

GRAPHITE

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Graphite, one of three known forms of carbon, occurs naturally in the Earth's crust in metamorphic rocks such as crystalline limestones, schists, and gneiss. It may be found in large crystalline hexagonal plates or disseminated in small flakes. A third class, so-called amorphous graphite is commonly found in microcrystalline form—thus the amorphous character—in weakly metamorphosed rocks, such as slates and shales. Artificial, or synthetic, graphite is manufactured on a large scale in electric furnaces using anthracite or petroleum coke as raw feed.

Graphite is an excellent thermal and electrical conductor. The high melting point of graphite, in absence of oxygen, 3,500° C, makes it suitable for a number of refractory applications. Excellent acid resistance and general chemical inertness make its use ideal in acid environments and other chemical applications. Graphite fibers—drawn from organic precursors, such as rayon, polyacrylonitrile and tar-pitch—are used as the reinforcing components in polymer composites.

Domestic graphite production information is developed by the U.S. Geological Survey from a voluntary survey of the U.S. producers. Out of 179 companies surveyed, 132 (74%) responded, an increase of 10% over the 1995 figures. Three plants no longer produce and were removed from the list. Synthetic graphite figures were not tabulated for 1996 as less than one-half of the producers responded to the survey.

There was no mining of natural graphite in the United States in 1996, thus all natural graphite is from foreign sources. Imports of natural graphite in 1996 were 53,400 metric tons at a value of \$28.6 million. In 1996, the United States consumption of natural graphite was 32,400 tons at a value of \$37.9 million, whereas the exports of manufactured goods from artificial and natural graphite were 92,500 tons, amounting to a dollar value of \$68 million. (*See table 3.*)

Legislation and Government Programs

Total graphite inventories, excluding nonstock grade, reached 20,227 tons with a dollar value of about \$5 million. This total amount was the inventory of stockpile natural graphite—Sri Lanka—as uncommitted inventory was reported to be 4,930 tons valued at \$2.57 million, none of it authorized for disposal. Madagascar natural graphite inventories reached 14,400 tons with a \$2.22 million value. (*See table 2.*)

Production

As was the case in previous years, there was no natural graphite mining in the United States in 1996, hence all the

natural graphite processed was obtained through import channels. Principal import sources of natural graphite were Canada, China, and Madagascar. Mexico supplied the most of the amorphous graphite, and Sri Lanka providing the chip and lump graphite. 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.*)

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 crushing, grinding, and flotation steps.

Consumption

U.S. consumption of natural graphite declined significantly from 39,400 tons to 32,400 tons. (*See table 3.*) The largest decline is reflected in the amorphous grade which decreased 30%, from 18,800 to 13,100 tons. The refractories industry was the major consumer of crystalline graphite followed by brake lining manufacturers and lubricants. Refractory applications of graphite include both castable ramming and 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 fine particle size—100 mesh—and high purity—95% to 99% graphite.

Graphite as a substitute for asbestos in brake lining manufacture, with its lubricating character and high thermal conductivity, significantly reduces the heat generated due to 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 three major uses, refractories, brake linings, and foundries accounted for over one-half the graphite consumed by the U.S. industry in 1996. (*See table 3.*)

Prices

Prices of graphite have remained constant over the last 3 years. Crystalline flake graphite concentrates command higher prices than the amorphous (microcrystalline) type. 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) decreased 12% from 1995 levels (from 60,700 tons in 1995 to 53,400 tons in 1996). Most imports were from Mexico, Canada, and Taiwan. Total exports, on the other hand, showed an increase of 2.1%, from 90,600 tons to 92,500 tons. (*See tables 5, 6, and 7.*)

World Review

World production of graphite is estimated to be 644,000 tons, showing a significant decrease from the 1995 value of 741,000 tons. The most significant decrease in production was in China. China, however, continued to be the leading producer, followed by India, North Korea, Brazil, and Mexico. These countries accounted for almost three-quarters of total world production of graphite. (*See table 8.*)

Brazil's dominant graphite producer, Nacional de Grafite Ltda., started a new flake graphite operation at Salto da Dava in Minas Gerais, about 200 kilometers east of company's large graphite mining operations at Pedra Azul. Commissioning of the plant was expected to be late in 1996. Around 90% of the production will be targeted at export markets, particularly in North America (Industrial Minerals, 1996, p. 9).

Current Research and Technology

That new technologies for graphite products are being constantly developed is due, for the most part, to the 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, 1997, p. 34).

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 rate would prevent any accumulation of snow on the ground under almost any conditions.

Outlook

The general trend in materials and service is toward just-in-time (JIT) delivery. Customers would like to reduce their inventories to the lowest acceptable levels. They expect immediate delivery and appropriate technical assistance from the supplier. Joint cooperation with the allied industries is also a growing trend. In the past, suppliers developed the best product they could and went about trying to market it. Today, industries work together to engineer the best possible products to match the application requirements.

Industry trends that appear to be common to advances in graphite technology and markets include higher purity, consistency in specifications and supply sources. Production of higher purity graphite for specific applications, primarily through thermal processing and acid leaching appears to be the current trend.

The opportunities for the graphite industry and carbon products are numerous and promising. The need for high-tech graphite or carbon composites, be it in sporting goods manufacture or high temperature applications, will continue to fuel the development of high purity and high consistency products. Use of synthetic graphite in antilock brake applications, where it is used as friction modifier to provide sufficient lubrication to prevent locking up of brakes, is another area where significant growth may take place.

References Cited

- Hand, G.P., 1997, Outlook for graphite and graphite technology: Mining Engineering, v. 49, no. 2, February, p. 34-36.
Industrial Minerals, 1996, New mine plant for Nacional de Grafite: p. 9.

SOURCES OF INFORMATION

U.S. Geological Survey Publication

Graphite. Ch. In Mineral Commodity Summaries, annual.

Other

Chemical Week.
European Chemical News.
Industrial Minerals (London).

TABLE 1
SALIENT NATURAL GRAPHITE STATISTICS 1/

		1992	1993	1994	1995	1996
United States:						
Production	metric tons	--	--	--	--	--
Apparent consumption 2/	do.	29,500	34,800	32,900	23,500	27,400
Exports	do.	20,200	17,400	20,300	37,300	26,000
Value	thousands	\$12,200	\$11,100	\$13,100	\$17,900	\$14,600
Imports for consumption	metric tons	49,700	52,200	53,100	60,700	53,400
Value	thousands	\$25,500	\$29,900	\$26,900	\$30,100	\$28,600
World: Production	metric tons	670,000	670,000 r/	552,000 r/	741,000 r/	644,000 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 1996, BY TYPE

(Metric tons)

Type	Goal	National stockpile inventory
Madagascar crystalline flake	(1/)	14,400
Sri Lanka amorphous lump	12,200	4,930
Crystalline, other than Madagascar and Sri Lanka	(1/)	945
Nonstockpile-grade, all types	(1/)	126

1/ This commodity no longer has a goal.

Source: Defense National Stockpile Center, Inventory of Stockpile Materials as of Dec. 31, 1996.

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
1995:						
Batteries	W	W	--	--	W	W
Brake linings	2,530	\$3,580	5,980	\$4,980	8,510	\$8,570
Carbon products 3/	544	1,580	281	352	824	1,930
Crucibles, retorts, stoppers, sleeves, and nozzles	969	861	10	19	980	880
Foundries 4/	523	473	1,790	877	2,310	1,350
Lubricants	523	985	1,490	1,090	2,020	2,080
Pencils	1,100	1,100	642	600	1,740	1,700
Powdered metals	1,970	4,310	35	56	2,010	4,360
Refractories	5,770	5,310	4,180	3,550	9,950	8,860
Rubber	220	420	583	358	802	778
Steelmaking	125	178	1,100	422	1,220	600
Other 5/	6,330	11,600	2,760	2,310	9,080	13,900
Total	20,600	30,400	18,800	14,600	39,400	45,000
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

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	1995	1996
Crystalline large flake, 85% to 90% carbon	\$450-\$550	\$450-\$550
Crystalline medium flake, 85% to 90% carbon	330- 500	330- 500
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. 339, Dec. 1995, p. 64 and No. 351, Dec. 1996, p. 72.

TABLE 5
U.S. EXPORTS OF NATURAL AND ARTIFICIAL GRAPHITE, BY COUNTRY 1/ 2/

Country	Natural 3/		Artificial 4/		Total	
	Quantity (metric tons)	Value 5/	Quantity (metric tons)	Value 5/	Quantity (metric tons)	Value 5/
1995:						
Canada	3,560	\$2,790,000	4,980	\$9,810,000	8,540	\$12,600,000
France	633	215,000	4,700	8,390,000	5,330	8,610,000
Japan	7,290	2,790,000	13,800	5,930,000	21,100	8,720,000
Korea, Republic of	393	323,000	8,680	4,530,000	9,070	4,860,000
Mexico	6,640	2,780,000	1,190	679,000	7,830	3,460,000
Netherlands	266	103,000	6,710	3,290,000	6,980	3,390,000
Taiwan	7,830	3,440,000	993	625,000	8,820	4,060,000
Other	10,600	5,370,000	12,300	15,200,000	22,900	20,700,000
Total	37,300	17,900,000	53,300	48,500,000	90,600	66,400,000
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

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/ (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)
1995:										
Brazil	--	--	--	--	3,100	\$4,030	--	--	3,100	\$4,030
Canada	15,200	\$10,300	--	--	124	30	--	--	15,400	10,300
China	3,450	1,720	--	--	9,930	3,600	2,920	\$676	16,300	5,990
Germany	--	--	--	--	155	603	--	--	155	603
Hong Kong	--	--	--	--	(4/)	11	396	40	396	51
India	38	63	--	--	256	259	--	--	294	322
Japan	--	--	--	--	4,700	2,080	--	--	4,700	2,080
Madagascar	4,180	2,690	--	--	--	--	--	--	4,180	2,690
Mexico	--	--	--	--	--	--	14,500	2,080	14,500	2,080
Mozambique	--	--	--	--	--	--	--	--	--	--
South Africa	117	87	--	--	55	224	--	--	172	311
Sri Lanka	--	--	746	\$455	--	--	--	--	746	455
Zimbabwe	581	278	--	--	--	--	--	--	581	278
Other 5/	149	502	--	--	41	439	40	29	230	970
Total	23,700	15,600	746	455	18,400	11,300	17,900	2,830	60,700	30,100
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 5/	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

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/ Less than 1/2 unit.

5/ Includes Austria, Belgium (1995), Czech Republic (1995), France, Italy (1995), Kazakstan (1995), the Republic of Korea, the Netherlands, Poland, Russia (1996), Switzerland, Taiwan (1995), 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)
1995:		
Canada	11,200	\$30,900
Germany	2,420	7,430
Italy	8,230	14,700
Japan	8,020	21,700
Mexico	11,600	16,100
Other 4/	6,080	11,000
Total	47,500	101,800
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

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	1992	1993	1994	1995	1996 e/
Argentina	20	-- r/	-- r/	-- r/	--
Austria	19,796	4,146	12,324	12,019	12,000
Brazil (marketable) 3/	29,414	29,472	35,965	36,000 e/	36,000
Canada (exports of natural graphite)	17,400	18,700	21,711	22,000 e/	23,000
China e/	300,000	310,000	183,000 r/	350,000	250,000
Czech Republic e/ 4/	XX	27,000	25,000	27,000 r/	25,000
Czechoslovakia 5/	20,000	XX	XX	XX	XX
Germany (marketable)	11,963	8,363	4,369 r/	5,000 r/	4,000
India (run-of-mine) 6/	72,996	82,398	93,597 r/	114,959 r/	120,000
Korea, North e/	38,000	38,000	38,000	40,000	40,000
Korea, Republic of	8,412	5,910	4,300	1,938 r/	2,000
Madagascar	8,910	11,182 r/ 7/	12,715 r/ 7/	16,522 r/ 7/	16,000
Mexico:					
Amorphous	30,500	42,600	43,000 e/	32,738 r/	34,000
Crystalline flake	985	960	1,000 e/	1,450 r/	1,500
Mozambique	--	--	--	4,100 e/	4,100
Namibia	200 e/	--	--	--	--
Norway e/	7,000	6,500	5,566 r/ 8/	3,000 r/	2,500
Romania	2,300	2,000 e/	2,335 r/	2,180 r/	2,200
Russia e/	15,000	10,000	8,000	8,000	6,000
Sri Lanka	3,307	5,163	2,950	3,000 e/	3,000
Tanzania	--	--	--	--	6,000
Turkey (run-of-mine) e/ 9/	20,978 8/	20,000	20,000	20,000	21,000
Ukraine e/	50,000	40,000	30,000	30,000	25,000
Zimbabwe	12,346	7,142	7,890	11,381 r/	11,000
Total	670,000	670,000 r/	552,000 r/	741,000 r/	644,000

e/ Estimated. r/ Revised. XX Not applicable.

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 13, 1997.

3/ Does not include the following quantities sold directly without beneficiation, in metric tons: 1992--8,957; 1993--9,960; 1994--9,670 (revised); 1995--10,000 (estimated); and 1996--10,000 (estimated).

4/ Formerly part of Czechoslovakia; data were not reported separately until 1993.

5/ Dissolved Dec. 31, 1992.

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

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

8/ Reported figure.

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