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GRAPHITE [ADVANCE RELEASE]

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Graphite

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In 2021, no domestic production of natural graphite was reported, but U.S. production of synthetic graphite was 259,000 metric tons (t) valued at $1.16 billion. U.S. exports and imports of natural graphite were 8,670 t and 53,100 t, respectively. U.S. exports and imports of synthetic graphite were 32,500 t and 116,000 t, respectively. U.S. apparent consumption of natural and synthetic graphite was 44,400 t and 342,000 t, respectively. World production of natural graphite was estimated to be 1.13 million metric tons (Mt) (tables 1, 9).

Graphite is one of four forms of crystalline carbon; the others are carbon nanotubes, diamonds, and fullerenes. In graphite, the carbon atoms are arranged densely 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 gray to black in color, opaque, and usually has a metallic luster; sometimes it exhibits a dull earthy luster. Graphite occurs naturally in metamorphic rocks. It is a soft mineral with a Mohs hardness of 1 to 2, and it exhibits perfect basal (one-plane) cleavage. Graphite is flexible but not elastic, has a melting point of 3,927 degrees Celsius (°C), and is highly refractory. It has a low specific gravity. Graphite is the most electrically and thermally conductive of the nonmetals and is chemically inert. All these properties combined make both natural and synthetic graphite desirable for many industrial applications.

Natural graphite is classified into three types—amorphous, 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. Large amorphous graphite deposits are found in Europe, China, Mexico, and the United States. Crystalline flake graphite is less common and higher quality than amorphous graphite. Flake graphite occurs as separate flakes that crystallized in metamorphic rock and high-quality flake graphite can be four times the price of amorphous graphite. Good quality flakes can be processed into expandable graphite for many uses, such as flame retardants. The foremost deposits are found in Austria, Brazil, Canada, China, Germany, Madagascar, Mozambique, Tanzania, and in Alabama, Alaska, and New York in the United States. Vein or lump graphite is the rarest, most valuable, and highest quality type of natural graphite. It occurs in veins along intrusive contacts in solid lumps, and it is only commercially mined in Sri Lanka.

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

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

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 99.95% 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 natural graphite included carbon-bonded brick, castable ramming, and gunning mixtures. Carbon-magnesite brick had applications in high-temperature corrosive environments, such as iron blast furnaces, ladles, and steel furnaces. Carbon-alumina linings were used principally in continuous casting steel operations. Alumina- and magnesite-carbon brick require graphite with a particle size of 100 mesh and a purity of 95% to 99%.

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 2021, but 259,000 t of synthetic graphite with a value of $1.16 billion was produced and shipped (tables 1, 3). This was a 15% increase in quantity produced and a slight increase in value compared with that in 2020. This increase in quantity was due to large increases in the production of electric motor brushes and machined and unmachined graphite shapes.

Synthetic graphite electrodes used to conduct electricity to melt scrap iron and steel or direct-reduced iron in electric arc furnaces are made from petroleum coke mixed with coal tar pitch. The mixture is extruded and shaped, then baked to carbonize the pitch, and finally graphitized by heating it to temperatures approaching 3,000 °C to convert the carbon to graphite. Synthetic graphite powder is made by heating powdered petroleum coke above the temperature of graphitization (3,000 °C), sometimes with minor modifications (Kopeliovich, 2020).

During 2021, three companies were evaluating and developing natural graphite projects in the United States. Westwater Resources, Inc. (Centennial, CO) was developing the Bama Mine and Coosa graphite projects in Alabama; Graphite One Inc. (Vancouver, British Columbia, Canada) was developing the Graphite Creek project in Alaska; and South Star Battery Metals Corp. (Vancouver, British Columbia, Canada) was developing the Ceylon project in Alabama.

During 2021, Westwater Resources continued exploring, evaluating, and developing the Bama Mine project and the Coosa graphite project. The Bama Mine project and the Coosa project were within the Alabama Graphite Belt, high-quality graphite deposits from which significant quantities of graphite were produced from the late 1800s through the 1950s. The Bama Mine, the southernmost mine in the Alabama Graphite Belt, previously produced larger quantities and higher quality flake graphite than any other graphite mine in Alabama. The Bama Mine stopped production in the 1930s because a fire destroyed the mill. Widespread occurrence of weathered graphitic schist is found around the surface area of the mine (Westwater Resources, Inc., 2022).

Westwater Resources also continued to develop the Coosa project in Coosa County, AL, located in an area that was a significant producer of high-grade crystal flake graphite in the past. A preliminary economic assessment (PEA) was completed in 2015, which reported an indicated resource of 78.5 Mt grading 2.39% graphite and an inferred resource of 79.4 Mt grading 2.56% graphite (Alabama Graphite Corp., 2015). In 2021, Westwater Resources completed a definitive feasibility study for Phase 1 of the Coosa battery-grade processing plant in Alabama, which was expected to begin operations in 2023. At full processing capacity, the plant was expected to produce up to 15,800 metric tons per year (t/yr) of coated spherical graphite and 16,600 t/yr of purified natural graphite powders (Westwater Resources, Inc., 2021).

In 2021, Graphite One was delineating, evaluating, and developing a massive, near-surface graphite deposit at its Graphite Creek project, which included 176 mineral claims in a known graphite mineralization region of 9,583 hectares (ha) [23,680 acres] on the Seward Peninsula in western Alaska, about 60 km (37 mi) north of Nome. The Graphite Creek deposit consisted of large-flake, high-grade graphite. Following the PEA results in 2017, Graphite One increased and updated the project's resource estimates from those of the PEA following a 2018 field program. With a cutoff grade of 5.0% graphitic carbon (Cg), indicated resources were estimated to be 9.26 Mt of 7.7% Cg for 715,000 t of graphite content, and measured resources were estimated to be 1.69 Mt of 8.0% Cg for 135,000 t of graphite content. In 2021, Graphite One announced that it planned to develop a manufacturing plant to produce spherical purified graphite (SPG), for use as battery anode material. The plant would be in Washington State. The plant was expected to convert 60,000 t/yr of concentrate into 41,900 t/yr of SPG when fully operational (Graphite One Inc., 2019, undated a–c).

In 2021, South Star continued to develop the Ceylon graphite project in Alabama. South Star joined the project by entering into a development agreement with Hexagon Energy Materials Ltd. (Perth, Western Australia, Australia) to acquire up to 75% of the project. The project covers approximately 200 ha (500 acres) located in the Alabama graphite belt and includes the Ceylon graphite mine, which was historically mined during World Wars I and II (South Star Battery Metals Corp., 2021).

In 2021, NOVONIX Ltd. (Brisbane, Queensland, Australia), a producer of synthetic graphite, announced the purchase of the former Alstom S.A.'s (Saint-Ouen-sur-Seine, France) turbine-manufacturing plant, located near its existing facility in Chattanooga, TN. The expansion would add production capacity of 8,000 t/yr, for a total of 10,000 t/yr of synthetic graphite for use as battery anode material. The company expected the new facility to begin production by 2023 (NOVONIX Ltd., 2021).

Consumption

The USGS obtained the consumption data in this chapter through a survey of companies that imported and used natural graphite in the United States. Consumption data for synthetic graphite were not collected. 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 natural graphite industry in the United States.

U.S. consumption of natural graphite reported by end use increased by 3% to 52,000 t in 2021 from that in 2020 (table 2). The reported natural graphite consumption data in table 2 include a small amount of mixed natural and synthetic graphite in the amorphous graphite category. Apparent consumption in table 1 does not include unreported changes in company stocks and therefore differs from reported consumption in table 2. Reported consumption of natural crystalline graphite increased by 11% in 2021 to 23,900 t from 21,600 t in 2020. Consumption of amorphous graphite decreased by 3% in 2021 to 28,100 t from 29,100 t in 2020. The main uses of natural graphite during 2021 were batteries; brake linings; carbon products (such as bearings and brushes), crucibles, moderator rods in nuclear reactors, nozzles, retorts, stoppers, and sleeves; chemically resistant materials; drilling-mud additives; electrical conductors; foundries; fuel cells; graphene; high-strength composites;

lubricants; pencils; powdered metals; refractories; rubber; and steelmaking. The leading applications for natural and synthetic graphite were as electrodes used in steel production and as refractories (tables 2, 3). Automobile manufacturing and construction influenced steelmaking activity, which in turn influenced electrode and refractories demand.

Crystalline flake graphite accounted for 46% of natural graphite use in the United States in 2021. It was consumed mainly in batteries, brake linings, lubricants, powdered metals, refractories, and rubber. Amorphous graphite, which includes a small amount of mixed natural and synthetic graphite, accounted for 54% of natural graphite use and was mainly used in brake linings, foundries, lubricants, powdered metals, refractories, steelmaking, and other applications where additions of graphite improve the process or the end product (table 2). Lump graphite was used in several areas, such as steelmaking, depending on purity and particle size.

U.S. apparent consumption of natural graphite increased by 48% to 44,400 t in 2021 from 30,000 t in 2020, and U.S. apparent consumption of synthetic graphite increased by 31% to 342,000 t in 2021 from 261,000 t in 2020. Total U.S. graphite consumption, combined natural and synthetic, increased by 33% to 387,000 t in 2021 from 291,000 t in 2020 (table 1).

Synthetic graphite was used in more applications in the United States than natural graphite and accounted for an 89% share by quantity and a 97% share by value of the graphite consumption (table 1). The main market for high-purity synthetic graphite was as an additive to increase carbon content in iron and steel. Other important uses of natural and synthetic graphite were in the manufacture of catalyst supports; low-current, long-life batteries; lithium-ion 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 was gradually giving way to carbon black, which was more economical. High-purity natural and synthetic graphite were 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 was used as pebbles for modular nuclear reactors and in high-strength composites for wind, tide, and wave turbines. In energy storage applications, graphite was 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 was used in high-performance polystyrene thermal insulation and for silicon chip heat dissipation. These new energy applications used value-added graphite products such as high-carbon purity, small-particle-size potato shapes called spherical graphite, expanded graphite, and graphene.

A recent and growing source of graphite consumption was that in lithium-ion batteries, owing to increased demand for electric vehicles and portable electronic devices. Graphite was an essential component of many types of batteries, making up the majority of the material contained in the anode. In recent years small amounts of silicon have been added to the anode to increase energy storage capacity. The addition of silicon was limited owing to its high cost and tendency to swell during charging, leading to increased degradation of the cell. Most demand for natural flake graphite traditionally came from the refractory and foundry market. Since 2017, the global graphite consumption by the refractory and foundry industry has grown by an estimated 4%, while graphite consumption in lithium-ion batteries grew by an estimated 300% during the same period (Benchmark Mineral Intelligence Ltd., undated a).

Spherical purified graphite is the specialized form of graphite used as battery anode material and is produced from natural flake graphite concentrate, which has been rounded, micronized, purified to 99.95%, and coated. Most SPG was produced in China. Although no major SPG facilities existed outside of China in 2021, 12 were currently in development, 4 of those in the United States (Benchmark Mineral Intelligence Ltd., undated a). In 2021, Syrah Resources Ltd. (Melbourne, Victoria, Australia) continued construction of a spherical graphite plant in Vidalia, LA, to be supplied with material from the Balama Mine in Mozambique. Capacity was expected to be 11,250 t/yr of battery-grade material in 2023, expanding to 45,000 t/yr by 2025. In December 2021, Syrah signed an offtake agreement to supply 8,000 t/yr of spherical graphite to Tesla, Inc. (Austin, TX) (Syrah Resources Ltd., 2022, p. 13).

Anode material can be made with natural or synthetic graphite. Some companies combined natural and synthetic to utilize the strengths of each, especially in the electric vehicle (EV) market. EV batteries were manufactured at giant factories, called gigafactories. Most gigafactories were in China, though in recent years more countries have begun to develop additional facilities. In 2021, there were 4 gigafactories in the United States, accounting for about 39 gigawatthours per year (GWh/yr), with 16 more in the planning stages. At full capacity, these facilities would have a capacity of approximately 726 GWh/yr. Worldwide, there were an additional 143 gigafactories (117 in China), and another 132 (101 in China) in the planning stages (Benchmark Mineral Intelligence Ltd., undated b).

Tesla continued to ramp up battery cell production at its large plant in Sparks, NV. Tesla partnered with battery maker Panasonic Corp. (Kadoma, Japan); both companies operated parts of the factory. In 2021, the factory had 13 production lines with a capacity of 35 GWh/yr (Randall, 2021). In July 2020, Tesla confirmed that Gigafactory 5 was to be built in Austin, TX, with construction to begin shortly after the announcement (Doll, 2021). In 2021, Ford Motor Co. (Dearborn, MI) announced a new battery center, Ford Ion Park, to be located in Romulus, MI. The site would be used to research new battery technologies and develop and manufacture lithium-ion battery cells. Ford also announced a joint venture, BlueOval SK, with SK Innovation (Seoul, Republic of Korea) to build three gigafactories in Tennessee and Kentucky. At full capacity, they expected to produce up to 129 GWh/yr (Ford Motor Co., 2021a, b). In 2019, General Motors Co. (Detroit, MI) announced a

joint venture with LG Energy Solution, Ltd. (Seoul, Republic of Korea), called Ultium Cells LLC, to produce battery cells for electric vehicles. In 2020, Ultium Cells began construction of a gigafactory in Lordstown, OH. In 2021, Ultium Cells announced plans to build an additional battery manufacturing plant, located in Spring Hill, TN, with production scheduled to begin in 2023. The plant would supply the General Motors Spring Hill vehicle assembly plant, which was transitioning to produce electric vehicles. The partnership also planned to build two additional gigafactories, one in Lansing, MI, and the other in an undisclosed location (General Motors Co., 2020, 2021).

Prices

During 2021, prices for all mesh sizes of 90% carbon natural crystalline flake graphite were not available, but prices were available for the higher quality 94% carbon natural crystalline flake graphite. Of the 94% carbon flake, the median yearend prices for fine mesh size increased by 41%, the median yearend prices for medium mesh size increased by 43%, and the median yearend prices for large mesh size increased by 39% from those in 2020. Average median yearend prices for all crystalline sizes combined increased by 41%. Prices for natural amorphous powder graphite increased by 66% compared with those in 2020. Prices for synthetic graphite could not be compared because data were not available (table 4).

Prices for crystalline and crystalline flake graphite concentrates ranged from $755 to $1,395 per metric ton; prices for amorphous powder ranged from $635 to $750 per metric ton (table 4). The average unit value of all U.S. natural graphite exports decreased by 20% to $2,770 per metric ton in 2021 from $3,440 per metric ton in 2020 (tables 1, 5). The average unit value of all U.S. natural graphite imports increased by 8% to $1,340 per metric ton in 2021 from $1,240 per metric ton in 2020 (tables 1, 6). Ash and carbon content, crystal and flake size, and size distribution affected the price of graphite. The average unit value of U.S. synthetic graphite production decreased by 12% to $4,480 per metric ton in 2021 from $5,070 per metric ton in 2020 (tables 1, 3). The average unit value of U.S. synthetic graphite exports decreased by 5% to $5,600 per metric ton in 2021 from $5,910 per metric ton in 2020 (tables 1, 5). The average unit value of all U.S. synthetic graphite imports decreased by 35% to $3,280 per metric ton in 2021 from $5,040 per metric ton in 2020 (tables 1, 8).

Foreign Trade

Total U.S. graphite exports increased by 25% in tonnage to 41,200 t valued at $206 million in 2021 from 32,900 t valued at $180 million in 2020 (table 5). The total graphite export tonnage was 21% natural graphite and 79% synthetic graphite. Total U.S. natural graphite imports increased by 48% in tonnage to 53,100 t in 2021 from 36,000 t in 2020, and the value increased by 60% to $71.2 million in 2021 from $44.6 million in 2020. The increase in natural graphite imports resulted from substantial increases in quantity and in value of all graphite categories during 2021. Principal import sources of natural graphite were, in descending order of tonnage, China, Canada, Mexico, Madagascar, and Brazil, which combined accounted for 87% of the tonnage and 89% of the value of total natural graphite imports. China and Mexico were the leading suppliers of amorphous graphite. Sri Lanka provided all the lump and chippy dust graphite. China was the leading supplier of high-purity graphite varieties, representing 88% of imports. Canada, China, Madagascar, and Brazil were, in descending order of tonnage, the leading suppliers of crystalline flake and flake dust graphite (table 6).

Total synthetic graphite imports increased by 85% in tonnage to 116,000 t in 2021 from 62,400 t in 2020, and the value increased by 20% to $379 million in 2021 from $314 million in 2020 (table 8). Principal import sources of synthetic graphite were, in descending order of tonnage, China, Mexico, Canada, Japan, Spain, Switzerland, and France, which combined accounted for 92% of the tonnage and 91% of the value of total synthetic graphite imports. Principal import sources of graphite electrodes, by tonnage, were Mexico, 31%; India, 23%; Russia, 15%; and China, 10% (table 7).

Spherical purified graphite, for use in lithium-ion batteries, was produced mainly in China. In 2021, the United States imported 2,300 t of spherical purified graphite valued at $3,930 per metric ton from China, compared with 375 t valued at $4,280 per metric ton in 2020. Imports of synthetic spherical graphite were 22,200 t valued at $5,520 per metric ton in 2021, compared with 16,400 t valued at $6,100 per metric ton in 2020 (Zen Innovations AG, 2022).

World Review

World production of natural graphite increased by 30% in 2021 to an estimated 1,130,000 t from 868,000 t in 2020. Of the natural graphite production, an estimated 19% was amorphous, 80.7% was crystalline flake, and 0.3% was vein or lump graphite. China maintained its position as the world's leading natural graphite producer, with an estimated 820,000 t, or 73% of total global production. Brazil ranked second with 82,000 t, or 7% of the total, followed by Mozambique, Madagascar, Russia, Canada, the Republic of Korea, Ukraine, North Korea, and India, in descending order of tonnage. These 10 countries accounted for 98% of world production (table 9).

Australia.—Australia had no natural graphite production, but seven companies were developing and evaluating deposits. In 2021, Renascor Resources Ltd. (Kent Town, South Australia, Australia) continued to develop the Siviour project. Renascor completed a definitive feasibility study and was granted a mining license in 2019. Using a cutoff grade of 2.3% Cg, measured resources were estimated to be 15.8 Mt of 8.8% Cg for 1.4 Mt of graphite content. Using feedstock from Siviour, Renascor expected to produce 28,000 t/yr of SPG for use in lithium-ion batteries. In September 2021, Renascor announced the filing of the Program for Environmental Protection and Rehabilitation, which was the second step in a two-step approval process to begin mining operations. The filing also sought approval for Renascor to increase production up to 150,000 t/yr of graphite concentrates. The company had nonbinding offtake agreements of up to 60,000 t/yr of SPG with POSCO Group (Pohang, Republic of Korea), Jiangxi Zhengtuo New Energy Technology (Yichun, China), Fujian Metallurgical Holding Corporation's subsidiary Minguang New Material (Linfen,

China), and Hanwa Corp. (Izumi, Japan) (Renascor Resources Ltd., 2021, undated).

Quantum Graphite Ltd. (Melbourne, Victoria, Australia) continued to develop the Uley 2 graphite project. The company completed a definitive feasibility study in 2019. The project was fully approved and was projected to produce 55,000 t/yr of coarse flake over a 12-year mine life. Quantum also was developing the Uley 3 project, located near the Uley 2 project. In 2021, Quantum formed a joint venture with The Sunlands Co. to produce thermal energy storage battery cells using graphite from the Uley 2 project (Quantum Graphite Ltd., 2021, undated).

Brazil.—In 2021, Brazil had an estimated production of 82,000 t of marketable natural graphite. Nacional de Grafite Ltda. (Sao Paulo) was the leading producer of natural flake graphite in Brazil from mines and plants at three sites in the State of Minas Gerais. Extrativa Metalquímica Ltda. (Sao Tiago) also produced natural flake graphite from its mine and plant located in Bahia State. High-grade crystalline flake graphite projects were being developed in Brazil with two companies conducting or considering graphite exploration and development.

In 2021, South Star continued to develop the Santa Cruz project, consisting of large and extra-large flakes with an average weighted price of $1,287 per metric ton. The project was fully permitted and licensed, with construction expected to begin in 2022. At full capacity, the open pit mine was expected to produce 5,000 t/yr of battery-grade material during phase one, expanding to 25,000 t/yr in phase two. The estimated mine life was 12 years (South Star Battery Metals Corp., 2022).

Canada.—In 2021, Canada had two active open pit mines with combined production of about 12,000 t of natural flake graphite. Most production came from the Lac des Iles flake graphite mine in Quebec Province. In December 2021, Northern Graphite Corp. (Ottawa, Ontario) announced that it would acquire full ownership of the Lac des Iles Mine from Imerys Graphite & Carbon (Paris, France). Northern Graphite also signed the option to acquire the Mousseau West graphite project, located in Quebec Province (Northern Graphite Corp., 2021, undated). The Black Crystal flake graphite quarry in British Columbia Province, owned by Eagle Graphite Corp. (Toronto, Ontario), also produced natural flake graphite.

In 2021, Nouveau Monde Graphite Inc. (Saint-Michel-des-Saints, Quebec), began tree clearing and access road construction for the Matawinie graphite mine in Quebec Province. When complete, Nouveau Monde expected to produce 103,000 t/yr of graphite concentrate and 43,000 t/yr of anode material from their Becancour battery materials plant. Using a cutoff grade of 1.78% Cg, measured resources were estimated to be 28.5 Mt of 4.28% Cg for 1.22 Mt of graphite content. The estimated mine life was 25 years (Nouveau Monde Graphite Inc., undated).

Mason Graphite Inc. (Laval, Quebec) continued to develop the Lac Gueret project in northeastern Quebec Province. The company completed a feasibility report in 2018. Using a cutoff grade of 5.75% Cg, measured resources were estimated at 19.0 Mt of 17.9% for 3.40 Mt of graphite content. The company estimated 51,900 t/yr of average graphite concentrate production over 25 years. In 2021, Mason Graphite announced successful trials, conducted by Sicona Battery Technologies, to produce battery anode material using a blend of Mason Graphite's SPG, synthetic graphite, and a few percent of silicon. The material showed a 19% increase in capacity over natural graphite-based anodes and a 22.5% increase over synthetic graphite. In 2021, Mason Graphite announced the launch of Black Swan Graphene Inc. The company would produce graphene for use in many industries including concrete, polymers, tires, and other carbon black applications (Mason Graphite Inc., 2021a, b, undated).

China.—In 2021, China was the world's leading producer, exporter, and consumer of natural and synthetic graphite. China also may have the largest natural graphite resources in the world. Graphite production in China was an estimated 820,000 t of natural graphite, of which an estimated 620,000 t was flake graphite and the remaining 200,000 t was amorphous graphite; this was about 73% of the total global production. Most of China's flake graphite was produced in Heilongjiang Province, and most of the country's amorphous graphite was produced in Hunan Province.

Continuing growth in Chinese natural flake and synthetic graphite production was being driven by the global lithium-ion battery industry, which was centered in China for almost all parts of the supply chain. China was the leading producer of battery-grade graphite (which included nearly all the world's spherical graphite processed from natural flake), anode materials, and the anodes and batteries themselves. Global demand for synthetic graphite also was growing, with the leading markets for synthetic graphite being electrodes (70%) and anode material (29%). In 2021, China led global synthetic graphite production, accounting for an estimated 65% of global production, a 7% increase from that in 2020 (Benchmark Mineral Intelligence Ltd., undated c).

Spherical purified graphite, for use in lithium-ion batteries, was produced mainly in China. China increased production of SPG by an estimated 32% in 2021 compared with that in 2020, accounting for nearly 100% of the global supply (Benchmark Mineral Intelligence Ltd., undated a). China exported 56,800 t of SPG in 2021 compared with 52,700 t in 2020. Top destinations in 2021 were the Republic of Korea (62%) and Japan (31%) (Zen Innovations AG, 2022). Most SPG produced in China was that of the uncoated variety. Traditionally, the Republic of Korea and Japan have added coatings to the imported SPG and exported the material back to China (Roskill Information Services Ltd., 2020, p. 227). In recent years, China also began producing and exporting synthetic graphite anode material. In 2021, China exported 57,600 t of synthetic anode material compared with 32,700 t in 2020. Top destinations in 2021 were the United States (39%), Hungary (25%), and the Republic of Korea (17%) (Zen Innovations AG, 2022).

Madagascar.—In 2021, Madagascar had estimated production of 70,000 t of natural flake graphite. Production of natural flake graphite had increased steadily in recent years from both new and existing capacity. In 2021, Greenwing Resources Ltd. (Brisbane, Queensland, Australia) continued to develop the Graphmada Complex, currently on care-and-maintenance status pending stage two expansion. The expansion would aim to increase production to 40,000 t/yr of graphite concentrate. The company also expanded its mineral resource estimate to 22.0 Mt at 4.0% Cg for 890,000 t of graphite content. In 2021,

Greenwing announced production of high-quality graphene using Graphmada concentrates. Material from the Graphmada complex also was tested for use as expandable graphite, lithium-ion batteries, and refractories (Greenwing Resources Ltd., 2021a, b).

In 2021, four companies were in advanced development stages and many more were exploring potential projects in Madagascar. In 2021, BlackEarth Minerals NL (Perth, Western Australia, Australia) continued to develop the Maniry project, currently in the bankable feasibility stage. Estimated resources include an indicated 8.0 Mt at 7.20% Cg and inferred resources of 12.2 Mt at 6.05% Cg. The project life was an estimated 10 years and was expected to produce up to 30,000 t/yr, expandable to 60,000 t/yr during stage two (BlackEarth Minerals NL, undated).

NextSource Materials Inc. (Toronto, Ontario, Canada) completed a bankable feasibility study in 2015 for its Molo project, which it updated in 2017 and 2019. Using a cutoff grade of 4% Cg, measured resources were 10.6 Mt of 8.4% Cg for 887,000 t of graphite content. The company planned to produce up to 45,000 t/yr of concentrate at full capacity. In 2021, NextSource began a technical study for expanding capacity to 150,000 t/yr (NextSource Materials Inc., 2021, p. 28–29; undated).

Tirupati Graphite PLC (London, United Kingdom) continued to develop the Sahamamy and Vatomina projects. When complete, Tirupati expected to produce 60,000 t/yr over 14 years from the Vatomina project and 21,000 t/yr over 14 years from the Sahamamy project. Additionally, Tirupati completed a feasibility study to expand the existing graphite-processing facility. The expansion would allow the facility to begin producing 12,000 t/yr of spherical graphite during phase one, expanding to 24,000 t/yr in phase two (Tirupati Graphite PLC, 2022a–c).

Mexico.—In 2021, Mexico had estimated production of 2,100 t of natural amorphous graphite. Mexico produced both natural and synthetic graphite. The United States has had a long tradition of investing in the Mexican graphite industry. United States companies owned shares in natural graphite mines and operated synthetic production capacity in Mexico. Almost all Mexican production of natural graphite was exported to the United States. In 2021, Mexico imported 2,030 t of natural graphite and exported 5,850 t of natural graphite (Merchant Research & Consulting Ltd., 2022, p. 106).

Mozambique.—In 2021, Mozambique had estimated production of 72,000 t of natural flake graphite. One of the largest known graphite deposits in the world was the Balama deposit owned by Syrah, located in Cabo Delgado Province. Using a cutoff grade of 7.2% Cg, total estimated reserves were 107 Mt of 15.7% Cg for 16.1 Mt of graphite content. In March 2020, production was suspended owing to effects of the coronavirus disease 2019 (COVID-19) pandemic but was restarted in March 2021. Production for the partial year in 2021 was 72,000 t, compared with 12,000 t in 2020 and 153,000 t in 2019 (Syrah Resources Ltd., 2021, p. 9; 2022, p. 10–12).

In 2021, three companies had projects in advanced planning stages. Battery Minerals Ltd. (Perth, Western Australia, Australia) continued to develop the Balama Central and Montepuez projects in Mozambique. The combined projects had a resource estimate of 152.5 Mt at 8.5% Cg for 13 Mt of graphite content. In August 2021, Battery Minerals agreed to sell both projects to Tirupati (Battery Minerals Ltd., 2018, p. 1; 2021).

In 2021, Triton Minerals Ltd. (Nedlands, Western Australia, Australia) continued to develop the Ancuabe project, located near the Balama deposit. Triton completed a definitive feasibility study on the Ancuabe project in December 2017, with plans to produce 60,000 t/yr of graphite concentrate over a 27-year mine life. The resource estimate was 46 Mt at 6.6% Cg with estimated reserves of 24.9 Mt at 6.2% Cg. In 2021, Triton signed a binding offtake agreement with Yichang Xincheng Graphite Ltd. (Dangyang, China) to supply up to 10,000 t/yr of graphite concentrate, representing the entirety of production from the planned pilot plant (Triton Minerals Ltd., 2021, undated).

Sweden.—In 2021, Talga Group Ltd. (Perth, Western Australia, Australia) continued to develop the Vittangi project. Talga continued to evaluate the mineral resources of the project by carrying out a scoping study on three nearby sites of the Nunasvaara deposits. The Australian Joint Ore Reserves Committee (JORC)-compliant resources were an indicated resource of 22.6 Mt at 24.9% Cg for 5.62 Mt of graphite content and an inferred resource of 7.48 Mt at 21.8% Cg for 1.63 Mt of graphite content. The company also was evaluating two additional projects in Sweden, the Jalkunen and Raitajärvi. Additionally, Talga continued to develop its lithium-ion battery anode plant and expected to commence production in 2022 using feedstock from the Vittangi project (Talga Group Ltd., 2022).

Tanzania.—Tanzania has been a recent target for exploration, with many companies developing potential projects. In 2021, seven companies had graphite projects in advanced development stages. Walkabout Resources Ltd. (Perth, Western Australia, Australia) began construction at the Lindi Jumbo graphite mine in September 2021, with first production planned in 2022. The processing plant was expected to produce up to 40,000 t/yr of coarse flake concentrate. The Lindi Jumbo Mine had an estimated mine life of 24 years. Using a cutoff grade of 10% Cg, measured resources were 6.5 Mt of 12.1% Cg for 782,000 t of graphite content (Walkabout Resources Ltd., 2022).

Volt Resources Ltd. (Perth, Western Australia, Australia) continued to advance the Bunyu graphite project. Volt completed a feasibility study for stage one in 2018, with a stage two definitive feasibility study planned during stage one development. The project contained a JORC-compliant resource estimate of 461 Mt at 4.9% Cg and a reserve estimate of 127 Mt at 4.4% Cg, the largest in Tanzania. Volt planned to begin production at a rate of 23,700 t/yr, expanding to 170,000 t/yr during stage two. Volt had binding offtake agreements with Qingdao Tianshengda Graphite Co., Ltd. (Qingdao, China) and GrapheneCA (Brooklyn, NY) (Volt Resources Ltd., 2022a).

Magnis Energy Technologies Ltd. (Sydney, New South Wales, Australia) completed a bankable feasibility study in 2016 for the Nachu project. Magnis expected to produce up to 220,000 t/yr of flake graphite concentrate, with 130,000 t/yr intended as feedstock for battery anodes. In December 2021, Magnis announced an offtake agreement with Traxys S.à.r.l. (Strassen,

Luxembourg) to supply 600,000 t of high-purity graphite over a 6-year period. The high-purity graphite would be used to produce battery cells at a 1.8-GWh/yr plant under construction in 2021 in Endicott, NY (Magnis Energy Technologies Ltd., 2022a, b).

In 2021, Black Rock Mining Ltd. (Perth, Western Australia, Australia) continued to develop the Mahenge project. Black Rock completed a definitive feasibility study in 2018 and an updated study in 2019. Measured resources were estimated to be 25.5 Mt of 8.6% Cg for 2.2 Mt of graphite content. Plans included an initial 85,000 t/yr of graphite concentrate, potentially expanding to 340,000 t/yr in four stages (Black Rock Mining Ltd., 2018, p. 75; Roskill Information Services Ltd., 2020, p. 283–284). In 2021, Black Rock signed binding offtake agreements with Taihe Soar Supply Chain Management Co., Ltd. (Dalian, China) and Qingdao Yujinxi New Material Co., Ltd. (Qingdao, China) for a combined total of 30,000 t/yr of large flake concentrate. Additionally, Black Rock had an offtake agreement with POSCO (Pohang, Republic of Korea) for 100% of fine flake produced at Mahenge, estimated to range between 25,000 and 30,000 t/yr (Black Rock Mining Ltd., 2021).

In 2021, Evolution Energy Minerals Ltd. (West Perth, Western Australia, Australia) acquired the Chilalo project from Graphex Mining Ltd. (Perth, Western Australia, Australia). Graphex completed a definitive feasibility study in 2020. Chilalo contained an estimated indicated and inferred resource of 67.3 Mt at 5.4% Cg for 3.67 Mt of graphite content. The project was expected to produce an average of 50,000 t/yr of graphite concentrate over an 18-year mine life (Evolution Energy Minerals Ltd., undated).

Armadale Capital PLC (London, United Kingdom) continued to develop the Mahenge Liandu project, which it acquired in 2016. In 2020, Armadale completed an updated definitive feasibility study on the project. The project would consist of two stages, with the first stage producing 60,000 t/yr of graphite concentrate and the second stage increasing production to 109,000 t/yr after the completion of a second processing plant. Using a cutoff grade of 7.5% Cg, measured resources were 1.60 Mt at 12.30% Cg. In September 2021, Armadale was granted a 10-year mining license following Environment and Social Impact Assessment approval earlier in the year (Armadale Capital PLC, undated).

Ukraine.— In 2021, Ukraine was the eighth-ranked graphite producer worldwide and produced about 10,000 t of graphite concentrate. All production came from the Zavalievsky graphite mine. In July 2021, Volt acquired a 70% controlling interest in the ZG Group, which controlled the Zavalievsky graphite mine and processing facilities. The company also announced plans for developing downstream processing facilities for producing SPG using Zavalievsky graphite (Volt Resources Ltd., 2022b).

Outlook

Worldwide demand for natural and synthetic graphite is expected to continue increasing as more nonhydrocarbon energy applications that use graphite are developed. Steel production and other types of metallurgical activity, which are important consumers of graphite, are expected to increase as well. Global graphite consumption is expected to increase owing to new technologically advanced applications, such as aerospace applications, fuel cells, graphene, lithium-ion batteries, energy storage, pebble-bed nuclear reactors, and solar power.

The ability to refine and modify graphite is expected to be the key to future growth in the graphite industry. Refining techniques have enabled the use of graphite with improved properties in electronics, foils, friction materials, and lubrication applications.

Batteries are expected to become the end-use sector with the largest increase in graphite use owing to growth in portable electronics and EVs. These applications require larger, more powerful, and more-graphite-intensive lithium-ion batteries. With an additional 726 GWh/yr of EV battery production facilities planned domestically, demand for graphite is expected to increase significantly in the near future. About 1,200 t of SPG is required for each GWh/yr of capacity. Worldwide graphite consumption has increased 58% since 2016, owing largely to the battery end-use market, which increased by 319% during the same period. In order to meet the increasing demand for graphite, an additional 97 natural flake mines and 54 synthetic graphite plants may be needed by 2035 (Benchmark Mineral Intelligence Ltd., 2022, undated a).

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TABLE 1
SALIENT NATURAL AND SYNTHETIC GRAPHITE STATISTICS[1]

		2017	2018	2019	2020	2021
United States:						
Natural:						
Exports:						
Quantity	metric tons	13,300 r	9,950	5,880 r	5,920 r	8,670
Value	thousands	$23,300 r	$23,600	$18,900	$20,400 r	$24,000
Imports for consumption:						
Quantity	metric tons	51,900	70,700	50,100	36,000	53,100
Value	thousands	$58,500	$64,500	$56,100	$44,600	$71,200
Apparent consumption:[2]						
Quantity	metric tons	38,600 r	60,700	44,200	30,000	44,400
Value	thousands	$35,200 r	$40,900	$37,200	$24,200 r	$47,100
Synthetic:						
Production:						
Quantity	metric tons	226,000	219,000	286,000	225,000 r	259,000
Value	thousands	$726,000	$1,170,000	$1,240,000	$1,140,000 r	$1,160,000
Exports:						
Quantity	metric tons	39,700 r	50,400 r	40,700	26,900	32,500
Value	thousands	$227,000 r	$279,000	$230,000	$159,000	$182,000
Imports for consumption:						
Quantity	metric tons	109,000 r	128,000 r	88,800 r	62,400 r	116,000
Value	thousands	$166,000 r	$417,000 r	$512,000 r	$314,000 r	$379,000
Apparent consumption:[2]						
Quantity	metric tons	295,000 r	296,000 r	334,000 r	261,000 r	342,000
Value	thousands	$665,000 r	$1,310,000 r	$1,520,000 r	$1,300,000 r	$1,360,000
World production, natural[3]	metric tons	1,270,000 r	1,500,000 r	1,560,000 r	868,000 r	1,130,000

rRevised.
[1]Table includes data available through August 17, 2022. Data are rounded to no more than three significant digits.
[2]Defined as domestic production plus imports minus exports.
[3]May include estimated data.

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

	Crystalline		Amorphous[2]	
End use	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
2020:				
Brake linings	1,050	$3,220	2,080	$1,800
Carbon products[3]	210	1,160	W	W
Foundries[4]	W	W	1,930	2,090
Lubricants[5]	W	W	W	W
Powdered metals	W	W	W	W
Refractories	W	W	W	W
Rubber	W	W	W	W
Other[6]	20,300	70,000	25,100	59,600
Total	21,600	74,400	29,100	63,400
2021:				
Brake linings	1,050	3,220	2,080	1,800
Carbon products[3]	226	1,210	W	W
Foundries[4]	W	W	1,920	2,100
Lubricants[5]	W	W	W	W
Powdered metals	W	W	W	W
Refractories	W	W	W	W
Rubber	W	W	406	945
Other[6]	22,600	94,300	23,700	39,200
Total	23,900	98,700	28,100	44,100

W Withheld to avoid disclosing company proprietary data; included in "Other."
[1]Table includes data available through August 17, 2022. Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Includes mixtures of natural and manufactured graphite.
[3]Includes bearings and carbon brushes.
[4]Includes foundries (other) and foundry facings.
[5]Includes ammunition packings.
[6]Includes antiknock gasoline additives and other compounds, batteries, crucibles, drilling mud, electrical and electronic devices, industrial diamonds, magnetic tape, mechanical products, nozzles, paints and polishes, pencils, retorts, sleeves, small packages, soldering and welding, steelmaking, stoppers, and other end-use categories.

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

End use	Quantity (metric tons)	Value (thousands)
2020:		
Cloth and fibers (low modulus)	W	W
Electrodes	93,100	W
Unmachined graphite shapes	7,630	W
Other[2]	125,000 r	$1,140,000 r
Total	225,000 r	1,140,000 r
2021:		
Cloth and fibers (low modulus)	W	W
Electrodes	93,100	W
Unmachined graphite shapes	9,050	W
Other[2]	157,000	1,160,000
Total	259,000	1,160,000

rRevised. W Withheld to avoid disclosing company proprietary data; included in "Other."
[1]Table includes data available through August 17, 2022. 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	2020	2021[2]
Crystalline fine, 94% to 97% carbon, −100 mesh	520–550	755
Crystalline medium, 94% to 97% carbon, +100 mesh	860–890	1,250
Crystalline large, 94% to 97% carbon, +80 mesh	1,000–1,010	1,395
Amorphous powder, 80% to 85% carbon	375–460	635–750

[1]Prices are cost, insurance, and freight China to main European port, unless otherwise specified.
[2]Price ranges are unavailable, unless otherwise specified.

Sources: Fastmarkets IM, December 2021 Price Movements.

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

Country or locality	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)
2020:						
Brazil	91	$236	587	$3,120	677	$3,360
Canada	1,190	938 r	4,050 r	16,000 r	5,240 r	16,900 r
China	279	1,010	1,420	21,900	1,700	23,000
France	129	595	1,040	7,140	1,170	7,730
Germany	337 r	848 r	319	10,200	656 r	11,000
India	522 r	1,440 r	553	2,020	1,070 r	3,460 r
Italy	35	130	807	9,380	841	9,510
Japan	371	1,740	1,070	9,080	1,440	10,800
Korea, Republic of	1,170	6,820	1,470	17,200	2,640	24,100
Mexico	483	673	6,780	15,900	7,260	16,600
Poland	43	98	752	3,110	795	3,210
Saudi Arabia	685	2,620	3,560	10,100	4,250	12,800
Taiwan	32	80	474	6,130	506	6,210
United Arab Emirates	--	--	718 r	1,490 r	718 r	1,490 r
United Kingdom	53	225	845	1,460	897	1,690
Other	503 r	2,950	2,500	24,800	3,000	27,700 r
Total	5,920 r	20,400 r	26,900	159,000	32,900	180,000
2021:						
Belgium	477	1,070	263	1,990	740	3,060
Brazil	161	229	1,060	6,560	1,220	6,790
Canada	2,130	2,000	5,500	17,000	7,630	19,000
China	198	918	2,130	26,800	2,330	27,700
France	75	214	1,620	10,600	1,690	10,900
Germany	336	935	448	12,700	783	13,600
India	489	1,770	735	4,000	1,220	5,770
Italy	81	263	1,140	11,400	1,220	11,600
Japan	695	3,040	743	6,290	1,440	9,330
Korea, Republic of	1,200	7,330	1,530	19,600	2,730	26,900
Mexico	1,940	2,520	11,000	21,900	13,000	24,400
Poland	155	329	789	1,940	944	2,260
Saudi Arabia	1	19	728	2,630	730	2,650
Taiwan	63	167	618	10,800	681	11,000
United Arab Emirates	2	11	620	1,330	622	1,340
United Kingdom	106	205	1,060	2,660	1,160	2,870
Other	557	3,010	2,530	24,000	3,090	27,000
Total	8,670	24,000	32,500	182,000	41,200	206,000

rRevised. -- Zero.

[1]Table includes data available through August 10, 2022. Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Numerous countries and (or) localities for which data were reported have been combined in "Other."

[3]Amorphous, crystalline flake, lump and chip, and natural, not elsewhere classified. The applicable Schedule B nomenclatures are "Natural graphite in powder or in flakes" and "Other," codes 2504.10.0000 and 2504.90.0000.

[4]Includes data from applicable Schedule B nomenclatures "Artificial graphite," "Colloidal or semicolloidal graphite," "Preparations based on graphite," and "Graphite products containing greater than 50% graphite by weight," codes 3801.10.0000, 3801.20.0000, 3801.90.0000, and 6903.10.0000.

[5]Free alongside ship value.

Source: U.S. Census Bureau.

TABLE 6
U.S. IMPORTS FOR CONSUMPTION OF NATURAL GRAPHITE, BY COUNTRY OR LOCALITY[1]

Country or locality	Crystalline flake and flake dust		Lump and chippy dust		Other natural crude, high-purity, expandable		Amorphous		Total	
	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)
2020:										
Austria	--	--	--	--	(3)	$8	488	$305	488	$313
Belgium	95	$151	--	--	--	--	--	--	95	151
Brazil	2,590	4,900	--	--	182	560	--	--	2,770	5,460
Canada	5,740	8,410	--	--	10	272	--	--	5,750	8,680
China	3,600	6,040	--	--	2,410	8,650	4,460	2,490	10,500	17,200 r
Germany	22	41	--	--	50	1,130	--	--	72	1,170
Hong Kong	--	--	--	--	--	--	407	290	407	290
India	8	12	--	--	--	--	--	--	8	12
Japan	60	140	--	--	36	322	--	--	96	462
Madagascar	2,540	2,680	--	--	20	95	1,850	1,020	4,410	3,800
Mexico	11	15	--	--	1	18	5,800	3,380	5,810	3,410
Mozambique	3,940	2,590	--	--	--	--	--	--	3,940	2,590
Netherlands	20	25	--	--	--	--	--	--	20	25
Norway	20	25	--	--	--	--	--	--	20	25
Russia	17	36	--	--	--	--	--	--	17	36
Sri Lanka	--	--	31	$91	--	--	--	--	31	91
United Kingdom	--	--	--	--	3	30	1,560	772	1,560	802
Other	--	--	--	--	2	68	--	--	2	68 r
Total	18,700	25,100	31	91	2,710	11,100	14,600	8,260	36,000	44,600
2021:										
Austria	157	150	--	--	1	15	97	63	255	228
Belgium	37	83	--	--	--	--	--	--	37	83
Brazil	2,990	5,410	--	--	164	550	--	--	3,150	5,960
Canada	9,980	14,100	--	--	66	415	23	6	10,100	14,500
China	6,440	10,700	--	--	4,840	16,500	8,130	5,390	19,400	32,600
France	--	--			72	292	--	--	72	292
Germany	116	225	--	--	117	669	--	--	233	894
Hong Kong	177	169	--	--	--	--	2,340	1,590	2,520	1,760
India	8	13	--	--	--	--	--	--	8	13
Italy	--	--			10	26	--	--	10	26
Japan	40	94	--	--	71	550	--	--	111	644
Madagascar	3,420	3,400	--	--	110	820	2,440	1,430	5,980	5,650
Mexico	1,070	1,040	--	--	--	--	6,680	3,770	7,740	4,810
Mozambique	2,770	2,450	--	--			--	--	2,770	2,450
Netherlands	20	26	--	--	14	40	--	--	34	67
Norway	70	98	--	--	6	33	--	--	76	132
Sri Lanka	--	--	340	684	--	--	--	--	340	684
Turkey	--	--	--	--	--	--	20	7	20	7
United Arab Emirates	41	52	--	--	--	--	--	--	41	52
United Kingdom	13	30	--	--	4	50	160	124	177	203
Other	--	--	--	--	7	76	--	--	7	74
Total	27,300	38,100	340	684	5,480	20,000	19,900	12,400	53,100	71,200

rRevised. -- Zero.
[1]Table includes data available through August 10, 2022. Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Customs value.
[3]Less than ½ unit.

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

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

Country or locality	Quantity (metric tons)	Value[3] (thousands)
2020:		
Austria	1,650	$16,000
Canada	89	51
China	11,700	24,900
France	225	488
Germany	264	4,040
India	8,900	22,100
Italy	3,860	18,900
Japan	1,040	13,700
Mexico	15,500	58,400
Poland	1,620	7,730
Russia	5,920	16,600
Spain	58	209
Taiwan	127	622
Ukraine	704	1,610
United Kingdom	1,010	3,610
Other	107	545
Total	52,800	190,000
2021:		
Austria	2,060	9,320
Canada	451	481
China	7,200	15,200
France	668	3,830
Germany	401	3,990
India	16,100	33,500
Italy	4,290	20,800
Japan	982	7,760
Macau	61	341
Mexico	21,900	74,400
Poland	1,330	6,080
Russia	10,300	24,500
Taiwan	59	362
Ukraine	2,540	4,990
United Kingdom	1,350	3,540
Other	26	88
Total	69,700	209,000

[1]Table includes data available through August 10, 2022. 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 OR LOCALITY[1, 2]

Country or locality	2020		2021	
	Quantity (metric tons)	Value[3] (thousands)	Quantity (metric tons)	Value[3] (thousands)
Austria	10	$6	38	$327
Belgium	28	328	1	83
Brazil	1,930	1,320	1,840	1,620
Canada	1,510	5,730	6,080	10,300
China	20,800 r	118,000	59,900	175,000
Czechia	6	165	67	110
France	3,160	20,500	2,970	20,100
Germany	951	11,500	941	10,300
India	360	2,490	915	4,940
Italy	416	2,420	150	1,400
Japan	5,550 r	54,000	4,550	36,100
Korea, Republic of	1,100	8,070	1,050	6,980
Malaysia	30	266	551	954
Mexico	18,600	49,600	26,300	69,400
Netherlands	76	746	544	973
Norway	228	195	232	203
Poland	126 r	683 r	1,400	3,980
Singapore	(4)	4	39	120
Spain	3,990	24,600	3,730	17,500
Sri Lanka	129	230	38	82
Sweden	(4)	17	93	119
Switzerland	3,140	12,000	3,320	15,100
Taiwan	16	249	34	384
Thailand	23	158	(4)	3
United Kingdom	317	1,110	772	1,990
Other	3 r	131 r	11	636
Total	62,400 r	314,000 r	116,000	379,000

rRevised.
[1]Table includes data available through August 10, 2022. Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Synthetic graphite data are for Harmonized Tariff of the United States codes 3801.10.1000, 3801.10.5000, 3801.20.0000, 3801.90.0000, and 6903.10.0000.
[3]Customs value.
[4]Less than ½ unit.

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

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

(Metric tons)

Country or locality	2017	2018	2019	2020	2021
Austria, amorphous[e]	1,000	500	500	500	500
Brazil, crystalline flake	53,332	96,800	84,700	67,020 [r]	82,000 [e]
Canada, crystalline flake	14,000	11,000	11,000	11,937 [r]	12,000 [e]
China:					
Amorphous	333,400 [2]	469,600 [2]	473,600 [2]	159,000 [r, e]	200,000 [e]
Crystalline flake	748,600	694,400	711,400	506,000 [r, e]	620,000 [e]
Total	1,082,000	1,164,000	1,185,000	665,000 [r, e]	820,000 [e]
Germany, crystalline flake[e]	422 [r]	222 [r]	207 [r]	108 [r]	250
India:[e, 3]					
Amorphous	3,500	800	800	600	700
Crystalline flake	31,500	7,100	7,200	5,400	6,300
Total	35,000	7,900	8,000	6,000	7,000
Korea, North:[e]					
Amorphous	1,000	3,600	3,600	3,600	3,600
Crystalline flake	4,500	4,500	4,500	4,500	4,500
Total	5,500	8,100	8,100	8,100	8,100
Korea, Republic of, crystalline flake	--	670	302	3,052	10,485
Madagascar, crystalline flake	13,300	47,900	53,400	48,500 [r]	70,000 [e]
Mexico, amorphous	10,310 [r]	4,130 [r]	2,300 [r, e]	2,033 [r]	2,100 [e]
Mozambique, crystalline flake	1,042	106,773	153,000 [e]	18,159 [r]	72,000 [e]
Namibia, crystalline flake	2,216	3,456	-- [4]	-- [4]	-- [4]
Norway, crystalline flake	9,600	10,000	9,780 [r]	5,549 [r]	6,293
Russia:					
Amorphous	8,300 [r]	-- [r]	-- [r]	-- [r]	--
Crystalline flake	11,200 [r]	11,900 [r]	17,500 [r]	12,900 [r]	15,000 [e]
Total	19,500 [r]	11,900 [r]	17,500 [r]	12,900 [r]	15,000 [e]
Sri Lanka, vein	3,769	3,800 [e]	2,648 [r]	2,000 [r, e]	3,000 [e]
Tanzania, crystalline flake	128	150 [e]	150 [e]	-- [e]	--
Turkey, amorphous[e, 5]	2,300	2,500	2,500	2,500	2,700
Ukraine, crystalline flake[e]	14,900	15,000	16,000	10,000 [r]	10,000
Uzbekistan, crystalline flake[e]	100	100	100	100	110
Vietnam, crystalline flake[e]	5,000	5,000	5,000	5,000	5,000
Zimbabwe, crystalline flake	1,577	-- [4]	-- [4]	-- [4]	-- [4]
Grand total	1,270,000 [r]	1,500,000 [r]	1,560,000 [r]	868,000 [r]	1,130,000
Of which:					
Amorphous	360,000 [r]	482,000 [r]	484,000 [r]	171,000 [r]	210,000
Crystalline flake	911,000 [r]	1,010,000 [r]	1,070,000 [r]	695,000 [r]	914,000
Vein or lump	3,770	3,800	2,650 [r]	2,000 [r]	3,000

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

[1]Table includes data available through August 8, 2022. All data are reported unless otherwise noted; grand totals may include estimated data. Grand totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

[2]Source: China Nonmetallic Mining Industry Association.

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

[4]The sole producing graphite mine in this country was in care-and-maintenance status.

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