



# 2013 Minerals Yearbook

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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, international data coordinator.**

In 2013, no domestic production of natural graphite was reported, but U.S. production of synthetic graphite was estimated to be 129,000 metric tons (t) valued at about \$976 billion. U.S. exports and imports of natural graphite were estimated to be 9,140 t and 61,300 t, respectively. U.S. exports and imports of synthetic graphite were estimated to be 29,000 t and 59,100 t, respectively. U.S. apparent consumption of natural and synthetic graphite was estimated to be 52,200 t and 159,000 t, respectively (table 1). World production of natural graphite was estimated to be 1.11 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 computed 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 1-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 deposits of amorphous graphite are found in China, Europe, 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 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, and Madagascar. 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 Mexico, the Republic of Korea, 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 reported mined in the United States in 2013, but 129,000 t of synthetic graphite with an estimated value of \$976 million was produced and shipped (tables 1, 3). This was a 9% decrease in quantity produced and a 3% increase in value compared with that of the previous year.

The first process 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, 2012).

## Exploration and Development

During 2013, three Canadian companies were exploring for graphite and developing graphite projects in the United States. Alabama Graphite Corp. was developing the Coosa Graphite Project in Alabama, Graphite One Resources Inc. was developing the Graphite Creek project in Alaska, and National Graphite Corp. was developing the Chedic Graphite Project in Nevada (Alabama Graphite Corp., undated; Bloomberg Business, 2013; Graphite One Resources Inc., undated).

Alabama Graphite's Coosa Graphite Project was in Coosa County, AL, in an area that was a significant producer of high-grade crystal flake graphite from the late 1800s through the 1950s. 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., undated).

Graphite One Resources' Graphite Creek Project was developing a massive, near-surface deposit, which included 129 mineral claims in a known graphite mineralization region of 6,799 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. 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). These inferred resources indicate that Graphite Creek may be the largest and highest grade of all known graphite deposits in the United States (Graphite One Resources Inc., undated).

National Graphite's Chedic Graphite Project near Carson City, NV, consisted of 20 mineral lode claims within 161 hectares. National Graphite reported strong assay results with the potential to produce more than 1 Mt of high-quality graphite. In 2013, National Graphite submitted an application to perform a drilling study, but in December 2013, the company announced that, because of delays encountered in its application to drill, it cancelled the drill program and abandoned the project (Bloomberg Business, 2013; EDGAR® Online, 2014).

## 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 by 4% to 52,200 t in 2013 from 50,400 t in 2012 (table 1), whereas U.S. apparent consumption of synthetic graphite decreased by 26% to 159,000 t in 2013 from 214,000 t in 2012 (table 1). Total U.S. graphite consumption, combined natural and synthetic, decreased by 20% to 211,000 t in 2013 from 265,000 t in 2012.

U.S. consumption of natural graphite reported by end use decreased slightly to 50,900 t in 2013 from 51,000 t in 2012 (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 excludes unreported changes in company stocks and therefore differs from reported consumption in table 2. Reported consumption of crystalline graphite increased slightly in 2013 to 34,100 t from 33,800 t in 2012. Consumption of amorphous graphite decreased slightly in 2013 to 16,800 t from 17,100 t in 2012. The major uses of graphite during 2013 were batteries; brakes; 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 5% of all forms of natural graphite consumption. The refractories industrial sector was the leading graphite consumer, accounting for 67% of crystalline flake graphite and 56% of all natural graphite in 2013. Automobile manufacturing and construction drove steelmaking, which, in turn, drove refractories demand. Battery applications accounted for about 2% of natural graphite during 2013, about the same as that of 2012.

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, driven by the consumption of electric and hybrid vehicles and portable electronic devices, such as mobile telephones, smartphones, and tablets (Moores and others, 2012, p. 11).

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 in 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 dramatically changes 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 67% of natural graphite usage in the United States in 2013. It was consumed mainly in batteries and refractories. Amorphous graphite was mainly used in brake linings, foundries, refractories, steelmaking, and other applications where additions of graphite improve the process or the end product. 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 major share of the graphite market. 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.” 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 better heat conductivity than copper, and has 20% more flexibility without any damage (Desjardins, 2012).

## Prices

During 2013, graphite prices for all forms of natural crystalline graphite decreased, with median yearend prices decreasing between 10% and 22%. Median yearend prices for amorphous powder graphite decreased by 25% compared with those of 2012. Median yearend prices for synthetic graphite remained the same as those of 2012 (table 4).

Prices for crystalline and crystalline flake graphite concentrates ranged from \$700 to \$1,300 per metric ton; prices for amorphous powder ranged from \$500 to \$550 per ton (table 4). The average unit value of all U.S. natural graphite exports decreased by 34% to \$1,810 per ton in 2013 from \$2,760 per ton in 2012. The average unit value of all U.S. natural graphite imports decreased by 5% to \$1,150 per ton in 2013 from \$1,210 per ton in 2012 (table 1). Ash and carbon content, crystal and flake size, and size distribution affect the price of graphite. The European port price of synthetic graphite in 2013 ranged from \$7,000 to \$20,000 per ton. The average unit value of U.S. synthetic graphite exports doubled to \$7,140 per ton in 2013 from \$3,510 per ton in 2012 (tables 1, 5). The average unit value of all U.S. synthetic graphite imports increased by 40% to \$2,200 per ton in 2013 from \$1,570 per ton in 2012 (table 1).

## Foreign Trade

Total graphite exports decreased by 30% in tonnage to 38,200 t valued at \$224 million in 2013 from 54,900 t valued at \$188 million in 2012. Total graphite export tonnage was 24% natural graphite and 76% synthetic graphite (table 5). Total natural graphite imports increased by 8% in tonnage to 61,300 t in 2013 from 56,700 t in 2012, and the value increased by 3% to \$70.5 million in 2013 from \$68.4 million in 2012 (table 6). This increase in quantity and value was due to an increase of 6,790 t in quantity and an increase of \$7.90 million in the value of the “crystalline flake and flake dust” graphite category during 2013. Principal import sources of natural graphite were, in descending order of tonnage, Mexico, China, Canada, Brazil, and Madagascar, which combined accounted for 96% of the tonnage and 89% of the value of total 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.

## World Review

World production of natural graphite decreased by 5% in 2013 to an estimated 1.11 Mt compared with 1.17 Mt in 2012. China maintained its position as the world’s leading graphite producer,

with an estimated 750,000 t or 67% of total global production. India ranked second with 170,000 t or 15% of the total, followed by Brazil, North Korea, Canada, and Russia, in decreasing order of tonnage produced. These six countries accounted for 97% of world production (table 8).

**Brazil.**—In 2013, Brazil produced 95,000 t of marketable natural graphite. Brazil was a leader in exploration and development projects for new natural graphite supplies with at least four companies conducting graphite exploration and development in that country.

**Canada.**—In 2013, Canada had two active mines with combined production of about 20,000 t of flake graphite: the Lac des Iles Flake Graphite Mine, owned by Timcal Ltd., in Quebec and the Black Crystal Flake Graphite Quarry, owned by Eagle Graphite Corp., in British Columbia. A third flake graphite mine, the Kearney Graphite Mine, owned by Ontario Graphite Ltd., in Ontario was expected to come online during the next few years. Companies in Canada were actively pursuing graphite exploration and development. In 2012 and continuing into 2013, 34 companies were conducting 65 graphite exploration and development projects in Canada. This exploration was primarily focused on properties in Ontario and Quebec, but there were also graphite exploration projects in British Columbia, Labrador, New Brunswick, Nova Scotia, and Saskatchewan (Moores and others, 2012, p. 12, 97–125; Topf, 2012).

**China.**—Beginning in 2011 and continuing into 2012 and 2013, the Government of China ordered the majority of amorphous graphite mines under its control in Hunan Province to be closed for environmental and resource protection. Amorphous graphite production declined, and flake graphite production remained stable until 2013, when the Government of China began closing and consolidating crystalline flake graphite mining in other Provinces, also for environmental and resource protection. 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 more modern equipment in order to control dust emissions (Lazenby, 2014; Moores, 2011). During 2013, these actions caused China’s production to decrease by 9%.

## Outlook

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

Global demand for graphite has grown by about 5% during the last decade, driven by automotive and steel manufacturing sectors (Desjardins, 2012). In 2013, the estimated global graphite market was 1.1 Mt, with an estimated value of \$12 billion. Global demand for natural and synthetic graphite has been projected to grow at a rate of 5.8% per year over the next few years. Future graphite demand is expected to increase

primarily because of three significant factors. Increases in manufactured goods shipments are expected to spur graphite consumption. Steelmaking and other types of metallurgical activity, which are important markets for graphite, are expected to increase over the next few years. The global graphite market is expected to increase owing to new technologically advanced applications, such as aerospace, fuel cells, graphene, lithium-ion batteries, pebble-bed nuclear reactors, and solar power (Freedonia Group, Inc., The, 2014). Most notable for graphite among these applications are fuel cells, lithium-ion batteries, and pebble-bed nuclear reactors (Desjardins, 2012).

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 applications (Desjardins, 2012).

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 amounts 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).

Increases in the number of electric vehicles have been predicted in the near future—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. 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 shutdown graphite mines and development of graphite resources globally (O’Driscoll, 2010).

Batteries are expected to be the fastest increasing end-use sector owing to growth in portable electronics that require larger, more powerful, and more graphite-intensive batteries. The increasing use of electric vehicle batteries is expected to have an effect on the graphite markets from 2014 onward, but fully electric vehicles are expected to have the most significant volume impact. The battery end-use sector is expected to increase its market share of graphite consumption from 8% to 10% by 2017. Production of spherical graphite feedstock material will need to increase to meet increased 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).

Increased global demand for 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.

Nuclear power also has the potential to use very large amounts 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 2 years, the Government of China has restricted natural graphite exports in order to protect its own domestic industries. This means that China will have some capacity to increase graphite flake production even with its recent production cap on amorphous graphite and its discouraging raw graphite material exports in favor of exports of value-added products like spherical graphite for batteries (Moore and others, 2012, p. 12; Topf, 2012).

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 produced by advanced refining technology in the next few years could increase profitability in the U.S. graphite industry.

Graphene is not likely to increase the volume demand for graphite markets. 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 consumption through 2016 (Moore and others, 2012, p. 12).

Brake linings and other friction materials are expected to steadily use more natural graphite as new 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 market but are expected to use small quantities of natural graphite compared to major end-use markets, 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; 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 was 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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TABLE 1  
SALIENT NATURAL AND SYNTHETIC GRAPHITE STATISTICS<sup>1</sup>

|                                        |             | 2009                 | 2010                   | 2011                   | 2012      | 2013      |
|----------------------------------------|-------------|----------------------|------------------------|------------------------|-----------|-----------|
| United States:                         |             |                      |                        |                        |           |           |
| Natural:                               |             |                      |                        |                        |           |           |
| Exports:                               |             |                      |                        |                        |           |           |
| Quantity                               | metric tons | 11,400               | 5,600                  | 6,280                  | 6,310     | 9,140     |
| Value                                  | thousands   | \$21,600             | \$15,200               | \$14,800               | \$17,400  | \$16,500  |
| Imports for consumption:               |             |                      |                        |                        |           |           |
| Quantity                               | metric tons | 33,100               | 65,400                 | 71,800                 | 56,700    | 61,300    |
| Value                                  | thousands   | \$29,700             | \$52,100               | \$81,300               | \$68,400  | \$70,500  |
| Apparent consumption: <sup>2</sup>     |             |                      |                        |                        |           |           |
| Quantity                               | metric tons | 21,700               | 59,800                 | 65,500                 | 50,400    | 52,200    |
| Value                                  | thousands   | \$8,050              | \$36,900               | \$66,500               | \$51,000  | \$54,000  |
| Synthetic:                             |             |                      |                        |                        |           |           |
| Production:                            |             |                      |                        |                        |           |           |
| Quantity                               | metric tons | 118,000              | 134,000                | 149,000                | 141,000   | 129,000   |
| Value                                  | thousands   | \$998,000            | \$1,070,000            | \$1,090,000            | \$946,000 | \$976,000 |
| Exports:                               |             |                      |                        |                        |           |           |
| Quantity                               | metric tons | 35,000               | 40,000                 | 53,900                 | 48,600    | 29,000    |
| Value                                  | thousands   | \$109,000            | \$136,000              | \$177,000              | \$170,000 | \$207,000 |
| Imports for consumption:               |             |                      |                        |                        |           |           |
| Quantity                               | metric tons | 33,800               | 44,000                 | 79,700                 | 122,000   | 59,100    |
| Value                                  | thousands   | \$79,400             | \$119,000              | \$176,000              | \$191,000 | \$130,000 |
| Apparent consumption: <sup>2</sup>     |             |                      |                        |                        |           |           |
| Quantity                               | metric tons | 116,000              | 138,000                | 174,000                | 214,000   | 159,000   |
| Value                                  | thousands   | \$969,000            | \$1,050,000            | \$1,080,000            | \$967,000 | \$899,000 |
| World production, Natural <sup>e</sup> | metric tons | 746,000 <sup>r</sup> | 1,030,000 <sup>r</sup> | 1,180,000 <sup>r</sup> | 1,170,000 | 1,110,000 |

<sup>r</sup>Revised. <sup>e</sup>Estimated.

<sup>1</sup>Data are rounded to no more than three significant digits.

<sup>2</sup>Domestic production plus imports minus exports.

TABLE 2  
U.S. CONSUMPTION OF NATURAL GRAPHITE, BY END USE<sup>1</sup>

| End use                      | Crystalline               |                      | Amorphous <sup>2</sup>    |                      |
|------------------------------|---------------------------|----------------------|---------------------------|----------------------|
|                              | Quantity<br>(metric tons) | Value<br>(thousands) | Quantity<br>(metric tons) | Value<br>(thousands) |
| 2012:                        |                           |                      |                           |                      |
| Brake lining                 | 396                       | \$1,540              | 2,280                     | W                    |
| Carbon products <sup>3</sup> | 286                       | 905                  | 424                       | W                    |
| Foundries <sup>4</sup>       | W                         | W                    | 1,130                     | W                    |
| Lubricants <sup>5</sup>      | 693                       | 2,730                | W                         | W                    |
| Powdered metals              | 340                       | W                    | --                        | --                   |
| Refractories                 | 22,400                    | 25,700               | W                         | \$9,920              |
| Rubber                       | W                         | 154                  | W                         | W                    |
| Other <sup>6</sup>           | 9,440                     | 16,400               | W                         | W                    |
| Total                        | 33,800                    | 49,300               | 17,100 <sup>†</sup>       | 58,700 <sup>†</sup>  |
| 2013:                        |                           |                      |                           |                      |
| Brake lining                 | 396                       | 1,540                | W                         | W                    |
| Carbon products <sup>3</sup> | 337                       | 1,090                | 583                       | W                    |
| Foundries <sup>4</sup>       | W                         | 420                  | 1,140                     | W                    |
| Lubricants <sup>5</sup>      | 699                       | 2,740                | W                         | W                    |
| Powdered metals              | 339                       | (7)                  | --                        | --                   |
| Refractories                 | 22,800                    | 25,200               | W                         | 9,930                |
| Rubber                       | W                         | 154                  | W                         | W                    |
| Other <sup>6</sup>           | 9,300                     | 17,400               | W                         | W                    |
| Total                        | 34,100                    | 48,600               | 16,800                    | 58,500               |

<sup>†</sup>Revised. W Withheld to avoid disclosing company proprietary data; included in "Total." -- Zero.

<sup>1</sup>Data are rounded to no more than three significant digits.

<sup>2</sup>Includes mixtures of natural and manufactured graphite.

<sup>3</sup>Includes bearings and carbon brushes.

<sup>4</sup>Includes foundries (other) and foundry facings.

<sup>5</sup>Includes ammunition packings.

<sup>6</sup>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.

<sup>7</sup>Withheld to avoid disclosing company proprietary data; included in "Other."

TABLE 3  
SHIPMENTS OF SYNTHETIC GRAPHITE BY U.S. COMPANIES, BY END USE<sup>1</sup>

| End use                        | Quantity<br>(metric tons) | Value<br>(thousands) |
|--------------------------------|---------------------------|----------------------|
| 2012:                          |                           |                      |
| Cloth and fibers (low modulus) | W                         | W                    |
| Electrodes                     | 90,900                    | \$511,000            |
| Unmachined graphite shapes     | 8,060                     | 83,600               |
| Other <sup>2</sup>             | 41,900                    | 352,000              |
| Total                          | 141,000                   | 946,000              |
| 2013:                          |                           |                      |
| Cloth and fibers (low modulus) | W                         | W                    |
| Electrodes                     | 81,500                    | 463,000              |
| Unmachined graphite shapes     | 6,140                     | 73,500               |
| Other <sup>2</sup>             | 40,900                    | 439,000              |
| Total                          | 129,000                   | 976,000              |

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

<sup>1</sup>Data are rounded to no more than three significant digits.

<sup>2</sup>Includes anodes, crucibles and vessels, electric motor brushes and machined shapes, graphite articles, high-modulus fibers, lubricants (alone/in greases), refractories, steelmaking carbon raisers, additives in metallurgy, and other powder data.

TABLE 4  
 REPRESENTATIVE YEAREND GRAPHITE PRICES<sup>1</sup>

(Dollars per metric ton)

| Type                                                | 2012         | 2013         |
|-----------------------------------------------------|--------------|--------------|
| Crystalline large, 94% to 97% carbon, +80 mesh      | 1,400–1,800  | 1,250–1,300  |
| Crystalline large, 90% carbon, +80 mesh             | 1,200–1,600  | 1,100–1,150  |
| Crystalline medium, 94% to 97% carbon, -100-80 mesh | 1,050–1,400  | 1,050–1,150  |
| Crystalline medium, 90% carbon, +100-80 mesh        | 950–1,200    | 900–1,000    |
| Crystalline medium, 85% to 87% carbon, +100-80 mesh | 900–1,150    | 700–900      |
| Crystalline fine, 94% to 97% carbon, -100 mesh      | 900–1,200    | 850–950      |
| Crystalline fine, 90% carbon, -100 mesh             | 850–1,050    | 750–850      |
| Amorphous powder, 80% to 85% carbon                 | 600–800      | 500–550      |
| Synthetic 99.95% carbon <sup>2</sup>                | 7,000–20,000 | 7,000–20,000 |

<sup>1</sup>Prices are cost, insurance, and freight main European port, unless otherwise specified.

<sup>2</sup>Swiss border.

Source: Industrial Minerals, no. 543, December 2012, p. 78; no. 552, September 2013, p. 85, no. 555, December 2013, p. 53.

TABLE 5  
U.S. EXPORTS OF NATURAL AND SYNTHETIC GRAPHITE, BY COUNTRY<sup>1,2</sup>

| Country            | Natural <sup>3</sup>      |                                   | Synthetic <sup>4</sup>    |                                   | Total                     |                                   |
|--------------------|---------------------------|-----------------------------------|---------------------------|-----------------------------------|---------------------------|-----------------------------------|
|                    | Quantity<br>(metric tons) | Value <sup>5</sup><br>(thousands) | Quantity<br>(metric tons) | Value <sup>5</sup><br>(thousands) | Quantity<br>(metric tons) | Value <sup>5</sup><br>(thousands) |
| 2012:              |                           |                                   |                           |                                   |                           |                                   |
| Canada             | 1,690                     | \$2,610                           | 4,830                     | \$13,800                          | 6,520                     | \$16,400                          |
| China              | 376                       | 986                               | 4,530                     | 15,900                            | 4,900                     | 16,800                            |
| France             | 7                         | 25                                | 2,110                     | 15,400                            | 2,110                     | 15,400                            |
| Germany            | 128                       | 299                               | 1,770                     | 7,570                             | 1,900                     | 7,870                             |
| Hong Kong          | 13                        | 67                                | 354                       | 1,050                             | 368                       | 1,110                             |
| Italy              | 87                        | 285                               | 542                       | 1,360                             | 629                       | 1,650                             |
| Japan              | 886                       | 2,490                             | 1,880                     | 11,200                            | 2,760                     | 13,700                            |
| Korea, Republic of | 89                        | 536                               | 6,510                     | 32,700                            | 6,600                     | 33,200                            |
| Mexico             | 1,340                     | 2,680                             | 9,180                     | 11,100                            | 10,500                    | 13,800                            |
| Netherlands        | 2                         | 30                                | 398                       | 1,390                             | 400                       | 1,420                             |
| Taiwan             | 127                       | 478                               | 1,050                     | 4,850                             | 1,180                     | 5,330                             |
| United Kingdom     | 90                        | 857                               | 1,390                     | 2,890                             | 1,480                     | 3,740                             |
| Other              | 1,470                     | 6,030                             | 14,000                    | 51,300                            | 15,500                    | 57,400                            |
| Total              | 6,310                     | 17,400                            | 48,600                    | 170,000                           | 54,900                    | 188,000                           |
| 2013:              |                           |                                   |                           |                                   |                           |                                   |
| Canada             | 3,180                     | 2,640                             | 2,960                     | 10,600                            | 6,130                     | 13,300                            |
| China              | 251                       | 862                               | 2,350                     | 19,200                            | 2,600                     | 20,000                            |
| France             | 17                        | 66                                | 2,870                     | 16,400                            | 2,890                     | 16,400                            |
| Germany            | 320                       | 579                               | 1,230                     | 6,730                             | 1,550                     | 7,310                             |
| Hong Kong          | 15                        | 64                                | 172                       | 1,120                             | 187                       | 1,180                             |
| 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             | 1,280                     | 2,420                             | 6,070                     | 9,410                             | 7,350                     | 11,800                            |
| Netherlands        | 6                         | 40                                | 326                       | 509                               | 332                       | 549                               |
| Taiwan             | 61                        | 218                               | 836                       | 4,700                             | 897                       | 4,920                             |
| United Kingdom     | 39                        | 135                               | 1,370                     | 2,500                             | 1,400                     | 2,630                             |
| Other              | 2,830                     | 5,740                             | 7,190                     | 26,300                            | 10,000                    | 32,000                            |
| Total              | 9,140                     | 16,500                            | 29,000                    | 207,000                           | 38,200                    | 224,000                           |

<sup>1</sup>Data are rounded to no more than three significant digits; may not add to totals shown.

<sup>2</sup>Numerous countries for which data were reported have been combined in "Other."

<sup>3</sup>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.

<sup>4</sup>Includes data from applicable HTS nomenclatures "Artificial graphite" and "Colloidal or semicolloidal graphite," codes 3801.10.0000 and 3801.20.0000.

<sup>5</sup>Values are free alongside ship.

Source: U.S. Census Bureau.

TABLE 6  
U.S. IMPORTS FOR CONSUMPTION OF NATURAL GRAPHITE, BY COUNTRY<sup>1</sup>

| Country        | Crystalline flake and flake dust |                                | Lump and chippy dust   |                                | Other natural crude; high-purity; expandable |                                | Amorphous              |                                | Total                  |                                |
|----------------|----------------------------------|--------------------------------|------------------------|--------------------------------|----------------------------------------------|--------------------------------|------------------------|--------------------------------|------------------------|--------------------------------|
|                | Quantity (metric tons)           | Value <sup>2</sup> (thousands) | Quantity (metric tons) | Value <sup>2</sup> (thousands) | Quantity (metric tons)                       | Value <sup>2</sup> (thousands) | Quantity (metric tons) | Value <sup>2</sup> (thousands) | Quantity (metric tons) | Value <sup>2</sup> (thousands) |
| 2012:          |                                  |                                |                        |                                |                                              |                                |                        |                                |                        |                                |
| Austria        | --                               | --                             | --                     | \$25                           | 15                                           | --                             | --                     | --                             | 15                     | \$25                           |
| Brazil         | --                               | --                             | 3,380                  | 7,690                          | --                                           | --                             | --                     | --                             | 3,380                  | 7,690                          |
| Canada         | 12,000                           | \$17,800                       | --                     | --                             | --                                           | --                             | --                     | --                             | 12,000                 | 17,800                         |
| China          | 13,800                           | 17,800                         | 4,830                  | 9,960                          | --                                           | --                             | --                     | --                             | 18,600                 | 27,700                         |
| Germany        | --                               | --                             | 178                    | 912                            | --                                           | --                             | --                     | --                             | 178                    | 912                            |
| India          | --                               | --                             | (3)                    | 3                              | --                                           | --                             | --                     | --                             | (3)                    | 3                              |
| Japan          | --                               | --                             | 235                    | 4,100                          | 439                                          | \$25                           | --                     | --                             | 674                    | 4,120                          |
| Madagascar     | 1,450                            | 1,750                          | --                     | --                             | --                                           | --                             | 19,700                 | 6,820                          | 1,450                  | 1,750                          |
| Mexico         | --                               | --                             | --                     | --                             | --                                           | --                             | --                     | --                             | 19,700                 | 6,820                          |
| Sri Lanka      | --                               | --                             | 526                    | \$1,030                        | --                                           | --                             | --                     | --                             | 526                    | 1,030                          |
| United Kingdom | --                               | --                             | --                     | --                             | 92                                           | 438                            | --                     | --                             | 92                     | 438                            |
| Other          | 6                                | 12                             | --                     | 96                             | 25                                           | --                             | --                     | --                             | 31                     | 108                            |
| Total          | 27,300                           | 37,300                         | 526                    | 1,030                          | 8,750                                        | 23,200                         | 20,200                 | 6,840                          | 56,700                 | 68,400                         |
| 2013:          |                                  |                                |                        |                                |                                              |                                |                        |                                |                        |                                |
| Austria        | --                               | --                             | --                     | 44                             | 16                                           | --                             | --                     | --                             | 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 | --                               | --                             | --                     | 256                            | 38                                           | --                             | --                     | --                             | 38                     | 256                            |
| Other          | 614                              | 648                            | --                     | 154                            | 102                                          | --                             | --                     | --                             | 716                    | 802                            |
| Total          | 34,000                           | 45,200                         | 524                    | 901                            | 5,560                                        | 16,400                         | 21,200                 | 7,940                          | 61,300                 | 70,500                         |

-- Zero.

<sup>1</sup>Data are rounded to no more than three significant digits; may not add to totals shown.

<sup>2</sup>Customs values.

<sup>3</sup>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<sup>1, 2</sup>

| Country        | Quantity<br>(metric tons) | Value <sup>3</sup><br>(thousands) |
|----------------|---------------------------|-----------------------------------|
| 2012:          |                           |                                   |
| Austria        | 2,000                     | \$10,200                          |
| Canada         | 13,800                    | 72,600                            |
| China          | 18,100                    | 63,400                            |
| Germany        | 2,860                     | 21,600                            |
| India          | 13,200                    | 32,500                            |
| Japan          | 24,300                    | 141,000                           |
| Mexico         | 10,100                    | 33,100                            |
| Poland         | 956                       | 4,570                             |
| Russia         | 10,400                    | 31,600                            |
| South Africa   | 233                       | 860                               |
| Ukraine        | 1,420                     | 4,190                             |
| United Kingdom | 262                       | 1,130                             |
| Other          | 858                       | 5,860                             |
| Total          | 98,600                    | 423,000                           |
| 2013:          |                           |                                   |
| Austria        | 157                       | 625                               |
| Canada         | 11,800                    | 52,300                            |
| China          | 9,310                     | 32,000                            |
| Germany        | 2,760                     | 13,200                            |
| India          | 5,320                     | 15,500                            |
| Japan          | 14,200                    | 71,700                            |
| Mexico         | 8,550                     | 25,900                            |
| Poland         | 1,090                     | 5,150                             |
| Russia         | 8,140                     | 23,800                            |
| South Africa   | 14                        | 56                                |
| Ukraine        | 468                       | 1,340                             |
| United Kingdom | 388                       | 1,680                             |
| Other          | 1,340                     | 7,700                             |
| Total          | 63,600                    | 251,000                           |

<sup>1</sup>Data are rounded to no more than three significant digits; may not add to totals shown.

<sup>2</sup>The applicable Harmonized Tariff Schedule of the United States (HTS) nomenclature is "Electric furnace electrodes," code 8545.11.0000.

<sup>3</sup>Customs values.

Source: U.S. Census Bureau.

TABLE 8  
NATURAL GRAPHITE: ESTIMATED WORLD PRODUCTION, BY COUNTRY<sup>1,2</sup>

(Metric tons)

| Country <sup>3</sup>             | 2009                 | 2010                   | 2011                   | 2012                   | 2013                |
|----------------------------------|----------------------|------------------------|------------------------|------------------------|---------------------|
| Austria                          | 750 <sup>4</sup>     | 420 <sup>4</sup>       | 925 <sup>4</sup>       | 219 <sup>r,4</sup>     | 500                 |
| Brazil, marketable               | 59,425 <sup>4</sup>  | 92,364 <sup>4</sup>    | 105,188 <sup>4</sup>   | 88,100 <sup>r,4</sup>  | 95,000 <sup>p</sup> |
| Canada                           | 15,000               | 20,000                 | 25,000                 | 24,000 <sup>r</sup>    | 20,000              |
| China                            | 450,000              | 700,000                | 800,000                | 820,000 <sup>r</sup>   | 750,000             |
| India, run-of-mine <sup>5</sup>  | 130,000              | 140,000                | 150,000                | 160,000                | 170,000             |
| Korea, North                     | 30,000               | 30,000                 | 30,000                 | 30,000                 | 30,000              |
| Korea, Republic of               | 48 <sup>r</sup>      | 34 <sup>r</sup>        | --                     | --                     | --                  |
| Madagascar                       | 3,437 <sup>4,6</sup> | 3,783 <sup>4,6</sup>   | 3,573 <sup>4,6</sup>   | 2,885 <sup>r,4,6</sup> | 4,300               |
| Mexico, amorphous <sup>4</sup>   | 5,105 <sup>r</sup>   | 6,628                  | 7,348                  | 7,520 <sup>r</sup>     | 7,148               |
| Norway                           | 4,562 <sup>4</sup>   | 6,270                  | 7,789 <sup>r,4</sup>   | 6,992 <sup>r,4</sup>   | 1,500               |
| Romania                          | 20,000               | 7,000                  | --                     | --                     | --                  |
| Russia                           | 14,000               | 14,000                 | 14,000                 | 14,000                 | 14,000              |
| Sri Lanka                        | 3,171 <sup>4</sup>   | 3,437 <sup>4</sup>     | 3,500                  | 3,600                  | 3,700               |
| Turkey, run-of-mine <sup>7</sup> | 2,400 <sup>4</sup>   | -- <sup>4</sup>        | 17,265 <sup>r,4</sup>  | -- <sup>r</sup>        | 5,300               |
| Ukraine                          | 5,500                | 6,000                  | 6,000                  | 5,800 <sup>r</sup>     | 5,800               |
| Zimbabwe                         | 2,463 <sup>4</sup>   | 4,000 <sup>r</sup>     | 7,000 <sup>r</sup>     | 6,000                  | 4,000               |
| Total                            | 746,000 <sup>r</sup> | 1,030,000 <sup>r</sup> | 1,180,000 <sup>r</sup> | 1,170,000              | 1,110,000           |

<sup>p</sup>Preliminary. <sup>r</sup>Revised. -- Zero.

<sup>1</sup>World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

<sup>2</sup>Includes data available through May 6, 2014.

<sup>3</sup>In addition to the countries listed, Uzbekistan is thought to produce graphite, but information is inadequate to make reliable estimates of output.

<sup>4</sup>Reported figure.

<sup>5</sup>India's marketable production is 10% to 20% of run-of-mine production.

<sup>6</sup>Reported exports.

<sup>7</sup>Turkey's marketable production averages approximately 5% of run-of-mine production. Almost all is for domestic consumption.