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2015 Minerals Yearbook

GRAPHITE [ADVANCE RELEASE]

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Graphite

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In 2015, no domestic production of natural graphite was reported, but U.S. production of synthetic graphite was estimated to be 119,000 metric tons (t) valued at about $816 million. U.S. exports and imports of natural graphite were estimated to be 11,600 t and 46,700 t, respectively. U.S. exports and imports of synthetic graphite were estimated to be 32,000 t and 80,600 t, respectively. U.S. apparent consumption of natural and synthetic graphite was estimated to be 35,100 t and 167,000 t, respectively. World production of natural graphite was estimated to be 1.16 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 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 °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.

There are three types of natural graphite—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 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 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 (Moores, 2007).

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 for nonrespondents were estimated 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 2015, but 119,000 t of synthetic graphite with an estimated value of $816 million was produced and shipped (tables 1, 3). This was a 12% decrease in quantity produced and a 13% decrease in value compared with that of the previous year.

The first method to produce synthetic graphite was invented in the mid-1890s by Edward Goodrich Acheson. He discovered that by heating carborundum 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 2015, two companies from Canada were exploring for graphite and developing graphite 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 (Alabama Graphite Corp., 2017a, b; Graphite One Resources Inc., undated).

During 2015, Alabama Graphite Corp. continued exploring, evaluating, and developing its Bama Mine Project, which it had acquired in September 2014. The Bama Mine Project is more than 520 hectares (1,300 acres) in Chilton County, AL, which included the Bama Mine. The Bama Mine was the southernmost mine in the Alabama Graphite Belt, 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 good 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 (Alabama Graphite Corp., 2017a). During 2015, 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 stated that the property has an indicated resource reported as 34.6 Mt grading 2.6% graphite and an inferred resource reported as 24.5 Mt grading 2.87% graphite (Alabama Graphite Corp., 2017b). The Bama Mine Project and the Coosa Graphite Project are located 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 (Alabama Graphite Corp., 2017a).

Graphite One's Graphite Creek Project was exploring, evaluating, and developing a massive, near-surface deposit, 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 that was delineated through 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 2015, Graphite One released an updated mineral resource estimate based on the analyses of a 2014 drilling program of 17.95 Mt indicated, grading 6.3% graphite, and 154.36 Mt inferred, with 5.7% graphite, using a 3% graphite cutoff grade. 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 39% to 35,100 t in 2015 from 57,400 t in 2014, whereas U.S. apparent consumption of synthetic graphite increased by 3% to 167,000 t in 2015 from 163,000 t in 2014. Total U.S. graphite consumption, including natural and synthetic, decreased by 8% to 202,000 t in 2015 from 220,000 t in 2014 (table 1).

U.S. consumption of natural graphite reported by end use decreased by 6% to 41,800 t in 2015 from 44,400 t in 2014 (table 2). The reported natural graphite consumption data in table 2 include mixtures of 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 decreased by 24% in 2015 to 20,900 t from 27,600 t in 2014. Consumption of amorphous graphite increased by 24% in 2015 to 20,900 t from 16,800 t in 2014. The major uses of graphite during 2015 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; in foundries; fuel cells; high-strength composites; lubricants; pencils; powdered metals; refractories; rubber; and in steelmaking. Brake linings and refractories, combined, accounted for 40% of all forms of natural graphite consumption. Foundries and lubricants accounted for another 13% of all forms of natural graphite consumption. The refractories industrial sector was the leading graphite consumer, accounting for 48% of crystalline flake graphite use in 2015. Automobile manufacturing and construction influenced steelmaking activity, which in turn influenced refractories demand. Battery applications only accounted for just over 2% of natural graphite during 2015, a slight increase from that of 2014.

An important and potentially increasing portion of graphite use was related to high-technology applications through the use of graphite as an anode material in batteries. The batteries end-use category was predicted to become the fastest increasing market with 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 2015, data for U.S. natural graphite consumption did not yet demonstrate this predicted growth rate.

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 about 50% of natural graphite use in the United States in 2015. It was consumed mainly in batteries, brake linings, lubricants, powdered metals, refractories, and rubber. Amorphous graphite accounted for about 50% 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 North America than natural graphite and accounts for an 83% 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, anodes for lithium-ion batteries, electrodes for supercapacitors, high-strength composites for fly wheels, phase change heat storage, and 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." This material 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 2015, graphite prices for all forms of natural and synthetic graphite either remained constant or increased, with median yearend prices increasing between 2% and 9%. The prices of two categories of natural crystalline graphite remained constant compared with that of 2014: crystalline medium (85% to 87% carbon, +100 to 80 mesh) and crystalline fine (90% carbon, -100 mesh). Median yearend price for amorphous powder graphite remained constant compared with that of 2014. Median yearend price for synthetic fine, 97% to 98% carbon and synthetic fine, 98% to 99% carbon also remained constant (table 4).

Prices for crystalline and crystalline flake graphite concentrates ranged from $700 to $1,400 per metric ton; prices for amorphous powder ranged from $430 to $480 per ton (table 4). The average unit value of all U.S. natural graphite exports increased by 17% to $1,860 per ton in 2015 from $1,590 per ton in 2014 (tables 1, 5). The average unit value of all U.S. natural graphite imports increased by 21% to $1,250 per ton in 2015 from $1,040 per ton in 2014 (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 decreased by 19% to $5,520 per ton in 2015 from $6,810 per ton in 2014 (tables 1, 5). The average unit value of all U.S. synthetic graphite imports decreased by 29% to $1,580 per ton in 2015 from $2,220 per ton in 2014 (tables 1, 8).

Foreign Trade

Total graphite exports decreased slightly in tonnage to 43,700 t valued at $198 million in 2015 from 44,600 t valued at $241 million in 2014. Total graphite export tonnage was

27% natural graphite and 73% synthetic graphite (table 5). Total natural graphite imports decreased by 33% in tonnage to 46,700 t in 2015 from 69,600 t in 2014, and the value decreased by 19% to $58.6 million in 2015 from $72.3 million in 2014 (table 6). These decreases in natural graphite imports resulted from a decrease of 4,530 t in quantity and an increase of $7.00 million in the value of the "crystalline flake and flake dust" graphite category during 2015 and from a decrease of 8,510 t in quantity and a decrease of $2.60 million in the value of the "amorphous" graphite category during 2015. Principal import sources of natural graphite were, in descending order of tonnage, China, Mexico, Canada, Brazil, and Madagascar, which combined accounted for 97% of the tonnage and 89% of the value of total natural graphite imports. Mexico provided all the amorphous graphite, and Sri Lanka provided all the lump and chippy dust variety. China, Canada, 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 33% in tonnage to 80,600 t in 2015 from 60,700 t in 2014, and the value decreased by 5% to $128 million in 2015 from $135 million in 2014 (table 8). Principal import sources of synthetic graphite were, in descending order of tonnage, China, Mexico, Japan, Germany, Switzerland, Canada, and Poland, which combined accounted for 90% of the tonnage and 83% of the value of total synthetic graphite imports.

World Review

World production of natural graphite remained essentially unchanged in 2015 at an estimated 1.160 Mt. China maintained its position as the world's leading graphite producer, with an estimated 780,000 t, or 67% of total global production. India ranked second with 170,000 t, or 15% of the total, followed by Brazil, Canada, North Korea, Mexico, and Russia, in decreasing order of tonnage produced. These seven countries accounted for 97% of world production (table 9).

Brazil.—In 2015, Brazil produced 80,000 t of marketable natural graphite. High-grade crystalline flake graphite projects were being developed in Brazil with at least three companies conducting or considering graphite exploration and development (Roskill Information Services Ltd., 2017, p. 144–146).

Canada.—In 2015, Canada had two active mines with combined production of about 30,000 t of flake graphite: the Lac des Iles flake graphite mine in Quebec, owned by Timcal Ltd. and the Black Crystal flake graphite quarry in British Columbia, owned by Eagle Graphite Corp. A third flake graphite mine, the Kearney graphite mine in Ontario, owned by Ontario Graphite Ltd., was expected to come online during the next few years. During 2015, 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 2015, China was the world's leading producer and exporter of both natural and synthetic graphite. China arguably may have the largest natural graphite resources in the world. China produced approximately 780,000 t of natural graphite, of which 435,000 t was flake graphite and the remainder was amorphous graphite. More than 60% of the flake graphite was produced in the Heilongjiang Province and the majority of the amorphous graphite was produced from the Hunan Province (Roskill Information Services Ltd., 2017, p. 151–178).

Beginning in 2011 and continuing through 2015, 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 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 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 had become a major issue, and although graphite is inert and not harmful, the air pollution from dust had become a problem to 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 in order to control dust emissions (Lazenby, 2014; Moores, 2011; Roskill Information Services Ltd., 2017, p. 151–178).

In 2015, China produced approximately 666,000 t of synthetic graphite from at least 29 plants. Synthetic graphite production has increased about 3.7% per year during the past 10 years. Synthetic graphite electrodes accounted for the majority of the synthetic graphite production of China (Roskill Information Services Ltd., 2017, p. 151–178).

Mozambique.—Although no natural graphite mining took place during 2015, the country was the focus of several natural flake graphite development projects. The planned production capacity for the country far exceeds 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'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 reserves of 1.1 billion metric tons containing more natural graphite than all other known global deposits combined. A third company, Metals of Africa Ltd., obtained three exploration licenses for the same area. Syrah Resources expects 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, The, 2014; Roskill Information Services Ltd., 2017, p. 199; Syrah Resources Ltd., undated).

Tanzania.—During 2015, several natural flake graphite deposits were the focus of exploration, but there was no graphite production. 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 holds four exploration licenses in the region. Assessment and sampling of graphitic schist outcrops in all four licenses 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 continue 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 as a result of 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 if the steelmaking industry activity does not increase (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 largest increase in graphite use in the near future owing to growth in portable electronics and electric vehicles. 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 from 8% to 10% by 2017. 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 (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) is increasing and continued growth is expected. In the United States, the demand for graphite for pencils has almost disappeared; most pencil “leads” now are imported directly from China. These uses, 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]

		2011	2012	2013	2014	2015
United States:						
Natural:						
Exports:						
Quantity	metric tons	8,750 r	7,980 r	10,000 r	12,200 r	11,600
Value	thousands	$17,200 r	$19,100 r	$18,300 r	$19,300 r	$21,700
Imports for consumption:						
Quantity	metric tons	71,800	56,700	61,300	69,600 r	46,700
Value	thousands	$81,300	$68,400	$70,500	$72,300	$58,600
Apparent consumption:[2]						
Quantity	metric tons	63,000 r	48,700 r	51,300 r	57,400 r	35,100
Value	thousands	$64,200 r	$49,300 r	$52,200 r	$52,900 r	$36,900
Synthetic:						
Production:						
Quantity	metric tons	149,000	141,000	129,000	135,000	119,000
Value	thousands	$1,090,000	$946,000	$976,000	$939,000	$816,000
Exports:						
Quantity	metric tons	54,000 r	48,900 r	29,700 r	32,500 r	32,000
Value	thousands	$180,000 r	$171,000 r	$210,000 r	$221,000 r	$177,000
Imports for consumption:						
Quantity	metric tons	79,700	122,000	59,100	60,700	80,600
Value	thousands	$176,000	$191,000	$130,000	$135,000 r	$128,000
Apparent consumption:[2]						
Quantity	metric tons	174,000 r	214,000 r	158,000 r	163,000 r	167,000
Value	thousands	$1,080,000 r	$966,000 r	$895,000 r	$852,000 r	$767,000
World production, natural[e]	metric tons	1,180,000	1,210,000	1,150,000	1,160,000	1,160,000

[e]Estimated. [r]Revised.

[1]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)
2014:				
Brake lining	396	$1,540	W	W
Carbon products[3]	394	1,150	545	W
Foundries[4]	W	W	W	W
Lubricants[5]	908	4,120	W	W
Powdered metals	315 r	W	--	--
Refractories	19,000	20,500	W	$11,400
Rubber	W	W	374	1,280
Other[6]	6,560	13,700	W	W
Total	27,600	42,500	16,800	60,200
2015:				
Brake lining	1,010	W	W	W
Carbon products[3]	371	1,190	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

[r]Revised. W Withheld to avoid disclosing company proprietary data; included in “Total.” -- Zero.
[1]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)
2014:		
Electrodes	81,500	$463,000
Unmachined graphite shapes	6,190	93,200
Other[2]	46,900	382,000
Total	135,000	939,000
2015:		
Electrodes	86,600	303,000
Unmachined graphite shapes	12,900	85,300
Other[2]	19,300	428,000
Total	119,000	816,000

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Includes anodes, cloth and fibers, 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	2014	2015
Crystalline large, 94% to 97% carbon, +80 mesh	1,350–1,400	1,400–1,500
Crystalline large, 90% carbon, +80 mesh	1,150–1,200	1,150–1,250
Crystalline medium, 94% to 97% carbon, +100-80 mesh	1,100–1,200	1,200–1,300
Crystalline medium, 90% carbon, +100-80 mesh	950–1,000	950–1,050
Crystalline medium, 85% to 87% carbon, +100-80 mesh	700–800	700–800
Crystalline fine, 94% to 97% carbon, -100 mesh	1,000–1,050	1,000–1,100
Crystalline fine, 90% carbon, -100 mesh	750–800	750–800
Amorphous powder, 80% to 85% carbon	430–480	430–480
Synthetic fine, 97% to 98% carbon[2]	950–1450	950–1450
Synthetic fine, 98% to 99% carbon[2]	1000–1500	1000–1500

[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. 567, December 2014, p. 59; no. 578, December 2015, p. 67.

TABLE 5

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

Country	Natural[3]		Synthetic[4]		Total	
	Quantity (metric tons)	Value[5] (thousands)	Quantity (metric tons)	Value[5] (thousands)	Quantity (metric tons)	Value[5] (thousands)
2014:						
Canada	6,780 r	$5,960 r	3,880 r	$14,600 r	10,700 r	$20,600 r
China	366 r	1,600 r	2,420	23,800	2,790 r	25,400 r
France	149	262	4,670 r	21,700 r	4,820 r	22,000 r
Germany	210	416	1,000 r	7,240	1,210 r	7,660 r
Hong Kong	19	68	10	1,110	29	1,180
Italy	31	260	217	1,200 r	249	1,460 r
Japan	959	2,810	896	5,620	1,860	8,430
Korea, Republic of	53	225 r	1,290	86,400	1,340	86,600
Mexico	1,260 r	2,060 r	6,120 r	10,800 r	7,380 r	12,900 r
Netherlands	5	17	410	1,330	414	1,350
Taiwan	47 r	220 r	509	5,060	555 r	5,280 r
United Kingdom	197	208	1,220	2,250 r	1,420	2,460 r
Other	2,090 r	5,220 r	9,840 r	40,300 r	11,900 r	45,500 r
Total	12,200 r	19,300 r	32,500 r	221,000 r	44,600 r	241,000 r
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

[r]Revised.

[1]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[1]

Country	Crystalline flake and flake dust Quantity (metric tons)	Crystalline flake and flake dust Value[2] (thousands)	Lump and chippy dust Quantity (metric tons)	Lump and chippy dust Value[2] (thousands)	Other natural crude; high-purity; expandable Quantity (metric tons)	Other natural crude; high-purity; expandable Value[2] (thousands)	Amorphous Quantity (metric tons)	Amorphous Value[2] (thousands)	Total Quantity (metric tons)	Total Value[2] (thousands)
2014:										
Austria	7	$14	--	--	--	--	--	--	7	$14
Brazil	--	--	--	--	4,270	$8,720	--	--	4,270	8,720
Canada	11,100	16,300	--	--	--	--	--	--	11,100	16,300
China	23,900	28,600	--	--	--	--	--	--	23,900	28,600
Germany	--	--	--	--	212	681	--	--	212	681
India	--	--	--	--	1	6	--	--	1	6
Japan	--	--	--	--	6,160 r	7,280 r	--	--	6,160 r	7,280 r
Madagascar	1,290	1,270	--	--	--	--	--	--	1,290	1,270
Mexico	--	--	--	--	--	--	22,000	$7,920	22,000	7,920
Sri Lanka	--	--	549	$1,030	--	--	--	--	549	1,030
United Kingdom	--	--	--	--	18	158	--	--	18	158
Other	72 r	111 r	--	--	58 r	207 r	--	--	130	318
Total	36,300	46,300 r	549	1,030	10,700 r	17,100	22,000	7,920	69,600 r	72,300
2015:										
Brazil	4,690	9,940	--	--	--	--	--	--	4,690	9,940
Canada	7,620	11,100	--	--	--	--	--	--	7,620	11,100
China	17,700	24,300	--	--	--	--	--	--	17,700	24,300
Czech Republic	--	--	--	--	20	83	--	--	20	83
France	--	--	--	--	36	39	--	--	36	39
Germany	--	--	--	--	103	1,040	--	--	103	1,040
Japan	--	--	--	--	713	4,070	--	--	713	4,070
Madagascar	1,830	1,650	--	--	--	--	--	--	1,830	1,650
Mexico	--	--	--	--	--	--	13,500	5,320	13,500	5,320
South Africa	--	--	--	--	33	78	--	--	33	78
Sri Lanka	--	--	480	861	--	--	--	--	480	861
United Kingdom	--	--	--	--	18	71	--	--	18	71
Other	--	--	--	--	3	69	--	--	3	69
Total	31,800	47,000	480	861	928	5,460	13,500	5,320	46,700	58,600

[r]Revised. -- Zero.
[1]Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Customs values.

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[1, 2]

Country	Quantity (metric tons)	Value[3] (thousands)
2014:		
Austria	2,390	$8,970
Canada	1,270	4,470
China	13,500 r	45,000 r
Germany	3,870	15,100
India	10,300 r	26,400 r
Italy	156	622
Japan	18,700	83,800
Mexico	12,300	37,400
Poland	1,440	6,550
Russia	11,900	26,400
Spain	6,140	23,000
Ukraine	538	1,420
United Kingdom	574	2,140
Venezuela	468	571
Other	492	2,930
Total	84,000 r	285,000 r
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

[r]Revised.
[1]Data are rounded to no more than three significant digits; may not add to shown.
[2]The applicable Harmonized Tariff Schedule of the United States (HTS) nomenclature is "Graphite electrodes, not exceeding 425 mm in diameter, of a kind used for furnaces," "Graphite electrodes, exceeding 425 mm in diameter, 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[1, 2]

Country	2014		2015	
	Quantity (metric tons)	Value[3] (thousands)	Quantity (metric tons)	Value[3] (thousands)
Belgium	84	$287	126	$671
Brazil	414	1,330	339	999
Canada	4,800	4,620	2,400	2,860
China	25,000	38,600	53,000	43,900
France	3,320	5,640	1,350	6,090
Germany	2,670	16,000 r	2,470	13,300
Hong Kong	2,540	731	729	724
India	2,330	4,350	1,840	2,380
Italy	133	1,540	89	1,050
Japan	3,890	25,900	3,860	25,100
Korea, Republic of	105	1,440	252	2,270
Malaysia	2,340	2,140	1,610	1,830
Mexico	8,490	14,600	6,400	7,910
Poland	641	1,670	2,070	5,100
Russia	4	15	177	119
South Africa	7	35	60	48
Spain	73	210	255	318
Switzerland	3,610	12,700	2,420	8,360
United Kingdom	142	1,610	631	2,520
Other	101	1,160 r	487	2,080
Total	60,700	135,000 r	80,600	128,000

[r]Revised.

[1]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 values.

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

TABLE 9

NATURAL GRAPHITE: ESTIMATED WORLD PRODUCTION, BY COUNTRY[1, 2]

(Metric tons)

Country[3]	2011	2012	2013	2014	2015
Austria	925 [4]	219 [4]	500	500	500
Brazil, marketable	105,188 [4]	88,110 [4]	91,908 [4]	80,000	80,000 [p]
Canada	25,000	24,000	20,000	30,000	30,000
China	800,000	820,000	750,000	780,000	780,000
India, run-of-mine[5]	150,000	160,000	170,000	170,000	170,000
Korea, North	30,000	30,000	30,000	30,000	30,000
Madagascar	3,573 [4]	2,885 [4]	4,300	5,000	5,000
Mexico, amorphous[6]	19,000	20,000	21,000	22,000	22,000
Norway, flake	7,789 [4]	6,992 [4]	6,000	8,000	8,000
Russia	14,000	14,000	14,000	15,000	15,000
Sri Lanka	3,500	3,600	3,700	4,000	4,000
Turkey, run-of-mine[7]	5,250 [4]	31,500 [4]	28,740 [4]	3,850 [4]	3,850
Ukraine	6,000	5,800	5,800	5,000	5,000
Zimbabwe	7,000	6,000	4,000	7,000	7,000
Total	1,180,000	1,210,000	1,150,000	1,160,000	1,160,000

[p]Preliminary.

[1]World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

[2]Includes data available through May 9, 2017.

[3]In addition to the countries listed, Uzbekistan may have produced graphite, but available information was inadequate to make reliable estimates of output.

[4]Reported figure.

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

[6]Figures based on U.S. import data from U.S. Census Bureau.

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