Graphite

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Graphite is one of four forms of crystalline carbon; the others are carbon nanotubes, diamonds, and fullerenes. Graphite occurs naturally in metamorphic rocks, such as gneiss, marble, and schist. It is a soft mineral also known by the names black lead, mineral carbon, and plumbago. The word graphite is derived from the Greek word "graphein," to write. It has a Mohs hardness of 1 to 2 and exhibits perfect basal (one-plane) cleavage. Depending upon purity, the specific gravity is 2.20 to 2.30. The specific gravity of pure graphite is 2.23. It is gray to black in color, opaque, and usually has a metallic luster; sometimes it exhibits a dull earthy luster. It is flexible but not elastic. It has a melting point of 3,927° C and is highly refractory. Graphite is the most electrically and thermally conductive of the nonmetals and is chemically inert. All these properties combined make graphite desirable for many industrial applications, and both natural and synthetic graphite have industrial uses.

Worldwide, natural graphite deposits occur as lenses or layers of disseminated or massive flakes. Naturally occurring organic carbon may be graphitized at temperatures from 300° C to 1,200° C. These temperatures could be associated with low-grade metamorphism or at the contact between an igneous intrusion and a carbonaceous body. The three principal types of natural graphite, which are amorphous, crystalline flake, and lump, are distinguished by physical characteristics that are the result of major differences in geologic origin and occurrence. Amorphous graphite is formed by the thermal metamorphism of coal. The designation "amorphous" is a misnomer. Its relatively low degree of crystalline order and very fine particle size make it appear amorphous. It is usually less pure than the crystalline flake graphite and, therefore, commands a lower price than its more ordered counterpart. Crystalline flake graphite consists of isolated, flat, plate-like particles with angular, irregular, or rounded edges. It is usually found in layers or pockets in metamorphic rocks. In some deposits, the flake graphite occurs as massive accumulations in lenses, pods, or veins. Lump graphite occurs in veins and is believed to be hydrothermal in origin. It typically appears as massive platy intergrowths of fibrous or acicular crystalline aggregates with the long axis parallel to the enclosing wall rock; the particle size ranges from extremely fine to coarse (Kenan, 1984).

Beneficiation processes for graphite may vary from a complex four-stage flotation at European and United States mills to simple hand sorting and screening of high-grade ore at Sri Lankan operations. 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. It is then screened to produce a variety of products marketed as flake graphite that contain 75% to 90% carbon.

Legislation and Government Programs

As of January 1, 2003, the National Defense Stockpile (NDS), maintained by the U.S. Department of Defense, contained graphite inventories of 5,210 metric tons (t) with a value of more than $2.16 million. Madagascar crystalline flake natural graphite inventories in the NDS were 18 t. The NDS also contained 1,480 t of Sri Lanka amorphous lump natural graphite and 3,710 t of natural graphite fines. During the first half of 2003, all the graphite in the Government stockpile inventory was sold (Phyllis Webster, market analyst, Defense National Stockpile Center, oral commun., July 8, 2003).

Production

The U.S. Geological Survey (USGS) obtained the production data in this report through a survey of U.S. synthetic graphite producers. The survey of U.S. synthetic graphite producers collected data from 17 of 21 producers. Estimated data were used for the producers that did not respond to the survey. This survey represented the majority of the synthetic graphite industry in the United States. All percentages in the report were computed based on the unrounded data.

No natural graphite was reported mined in the United States in 2003, but the reported U.S. production of synthetic graphite reached 236,000 t with an estimated value of $625 million (table 3). Natural graphite is mined from open pit and underground mine operations. Production from open pit operations is less expensive and is preferred 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.

Consumption

The USGS obtained the data in this report through a survey of natural graphite companies in the United States. The survey of natural graphite companies collected data from 79 of 99 companies and plants. Estimated data were used for the companies that did not respond to the survey. This survey represented the majority of the graphite industry in the United States.

Graphite uses have changed dramatically in the past 20 years. Graphite has properties of both metals and nonmetals, which makes 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. Today's advanced technology products, such as friction materials and battery and fuel cells, require high-purity graphite.

U.S. consumption of natural graphite decreased by about 3% to 38,200 t in 2003 from 39,400 t in 2002 (table 2). The natural graphite consumption data in table 2 include mixtures of natural and manufactured graphite with the amorphous graphite. Consequently, the table 2 consumption numbers are higher than the computed apparent consumption numbers given in table 1. The consumption of crystalline grade decreased in 2003 by nearly 20% to 14,000 t from 17,500 t in 2002, and consumption of amorphous grade increased by more than 10% to 24,200 t in 2003 from 21,900 t in 2002. These changes in end use translated to about a 6% decrease in total graphite value in 2003. Three major industries continued to dominate in graphite usage and accounted for more than 55% of the graphite consumed by U.S. industry in 2003 (table 2). These three industries were brake linings, refractories, and steelmaking. Foundries and lubricants industries together made up almost another 16% of U.S. graphite consumption. The refractories industry was the largest consumer of crystalline flake graphite, increasing its graphite use by 3% compared with 2002.

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 a particle size of 100 mesh and a purity of 95% to 99% graphite.

Crystalline flake graphite accounted for almost 37% of graphite usage in the United States. It was used mainly in refractories, lubricants, and other electrical and thermal-conductivity applications, in descending order of quantity consumed. Amorphous graphite is mainly used in steelmaking, as a pigment in paints, in refractories, and in other applications where additions of graphite improve the process or the end product. Lump graphite finds appropriate uses in a number of areas, such as steelmaking, depending on the purity and particle size.

Synthetic graphite is the type most often chosen in North America instead of natural graphite and accounts for a significant share of the graphite market. The main market for high-purity synthetic graphite is as a carbon raiser additive in iron and steel. This market consumes a significant portion of the synthetic graphite. Other significant 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.

Prices

Natural graphite prices remained unchanged during 2003. Prices for crystalline and crystalline flake graphite concentrates ranged from $230 to $750 per metric ton; prices for amorphous powder were not available (table 4). Ash and carbon content, crystal and flake size, and size distribution affect the price of graphite. The prices of synthetic graphite were not available; however, the average unit value of synthetic graphite exports decreased to $1,118 per ton in 2003 from $1,339 per ton in 2002 (table 5).

Foreign Trade

Total imports of natural graphite increased in tonnage to 52,300 t in 2003 from 45,100 t in 2002, an increase of almost 16%, and the value increased to $24.4 million in 2003 from $22.3 million in 2002 (table 6). Principal import sources of natural graphite, in descending order of tonnage, were China, Mexico, Canada, Brazil, and Japan, which accounted for more than 78% of the value of total imports. China and Mexico were the major suppliers of amorphous graphite, and Sri Lanka provided the lump variety. China and Canada, in descending order of tonnage, were the major suppliers of crystalline flake and dust graphite. A number of other producers supplied several types and grades of graphite to the United States; among the most notable are China and Japan. Total graphite exports increased by about 12% in tonnage to 91,900 t valued at $97.5 million in 2003 compared with 81,700 t valued at about $99.6 million in 2002 (table 5).

World Review

World production of natural graphite decreased by about 3% in 2003 to an estimated 742,000 t from 763,000 t in 2002. China maintained its position as the world's leading graphite producer with 450,000 t. India was the second largest graphite producer with 110,000 t, followed by Brazil, Canada, North Korea, the Czech Republic, Mexico, and Turkey, in decreasing order of tonnage produced. These eight countries accounted for more than 96% of the world production (table 8). Sri Lanka continued to account for nearly all the high-purity lump graphite produced with deposits estimated to average 95% graphite in situ. China accounted for about 61% of world production.

Current Research and Technology

New technology in processing and treatment expanded the use of natural graphite in battery applications. Graphite for these applications is purified to 99.9% carbon. Most new uses for graphite products are being developed through advances in graphite thermal technology. The ability to refine and modify graphite and carbon products will be the key to future growth in the graphite industry. Innovative refining techniques have enabled the use of improved graphite in electronics, foils, friction materials, and lubrication applications (Hand, l997). One of the new application areas is in electrically conductive asphalt for heated runways at airports and roadway bridges. With its low corrosion resistance, refractory property, and specific gravity, graphite is critical for many industrial applications, for example dies for continuous casting, heat exchangers for the chemical industry, and rocket nozzles. The relatively poor wear and oxidation resistance of graphite, however, limit its use. A class of high-performance materials based on titanium-carbide-coated graphite makes the material suitable for some of the most demanding applications (Webb, 2000). Because titanium carbide is one of the hardest and most durable materials, the resulting components are extremely resistant to corrosion, elevated temperatures, and wear. These composites can be engineered for many industrial uses through control of the coating composition, microstructure, surface finish, and thickness. In metal melting applications, titanium-carbide coatings have been shown to improve the service life of the graphite components by as much as fivefold.

Graphite is now 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, and semiconductive cable compounds, and electrostatic paint and powder coatings (George C. Hawley, President, George C. Hawley and Associates, written commun., January 16, 2004).

Graphite is formed of 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. Lithium ions can be inserted to create graphite anodes for lithium ion batteries. Graphite can be intercalated with sulfuric and nitric acid to produce expanded graphite from which foils are formed that are used in seals and gaskets and are beginning to be used in fuel cells (Hawley, 2001).

Outlook

Refractory use trends for graphite closely follow events in the steel industry because graphite is mostly used in the manufacture of refractory brick used in iron and steel furnace linings. Brake linings and other friction materials will steadily use more natural graphite as new automobile production continues to increase and more replacement parts are required for the growing number of vehicles. Flexible graphite products, such as grafoil (a thin graphite cloth), will probably be the fastest growing market but will use small amounts of natural graphite compared with major end-use markets, such as brake linings and refractories. Advanced refining technology in the next few years, despite a weak refractory market and pricing pressure from Chinese material, could increase profitability in the graphite industry.

Hybrid and electric vehicles are expected to increase demand for high-purity graphite in fuel cell and battery applications. One prediction is that the demand for high-quality, high-carbon graphite could increase to more than 100,000 metric tons per year (t/yr) for fuel cell and battery applications alone (Crossley, 2000). The global demand for graphite used in batteries may increase to more than 25,000 t/yr in the next 5 years. This demand is expected to be spread between two main consuming sectors—alkaline batteries and lithium-metal 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 whether to use synthetic or natural graphite will be based on weighing the differences in performance and price. The growth of the lithium-ion battery market could have a more dramatic effect on the graphite market as the demand for mobile energy storage systems rises.

Fuel cells convert hydrogen into electricity by an electrochemical reaction. The hydrogen molecules break down into protons and electrons at the cell's anode. Protons are then conducted through the electrolyte to the cathode, and the electrons travel through an external circuit and generate electricity. Graphite, as cathode material, forms a crucial part of fuel cell technology. Some predictions show that consumption of graphite in fuel cell electrodes could reach 80,000 t/yr in just 2 to 3 years. Canada, Germany, Japan, and the United States are aggressively promoting fuel cell development. The cost of the fuel cells is still very high for commercial vehicles. The price per unit must drop to about $1,500 to be competitive with gasoline-powered vehicles. Daimler-Chrysler Corporation pledged to have an economically competitive fuel cell vehicle by 2004, and trials for fuel cell bicycles, buses, and taxis have already begun.

There is a common industry trend towards higher purity and consistency in specifications for some specialized and high tech applications. The trend to produce higher purity graphite using thermal processing and acid leaching techniques continues. This material has applications in advanced carbon graphite composites.

The graphite industry has been plagued with closures and declining profits in recent years, and just a handful of producers remain. The world's two largest producers of natural graphite are Timcal Ltd. and Nacional de Grafite. These companies have made recent refinements to their business strategies to avoid losing growth opportunities. Timcal is an international company headquartered in Switzerland; it produces natural and synthetic graphite. In the past 4 years, Timcal has doubled in size and plans to double again in the next 4 years. Timcal's strategy has been to diversify into various types of carbon products, including byproduct silicon carbide, carbon black, cokes, dispersions, natural graphite, scrap, and synthetic graphite. This diversification has afforded the company a competitive edge by being able to offer multiple carbon products in numerous grades from one source. Brazil's Nacional de Grafite produces natural graphite from three mines. The company has concentrated on the largest value graphite products, in particular on developing expanded graphite for battery applications. The company's strategy has been to be diverse and to invest in high-purity graphite grades. It has established a strong market in Brazil to give a base for developing exports and to invest in graphite purification technology. The company now produces expandable, high-purity, and micronized graphite for alkaline batteries and lubricants. Nacional de Grafite has now built up a 35% share of the world graphite market. Other graphite producers who are looking to grow could use the examples of these two largest companies (Crossley, 2003).

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TABLE 1
SALIENT NATURAL GRAPHITE STATISTICS[1]

(Metric tons)

		1999	2000	2001	2002	2003
United States:						
Apparent consumption[2]		26,400	39,000	28,200	23,600	30,000
Exports:						
Quantity		29,400	21,800	23,900	21,600	22,200
Value	thousands	$15,200	$12,500	$16,900	$19,200	$19,500
Imports for consumption:						
Quantity		55,800	60,800	52,100	45,100	52,300
Value	thousands	$34,700	$32,500	$23,300	$22,300	$24,400
World, production		682,000 r	846,000 r	803,000 r	763,000 r	742,000 e

[e]Estimated. [r]Revised.

[1]Data are rounded to no more than three significant digits.

[2]Domestic production plus imports minus exports.

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

End use	Crystalline		Amorphous[2]		Total	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
2002:						
Batteries	W	W	W	W	W	W
Brake linings	W	$1,770	3,420	$3,220	W	$4,990
Carbon products[3]	454	851	W	299	W	1,150
Crucibles, retorts, stoppers, sleeves, nozzles	W	W	W	W	W	W
Foundries[4]	W	W	75	2,140	W	W
Lubricants[5]	2,130	2,230	W	W	W	W
Pencils	W	W	W	W	W	W
Powdered metals	477	743	W	W	W	W
Refractories	W	W	5,300	4,180	W	W
Rubber	22	42	18	W	40	W
Steelmaking	W	W	W	6,290	W	W
Other[6]	W	W	W	W	W	W
Total	17,500	16,800	21,900	18,400	39,400	35,300
2003:						
Batteries	W	W	W	W	W	W
Brake linings	W	1,630	3,490	2,660	W	4,290
Carbon products[3]	445	920	W	253	W	1,170
Crucibles, retorts, stoppers, sleeves, nozzles	W	W	W	W	W	106
Foundries[4]	W	W	W	2,090	W	W
Lubricants[5]	W	W	W	W	W	W
Pencils	W	W	W	42	W	W
Powdered metals	460	654	W	W	W	W
Refractories	W	W	W	3,630	9,110	W
Rubber	W	W	19	W	W	W
Steelmaking	W	W	W	6,290	W	W
Other[6]	2,820	W	4,940	3,360	7,750	W
Total	14,000	13,900	24,200	19,400	38,200	33,300

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

[1]Data are rounded to no more than three significant digits.

[2]Includes mixtures of natural and manufactured graphite.

[3]Includes bearings and carbon brushes.

[4]Includes foundries (other) and foundry facings.

[5]Includes ammunition and packings.

[6]Includes antiknock and other compounds, drilling mud, electrical/electronic devices, industrial diamonds, magnetic tape, mechanical products, paints and polishes, small packages, soldering/welding, 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)
2002:		
Anodes	W	W
Cloth and fibers (low modulus)	W	$97,700
Crucibles and vessels, refractories	W	W
Electric motor brushes and machined shapes	W	W
Electrodes	159,000	335,000
High-modulus fibers	1,980 r	41,100 r
Unmachined graphite shapes	8,490	65,800
Synthetic graphite powder and scrap[2]	W	W
Other	W	W
Total	256,000	666,000 r
2003:		
Anodes	W	W
Cloth and fibers (low modulus)	W	W
Crucibles and vessels, refractories	W	W
Electric motor brushes and machined shapes	W	W
Electrodes	147,000	335,000
High-modulus fibers	3,060	68,700
Unmachined graphite shapes	6,040	43,100
Synthetic graphite powder and scrap[2]	W	W
Other	W	W
Total	236,000	625,000

[r]Revised. W Withheld to avoid disclosing company proprietary data; included in "Total."
[1]Data are rounded to no more than three significant digits.
[2]Includes lubricants (alone/in greases), steelmaking carbon raisers, additives in metallurgy, and other powder data.

TABLE 4
REPRESENTATIVE YEAREND GRAPHITE PRICES[1]

(Dollars per metric ton)

Type	2002	2003
Crystalline large, 94% to 97% carbon, +80 mesh	570-750	570-750
Crystalline large, 90% carbon, +80 mesh	480-550	480-550
Crystalline medium, 94% to 97% carbon, +100-80 mesh	560-640	560-640
Crystalline medium, 90% carbon, +100-80 mesh	370-410	370-410
Crystalline medium, 85% to 87% carbon, +100-80 mesh	230-350	230-350
Crystalline fine, 94% to 97% carbon, +100 mesh	450-600	450-600
Crystalline fine, 90% carbon, -100 mesh	350-400	350-400

[1]Prices are normally cost, insurance, and freight main European port.

Source: Industrial Minerals, no. 423, December 2002, p. 70; no. 435, December 2003, p. 74.

TABLE 5

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

	Natural[3]		Artificial[4]		Total	
Country	Quantity (metric tons)	Value[5] (thousands)	Quantity (metric tons)	Value[5] (thousands)	Quantity (metric tons)	Value[5] (thousands)
2002:						
Australia	285	$572	1,240	$4,660	1,520	$5,230
Belgium	21	20	2,330	4,570	2,350	4,590
Canada	3,720	2,410	5,760	10,900	9,480	13,300
China	243	174	2,740	1,860	2,980	2,030
France	837	1,210	2,640	14,600	3,480	15,900
Germany	1,150	1,260	442	1,430	1,590	2,690
Italy	1,090	1,940	742	3,380	1,830	5,320
Japan	83	146	14,200	9,170	14,300	9,320
Korea, Republic of	541	510	5,360	5,860	5,910	6,370
Malaysia	839	1,240	216	264	1,060	1,510
Mexico	3,630	1,590	6,090	3,690	9,720	5,280
Netherlands	2,860	1,020	10,900	4,240	13,700	5,260
Spain	1,010	1,260	197	418	1,210	1,680
United Kingdom	1,190	766	1,830	4,060	3,020	4,830
Venezuela	74	85	968	1,450	1,040	1,530
Other[6]	3,990	4,970	4,470	9,840	8,450	14,800
Total	21,600	19,200	60,100	80,500	81,700	99,600
2003:						
Australia	403	699	1,230	4,300	1,630	4,990
Belgium	107	74	3,680	4,460	3,790	4,530
Brazil	357	262	1,030	2,700	1,380	2,960
Canada	2,240	1,720	7,700	11,200	9,930	12,900
China	122	96	7,080	3,670	7,200	3,760
France	1,220	1,330	2,810	11,900	4,020	13,300
Germany	726	1,310	1,970	1,980	2,690	3,290
Israel	545	988	497	243	1,040	1,230
Italy	709	1,140	569	1,200	1,280	2,340
Japan	1,550	727	10,400	8,320	12,000	9,050
Korea, Republic of	486	463	4,360	3,980	4,840	4,450
Mexico	4,930	2,010	10,900	5,440	15,800	7,450
Netherlands	1,350	624	8,450	4,030	9,800	4,650
Taiwan	183	191	2,700	2,170	2,880	2,360
United Kingdom	2,670	1,640	3,520	6,290	6,190	7,930
Other[6]	4,640	6,270	2,850	6,080	7,500	12,300
Total	22,200	19,500	69,700	77,900	91,900	97,500

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

[2]Numerous countries for which data were reported have been combined in "Other."

[3]Amorphous, crystalline flake, lump and chip, and natural, not elsewhere classified. The applicable Harmonized Tariff Schedule (HTS) nomenclature titles and codes are "Natural graphite in powder or in flakes" and "Other," HTS codes 2504.10.0000 and 2504.90.0000, respectively.

[4]Includes data from the applicable HTS nomenclatures "Artificial graphite" and "Colloidal or semicolloidal graphite," HTS codes 3801.10.0000 and 3801.20.0000, respectively.

[5]Values are free alongside ship.

[6]Includes data for countries that receive less than 1,000 metric tons of total exports from the United States.

Source: U.S. Census Bureau.

TABLE 6
U.S. IMPORTS FOR CONSUMPTION OF NATURAL GRAPHITE, BY COUNTRY[1, 2]

Country or territory	Crystalline flake and flake dust		Lump and chippy dust		Other natural crude, high-purity, expandable		Amorphous		Total	
	Quantity (metric tons)	Value[3] (thousands)	Quantity (metric tons)	Value[3] (thousands)	Quantity (metric tons)	Value[3] (thousands)	Quantity (metric tons)	Value[3] (thousands)	Quantity (metric tons)	Value[3] (thousands)
2002:										
Brazil	4,190	$3,660	--	--	3	$7	--	--	4,190	$3,670
Canada	8,360	4,310	--	--	1	8	--	--	8,360	4,310
China	13,100 r	5,550 r	--	--	12 r	36 r	5,420 r	$967 r	18,500	6,550
Germany	173	136	--	--	11	96	--	--	184	232
India	36	52	--	--	(4)	3	--	--	36	55
Japan	--	--	--	--	293	1,550	391	37	684	1,580
Madagascar	2,030	970	--	--	--	--	--	--	2,030	970
Mexico	--	--	--	--	(4)	2	9,920	1,150	9,920	1,150
Sri Lanka	--	--	342	$416	--	--	--	--	342	416
Zimbabwe	80	43	--	--	--	--	--	--	80	43
Other[5]	61	41	--	--	748	3,320	--	--	809	3,360
Total	28,000 r	14,800 r	342	416	1,070 r	5,020 r	15,700 r	2,150 r	45,100	22,300
2003:										
Brazil	3,100	3,800	--	--	40	71	--	--	3,140	3,870
Canada	8,020	4,830	--	--	1	13	--	--	8,030	4,840
China	9,100	4,010	--	--	89	188	15,000	2,910	24,100	7,110
Germany	40	24	--	--	36	164	--	--	76	188
India	--	--	--	--	37	74	--	--	37	74
Japan	--	--	--	--	392	1,790	2,620	147	3,010	1,930
Madagascar	1,740	984	--	--	--	--	--	--	1,740	984
Mexico	4	3	--	--	2	42	10,700	1,240	10,700	1,280
Sri Lanka	--	--	531	1,200	--	--	--	--	531	1,200
Zimbabwe	120	60	--	--	--	--	--	--	120	60
Other[5]	92	56	--	--	638	2,770	20	3	750	2,830
Total	22,200	13,800	531	1,200	1,240	5,110	28,300	4,300	52,300	24,400

r Revised. -- Zero.

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

[2] The information framework from which data for this material were derived originated from Harmonized Tariff Schedule base data.

[3] Customs values.

[4] Less than 1/2 unit.

[5] Includes Austria, Belgium (2002), Finland (2003), France, Hong Kong (2002), Israel (2003), Italy, the Republic of Korea (2003), the Netherlands (2003), Russia (2003), Seychelles, South Africa (2002), Sweden, Switzerland, Taiwan (2002), the United Kingdom, and Venezuela (2002).

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

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

Country	Quantity (metric tons)	Value[3] (thousands)
2002:		
Brazil	3,870	$6,600
Canada	2,910	5,630
China	3,270	4,680
France	8,680	13,000
Germany	3,630	8,230
Italy	1,380	2,030
Japan	6,740	15,600
Mexico	27,500	44,000
Poland	2,310	3,610
South Africa	1,990	2,610
Spain	3,520	5,210
Other[4]	1,470	2,200
Total	67,300	114,000
2003:		
Brazil	3,080	4,880
Canada	4,570	10,100
China	10,900	15,100
France	5,040	7,720
Germany	1,380	4,950
Italy	2,410	3,840
Japan	10,600	22,800
Mexico	38,600	57,500
Russia	2,390	2,510
South Africa	3,070	4,420
Spain	2,990	4,140
Other[4]	248	564
Total	85,300	139,000

[1]Data are rounded to no more than three significant digits; may not add to totals shown.
[2]The applicable Harmonized Tariff Schedule code and nomenclature title are 8545.11.0000, "Electric furnace electrodes."
[3]Customs values.
[4]Includes data for countries that ship less than 1,000 metric tons per year to the United States.

Source: U.S. Census Bureau.

TABLE 8
GRAPHITE: WORLD PRODUCTION, BY COUNTRY[1, 2]

(Metric tons)

Country	1999	2000	2001	2002	2003[e]
Austria	2,635 [r]	669 [r]	116 [r]	-- [r]	--
Brazil, marketable	53,503	71,208	70,091	60,922 [r]	61,000
Canada[e]	25,000 [3]	25,000	25,000	25,000	25,000
China[e]	300,000	430,000	450,000	450,000	450,000
Czech Republic	22,000	23,000	17,000 [r, e]	16,000 [r, e]	15,000
Germany, marketable[e]	300 [4]	300	300	300	300
India, run-of-mine[e, 5]	145,000	140,000	140,000	130,000	110,000
Korea, North[e]	33,000	30,000	25,000	25,000	25,000
Korea, Republic of	62	65	65	94 [r]	100
Madagascar	16,137	40,328	2,013	1,300 [r, e]	2,000
Mexico, amorphous	27,781	30,330	21,442	14,065 [r]	15,000
Mozambique	4,007	--	--	--	--
Norway[e]	2,500	2,500	2,500	2,400	2,400
Romania	1,041	1,251	1,176	1,001 [r]	1,000
Russia[e]	6,000	6,000	6,000	-- [r]	--
Sri Lanka	4,592	5,902	6,585	3,619 [r]	3,800
Sweden	4,500 [e]	5,108	963	900 [e]	850
Turkey, run-of-mine[e, 6]	15,000	15,000	15,000	15,000	15,000
Ukraine	7,461	7,431	7,500 [e]	7,500 [e]	7,500
Uzbekistan[e]	60	60	60	60	60
Zimbabwe	11,405	11,838	11,836	9,912	8,000
Total	682,000 [r]	846,000 [r]	803,000 [r]	763,000 [r]	742,000

[e]Estimated. [r]Revised. -- Zero.
[1]World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.
[2]Table includes data available through May 13, 2004.
[3]Source: World Mineral Statistics, British Geological Survey, 1995-99.
[4]Reported figure.
[5]Indian marketable production is 10% to 20% of run-of-mine production.
[6]Turkish marketable production averages approximately 5% of run-of-mine production. Almost all is for domestic consumption.