GRAPHITE

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Graphite, one of three known forms of carbon, the other two are coal and diamond, occurs naturally in the Earth's crust in metamorphic rocks such as crystalline limestone, schist, and gneiss. It is a soft, black, naturally occurring form of carbon with a hardness of 2 on the Moh's scale and specific gravity between 2.1 and 2.3. High chemical inertness and acid resistance make its use ideal in acid environments and other chemical applications. Graphite exhibits outstanding thermal and electrical conductivities. Such properties, combined with high melting point of 3,500°C, in absence of oxygen, make it ideal for a number of refractory applications. Graphite fibers, drawn from organic precursors such as rayon, polyacrilonitrile, and tar pitch, are used as reinforcing components in polymer composites. Its high electrical conductivity is essential for use in the manufacture of carbon brushes for electric motors and batteries. Its low coefficient of friction makes it suitable for use as a high temperature lubricant, as a component in foundry facings, and as an ingredient in paint.

Two general types of graphite, natural and synthetic, are encountered. In the graphite industry, natural graphite is classified into three types: flake, high-crystalline, and amorphous. These, in turn, are subdivided into numerous grades for commercial purposes on the basis of such factors as graphite content, particle size, and impurity types.

Flake graphite consists of isolated, flat, platelike particles with angular, rounded or irregular edges. It is usually found in layers or pockets in metamorphic rocks. In some deposits, the flake graphite occurs as massive accumulations in veins, lenses, or podlike forms. It is thought to be derived from the metamorphism of methane and small droplets of crude oil in sedimentary deposits.

High-crystalline (vein-type) graphite occurs in fissure veins, fractures, and other cavities in igneous or metamorphic rocks, generally of Precambrian age. The graphite veins range from thin films to massive bodies more than 3 meters thick, and the particle size ranges from fine grains to large lumps of up to 10 centimeters in diameter. High-crystalline graphite is also thought to be formed from crude oil during metamorphism.

Amorphous graphite is formed by the thermal metamorphism of coal seams. Though crystalline in nature, its low degree of crystalline order and small particle size makes it appear amorphous. It is usually of lower purity than the crystalline flake graphite and, therefore, commands a lower price than its crystalline counterpart.

The terms "manufactured," "artificial," "electric furnace," and "synthetic" are all used to describe synthetic graphite. Three types of synthetic graphite are primary (electrographite), secondary, and graphite fibers. Primary graphite is essentially pure carbon produced from petroleum coke in electric furnaces and is used mainly in the manufacture of electrodes and carbon brushes. Secondary synthetic graphite more closely resembles the natural graphite in terms of purity, but has a lower density, higher electrical resistance, and higher porosity. Graphite fibers are used mostly in aerospace and sporting goods applications.

Legislation and Government Programs

Total National Defense Stockpile graphite inventories, excluding nonstock grade, were 15,600 metric tons with a dollar value of about $4.9 million. The uncommitted inventory was reported to be 4,930 tons valued at $2.5 million, all of which was authorized for disposal. Madagascar natural graphite inventories in the U.S. were 10,510 tons with a $1.65 million value. *(See table 2.)*

Production

Domestic graphite production information is gathered by the U.S. Geological Survey from a voluntary survey of the U.S. producers. Out of 179 companies surveyed, 107 (60%) responded, a decline of 14% over the l996 figures. Natural graphite was not mined in the United States in 1997; thus, all natural graphite is from foreign sources. Imports of natural graphite in 1997 into the United States were 58,100 tons at a value of $32.4 million. *(See table 6.)*

Graphite is mined from open pit and underground mine operations. Open pit operations are more economical and, thus, are preferred where the overburden is thin enough to remove. Madagascar mines are mostly open pit type. In the Republic of Korea, Mexico, and Sri Lanka, however, where the deposits are deep, underground mining is usually developed. Higher purity material is obtained by further refining steps.

Consumption

U.S. consumption of natural graphite declined moderately from 32,400 tons in 1996 to 30,100 tons in 1997. *(See table 3.)* The amorphous grade, in contrast to a 30% decline in 1996, increased from 13,100 tons in 1996 to 15,400 tons in 1997, an increase of 17.5%. The refractories industry, once again, was the major consumer of crystalline graphite followed by manufacture of brake linings and lubricants. Refractory applications of graphite include castable ramming, gunning mixtures, and shaped carbon-bonded brick. Carbon-magnesite brick containing crystalline flake graphite has applications in high-temperature corrosive environments such as steel furnaces, ladles, and blast furnaces. Carbon-alumina linings are principally employed in continuous steel casting operations. Both magnesite- and alumina-carbon refractory bricks require a fine particle size of 100 mesh and a purity of 95% to 99% graphite.

With its lubricating character and high thermal conductivity, graphite as substitution for asbestos in brake lining manufacture significantly reduces the heat generated because of friction, thus enhancing brake life. Other significant uses of graphite include the manufacture of long-life batteries furnishing low currents, steelmaking, rubber manufacture, and powder metallurgy. The use of graphite in low-current batteries is gradually giving way to carbon black, which is more economical and more efficient. The four major industries, refractories, brake linings, lubricants, and foundries again

led the way in graphite usage, accounting for over one-half the graphite consumed by U.S. industry in l997. *(See table 3.)*

Prices

Graphite price ranges have remained mostly constant over the last 4 years. Crystalline flake graphite concentrates, at $480 to $550 per ton, command higher prices than the amorphous (microcrystalline) type, priced at $220 to $300 per ton. Carbon content, flake and crystal size, size distribution, and ash content affect the price of graphite. Natural graphite prices are often subject to negotiations between the buyer and the seller, leading to a wide price range throughout the year. *(See table 4.)*

Foreign Trade

Total imports of natural graphite (flake crystalline and amorphous) increased significantly from l996 levels of 53,400 tons to 58,100 tons in 1997. This represents an increase of 9.0%.
Principal import sources of natural graphite were China, Canada, and Madagascar. Mexico continued to be the major supplier of amorphous graphite, Sri Lanka providing the chip and lump variety. In addition to the above four major countries, a number of other producers supplied various types and grades of graphite to the United States, among the more notable ones being Brazil, Germany, India, Japan, and South Africa *(See table 6).* Total exports also showed a healthy rise from 92,500 tons in 1996 to 119,000 tons in 1997, amounting to an impressive 28.6% increase over the 1996 value. *(See tables 5, 6, and 7.)*

World Review

World production of graphite, in 1997, estimated to be 575,000 tons in 1997, is a 2.5% increase over the 1996 output of 561,000 tons. China maintained its position as the world's leading graphite producer, with its production of 190,000 tons, with India claiming second place (120,000 tons), followed by Mexico, Republic of Korea, and Brazil. These five countries continued to account for three-quarters of the world production. *(See table 8.)*

Sri Lanka has, over the years, accounted for nearly all of the high-crystalline graphite produced. Sri Lankan deposits are estimated to average 95% graphite in situ, with estimates as high as 98 to 99%. The major consumption of high-crystalline graphite is in the production of carbon brushes, batteries, and friction materials.

Combined with the fall in world demand in the early 1990's, competition from cheap Chinese material led to non-Chinese producers reducing production or even leaving the market altogether. China now accounts for one-third of world production. However, economic recovery has now encouraged the opening of new operations in Canada, Mozambique, and Tanzania, producing high-quality crystalline flake (Roskill Information Services Ltd., 1998).

Current Research and Technology

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 friction materials, electronics, foil, and lubrication applications (Hand, l997).

Some of the new application areas include electrically conductive asphalt for heated runways at airports and roadway bridges with capability of melting an inch of snow per hour.
Such a rate would prevent accumulation of snow under almost any conditions.

Outlook

The main areas of natural graphite consumption in the near future will be in refractory applications for the iron and steel industry as existing users replace worn-out products and new users modernize their production facilities. Brake linings and other friction materials will steadily consume more natural graphite as new motor vehicle production continues to increase and more replacement parts are required for the growing number of existing vehicles. Flexible graphite product lines such as 'grafoil' will probably be the fastest growing market but will consume relatively small amounts of natural graphite compared with major end-use markets.

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

Industry trends that appear to be common to advances in graphite technology and markets include higher purity and consistency in specifications for high-tech applications. Production of higher purity graphite for applications such as advanced carbon-graphite composites, primarily through thermal processing and acid leaching, continues to be the current trend.

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[1]Prior to January 1996, published by the U.S. Bureau of Mines.

TABLE 1
SALIENT NATURAL GRAPHITE STATISTICS 1/

		1993	1994	1995	1996	1997
United States:						
Production	metric tons	--	--	--	--	--
Apparent consumption 2/	do.	34,800	32,900	23,500	27,400	18,400
Exports	do.	17,400	20,300	37,300	26,000	39,700
Value	thousands	$11,100	$13,100	$17,900	$14,600	$20,500
Imports for consumption	metric tons	52,200	53,100	60,700	53,400	58,100
Value	thousands	$29,900	$26,900	$30,100	$28,600	$32,400
World: Production	metric tons	648,000 r/	517,000 r/	585,000 r/	561,000 r/	575,000 e/

e/ Estimated. r/ Revised.

1/ Data are rounded to three significant digits.

2/ Domestic production plus imports minus exports.

TABLE 2
U.S. GOVERNMENT STOCKPILE GOALS AND YEAREND
STOCKS OF NATURAL GRAPHITE IN 1997, BY TYPE

(Metric tons)

Type	Goal	National stockpile inventory
Madagascar crystalline flake	(1/)	10,510
Sri Lanka amorphous lump	(1/)	4,930
Crystalline, other than Madagascar and Sri Lanka	(1/)	76
Nonstockpile-grade, all types	(1/)	51

1/ This commodity no longer has a goal.

Source: Defense National Stockpile Center, Inventory of Stockpile Materials as of December 31, 1997.

TABLE 3
U.S. CONSUMPTION OF NATURAL GRAPHITE, BY USE 1/

(Thousand metric tons and thousand dollars)

End use	Crystalline		Amorphous 2/		Total	
	Quantity	Value	Quantity	Value	Quantity	Value
1996:						
Batteries	W	W	--	--	W	W
Brake linings	1,090	$1,360	5,100	$4,270	6,190	$5,630
Carbon products 3/	472	1,410	376	365	847	1,770
Crucibles, retorts, stoppers, sleeves, and nozzles	898	824	7	14	906	839
Foundries 4/	560	478	724	346	1,280	824
Lubricants	434	942	1,620	1,440	2,050	2,380
Pencils	849	1,020	163	105	1,010	1,130
Powdered metals	511	1,170	19	42	530	1,210
Refractories	8,260	9,050	2,520	684	10,800	9,700
Rubber	168	326	584	336	753	662
Steelmaking	30	27	86	49	116	76
Other 5/	6,000	11,700	1,910	1,980	7,910	13,700
Total	19,300	28,300	13,100	9,630	32,400	37,900
1997:						
Batteries	W	W	--	--	W	W
Brake linings	782	877	4,720	3,620	5,500	4,500
Carbon products 3/	448	1,560	363	278	811	1,840
Crucibles, retorts, stoppers, sleeves, and nozzles	872	758	5	10	877	768
Foundries 4/	423	337	674	225	1,100	562
Lubricants	141	300	1,540	1,230	1,680	1,530
Pencils	680	757	152	30	832	787
Powdered metals	420	1,000	33	73	453	1,080
Refractories	5,810	4,260	5,560	4,030	11,400	8,290
Rubber	66	102	645	389	711	491
Steelmaking	22	18	907	300	929	318
Other 5/	5,090	7,690	787	782	5,880	8,470
Total	14,800	17,700	15,400	11,000	30,100	28,600

W Withheld to avoid disclosing company proprietary data; included with "Other."
1/ Data are rounded to 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, antiknock and other compounds, drilling mud, electrical/electronic devices, industrial diamonds, magnetic tape, mechanical products, packings, paints and polishes, seed coating, small packages, soldering/welding, and other end-use categories.

TABLE 4
REPRESENTATIVE YEAREND GRAPHITE PRICES 1/

(Per metric ton)

Type	1996	1997
Crystalline large flake, 85% to 90% carbon	$450-$550	$480-$550
Crystalline medium flake, 85% to 90% carbon	330- 500	330- 450
Crystalline small flake, 80% to 95% carbon	270- 500	270- 500
Amorphous powder, 80% to 85% carbon	220- 300	220- 300

1/ Prices are normally "Cost, insurance, and freight" (c.i.f.) main European port.

Source: Industrial Minerals; no. 351, December 1996, p. 72 and no. 363, December 1997, p. 78.

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/	Quantity (metric tons)	Value 5/	Quantity (metric tons)	Value 5/
1996:						
Canada	3,830	$3,290,000	6,770	$9,410,000	10,600	$12,700,000
France	324	151,000	8,280	8,830,000	8,610	8,980,000
Japan	811	642,000	17,700	8,200,000	18,500	8,860,000
Korea, Republic of	1,010	459,000	6,330	4,400,000	7,340	4,860,000
Mexico	9,250	3,510,000	3,950	2,130,000	13,200	5,640,000
Netherlands	366	186,000	7,690	3,470,000	8,050	3,650,000
Taiwan	2,390	1,520,000	1,100	1,110,000	3,490	2,630,000
Other	7,980	4,830,000	14,700	15,900,000	22,700	20,700,000
Total	26,000	14,600,000	66,600	53,400,000	92,500	68,000,000
1997:						
Canada	3,770	2,890,000	7,980	10,800,000	11,700	13,700,000
France	357	219,000	9,540	5,960,000	9,900	6,180,000
Japan	1,170	1,090,000	19,000	9,930,000	20,200	11,000,000
Korea, Republic of	3,130	1,250,000	9,180	5,550,000	12,300	6,800,000
Mexico	19,400	8,570,000	4,000	2,650,000	23,400	11,200,000
Netherlands	281	116,000	8,160	3,370,000	8,440	3,490,000
Taiwan	3,080	1,420,000	1,670	1,380,000	4,750	2,790,000
Other	8,470	4,900,000	20,200	14,200,000	28,700	19,100,000
Total	39,700	20,500,000	79,800	53,800,000	119,000	74,300,000

1/ Data are rounded to 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 title and code(s) are: "Natural graphite in powder or in flakes"/"Other;" HTS nos. 2504.10/90.0000.
4/ Includes data from the applicable "Harmonized Tariff Schedule" (HTS) nomenclatures: "Artificial graphite" and "Colloidal or semicolloidal graphite;" their respective HTS code nos. are 3801.10/20.0000.
5/ Values are f.a.s.

Source: Bureau of the Census.

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/ (thou-sands)	Quantity (metric tons)	Value 3/ (thou-sands)	Quantity (metric tons)	Value 3/ (thou-sands)	Quantity (metric tons)	Value 3/ (thou-sands)	Quantity (metric tons)	Value 3/ (thou-sands)
1996:										
Brazil	--	--	--	--	1,820	$2,940	--	--	1,820	$2,940
Canada	13,800	$9,740	--	--	308	198	--	--	14,200	9,940
China	2,270	1,080	--	--	6,540	2,250	5,810	$1,450	14,600	4,780
Germany	--	--	--	--	144	669	--	--	144	669
India	--	--	--	--	155	223	--	--	155	223
Japan	--	--	--	--	789	2,050	--	--	789	2,050
Madagascar	4,120	3,120	--	--	--	--	--	--	4,120	3,120
Mexico	--	--	--	--	--	--	14,800	1,980	14,800	1,980
Mozambique	472	464	--	--	--	--	--	--	472	464
South Africa	76	70	--	--	193	502	--	--	269	572
Sri Lanka	--	--	1,400	$945	--	--	--	--	1,400	945
Zimbabwe	448	298	--	--	--	--	--	--	448	298
Other 4/	63	157	--	--	79	263	80	166	222	586
Total	21,300	14,900	1,400	945	10,000	9,100	20,700	3,600	53,400	28,600
1997:										
Brazil	--	--	--	--	3,100	4,950	--	--	3,100	4,950
Canada	15,900	10,000	--	--	46	20	--	--	15,900	10,000
China	3,470	1,870	--	--	9,970	3,900	3,330	1,030	16,800	6,800
Germany	--	--	--	--	154	581	--	--	154	581
India	62	116	--	--	--	--	--	--	62	116
Japan	--	--	--	--	944	2,390	--	--	944	2,390
Madagascar	3,700	2,080	--	--	--	--	--	--	3,700	2,080
Mexico	--	--	--	--	--	--	14,600	2,230	14,600	2,230
Mozambique	378	316	--	--	--	--	--	--	378	316
South Africa	54	93	--	--	380	967	--	--	434	1,060
Sri Lanka	--	--	809	820	--	--	--	--	809	820
Zimbabwe	198	136	--	--	--	--	--	--	198	136
Other 4/	342	390	--	--	281	454	400	67	1,020	911
Total	24,100	15,000	809	820	14,900	13,300	18,300	3,320	58,100	32,400

1/ Data are rounded to 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 (HTS) base data.

3/ Customs values.

4/ Includes Australia (1997), Austria (1996), Belgium (1997), France, Hong Kong (1997), Italy (1997), the Republic of Korea, Namibia (1997), the Netherlands, Poland, Russia (1996), Sweden (1997), Switzerland, Taiwan (1997), Tanzania (1997), and the United Kingdom.

Source: Bureau of the Census, 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)
1996:		
Canada	14,900	$39,800
Germany	4,710	14,000
Italy	8,290	17,400
Japan	8,870	25,300
Mexico	14,600	22,600
Other 4/	8,000	16,000
Total	59,300	135,000
1997:		
Canada	12,900	38,400
Germany	5,550	16,100
Italy	11,600	25,600
Japan	7,160	24,300
Mexico	12,800	27,100
Other 4/	20,200	42,400
Total	70,200	174,000

1/ Data are rounded to 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 for yearly imports.

Source: Bureau of the Census.

TABLE 8
GRAPHITE: WORLD PRODUCTION, BY COUNTRY 1/ 2/

(Metric tons)

Country	1993	1994	1995	1996	1997 e/
Austria	4,146	12,324	12,019	12,000 e/	12,000
Brazil (marketable) 3/	29,472	35,965	28,028 r/	35,961 r/	36,000
Canada (exports of natural graphite)	-- r/	-- r/	-- r/	-- r/	--
China e/	310,000	183,000	204,000 r/	185,000 r/	190,000
Czech Republic e/	27,000	25,000	27,000	30,000 r/	30,000
Germany (marketable)	4,473 r/	4,369	5,214 r/	2,603 r/	2,800
India (run-of-mine) 4/	82,398	93,597	129,368 r/	115,233 r/	120,000
Korea, North e/	38,000	38,000	40,000	40,000	40,000
Korea, Republic of	5,910	4,300	1,938	1,113 r/	1,000
Madagascar 5/	11,182	12,715	16,119 r/	16,000 e/	16,000
Mexico:					
Amorphous	42,600	29,903 r/	32,938 r/	38,967 r/	40,000
Crystalline flake	960	960 r/ e/	1,450	1,445 r/	1,500
Mozambique	10 r/	430 r/	4,000 r/	5,000 r/ e/	7,500
Norway	6,500 e/	5,566	2,588 r/	2,500 e/	2,600
Romania	3,160 r/ e/	2,335	2,179 r/	2,931 r/	2,500
Russia e/	10,000	8,000	8,000	6,000	6,000
Sri Lanka	5,163	2,946 r/	8,000 r/	5,618 r/	6,000
Tanzania	--	--	359 r/	6,776 r/	6,800
Turkey (run-of-mine) e/ 6/	20,000	20,000	20,000	21,000	21,000
Ukraine e/	40,000	30,000	30,000	25,000	25,000
Zimbabwe	7,142	7,890	11,381	7,691 r/	8,000
Total	648,000 r/	517,000 r/	585,000 r/	561,000 r/	575,000

e/ Estimated. r/ Revised.

1/ World totals and estimated data have been rounded to three significant digits; may not add to totals shown.

2/ Table includes data available through May 11, 1998.

3/ Does not include the following quantities sold directly without beneficiation, in metric tons: 1993--3,516 (revised); 1994--2,735 (revised); 1995--3,368 (revised); 1996--4,134 (revised); and 1997--4,500 (estimated).

4/ Indian marketable production is 10% to 20% of run-of-mine production.

5/ Exports. Source: United Nations, Department of International Economic and Social Affairs, Statistical Office.

6/ Turkish marketable production averages approximately 5% of run-of-mine production. Almost all is for domestic consumption.