakes that crystallized in metamorphic rock and high-quality flake graphite can be four times the price of amorphous graphite. Good quality 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. It occurs in veins along intrusive contacts in solid lumps, and it is only commercially mined in Sri Lanka.

Natural graphite is mined from open pits and underground mines. Production from open pit operations is preferred and is less expensive 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 may 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 contain 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 2017, but 220,000 t of synthetic graphite with an estimated value of $682 million was produced and shipped (tables 1, 3). This was a 6% increase in quantity produced and a 4% increase in value compared with that of the previous year.

Synthetic graphite electrodes used to 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 2017, 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 2017, Alabama Graphite Corp. continued exploring, evaluating, and developing its Bama Mine project, which it had acquired in September 2014. The Bama Mine project encompasses more than 520 hectares (1,300 acres) in Chilton County, AL, and includes the Bama Mine. The Bama Mine, the southernmost mine in the Alabama Graphite Belt, previously 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 good power, water, road, and rail infrastructure established, and is 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 2017, Alabama Graphite Corp. also continued exploring and developing 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 producer of high-grade crystal flake graphite in the past. Alabama Graphite evaluated the deposit and reported an indicated resource of 71.2 million metric tons (Mt) grading 2.39% graphite and an inferred resource of 72.1 Mt grading 2.56% graphite (Westwater Resources, Inc., 2017b). The Bama Mine project and the Coosa Graphite project are within the geologic trend of high-quality graphite deposits called the Alabama Graphite Belt from which significant quantities of graphite were produced from the late 1800s through the 1950s (Westwater Resources, Inc., 2017a).

During 2017, Graphite One was delineating, evaluating, and developing a massive, near-surface deposit at its Graphite Creek project, which 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. In July 2017, Graphite One released the project's completed preliminary economic assessment based on exploration drilling and test work. The report included an economic analysis of the viability of the Graphite Creek project's mineral resources, including its inferred resources. An estimated 44 Mt of graphite mineralization at 7% graphitic carbon (Cg) would be available for mining, would process at a recovery rate of 80% Cg, and would support a project life of 40 years producing 60,000 metric tons per year (t/yr) of graphite concentrate at 95% Cg. Full production level would be reached is reached in 6 years. The manufacturing plant is expected to convert 60,000 t/yr of concentrate into 41,850 t/yr of coated spherical graphite (CSG) and 13,500 t/yr of purified graphite powders. Graphite One assumed a selling price for CSG of $6,200 per metric ton and $1,500 per metric ton for purified graphite powders, which was expected to generate estimated annual sales of $280 million and annual post-tax earnings of $118 million or $2,132 per metric ton (Graphite One Resources Inc., 2016, 2017).

Consumption

The USGS obtained the consumption data in this report through a survey of 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 increased by 54% to 38,000 t in 2017 from 24,700 t in 2016, whereas U.S. apparent consumption of synthetic graphite increased by 17% to 294,000 t in 2017 from 252,000 t in 2016. Total U.S. graphite consumption, combined natural and synthetic, increased by 20% to 332,000 t in 2017 from 277,000 t in 2016 (table 1).

U.S. consumption of natural graphite reported by end use decreased slightly to 42,800 t in 2017 from that of 2016 (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 5% in 2017 to 22,600 t from 21,600 t in 2016. Consumption of amorphous graphite decreased by 5% in 2017 to 20,200 t from 21,300 t in 2016. The main uses of graphite during 2017 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 accounted for 8% and lubricants accounted for another 5% of all forms of natural graphite consumption. Automobile manufacturing and construction influenced steelmaking activity, which in turn influenced refractories demand.

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 have the largest increase of growth (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). Graphite is an essential component of many types of batteries; battery applications accounted for 1,660 t or 4% of all forms of U.S. natural graphite consumption during 2017, which was an increase from 2% in 2016.

Tesla Motors, Inc. was building a large plant, in Sparks, NV, to manufacture lithium-ion electric vehicle batteries. Tesla partnered with battery maker, Panasonic Corp. with both companies operating parts of the factory. Panasonic agreed to make the battery cells, and Tesla would assemble the cells into battery packs (Valdes-Dapena, 2016). When complete, the plant would require 95,000 t of flake graphite per year to produce 35,000 t of spherical graphite for use as anode material for lithium-ion batteries. The factory started limited production of battery packs in the first quarter of 2016 and reached initial capacity of battery cells in January 2017 (Randall, 2017).

Graphite has metallic and nonmetallic properties, which 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 that is 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 that are used in seals, gaskets, and fuel cells.

Refractory applications of graphite included 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 53% of natural graphite use in the United States in 2017. It was consumed mainly in batteries, brake linings, lubricants, powdered metals, refractories, and rubber. Amorphous graphite accounted for 47% of natural graphite use and was mainly used in brake linings, foundries, lubricants, powdered metals, refractories, steelmaking, and other applications where additions of graphite improve the process or the end product (table 2). Lump graphite is used in a number of areas, such as steelmaking, depending on purity and particle size.

Synthetic graphite is used in more applications in the United States than natural graphite and accounts for an 89% share by quantity and a 95% share by value of the graphite consumption (table 1). The main 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 types of graphite 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 have played an important role in the emerging nonhydrocarbon energy sector and have been used in several new energy applications. In energy production applications, graphite is used as pebbles for modular nuclear reactors and 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, in anodes for lithium-ion batteries, in electrodes for supercapacitors, in high-strength composites for fly wheels, in phase change heat storage, and in solar boilers. In energy management applications, graphite is used in high-performance polystyrene thermal insulation and in silicon chip heat dissipation. These new energy applications use value-added graphite products such as high-carbon purity, small particle size, potato shapes 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." It consists of a single atomic layer of carbon atoms arranged in a flat honeycomb pattern. Within a 1-millimeter-thick graphite flake, there 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, very powerful transistors, and wafer-thin tablet computers that could be the next-generation tablets (Topf, 2012). Graphene's unique properties have the potential to make high-tech products thinner, transparent, flexible, and more powerful. It 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 has 20% more flexibility without any damage than copper (Desjardins, 2012).

Prices

During 2017, prices for all mesh sizes of natural crystalline flake graphite either were unchanged or increased from those of 2016, with median yearend prices remaining unchanged or increasing by up to 36%. Prices for natural amorphous powder graphite decreased slightly compared with those of 2016. Prices for synthetic graphite could not be compared because data were not available for 2017 (table 4).

Prices for crystalline and crystalline flake graphite concentrates ranged from $400 to $1,070 per metric ton; prices for amorphous powder ranged from $400 to $430 per ton (table 4). The average unit value of all U.S. natural graphite exports increased by 21% to $1,790 per ton in 2017 from $1,480 per ton in 2016 (tables 1, 5). The average unit value of all U.S. natural graphite imports decreased by 8% to $1,130 per ton in 2017 from $1,220 per ton in 2016 (tables 1, 6). Ash and carbon content, crystal and flake size, and size distribution affect the price of graphite. The average unit value of U.S. synthetic graphite exports increased by 9% to $5,250 per ton in 2017 from $4,820 per ton in 2016 (tables 1, 5). The average unit value of all U.S. synthetic graphite imports decreased by 7% to $1,590 per ton in 2017 from $1,700 per ton in 2016 (tables 1, 8).

Early in 2017, graphite prices decreased following the cancellation by the Government of China of a 20% export tax at the end of 2016. China-based graphite producers decreased their prices by 10% to 15% in January while uncertain about the new policy. A new environmental tax, which also was introduced at the end of December 2016 and reduced graphite production in China, began to take effect on prices shortly after the initial price downturn, and prices recovered when the graphite supply was reduced (Lismore-Scott, 2017).

Graphite prices increased between 30% and 40% in the second half of 2017 owing to increased steel production, environment-related production problems in China, and continued strong demand growth from the lithium-ion battery industry. Prices for large flake graphite (+80 mesh) recovered from their lows of $750 per ton to approximately $1,200 per ton at yearend but were still well below the 2012 peak price of $2,800 per ton. China has substantial resources and excess production capacity for small flake graphite (-100 mesh), which is used to make battery anode material, and this has kept prices low (Northern Graphite Corp., undated).

Foreign Trade

Total graphite exports increased by 12% in tonnage to 49,900 t valued at $214 million in 2017 from 44,400 t valued at $166 million in 2016. Total graphite export tonnage was 28% natural graphite and 72% synthetic graphite (table 5). Total natural graphite imports increased by 33% in tonnage to 51,900 t in 2017 from 38,900 t in 2016, and the value increased by 23% to $58.5 million in 2017 from $47.6 million in 2016 (table 6). These increases in natural graphite imports resulted from substantial increases in quantity and in value of the "crystalline flake and flake dust" graphite category during 2017. Principal import sources of natural graphite were, in descending order of tonnage, China, Mexico, Canada, Brazil, and Madagascar, which combined accounted for 99% of the tonnage and 94% of the value of total natural graphite imports. Mexico, Brazil, and Madagascar were the leading suppliers of amorphous graphite. Sri Lanka provided all the lump and chippy dust. China, Japan, and Germany were the leading suppliers of high-purity, expandable graphite 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 increased by 48% in tonnage to 111,000 t in 2017 from 75,000 t in 2016, and the value increased by 38% to $176 million in 2017 from $128 million in 2016 (table 8). Principal import sources of synthetic graphite were, in descending order of tonnage, China, Japan, France, Spain, Mexico, India, and Switzerland, which combined accounted for 93% of the tonnage and 86% of the value of total synthetic graphite imports.

World Review

World production of natural graphite increased by 4% in 2017 to an estimated 897,000 t from 864,000 t in 2016. China maintained its position as the world's leading graphite producer, with an estimated 625,000 t, or 70% of total global production. Brazil ranked second with 90,000 t, or 10% of the total, followed by Canada, India, Ukraine, Russia, Norway, and Pakistan, in decreasing order of tonnage. These eight countries accounted for 96% of world production (table 9).

Brazil.—In 2017, Brazil had estimated production of 90,000 t of marketable natural graphite. Nacional de Grafite Ltda. was thought to be the only producer of natural flake graphite in Brazil during 2017. The company operated mines and plants at three sites in the State of 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; 2018, p. 23, 161–164, 468–470).

Canada.—In 2017, Canada had two active open pit mines with combined production of about 40,000 t of natural flake graphite—About 80% from the Lac des Iles flake graphite mine in Quebec, operated by Imerys Graphite & Carbon, and approximately 20% from the Black Crystal flake graphite quarry in British Columbia, owned by Eagle Graphite Corp.

During 2017, 24 potential graphite producers were exploring and developing flake graphite projects in Canada. Exploration was primarily focused on properties in Ontario and Quebec, but other graphite exploration projects were underway in British Columbia. Low graphite prices limited project development in recent years, but this was likely to reverse after the price recovery in late 2017 (Roskill Information Services Ltd., 2017, p. 146–150; 2018, p. 23, 164–168).

China.—In 2017, China was the world's leading producer, exporter, and consumer of natural and synthetic graphite. China also may have the largest natural graphite resources in the world. China produced approximately 625,000 t of natural graphite, of which an estimated 350,000 t was flake graphite and the remainder was amorphous graphite; this was about 70% of the total global production. More than 60% of China's flake graphite was produced in the Heilongjiang Province, and most of the country's amorphous graphite was produced in Hunan Province (Roskill Information Services Ltd., 2017, p. 151–178). The iron and steel industry was the leading consuming market of natural and synthetic graphite in China (Roskill Information Services Ltd., 2017, p. 151; 2018, p. 169–170).

During 2017, increased crystalline flake graphite production in China was spurred by increased demand from the lithium-ion battery industry, which was centered in China for most parts of the supply chain. China was the leading producer of battery-grade graphite, including spherical graphite, anode materials, anodes, and the lithium-ion batteries themselves. All the world's spherical graphite was processed from natural flake graphite in China (Roskill Information Services Ltd., 2018, p. 169).

Beginning in 2011 and continuing through 2017, owing to environmental and resource protection concerns, the Government of China ordered most amorphous graphite mines under its control in Hunan Province to be closed or consolidated and further ordered upgrading of the processing plants. This 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, also for environmental and resource protection concerns. By the beginning of 2015, more than 200 crystalline flake graphite mines had been closed. These mine closings and consolidations were primarily focused in Heilongjiang Province, which at one time produced 43% of the world's flake graphite (Razoumova, 2014). China closed more than 20% of its crystalline flake capacity from 2012 through 2014 (Paradigm Metals Ltd., 2014). Dust emissions from the mining of crystalline flake graphite had become a major issue, and although graphite is inert and not harmful, the air pollution from dust had become 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).

The Government of China announced a new Environmental Protection Law in December 2016 that was intended to tax companies that disobey or ignore the Government's environmental measures. In January, the Government of China intensified its pollution crackdown. The new law was more likely to be implemented than previous regulations because local governments no longer were able to intervene on behalf of companies (Lismore-Scott, 2017).

In 2017, China produced approximately 714,000 t of synthetic graphite from at least 29 plants, which accounted for approximately 48% of global synthetic graphite production. Synthetic graphite production increased slightly during 2017 compared with production during the previous year. Most of this output was in the form of synthetic graphite electrodes for export (Roskill Information Services Ltd., 2017, p. 151–178; 2018, p. 35, 169–170, 184–185).

Mozambique.—Mozambique has been a focus for several natural flake graphite development projects in recent years. 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. During 2017, Mozambique's estimated production was 300 t of crystalline flake graphite. Production of natural flake graphite began as a result of foreign investment. The Ancuabe operation in the Cabo Delgado Province was operated by Triton Minerals Ltd. (Australia). Startup of Ancuabe began in June. According to Triton Minerals, Ancuabe had the potential to become a major high-grade graphite project. The largest known graphite deposit in the world was the nearby Balama deposit owned by Syrah Resources Ltd. (Australia), also in the Cabo Delgado Province. Resources at Balama were estimated to be 1.1 billion metric tons, which was more natural graphite than that contained in all other known global deposits combined. Production at the project began in November 2017, and it was expected to rise rapidly in coming years as production ramped up. A number of other graphite projects were under development in Cabo Delgado. Graphite mining in the Balama District of Mozambique was projected to be relatively low cost because ores were easily accessible by open pit mining, of high quality, and 240 kilometers (149 miles) from the deepwater port of Pemba (Economist Intelligence Unit, The, 2014; Roskill Information Services Ltd., 2017, p. 199; 2018, p. 223–225; Syrah Resources Ltd., undated).

Tanzania.—During 2017, several natural flake graphite deposits were being explored in Tanzania, 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 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; 2018, p. 235–236).

Outlook

Worldwide demand for natural and synthetic graphite is expected to continue increasing 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. Battery production is predicted to increase and become the leading graphite market by 2027, surpassing the traditional leading graphite markets of electrodes and refractories. Electrodes and refractories are expected to decline whenever steelmaking declines (Roskill Information Services Ltd., 2017, p. 43; 2018, p. 49–55).

Batteries are expected to become the end-use sector with the largest increase in graphite use owing to growth in portable electronics and electric vehicles. These applications require larger, more-powerful, and more-graphite-intensive lithium-ion batteries. Production of spherical graphite feedstock material will need 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 all current battery technologies. Consumption of all types of graphite used in battery applications may increase to account for about 26% of total graphite consumption by 2026 (Roskill Information Services Ltd., 2017, p. 43; 2018, p. 49–55).

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 graphite with improved properties 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 is increasing and continued growth is expected. The United States market for graphite in pencils has almost disappeared; most pencil "leads" now are imported 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]

		2013	2014	2015	2016	2017
United States:						
Natural:						
Exports:						
Quantiy	metric tons	10,000	12,200	11,600	14,300	13,900
Value	thousands	$18,300	$19,300	$21,600	$21,100 r	$24,800
Imports for consumption:						
Quantity	metric tons	61,300	69,600	46,700	38,900	51,900
Value	thousands	$70,500	$72,300	$58,600	$47,600	$58,500
Apparent consumption:[2]						
Quantity	metric tons	51,300	57,400	35,100	24,700 r	38,000
Value	thousands	$52,200	$52,900	$36,900	$26,500 r	$33,700
Synthetic:						
Production:						
Quantity	metric tons	129,000	135,000	119,000	207,000	220,000
Value	thousands	$976,000	$939,000	$816,000	$658,000	$682,000
Exports:						
Quantity	metric tons	29,700	32,500	32,000	30,100	36,000
Value	thousands	$210,000	$221,000	$177,000	$145,000	$189,000
Imports for consumption:						
Quantity	metric tons	59,100	60,700	80,600	75,000	111,000
Value	thousands	$130,000	$135,000	$128,000	$127,000	$176,000
Apparent consumption:[2]						
Quantity	metric tons	158,000	163,000	167,000	252,000	294,000
Value	thousands	$895,000	$852,000	$767,000	$640,000	$669,000
World production, natural[e]	metric tons	699,000 r	905,000 r	946,000 r	864,000 r	897,000

[e]Estimated. [r]Revised.
[1]Table includes data available through October 1, 2019. Data are rounded to no more than three significant digits; may not add to totals shown.
[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)
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
2017:				
Brake lining	753	2,020	2,700	4,760
Carbon products[3]	225	939	423	252
Foundries[4]	W	W	W	W
Lubricants[5]	742	3,100	1,320	1,470
Powdered metals	W	W	W	W
Refractories	W	W	W	W
Rubber	W	W	834	1,780
Other[6]	6,460	60,200	8,670	8,830
Total	22,600	84,100	20,200	26,200

W Withheld to avoid disclosing company proprietary data; included in "Total."
[1]Table includes data available through October 1, 2019. 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/electronic devices, industrial diamonds, magnetic tape, mechanical products, nozzles, paints and polishes, pencils, retorts, sleeves, small packages, soldering/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)
2016:		
Electrodes	84,900	$227,000
Unmachined graphite shapes	15,300	47,000
Other[2]	107,000	384,000
Total	207,000	658,000
2017:		
Electrodes	86,600	223,000
Unmachined graphite shapes	9,440	W
Other[2]	124,000	459,000
Total	220,000	682,000

W Withheld to avoid disclosing company proprietary data; included in "Other."
[1]Table includes data available through October 1, 2019. Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Includes anodes, cloth and fibers (low modulus), 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	2016	2017
Crystalline medium, 85% to 87% carbon, +100-80 mesh	400–500	400–500
Crystalline fine, 90% carbon, -100 mesh	500–550	500–550
Crystalline medium, 90% carbon, +100-80 mesh	550–620	550–620
Crystalline large, 90% carbon, +80 mesh	600–650	600–650
Crystalline fine, 94% to 97% carbon, -100 mesh	620–650	785–940
Crystalline medium, 94% to 97% carbon, +100-80 mesh	700–750	865–1,040
Crystalline large, 94% to 97% carbon, +80 mesh	700–850	925–1,070
Amorphous powder, 80% to 85% carbon	400–450	400–430
Synthetic fine, 97% to 98% carbon[2]	950–1,450	NA
Synthetic fine, 98% to 99% carbon[2]	1,000–1,500	NA

NA Not available.
[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. 589, December 2016−January 2017, p. 66; no. 598, December 2017−January 2018, p. 34–38, 42, 53.

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)
2016:						
Brazil	132	$353	953	$4,900	1,080	$5,250
Canada	8,590	4,190	4,510	11,000	13,100	15,200
China	176	401	2,050 r	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	7,580 r	1,420	7,670 r
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	547 r	1,520	1,900 r	9,560 r	2,440	11,100 r
Total	14,300	21,100 r	30,100	145,000	44,400	166,000
2017:						
Brazil	82	196	253	1,610	334	1,800
Canada	8,490	4,730	4,170	14,700	12,700	19,500
China	322	888	2,250	28,300	2,570	29,200
France	44	127	2,620	12,600	2,660	12,700
Germany	151	499	1,050	7,330	1,200	7,830
Hong Kong	5	21	77	6,190	82	6,220
India	422	1,100	523	1,030	944	2,130
Italy	23	83	1,760	9,230	1,780	9,320
Japan	910	2,830	2,470	14,500	3,380	17,400
Korea, Republic of	288	1,170	2,160	36,000	2,450	37,200
Mexico	1,480	6,230	11,900	12,900	13,300	19,100
Netherlands	333	2,370	144	527	477	2,900
Poland	--	--	473	2,320	473	2,320
Saudi Arabia	47	20	1,950	7,240	2,000	7,260
Taiwan	80	281	339	3,240	418	3,520
United Kingdom	32	122	1,080	1,380	1,110	1,500
Venezuela	191	1,970	1	17	191	1,990
Vietnam	75	212	258	19,400	333	19,600
Other	918	1,990	2,540	10,100	3,460	12,100
Total	13,900	24,800	36,000	189,000	49,900	214,000

[r]Revised. -- Zero.
[1]Table includes data available through October 1, 2019. Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Numerous countries and (or) localities 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)
2016:										
Brazil	3,450	$6,750	--	--	--	--	598 r	$675 r	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
Hong Kong	73	156	--	--	--	--	18	13	91	169
Japan	7 r	59 r	--	--	273 r	3,740 r	--	--	280	3,800
Madagascar	435	539	--	--	--	--	1,800	1,740	2,230	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	64 r	786
Other	21 r	45 r	--	--	2	51	-- r	-- r	23 r	96 r
Total	15,900 r	26,000 r	447	840	2,470 r	9,300 r	20,100 r	11,500 r	38,900	47,600
2017:										
Brazil	4,250	6,840	--	--	--	--	808	760	5,050	7,600
Canada	9,250	12,900	--	--	(3)	2	18	23	9,270	12,900
China	20,400	24,700	--	--	1,050	2,460	5	5	21,400	27,100
France	--	--	--	--	1	6	--	--	1	6
Germany	44	160	--	--	48	874	--	--	92	1,030
Japan	13	66	--	--	99	1,460	--	--	112	1,520
Madagascar	1,490	1,370	--	--	--	--	574	528	2,060	1,900
Mexico	--	--	--	--	--	--	13,300	5,310	13,300	5,310
Sri Lanka	--	--	442	840	--	--	--	--	442	840
Sweden	--	--	--	--	3	69	--	--	3	69
Taiwan	--	--	--	--	1	28	--	--	1	28
United Kingdom	17	41	--	--	(3)	38	40	22	57	101
Other	1	4	--	--	(3)	9	56	39	57	51
Total	35,400	46,100	442	840	1,200	4,940	14,800	6,680	51,900	58,500

[r]Revised. -- Zero.

[1]Table includes data available through October 1, 2019. Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Customs value.

[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)
2016:		
Austria	2,550	$6,000
Canada	70	29
China	4,510 r	11,200 r
Germany	3,480	10,800
India	4,140	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	5,070
Other	140	1,290 r
Total	58,900	143,000
2017:		
Austria	1,160	2,530
Brazil	292	1,930
Canada	345	185
China	7,700	58,100
Germany	4,670	12,500
Hong Kong	510	12,600
India	7,860	17,500
Indonesia	174	1,580
Japan	12,300	33,400
Malaysia	1,560	3,430
Mexico	20,700	40,900
Poland	3,460	9,850
Russia	11,300	24,100
Spain	677	1,310
Ukraine	1,140	2,010
United Kingdom	1,210	4,820
Other	153	755
Total	75,300	228,000

[r]Revised.
[1]Table includes data available through October 1, 2019. 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) nomenclatures are “Graphite electrodes, not exceeding 425 mm in diameter, of a kind used for furnaces,” “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 value.

Source: U.S. Census Bureau.

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

Country or locality	2016 Quantity (metric tons)	2016 Value[3] (thousands)	2017 Quantity (metric tons)	2017 Value[3] (thousands)
Belgium	171	$1,370	28	$443
Brazil	2,280	1,540	1,270	1,610
Canada	1,080	2,700	929	4,130
China	42,500	32,800	70,500	53,700
Czechia	6	69	34	918
France	4,540	11,600	5,980	15,600
Germany	1,770	11,000	1,160	10,000
Hong Kong	2,070	3,210	2,690	1,290
India	797	2,160	3,750	4,990
Italy	37	703	24	545
Japan	3,200	24,100	8,090	52,600
Korea, Republic of	615	2,410	259	2,650
Malaysia	1,560	1,620	736	740
Mexico	6,860	11,100	5,130	6,240
Netherlands	23	2,770	52	210
Norway	664	436	285	192
Poland	90	164	97	110
Russia	1,950	1,130	200	185
South Africa	1	8	12	36
Spain	494	656	5,610	8,110
Sweden	2	82	228	219
Switzerland	3,770	13,700	3,370	10,300
Taiwan	112	338	79	256
United Kingdom	179	1,490	43	399
Other	134 r	314 r	13	180
Total	75,000	127,000	111,000	176,000

[r]Revised.
[1]Table includes data available through October 1, 2019. Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Synthetic graphite data are for Harmonized Tariff of the United States codes 3801.10.1000, 3801.10.5000, 3801.20.0000, 3801.90.0000, and 6903.10.0000.
[3]Customs value.

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	2013	2014	2015	2016	2017
Australia, crystalline flake	--	--	500	--	--
Austria, amorphous[e]	500 [r]	500 [r]	700 [r]	800 [r]	1,000
Brazil, crystalline flake	91,908	87,026 [r]	81,762 [r]	80,000 [r, e]	90,000 [e]
Canada, crystalline flake[e]	20,000	30,000 [r]	30,000	35,000 [r]	40,000
China:					
Amorphous[e]	200,000	250,000	275,000	300,000	275,000
Crystalline flake	283,000 [r]	425,000 [r, e]	450,000 [r, e]	325,000 [r, e]	350,000 [e]
Total	483,000	675,000	725,000	625,000	625,000
Germany, crystalline flake[e]	300	500	400	500	800
India:[e]					
Amorphous	2,900	2,300	2,700	3,000	3,500
Crystalline flake	26,400	21,000	24,200	27,000	31,500
Total	29,300	23,300	26,900	30,000	35,000
North Korea:[e]					
Amorphous	1,000	1,000	1,000	1,000	1,000
Crystalline flake	4,500	4,500	4,500	4,500	4,500
Total	5,500	5,500	5,500 [r]	5,500	5,500
Madagascar, crystalline flake	6,100 [e]	5,700 [e]	8,006 [r]	9,224 [r]	9,000 [e]
Mexico, amorphous[e]	7,000 [r]	9,200 [r]	8,100 [r]	8,500	9,000
Mozambique, crystalline flake	--	--	--	--	300
Namibia, crystalline flake	--	--	--	--	2,216
Norway, crystalline flake	6,200 [r]	8,300 [r]	9,200 [r]	11,500 [r, e]	15,500 [e]
Pakistan, crystalline flake[e]	6,200	14,300 [r]	2,900 [r]	10,000 [r]	14,000
Russia:[e]					
Amorphous	8,000	8,000	8,000	8,000	8,000
Crystalline flake	6,300	7,000	7,800	8,500	9,000
Total	14,300	15,000	15,800	16,500	17,000
Sri Lanka, vein	3,143	3,100 [r, e]	3,100 [r, e]	3,300 [r, e]	3,500 [e]
Sweden, crystalline flake	--	--	100	--	--
Turkey, amorphous[e]	1,400	1,400	1,800	2,000	2,300
Ukraine, crystalline flake[e]	12,000 [r]	13,800 [r]	14,500 [r]	15,000 [r]	20,000
Uzbekistan, crystalline flake[e]	100	100	100	100	100
Vietnam, crystalline flake[e]	5,000	5,000	5,000	5,000	5,000
Zimbabwe, crystalline flake	6,934 [r]	6,853 [r]	6,362 [r]	5,622 [r]	1,577
Grand total[e]	699,000 [r]	905,000 [r]	946,000 [r]	864,000 [r]	897,000
Of which:					
Amorphous	221,000	272,000	297,000	323,000	300,000
Crystalline flake	475,000	629,000	645,000	537,000	593,000
Vein or lump	3,140	3,100	3,100	3,300	3,500

[e]Estimated. [r]Revised. -- Zero.

[1]Table includes data available through November 6, 2018. 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.