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GRAPHITE [ADVANCE RELEASE]

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Graphite

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Domestic survey data and tables were prepared by Mahbood Mahdavi, statistical assistant, and the world production tables were prepared by Lisa D. Miller,[1] international data coordinator.

In 2014, no domestic production of natural graphite was reported, but U.S. production of synthetic graphite was estimated to be 135,000 metric tons (t) valued at about $939 million. U.S. exports and imports of natural graphite were estimated to be 11,600 t and 64,200 t, respectively. U.S. exports and imports of synthetic graphite were estimated to be 32,000 t and 60,700 t, respectively. U.S. apparent consumption of natural and synthetic graphite was estimated to be 52,600 t and 163,000 t, respectively (table 1). World production of natural graphite was estimated to be 1.16 million metric tons (Mt).

This report includes information on U.S. trade and use of natural graphite and U.S. production, trade, and use of synthetic graphite. Trade data in this report are from the U.S. Census Bureau. All percentages in the report were calculated using unrounded data.

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 (Topf, 2012). 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 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. Flake graphite occurs as separate flakes that crystallized in metamorphic rock and high-quality flake can be four times the price of amorphous. 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, and Tanzania. 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 75% 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 2014, but 135,000 t of synthetic graphite with an estimated value of $939 million was produced and shipped (tables 1, 3). This was a 5% increase in quantity produced and a 4% 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).

[1]Deceased.

Exploration and Development

During 2014, 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).

In September 2014, Alabama Graphite Corp. acquired the mineral rights to more than 526 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 14.5 kilometers (9 miles) from an interstate highway and less than 1.5 kilometers (1 mile) from a major railroad (Alabama Graphite Corp., 2017a). During 2014, Alabama Graphite Corp. also explored 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 that the property has an indicated resource of 34.6 Mt grading 2.6% graphite and an inferred resource of 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 was exploring and developing the Graphite Creek Project, 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 Alaska. The Graphite Creek deposit consists of large-flake, high-grade graphite that was delineated through a 2013 drilling program and further studied during 2014. Graphite One reported that the project contained inferred resources of 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 known graphite deposits in the United States (Graphite One Resources Inc., undated).

Consumption

The USGS obtained the consumption data in this report through a survey of natural graphite companies 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 slightly to 52,600 t in 2014 from 52,100 t in 2013, whereas U.S. apparent consumption of synthetic graphite increased by 3% to 163,000 t in 2014 from 159,000 t in 2013 (table 1). Total U.S. graphite consumption, including natural and synthetic, increased slightly to 216,000 t in 2014 from 211,000 t in 2013.

U.S. consumption of natural graphite reported by end use decreased by 9% to 44,500 t in 2014 from 48,900 t in 2013 (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 10% in 2014 to 27,600 t from 30,700 t in 2013. Consumption of amorphous graphite decreased by 8% in 2014 to 16,800 t from 18,200 t in 2013. The major uses of graphite during 2014 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; high-strength composites; lubricants; pencils; powdered metals; refractories; rubber; and steelmaking. Brake linings and refractories, combined, accounted for 60% of all forms of natural graphite consumption. Foundries and lubricants accounted for another 6% of all forms of natural graphite consumption. The refractories industrial sector was the leading graphite consumer, accounting for 69% of crystalline flake graphite use in 2014. Automobile manufacturing and construction influenced steelmaking activity, which in turn influenced refractories demand. Battery applications only accounted for a little over 2% of natural graphite during 2014, a slight increase from that of 2013.

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 2014, 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 steel-casting 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 62% of natural graphite consumption in the United States in 2014. It was used mainly in batteries and refractories. Amorphous graphite accounted for about 38% of natural graphite consumption and was mainly used in brake linings, foundries, 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 a 76% share by quantity and a 94% 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 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 2014, graphite prices for most forms of natural crystalline graphite increased, with median yearend prices increasing between 3% and 14%. The prices of two categories of natural crystalline graphite decreased: crystalline medium (85% to 87% carbon, +100 to 80 mesh), the median yearend price of which decreased by 6% and crystalline fine (90% carbon, -100 mesh), the median yearend price of which decreased by 3% from those of 2013. Median yearend price for amorphous powder graphite decreased by 13% compared with that of 2013 (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 decreased by 16% to $1,510 per ton in 2014 from $1,800 per ton in 2013 (tables 1, 5). The average unit value of all U.S. natural graphite imports decreased slightly to $1,130 per ton in 2014 from $1,150 per ton in 2013 (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 4% to $6,860 per ton in 2014 from $7,150 per ton in 2013 (tables 1, 5). The average unit value of all U.S. synthetic graphite imports increased slightly to $2,220 per ton in 2014 from $2,190 per ton in 2013 (tables 1, 8).

Foreign Trade

Total graphite exports increased by 14% in tonnage to 43,700 t valued at $237 million in 2014 from 38,200 t valued at $224 million in 2013. Total graphite export tonnage was 27% natural graphite and 73% synthetic graphite (table 5). Total natural graphite imports increased by 5% in tonnage to 64,200 t in 2014 from 61,300 t in 2013, and the value increased by 3% to $72.3 million in 2014 from $70.5 million in 2013 (table 6). These increases in natural graphite imports resulted from an increase of 2,270 t in quantity and an increase of $1.03 million in the value of the “crystalline flake and flake dust” graphite category during 2014. 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 87% 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, and Madagascar were, in descending order of tonnage, the leading suppliers of crystalline flake and flake dust graphite. Total synthetic graphite imports increased by 3% in tonnage to 60,700 t in 2014 from 59,100 t in 2013, and the value increased by 4% to $134 million in 2014 from $130 million in 2013 (table 8). Principal import sources of synthetic graphite were, in descending order of tonnage, China, Mexico, Canada, Japan, Switzerland, and France, which combined, accounted for 81% of the tonnage and 76% of the value of total synthetic graphite imports.

World Review

World production of natural graphite increased slightly in 2014 to an estimated 1.16 Mt compared with 1.15 Mt in 2013. 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, and Mexico, in decreasing order of tonnage produced. These six countries accounted for 96% of world production (table 9).

Brazil.—In 2014, Brazil produced 80,000 t of marketable natural graphite. High-grade crystalline flake graphite projects were being developed in Brazil with at least four companies conducting graphite exploration and development (Paradigm Metals Ltd., 2014).

Canada.—In 2014, 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 2014, graphite mining companies in Canada were actively pursuing more than 60 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 (Moores and others, 2012, p. 12, 97–125; Scogings, 2015; Scogings and others, 2015; Syrett, 2015; Topf, 2012).

China.—Beginning in 2011 and continuing through 2014, 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 yearend 2014, 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 2 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).

Mozambique.—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 commission its graphite mine in the final quarter of 2015; 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).

Tanzania.—Discovery Africa Ltd. (Australia), through its Tanzania Graphite Project, discovered a very large high-grade flake graphite deposit in the 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 (TGC). The average grade of samples within the licenses was 15.3% TGC (Discovery Africa Ltd., 2014).

Outlook

Worldwide demand for natural and synthetic graphite is expected to continue to increase as global economic conditions improve. Demand is also expected to continue to increase as more nonhydrocarbon energy applications that use graphite are developed.

Global consumption of graphite has increased steadily during the past decade, driven by automotive and steel manufacturing sectors. In 2014, estimated global natural graphite production was almost 1.2 Mt, with an estimated value of $13 billion. Global consumption of natural and synthetic graphite has been projected to increase at a rate of 5.8% per year during the next few years. Steelmaking and other types of metallurgical activity, which are important uses 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, 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 (Desjardins, 2012; Freedonia Group, Inc., The, 2014).

Fuel cells have the potential to use as much graphite as all other uses of graphite combined. Proton exchange membrane technology, which requires large amounts of graphite, is the most likely fuel-cell technology to be developed for use in lightweight vehicles, buildings, and smaller devices (Desjardins, 2012).

Fuel cells are a potential high-growth, large-volume graphite (natural and synthetic) end use but are currently a very small part of consumption. High volumes of graphite are not expected to be consumed in fuel cells for many years but may be used in the longer term. In general, the anticipated need to double present graphite supplies to produce value-added graphite products for new energy applications has triggered reopening of idled graphite mines and development of new graphite resources globally (O'Driscoll, 2010).

Most modern electronic devices use lithium-ion batteries, which contain high-purity, high-quality spherical or synthetic graphite as the anode material. Electric vehicles use lithium-ion batteries that contain significant quantities of graphite. The average fully electric vehicle requires about 50 kilograms of graphite; the average hybrid vehicle, around 10 kilograms; and an electric bicycle, about 1 kilogram. Laptop computers and smartphones use proportionally smaller amounts, with the average smartphone battery containing about 15 grams of graphite (Desjardins, 2012; Industrial Minerals, 2013).

Increased global consumption of graphite used in batteries is expected to be divided between two main types—alkaline and lithium-ion batteries. Synthetic and natural graphite are used in these batteries. In alkaline batteries, graphite is the conductive material in the cathode. Until recently, synthetic graphite was predominantly used in these batteries. With the advent of new purification techniques and more efficient processing methods, it has become possible to improve the conductivity of most natural graphite to the point where it can be used in batteries. The decision of whether to use synthetic or natural graphite will be based on performance and price. The growth of the lithium-ion battery market could have a greater effect on the graphite market as the demand for mobile energy storage systems rises.

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. About 3 million electric vehicles are expected to be in use by 2017. The increase in manufacture and sales of hybrid and electric vehicles is likely to increase demand for high-purity graphite in fuel-cell and battery applications from 2014 onward, with fully electric vehicles expected to have the most significant impact. 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 (Moores and others, 2012, p. 12–13).

Nuclear power also has the potential to use very large quantities of graphite with high-temperature gas-cooled pebble-bed technology. A 1-gigawatt pebble-bed reactor needs 3,000 t of graphite to start up and up to 1,000 t of graphite to operate on an annual basis. China is now testing and building pebble-bed reactors, with a goal to exponentially expand nuclear power in China (Desjardins, 2012).

During the past 3 years, the Government of China has restricted natural graphite exports in order to protect its own domestic industries. China recently imposed a production cap on amorphous graphite and measures discouraging raw graphite material exports in favor of exports of value-added products like spherical graphite for batteries. In order to accomplish this, the Government of China has instituted a 20% export duty on graphite, a 17% value-added tax, and an export licensing system (Moores and others, 2012, p. 12; Paradigm Metals Ltd., 2014; Topf, 2012). The loss of graphite production capacity as a result of actions taken by the Government of China for environmental concerns combined with these new taxes could have the effect of reducing the world graphite supply and increasing graphite prices (Razoumova, 2014).

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.

Graphene is not likely to increase the demand for graphite. It is expected to remain as a niche research and development product for the next 5 years unless important innovations are realized. Refractory end uses will remain the leading end market for natural graphite, accounting for a steady 38% of annual consumption (Moores and others, 2012, p. 12).

Brake linings and other friction materials are expected to steadily use more natural graphite as automobile production continues to increase and more replacement parts are required for the increasing number of vehicles. Natural graphite (amorphous and fine flake) is used as a substitute for asbestos in brake linings for vehicles heavier than cars and light trucks. Flexible graphite products, such as grafoil (a thin graphite cloth), are expected to be the fastest growing end use but are expected to use small quantities of natural graphite compared with major end uses, such as brake linings and refractories.

Specialized and high-tech applications require higher purity graphite and more consistent products. Higher purity graphite increasingly is being produced as thermal processing and acid leaching techniques continue. High-purity graphite has applications in advanced carbon graphite composites.

The markets for graphite used in rubber and plastics (including Styrofoam® coatings) are increasing and continued growth is expected. The U.S. 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.

A California-based company is developing a technology that turns carbon dioxide emissions into high-purity synthetic graphite. With the world's industrialized nations pledging to reduce their carbon dioxide emissions by 50% by 2050, this technology could become a promising new synthetic graphite source while helping industrialized nations reach their target emissions goals (Industrial Minerals, 2009).

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Graphite. Ch. in Mineral Facts and Problems, U.S. Bureau of Mines Bulletin 675, 1985

TABLE 1
SALIENT NATURAL AND SYNTHETIC GRAPHITE STATISTICS[1]

		2010	2011	2012	2013	2014
United States:						
Natural:						
Exports:						
Quantity	metric tons	5,600	6,430 r	6,280 r	9,180 r	11,600
Value	thousands	$15,200	$15,000 r	$17,300 r	$16,600 r	$17,600
Imports for consumption:						
Quantity	metric tons	65,400	71,800	56,700	61,300	64,200
Value	thousands	$52,100	$81,300	$68,400	$70,500	$72,300
Apparent consumption:[2]						
Quantity	metric tons	59,800	65,400 r	50,400	52,100 r	52,600
Value	thousands	$37,000 r	$66,300 r	$51,100 r	$53,900 r	$54,700
Synthetic:						
Production:						
Quantity	metric tons	134,000	149,000	141,000	129,000	135,000
Value	thousands	$1,070,000	$1,090,000	$946,000	$976,000	$939,000
Exports:						
Quantity	metric tons	40,000	53,500 r	48,600	29,000	32,000
Value	thousands	$136,000	$179,000 r	$170,000	$207,000	$220,000
Imports for consumption:						
Quantity	metric tons	43,900 r	79,700	122,000	59,100	60,700
Value	thousands	$113,000 r	$176,000	$191,000	$130,000	$134,000
Apparent consumption:[2]						
Quantity	metric tons	138,000	175,000 r	214,000	159,000	163,000
Value	thousands	$1,050,000	$1,080,000	$967,000	$898,000 r	$854,000
World production, natural[e]	metric tons	1,040,000 r	1,180,000 r	1,210,000 r	1,150,000 r	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		Amorphous[2]	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
2013:				
Brake lining	396	$1,540	W	W
Carbon products[3]	337	1,090	583	W
Foundries[4]	W	420	1,140	W
Lubricants[5]	699	2,740	W	W
Powdered metals	339	(6)	--	--
Refractories	19,400 r	21,300 r	W	$11,600 r
Rubber	W	154	W	W
Other[7]	9,300	16,000 r	W	W
Total	30,700 r	44,700 r	18,200 r	60,200 r
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	337	W	--	--
Refractories	19,000	20,500	W	11,400
Rubber	W	W	374	1,280
Other[7]	6,560	13,700	W	W
Total	27,600	42,500	16,800	60,200

[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]Withheld to avoid disclosing company proprietary data; included in "Other."

[7]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)
2013:		
Cloth and fibers (low modulus)	W	W
Electrodes	81,500	$463,000
Unmachined graphite shapes	6,140	73,500
Other[2]	40,900	439,000
Total	129,000	976,000
2014:		
Cloth and fibers (low modulus)	W	W
Electrodes	81,500	463,000
Unmachined graphite shapes	6,190	93,200
Other[2]	46,900	382,000
Total	135,000	939,000

W Withheld to avoid disclosing company proprietary data; included in "Other."

[1]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	2013	2014
Crystalline large, 94% to 97% carbon, +80 mesh	1,250–1,300	1,350–1,400
Crystalline large, 90% carbon, +80 mesh	1,100–1,150	1,150–1,200
Crystalline medium, 94% to 97% carbon, +100–80 mesh	1,050–1,150	1,100–1,200
Crystalline medium, 90% carbon, +100–80 mesh	900–1,000	950–1,000
Crystalline medium, 85% to 87% carbon, +100–80 mesh	700–900	700–800
Crystalline fine, 94% to 97% carbon, -100 mesh	850–950	1,000–1,050
Crystalline fine, 90% carbon, -100 mesh	750–850	750–800
Amorphous powder, 80% to 85% carbon	500–550	430–480
Synthetic 99.95% carbon[2]	7,000–20,000	NA

NA Not available.

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

[2]Swiss border.

Sources: Industrial Minerals, no. 555, December 2013, p. 53; no. 567, December 2014, p. 59.

TABLE 5

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

Country	Natural[3] Quantity (metric tons)	Natural[3] Value[5] (thousands)	Synthetic[4] Quantity (metric tons)	Synthetic[4] Value[5] (thousands)	Total Quantity (metric tons)	Total Value[5] (thousands)
2013:						
Canada	3,200 r	$2,650 r	2,960	$10,600	6,160 r	$13,300
China	251	862	2,350	19,200	2,600	20,000
France	17	66	2,870	16,300 r	2,890	16,400
Germany	320	579	1,230	6,740 r	1,550	7,320 r
Hong Kong	15	64	175 r	1,140 r	190 r	1,200 r
Italy	38	346	408	1,580	446	1,930
Japan	1,000	2,970	859	7,990	1,860	11,000
Korea, Republic of	102	430	2,420	100,000	2,530	101,000
Mexico	1,290 r	2,430 r	6,070	9,410	7,350	11,800
Netherlands	6	40	326	509	333 r	549
Taiwan	61	218	796 r	4,710 r	857 r	4,930 r
United Kingdom	39	135	1,360 r	2,490 r	1,400	2,630
Other	2,850 r	5,730 r	7,190	26,200 r	9,990 r	32,000
Total	9,180 r	16,500	29,000	207,000	38,100 r	224,000
2014:						
Canada	6,360	5,160	3,710	13,700	10,100	18,900
China	292	983	2,420	23,800	2,710	24,700
France	149	262	4,630	21,600	4,780	21,900
Germany	210	416	988	7,240	1,200	7,650
Hong Kong	19	68	10	1,110	29	1,180
Italy	31	260	217	1,170	249	1,430
Japan	959	2,810	896	5,620	1,860	8,430
Korea, Republic of	53	221	1,290	86,400	1,340	86,600
Mexico	1,230	2,000	5,910	10,500	7,140	12,500
Netherlands	5	17	410	1,330	414	1,350
Taiwan	46	209	509	5,060	554	5,270
United Kingdom	197	208	1,220	2,230	1,420	2,440
Other	2,070	4,940	9,830	40,000	11,900	44,900
Total	11,600	17,600	32,000	220,000	43,700	237,000

[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]Free alongside ship value.

Source: U.S. Census Bureau.

TABLE 6

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

	Crystalline flake and flake dust		Lump and chippy dust		Other natural crude, high-purity, expandable		Amorphous		Total	
Country	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)
2013:										
Austria	--	--	--	--	16	$44	--	--	16	$44
Brazil	--	--	--	--	4,490	9,900	--	--	4,490	9,900
Canada	10,500	$14,300	--	--	--	--	--	--	10,500	14,300
China	20,500	27,800	--	--	--	--	--	--	20,500	27,800
Germany	--	--	--	--	173	959	--	--	173	959
India	--	--	--	--	(3)	17	--	--	(3)	17
Japan	--	--	--	--	747	5,100	--	--	747	5,100
Madagascar	2,450	2,450	--	--	--	--	--	--	2,450	2,450
Mexico	--	--	--	--	--	--	21,200	$7,940	21,200	7,940
Sri Lanka	--	--	524	$901	--	--	--	--	524	901
United Kingdom	--	--	--	--	38	256	--	--	38	256
Other	614	648	--	--	102	154	--	--	716	802
Total	34,000	45,200	524	901	5,560	16,400	21,200	7,940	61,300	70,500
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	--	--	--	--	766	7,260	--	--	766	7,260
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	66	86	--	--	64	232	--	--	130	318
Total	36,300	46,200	549	1,030	5,330	17,100	22,000	7,920	64,200	72,300

-- Zero.

[1]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[1, 2]

Country	Quantity (metric tons)	Value[3] (thousands)
2013:		
Austria	157	$625
Canada	11,800	52,200 r
China	8,530 r	29,900 r
Germany	2,550 r	12,200 r
India	2,030 r	7,550 r
Japan	14,100 r	70,400 r
Mexico	8,550	25,900
Poland	1,090	5,150
Russia	348 r	909 r
South Africa	14	56
Ukraine	468	1,340
United Kingdom	385 r	1,520 r
Other	1,240 r	5,730 r
Total	51,300 r	213,000 r
2014:		
Austria	2,390	8,970
Canada	1,270	4,470
China	13,300	43,900
Germany	3,870	15,100
India	9,890	25,300
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	83,400	282,000

[r]Revised.
[1]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, 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 [1, 2]

Country	2013 Quantity (metric tons)	2013 Value[3] (thousands)	2014 Quantity (metric tons)	2014 Value[3] (thousands)
Belgium	83	$303	84	$287
Brazil	178	573	414	1,330
Canada	3,890	9,450	4,800	4,620
China	30,300	37,600	25,000	38,600
France	1,780	5,700	3,320	5,640
Germany	2,670	11,900	2,670	15,900
Hong Kong	1,080	405	2,540	731
India	4,370	8,420	2,330	4,350
Indonesia	54	151	--	--
Italy	60	780	133	1,540
Japan	4,440	25,400	3,890	25,900
Korea, Republic of	30	570	105	1,440
Malaysia	16	195	2,340	2,140
Mexico	5,110	9,050	8,490	14,600
Poland	(4)	2	641	1,670
Russia	78	74	4	15
South Africa	196	987	7	35
Spain	(4)	8	73	210
Switzerland	4,230	14,200	3,610	12,700
United Kingdom	538	2,770	142	1,610
Other	50	988	101	1,150
Total	59,100	130,000	60,700	134,000

-- Zero.

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

[2]Synthetic graphite data is 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.

[4]Less than ½ unit.

Source: U.S. Census Bureau.

TABLE 9

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

(Metric tons)

Country[3]	2010	2011	2012	2013	2014
Austria	420 [4]	925 [4]	219 [4]	500	500
Brazil, marketable	92,364 [4]	105,188 [4]	88,110 [r, 4]	91,908 [r, 4]	80,000
Canada	20,000	25,000	24,000	20,000	30,000
China	700,000	800,000	820,000	750,000	780,000
India, run-of-mine[5]	140,000	150,000	160,000	170,000	170,000
Korea, North	30,000	30,000	30,000	30,000	30,000
Korea, Republic of	34	--	--	--	--
Madagascar	3,783 [4, 6]	3,573 [4, 6]	2,885 [4, 6]	4,300	5,000
Mexico, amorphous[4, 6, 7]	11,458 [r]	18,967 [r]	19,730 [r]	21,163 [r]	22,018
Norway, flake	6,270	7,789 [4]	6,992 [4]	6,000 [r]	8,000
Romania	7,000	--	--	--	--
Russia	14,000	14,000	14,000	14,000	15,000
Sri Lanka	3,437 [4]	3,500	3,600	3,700	4,000
Turkey, run-of-mine[4, 8]	--	5,250 [r]	31,500 [r]	28,740 [r]	3,850
Ukraine	6,000	6,000	5,800	5,800	5,000
Zimbabwe	4,000	7,000	6,000	4,000	7,000
Total	1,040,000 [r]	1,180,000	1,210,000 [r]	1,150,000 [r]	1,160,000

[r]Revised. -- Zero.

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

[2]Includes data available through May 4, 2017.

[3]In addition to the countries listed, Uzbekistan is thought to produce graphite, but available information is inadequate to make reliable estimates of output.

[4]Reported figure.

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

[6]Reported exports.

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

[8]Turkish marketable production averages approximately 5% of run-of-mine production. Almost all is for domestic consumption.