Graphite

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Graphite is one of three forms of crystalline carbon; the other two are diamond 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 the 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 and opaque and usually has a metallic luster; sometimes it exhibits a dull earthy luster. It is flexible, but not elastic. It has high electrical and thermal conductivities, is highly refractory, and is chemically inert.

Two general types of graphite, natural and synthetic, are found. Worldwide, natural graphite deposits occur as lenses or layers of disseminated or massive flakes. Graphitization of naturally occurring organic carbon may happen at temperatures from 300° C to 1,200° C. These temperatures could come from low-grade metamorphism or when an igneous intrusion contacts 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 comprises 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 U.S. 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 clay fractions 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.

The U.S. Geological Survey (USGS) obtained data in this report through a canvass of U.S. synthetic graphite producers and a canvass of natural graphite companies in the United States. The canvass of U.S. synthetic graphite producers collected data from 21 of 22 producers, and the canvass of natural graphite companies collected data from 97 of 106 companies and plants. Estimated data were used for the producers and companies that did not respond to the canvass. These two canvasses represented the majority of the graphite industry in the United States. All percentages in the report were computed based on the unrounded data.

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 $216,000. Madagascar crystalline flake natural graphite inventories in 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 (table 2). During 2002, total graphite sales from the strategic and critical materials stockpile were 33,620 t, the same amount as was sold in 2001. The value of the 2002 graphite sales was about $825,000. The remaining graphite in the Government stockpile inventory was sold in the first half of 2003 (Phyllis Webster, Market Analyst, Defense National Stockpile Center, oral commun., July 8, 2003).

Production

No natural graphite was mined in the United States in 2002, but the reported U.S. production of synthetic graphite reached 256,000 t with an estimated value of $657 million (table 4). Graphite is mined from open pit and underground mine operations. Open pit operations are more economical and, thus, are preferred where the overburden can be removed economically. Mines in Madagascar are mostly of this type. In the Mexico, Republic of Korea, and Sri Lanka where the deposits are deep, underground mining techniques are required.

Consumption

The use of graphite has changed dramatically in the past 20 years. Graphite exhibits properties of a metal and a nonmetal, 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 batteries, fuel cells, and refractories. Lubricity and thermal conductivity make it an excellent material for high-temperature applications because it results in a material that 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 high-technology products, such as friction materials and battery and fuel cells, require higher purity graphite.

U.S. consumption of natural graphite increased by about 17% to 39,400 t in 2002 from 33,800 t in 2001 (table 3). The natural graphite consumption data in table 3 includes mixtures of natural and manufactured graphite with the amorphous graphite. Consequently, the table 3 consumption numbers are higher than the computed apparent consumption numbers given in table 1. The crystalline grade increased in 2002 by nearly 17% to 17,500 t from 15,000 t in 2001, and amorphous grade increased by more than 16% to 21,900 t in 2002 from 18,800 t in 2001. This increased use translated to about a 16% increase in total graphite value in 2002. Three major industries continued to dominate in graphite usage and accounted for more than 55% of the graphite consumed by U.S. industry in 2002 (table 3). These three industries, in descending order of quantity consumed, were refractories, steelmaking, and brake linings. Foundries and lubricants industries together made up almost another 17% of U.S. graphite consumption. The refractories industry was the major consumer of crystalline flake graphite, increasing its graphite use by nearly 6% compared with 2001.

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 more than 44% of graphite usage in the United States. It was used mainly in batteries, refractories, and other electrical and thermal conductivity applications. Amorphous graphite is mainly used as a lubricant additive, and as a pigment in paints, and in plastic 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 remains the primary choice in North America, accounting 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 low-current, long-life batteries; porosity-enhancing inert fillers; powder metallurgy; valve and stem packing; rubber; static and dynamic seals; solid carbon shapes; catalyst supports; and steel. The use of graphite in low-current batteries is gradually giving way to carbon black, which is more economical.

Prices

Natural graphite prices apparently remained unchanged during 2002. Prices for crystalline and crystalline flake graphite concentrates ranged from $230 to $750 per metric ton, and prices for amorphous powder were not available (table 5). Ash content, 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 increased to $1,338 per ton in 2002 from $1,226 per ton in 2001.

Foreign Trade

Total imports of natural graphite decreased to 45,100 t in 2002 from 52,100 t in 2001, a decline of a little more than 13%, and the value declined to $22.3 million in 2002 from $23.3 million in 2001 (table 1). Principal import sources of natural graphite, in descending order of tonnage, were China, Mexico, Canada, and Brazil, which accounted for more than 70% of the value of total imports. Mexico continued to be the major supplier of amorphous graphite, and Sri Lanka provided the lump variety. A number of other producers supplied various types and grades of graphite to the United States; among the more notable were China and Japan. Total graphite exports decreased by about 11% to 81,700 t valued at $99.6 million in 2002 compared with 91,900 t valued at $100 million in 2001 (table 6).

World Review

World production of natural graphite decreased about 1% in 2002 to an estimated 813,000 t from 821,000 t in 2001. China maintained its position as the world's leading graphite producer with 450,000 t. India was the second largest graphite producer with 130,000 t, followed by Brazil, Canada, the Czech Republic, Mexico, and North Korea. These seven countries accounted for more than 92% of the world production (table 9). 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 more than 55% 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, 1997). Some of the new application areas include 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, such as 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 to fit 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. Advanced refining technology in the next few years, despite a weak refractory market and pricing pressure from Chinese material, could bring a reversal of fortune to the graphite industry.

Enigmatic clusters of carbon atoms called fullerenes, which are found as large carbon-cage molecules, have been puzzling scientists since 1985 when they were first discovered among the byproducts of laser-vaporized graphite (Pierson, 1993, p. 356-357). Their hollow spherical structure, which is reminiscent of the geodesic domes of architect Buckminster Fuller, earned them the names "buckyballs" and "fullerenes." Mistakenly called a new form of carbon, fullerenes have been found to exist in interstellar dust and in geologic formations on Earth. Fullerenes are fascinating because they exhibit unusual properties for carbon materials. For example, adding three alkali atoms per fullerene unit (C_{60}) results in a material that exhibits superconductivity at quite high temperatures (10 K to 40 K). These materials also exhibit lubricity superior to that of graphite. To date, no product based on fullerenes has been offered in the market. The full potential of fullerenes in practical applications remains to be explored.

Outlook

Refractory use trends of graphite will closely follow the events in the steel industry because it is mostly used in the manufacture of refractory brick used in iron and steel furnace linings. If the U.S. steel industry continues to benefit from the tariff levy on steel imports, then the share of graphite use in refractories may reach or exceed the levels of 2000. Brake linings and other friction materials will steadily consume 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 consume small amounts of natural graphite compared with major end-use markets, such as brake linings and refractories.

The advent of hybrid and electric vehicles is expected to bring increased demand for high-purity graphite in fuel cell and battery applications. One optimistic prediction is that the demand for high-quality high-carbon graphite could increase to more than 100,000 metric tons per year for fuel cell and battery applications alone (Crossley, 2000). The global demand for graphite used in batteries may increase to more than 25,000 tons per year 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 dominantly used in these batteries; but 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 a balancing act between 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 tons per year in just 2 to 3 years. Canada, Germany, Japan, and the United States are aggressively promoting fuel cell development. The cost of fuel cells, however, is still too high for commercial vehicles. The price per unit must drop to about $1,500 before they will be viable. Daimler-Chrysler Corporation pledged to have a commercially viable fuel cell vehicle by 2004, and trials for fuel cell bicycles, buses, and taxis have already begun.

In the event of price increases, China may increase its production to take advantage of potentially increased profits, leading to a sharp price decline in certain grades and possibly to a production stoppage in other countries. If the Chinese iron and steel industry, however, expands its consumption of natural graphite, then Chinese exports may eventually decline, encouraging new producers to enter the market (Roskill Information Services Ltd., 1998, p. 122).

Industry trends that appear to be common to advances in graphite technology and markets include higher purity and consistency in specifications for some specialized and high-tech applications. Production of higher purity graphite using thermal processing and acid leaching techniques continues to be the trend. This material has applications as advanced carbon-graphite composites.

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TABLE 1
SALIENT NATURAL GRAPHITE STATISTICS[1]

(Metric tons and thousand dollars)

	1998	1999	2000	2001	2002
United States:					
Apparent consumption[2]	33,600	26,400	39,000	28,200	23,600
Exports	28,000	29,400	21,800	23,900	21,600
Value	$14,100	$15,200	$12,500	$16,900	$19,200
Imports for consumption	61,600	55,800	60,800	52,100	45,100
Value	$34,800	$34,700	$32,500	$23,300	$22,300
World, production	651,000	692,000	857,000	821,000 r	813,000 e

eEstimated. rRevised.
[1]Data are rounded to no more than three significant digits.
[2]Domestic production plus imports minus exports.

TABLE 2
U.S. GOVERNMENT STOCKPILE GOALS AND YEAREND STOCKS OF NATURAL GRAPHITE IN 2002, BY TYPE[1, 2]

(Metric tons)

Type	Stocks
Sri Lanka amorphous lump	1,480
Madagascar crystalline flake	18
Natural graphite fines	3,710
Total	5,210

[1]Graphite no longer has a goal.
[2]Data are rounded to no more than three significant digits; may not add to total shown.

Source: Defense National Stockpile Center, Total Uncommitted Inventory of Stockpile Material as of December 31, 2002, as reported by Phyllis Webster, Market Analyst.

TABLE 3
U.S. CONSUMPTION OF NATURAL GRAPHITE, BY END USE[1]

	Crystalline		Amorphous[2]		Total	
End use	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
2001:						
Batteries	W	W	--	--	W	W
Brake linings	886	$1,610	5,540	$4,400	6,420	$6,010
Carbon products[3]	358 r	1,060	254 r	266 r	612 r	1,320 r
Crucibles, retorts, stoppers, sleeves, nozzles	W	W	W	W	W	W
Foundries[4]	W	576	W	1,460	W	2,030
Lubricants[5]	322 r	487 r	284	444	606 r	931 r
Pencils	334	W	82	W	416	W
Powdered metals	444 r	809 r	W	W	W	W
Refractories	W	2,420 r	3,860	2,780	W	5,200 r
Rubber	52	79	W	319	W	397
Steelmaking	W	W	W	4,200	W	W
Other[6]	W	W	W	675 r	W	W
Total	15,000 r	15,800 r	18,800	14,700 r	33,800 r	30,400 r
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

[r]Revised. W Withheld to avoid disclosing company proprietary data; included in "Total." -- Zero.
[1]Data are rounded to no more than three significant digits.
[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 4

U.S. PRODUCTION OF SYNTHETIC GRAPHITE, BY END USE[1]

End use	Quantity (metric tons)	Value (thousands)
2001:		
Anodes	W	W
Cloth and fibers (low modulus)	W	W
Electric motor brushes and machined shapes	W	$22,000
Electrodes	185,000	484,000
High-modulus fibers	2,680	52,300
Unmachined graphite shapes	6,030	69,000
Synthetic graphite powder and scrap[2]	95,000	W
Other	W	W
Total	298,000	906,000
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	2,000	44,200
Unmachined graphite shapes	8,490	65,800
Synthetic graphite powder and scrap[2]	W	W
Other	W	W
Total	256,000	657,000

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

TABLE 5

REPRESENTATIVE YEAREND GRAPHITE PRICES[1]

(Per metric ton)

Type	2001	2002
Crystalline large, 94% to 97% carbon, + 80 mesh	XX	$570-$750
Crystalline large flake, 94% carbon	$570-$750	570-750
Crystalline large, 90% carbon, +80 mesh	XX	480-550
Crystalline large flake, 90% carbon	480-550	480-550
Crystalline medium, 94% to 97% carbon, + 100-80 mesh	XX	560-640
Crystalline medium, 90% carbon, +100-80 mesh	XX	370-410
Crystalline medium flake, 90% carbon	370-410	370-410
Crystalline medium, 85% to 87% carbon, + 100-80 mesh	XX	230-350
Crystalline fine, 94% to 97% carbon, + 100 mesh	XX	450-600
Crystalline fine, 90% carbon, +100 mesh	XX	350-400
Crystalline small flake, 80% to 95% carbon	270-500	XX
Amorphous powder, 80% to 85% carbon	220-235	NA
Synthetic, 99.95% carbon, Swiss border	2,070	NA

NA Not available. XX Not applicable.

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

TABLE 6
U.S. EXPORTS OF NATURAL AND ARTIFICIAL GRAPHITE, BY COUNTRY[1, 2]

Country	Natural[3] Quantity (metric tons)	Natural[3] Value[5] (thousands)	Artificial[4] Quantity (metric tons)	Artificial[4] Value[5] (thousands)	Total Quantity (metric tons)	Total Value[5] (thousands)
2001:						
Australia	528	$869	1,110	$3,150	1,630	$4,020
Brazil	67	56	1,110	3,280	1,170	3,340
Canada	7,270	3,500	6,260	11,800	13,500	15,300
France	589	238	2,820	15,300	3,410	15,600
Germany	189	304	862	2,830	1,050	3,130
Italy	698	1,330	383	858	1,080	2,180
Japan	368	370	20,000	17,000	20,400	17,400
Korea, Republic of	355	485	5,460	4,730	5,810	5,210
Malaysia	935	970	264	366	1,200	1,340
Mexico	1,950	1,100	2,910	3,420	4,870	4,520
Netherlands	3,280	1,170	18,900	7,450	22,100	8,620
Singapore	171	229	1,210	731	1,380	960
Switzerland	2,840	1,120	81	170	2,920	1,290
United Kingdom	682	474	1,380	4,200	2,060	4,680
Other[6]	3,980	4,680	5,290	8,040	9,280	12,700
Total	23,900	16,900	68,000	83,400	91,900	100,000
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

[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 within the "Other" category under the "Country" list.
[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.
[4]Includes data from the applicable HTS nomenclatures: "Artificial graphite" and "Colloidal or semicolloidal graphite," HTS codes 3801.10.0000 and 3801.20.0000.
[5]Values are free alongside ship.
[6]Includes data for countries reflecting less than 1,000 metric tons of total exports from the United States.

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

	Crystalline flake and flake dust		Lump and chippy dust		Other natural crude, high-purity, expandable		Amorphous		Total	
Country or territory	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)
2001:										
Brazil	974	$521	--	--	1,910	$3,070	--	--	2,890	$3,590
Canada	9,520	5,040	--	--	4	21	65	$4	9,590	5,070
China	6,390	3,190	--	--	7,960	2,430	1,100	238	15,400	5,860
Germany	126	106	--	--	17	85	--	--	142	191
India	168	195	--	--	100	268	--	--	267	463
Japan	--	--	--	--	550	3,110	2,470	138	3,020	3,240
Madagascar	2,500	1,180	--	--	--	--	--	--	2,500	1,180
Mexico	2	2	--	--	1	10	14,100	1,980	14,100	2,000
Norway	--	--	--	--	--	--	2,550	238	2,550	238
Sri Lanka	--	--	221	$301	--	--	--	--	221	301
Zimbabwe	140	65	--	--	--	--	--	--	140	65
Other[4]	205	92	--	--	316	855	784	172	1,310	1,120
Total	20,000	10,400	221	301	10,900	9,840	21,100	2,780	52,100	23,300
2002:										
Brazil	4,190	3,660	--	--	3	7	--	--	4,190	3,670
Canada	8,360	4,310	--	--	1	8	--	--	8,360	4,310
China	8,300	3,850	--	--	9,060	2,550	1,150	152	18,500	6,550
Germany	173	136	--	--	11	96	--	--	184	232
India	36	52	--	--	(5)	3	--	--	36	55
Japan	--	--	--	--	293	1,550	391	37	684	1,580
Madagascar	2,030	970	--	--	--	--	--	--	2,030	970
Mexico	--	--	--	--	(5)	2	9,920	1,150	9,920	1,150
Sri Lanka	--	--	342	416	--	--	--	--	342	416
Zimbabwe	80	43	--	--	--	--	--	--	80	43
Other[4]	61	41	--	--	748	3,320	--	--	809	3,360
Total	23,200	13,100	342	416	10,100	7,530	11,500	1,330	45,100	22,300

-- 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]Includes Austria, Belgium, France, Hong Kong, Italy, the Republic of Korea (2001), the Netherlands (2001), Seychelles, South Africa, Sweden, Switzerland, Taiwan, the United Kingdom, and Venezuela (2002).
[5]Less than 1/2 unit.

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

TABLE 8
U.S. IMPORTS FOR CONSUMPTION
OF GRAPHITE ELECTRODES, BY COUNTRY[1, 2]

Country	Quantity (metric tons)	Value[3] (thousands)
2001:		
Brazil	1,610	$3,310
Canada	1,960	5,140
China	3,670	6,110
France	3,290	6,210
Germany	3,580	8,970
India	1,400	2,510
Italy	2,840	4,450
Japan	9,520	24,500
Mexico	19,300	31,100
Russia	1,370	1,580
Other[4]	1,130	2,460
Total	49,700	96,300
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

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

[2]The applicable Harmonized Tariff Schedule (HTS) code and nomenclature title are HTS 8545.11.0000, "Electric furnace electrodes."

[3]Customs values.

[4]Includes data for countries reflecting less than 1,000 metric tons per year for imports.

TABLE 9
GRAPHITE: WORLD PRODUCTION, BY COUNTRY[1, 2]

(Metric tons)

Country	1998	1999	2000	2001	2002[e]
Austria	10,738	12,635	12,000 e	12,000 e	12,000
Brazil, marketable[3]	61,369	53,503	71,208	70,091 r	70,000
Canada[e]	25,000 4	25,000 4	25,000	25,000	25,000
China[e]	224,000	300,000	430,000	450,000	450,000
Czech Republic	28,000	22,000	23,000	23,000 r, e	25,000
Germany, marketable	270	300	300 e	300 e	300
India, run-of-mine[e, 5]	143,333 6	145,000	140,000	140,000	130,000
Korea, North[e]	35,000	33,000	30,000	25,000	25,000
Korea, Republic of	62	62	65	65 e	65
Madagascar[7]	20,629	16,137	40,328	2,013 r	1,000
Mexico:					
Amorphous	42,893	27,781	30,330	21,442 r	25,000
Crystalline flake	568	--	--	-- e	--
Mozambique	5,889	4,007	--	-- e	-- 6
Norway[e]	2,600	2,500	2,500	2,500	2,400
Romania	1,951	1,041	1,251	1,176 r	1,200
Russia[e]	6,000	6,000	6,000	6,000	6,000
Sri Lanka	5,910	4,592	5,902	6,585 r	6,600
Sweden	3,011	4,500 e	5,108 r	963 r	900
Turkey, run-of-mine[e, 8]	15,000	15,000	15,000	15,000	15,000
Ukraine	5,104	7,461	7,431	7,500 e	7,500
Uzbekistan[e]	60	60	60	60	60
Zimbabwe	13,806	11,405	11,838 r	11,836 r	9,912 6
Total	651,000	692,000	857,000	821,000 r	813,000

[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, 2003.

[3]Does not include the following quantities sold directly without beneficiation, in metric tons: 1998--10,747; 1999--10,700 (estimated); and 2000-2002--not available.

[4]Source: World Mineral Statistics, British Geological Survey, 1995-99.

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

[6]Reported figure.

[7]Exports. Source: United Nations, Department of International Economic and Social Affairs, Statistical Office.

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