BERYLLIUM

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Beryllium, silver in color and one of the lightest of all metals, has one of the highest melting points (about 1,280° C) of all light metals. It has physical and chemical properties, such as its stiffness, resistance to corrosion from acids, and electrical and thermal conductivity, that make it useful for various applications in its alloyed, oxide, and metallic forms. Only two beryllium minerals, beryl and bertrandite, are of commercial importance; beryl contains about 4% beryllium and bertrandite contains less than 1% beryllium. Bertrandite is the principal beryllium mineral mined in the United States, and beryl is the principal mineral produced in the rest of the world.

In 2003, U.S. production of beryllium ore and total ore consumption for the production of beryllium alloys, beryllium metal, and beryllium oxide increased from those of 2002 (table 1). The telecommunications and computer sector was the major market for beryllium.

The Defense National Stockpile Center (DNSC), U.S. Department of Defense, offered and sold selected beryllium materials from the National Defense Stockpile (NDS) (table 2). Yearend published price quotations for selected beryllium products remained unchanged from those of 2002 (table 3). Overall U.S. exports of beryllium were up substantially, and overall imports of beryllium were down significantly in 2003 compared with those in 2002 (tables 4, 5).

Legislation and Government Programs

To ensure a supply of beryllium during an emergency, various materials have been purchased for the NDS. The NDS goal for beryllium metal, effective as of December 28, 2001, was about 45 metric tons (t) (table 2). However, a goal of 155 t of hot-pressed beryllium metal powder was proposed in the 2003 National Defense Stockpile Requirements Report to the Congress. For fiscal year (FY) 2003 (October 1, 2002, through September 30, 2003), the DNSC sold about 32 t of beryllium metal valued at about $5.67 million from the NDS. There were no sales of beryl ore or beryllium-copper master alloy (BCMA) from the NDS. As of September 30, 2003, beryllium inventory sold but not shipped from the NDS included about 840 t of beryl ore (about 34 t of beryllium content), about 234 t of BCMA (about 9 t of beryllium content), and about 37 t of beryllium metal (U.S. Department of Defense, 2004, p. 12, 50, 55). In its revised Annual Materials Plan (AMP) for FY 2004 (October 1, 2003, through September 30, 2004) and proposed AMP for FY 2005 (October 1, 2004, through September 30, 2005), the DNSC had authority to sell about 3,630 t of beryl ore (about 145 t of beryllium content, actual quantity limited to remaining sales authority or inventory), about 1,090 t of BCMA (about 44 t of beryllium content, actual quantity limited to remaining sales authority or inventory), and about 36 t of beryllium metal (Defense National Stockpile Center, 2004a, b). For FY 2004, through June 30, 2004, the DNSC sold about 1,050 t of BCMA (about 42 t of beryllium content) valued at about $6.48 million and about 1,700 t of beryl ore (about 68 t of beryllium content) valued at about $148,000 from the NDS. There were no reported sales of beryllium metal from the NDS.

Production

The U.S. Geological Survey collects beryllium data from two voluntary surveys of U.S. operations. In 2003, respondents to the "Beryllium" and the "Mineral Concentrate and Beryllium Ore" surveys produced 100% of total domestic mine shipments presented in tables 1 and 7. A small number of unidentified producers may have shipped negligible quantities of byproduct beryl, which have not been included. In 2003, domestic mine shipments were up compared with those of 2002.

The United States, one of only three countries that processes beryllium ores and concentrates into beryllium products, supplies most of the rest of the world with these products. Brush Wellman Inc., Cleveland, OH, mined bertrandite and converted ore of this mineral, along with imported beryl, into beryllium hydroxide at its operations near Delta, UT. Beryllium hydroxide was shipped to the company's plant in Elmore, OH, where it was converted into beryllium alloys, metal, and oxide.

NGK Metals Corp. (a subsidiary of NGK Insulators, Ltd. of Japan), headquartered in Reading, PA, produced beryllium alloy products at a plant in Sweetwater, TN. Because NGK Metals does not have facilities to process beryllium ores and concentrates, the company purchases beryllium hydroxide from Brush Wellman.

Environment

Because of the toxic nature of beryllium, the industry must maintain careful control over the quantity of beryllium dust and fumes in the workplace. The U.S. Environmental Protection Agency issues standards for certain hazardous air pollutants, including beryllium, under the Clean Air Act, and the Occupational Safety and Health Administration (OSHA) issues standards for airborne beryllium particles. To comply with these standards, plants are required to install and maintain pollution-control equipment. In beryllium-processing plants, harmful effects are prevented by maintaining clean workplaces; requiring the use of safety equipment, such as personal respirators; collecting dust, fumes, and mists at the source; establishing medical programs; and implementing other procedures to provide safe working conditions. Standards for exposure to beryllium were under review by OSHA and private standard-setting organizations (Petkof, 1985, p. 80; Rossman, Preuss, and

Powers, 1991, p. 278-280; Kramer, 1998, p. 107-108; Brush Engineered Materials Inc., 2004, p. 21). Control of potential health hazards adds to the final cost of beryllium products.

Consumption

In 2003, domestic beryllium-containing ore consumption increased for the first time since 1998. According to its annual report, Brush Engineered Materials Inc.'s (BEM) worldwide sales were about $401 million in 2003 compared with about $373 million in 2002 and about $473 million in 2001. The increase in sales was due in part to "higher precious metal prices and favorable foreign currency translation effect." The domestic market accounted for 69% of the company's revenue; telecommunications and computer (35%), automotive electronics (14%), optical media (13%), and industrial components (11%) were the leading revenue markets. The Metal Systems Group, the company's largest reportable segment, which included Brush Wellman Inc.'s Alloy Products and Beryllium Products business units, had sales of about $239 million compared with about $228 million in 2002 and accounted for about 60% of total company sales and almost 70% of total assets. Alloy Products, the company's largest business unit, had sales of about $162 million compared with about $152 million in 2002, and accounted for about 40% of company's revenue, supplying strip and bulk products. The sales growth was due to the increased demand for higher beryllium-containing/higher priced alloy strip products. Bulk products sales decreased. Alloy strip products (major markets include appliances, automotive electronics, and telecommunications and computer products) and alloy bulk products (applications include bearings, bushings, plastic mold tooling, telecommunications housing equipment, and welding rods) were manufactured at company facilities in Ohio and Pennsylvania. Beryllium Products (consisting of pure beryllium metal and beryllium aluminum alloys) were manufactured at company facilities in California and Ohio. Sales were up by 11% compared with sales in 2002, with strong sales for defense and government-related applications. The company's international sales totaled about $124 million ($89 million from international operations, with service centers in Germany, Japan, Singapore, the United Kingdom, and about $35 million from exports of U.S. operations) compared with about $104 million in 2002. Company international sales were mostly to Canada, Europe, and the Pacific Rim. Automotive electronics and telecommunications and computers were the major markets served by the international operations (Brush Engineered Materials Inc., 2004, p. 1, 14, 16-18, 20).

BEM has agreements, which expire in 2007, with the U.S. Defense Logistics Agency to purchase beryl ore, BCMA, and beryllium metal from the NDS. Annual purchase commitments total approximately $6.4 million in 2004 through 2007. "The beryllium component of the contract price is adjusted quarterly from these stated totals based upon fluctuations in the nonseasonally adjusted consumer price index. The company may elect to take delivery of the materials in advance of the commitment date." Purchases totaled approximately $5.7 million in 2003, $3.9 million in 2002, and $6.4 million in 2001. The purchased material serves as raw material input for operations within the company's Brush Wellman and Brush Resources Inc. subsidiaries (Brush Engineered Materials Inc., 2004, p. 48).

BEM also has a long-term supply arrangement, signed in 2000 and amended in 2001 and 2003, with Ulba/Kazatomprom in Kazakhstan and its marketing representative Nukem Inc. in Connecticut to purchase BCMA and beryllium vacuum-cast billets through 2012. All materials are sourced from Ulba/Kazatomprom. Annual base purchase commitments total between $5.3 million and $5.6 million for 2004 through 2007, with the price per pound escalating each year through 2007. "A new price will be renegotiated for the years 2008 through 2012. If a new price cannot be agreed to by December 31, 2007, then the material purchases will terminate with the 2008 delivery volumes. The contract allows for the company to purchase additional quantities of copper beryllium master alloy up to an annual maximum of 150,000 pounds of beryllium contained in the master alloy. The purchase of beryllium vacuum cast billets can be plus or minus 10% of the annual base quantity," according to the BEM annual report. Purchases of beryllium-containing material from Nukem totaled $3.3 million in 2001 and were negligible in 2002 and 2003 (Brush Engineered Materials Inc., 2004, p. 48).

U.S. apparent consumption of all beryllium materials was estimated to be about 200 t of contained beryllium in 2003 compared with about 180 t in 2002.

Beryllium-Copper Alloys.—Beryllium-copper alloys, most of which contain approximately 2% beryllium, are used in a wide variety of applications. These alloys are used because of their electrical and thermal conductivity, good corrosion and fatigue resistance, high strength and hardness, and nonmagnetic properties. Beryllium-copper strip is manufactured into connectors, springs, and switches for use in applications in aerospace, automobiles, computers, factory automation, home appliances, instrumentation and control systems, and radar and telecommunications. The principal use of large-diameter beryllium-copper tubing is in oil and gas drilling equipment and in bushings and bearings in aircraft landing gear and heavy machinery. Connectors in fiber-optic telecommunications systems are the main application for beryllium-copper rod. Small pluggable sockets for joining integrated circuits to printed circuit boards are the main application for beryllium-copper wire. Beryllium-copper bar and plate are used in resistance-welding parts components for machinery and materials-handling systems and for molds to make glass, metal, and plastic components.

Beryllium also is used in small quantities in aluminum- and nickel-base alloys. Miniature electronic connector components that operate at high temperatures are the main use for beryllium-nickel alloys. These alloys also are used in automotive passive restraint systems (airbags). Beryllium-aluminum alloys are used as castings by the aerospace industry. The addition of small quantities of beryllium to magnesium alloys inhibits oxidation.

Beryllium Metal.—Beryllium metal is used principally in aerospace and defense applications. Its dimensional stability within a wide temperature range, high level of stiffness, and light weight, make it useful in inertial guidance systems,

military aircraft brakes, satellite and space vehicle structures, and space optical system components. Because beryllium is transparent to most x rays, it is used for x-ray windows. In nuclear reactors, beryllium also serves as a canning material and a neutron moderator in control rods. In the past, the metal had been used as a triggering device in nuclear warheads. Other applications for metallic beryllium include audio components, high-speed computer components, and mirrors.

Beryllium Oxide.—Beryllium oxide (BeO, beryllia), which has a high level of hardness and strength, is an excellent heat conductor. This material also acts as an electrical insulator in some applications. Beryllium oxide serves mainly as a substrate for high-density electronic circuits for automotive ignition systems, high-speed computers, lasers, and radar electronic countermeasure systems. Because it is transparent to microwaves, microwave communications systems and microwave ovens may use beryllium oxide.

Because the cost of beryllium is high compared with that of other materials, it is used in applications in which its properties are crucial. Graphite, steel, and titanium may be substituted for beryllium metal in some applications, and phosphor bronze may be substituted for beryllium-copper alloys, but these substitutions can result in substantial loss in performance. In some applications, aluminum nitride may be substituted for beryllium oxide.

Recycling

Beryllium was recycled mostly from new scrap that was generated during the manufacture of beryllium-related components. Detailed data on the quantities of beryllium recycled are not available but may compose as much as 10% of U.S. apparent consumption (Cunningham, 2004, p. P1-P3). Processing methods, such as casting, crushing, grinding, melting, shot-blasting, shredding, sparking, or welding beryllium products, used by scrap recyclers can produce potentially hazardous particles (Scrap, 2002). "Handling beryllium or beryllium-containing materials in solid form posses [sic] no special health risks. Yet, as a dust or airborne particulate, beryllium and beryllium-containing materials, like many other materials or substances, may require special handling to reduce potential health risks." Since 1985, suppliers of scrap materials to scrap handlers or recyclers have been obligated under OSHA Hazard Communication regulations (29 CFR §1910.1200) to inform the recipients of potential health risks (Scrap, 2003).

Prices

Yearend price quotes for beryllium materials and products are shown in table 3. The American Metal Market (AMM) published prices for selected beryllium products (discontinued in February 2002) were as follows: beryllium vacuum-cast ingot, a range of $325 to $350 per pound; beryllium-aluminum alloy, $260 per pound; BeO powder, $100 per pound; and beryllium-copper strip, $8.90 per pound. The AMM published price for 99% pure beryllium metal powder was discontinued in February 2003 at a range of $350 to $400 per pound. The yearend Platts Metals Week published prices for selected beryllium products were as follows: BCMA, $160 per pound of contained beryllium; beryllium-copper alloy, $9.95 per pound; and beryllium-copper cast ingot, $6.40 per pound. The Metal Bulletin published price for beryl ore was discontinued in October 2001 at a range of $75 to $80 per short ton unit of contained BeO.

Foreign Trade

Data for U.S. exports and imports are summarized in tables 4 and 5, respectively. Overall beryllium exports were up substantially compared with those of 2002. Japan was the major recipient of the materials, with more than 75% of the total in 2003. Other major recipients of the materials included Canada, Germany, Singapore, and the United Kingdom. Overall, beryllium imports were down by almost 20%, with a significant decrease in BCMA imports. The schedule of tariffs applied during 2003 to U.S. imports of selected beryllium materials is found in the U.S. International Trade Commission's Publication 3565, 2003 Harmonized Tariff Schedule of the United States (U.S. International Trade Commission, 2002).

Net import reliance as a percentage of apparent consumption is used to measure the adequacy of current domestic beryllium production to meet U.S. demand. For 2003, net import reliance as a percentage of apparent consumption was estimated to be about 58% compared with about 56% in 2002. In descending order, Kazakhstan, Spain, Brazil, and Mexico were the major sources for U.S. beryllium imports, on the basis of contained beryllium, accounting for about 95% of the total. Other sources of imports included China and Nigeria.

The U.S. Census Bureau does not separately identify all imports and exports of beryllium products. The Journal of Commerce Port Import/Export Reporting Service (PIERS) provides some data on materials that are transported by ship. According to PIERS, about 515 t, gross weight, of beryllium products (mostly beryllium ore from Brazil and beryllium-copper from Japan) was imported in 2003. Exports of beryllium products (mostly beryllium-copper in various forms) totaled about 340 t, gross weight; Hong Kong and Japan received more than 80% of this material.

World Review

Annual world beryllium mine production capacity (beryl and bertrandite) (metric tons of contained beryllium) is listed in table 6. Estimated world beryllium mine production (metric tons, gross weight) is listed in table 7. In 2003, estimated world beryllium mine production increased by about 5% compared with that of 2002. The two major producers, Russia and the United States, accounted for about 94% of total production.

In Kazakhstan, the 5-year $25 million investment at the Ulba Metallurgical Plant ($13 million allocated for the beryllium business) was scheduled for completion in 2005. The beryllium investment included increasing production capacity for BCMA by 3,000 metric tons per year (t/yr), extending the beryllium-copper product range and increasing production capacity by up to 1,000 t/yr, and developing of digestive and

refining production methods to produce beryllium hydroxide to international standards (McNeil, 2003).

In China, the Ningxia Non-Ferrous Metals Smelter (NNMS), the Shuikoushan Non-Ferrous Metal Co. (SNMC), and the Ningxia Orient Tantalum Industry Co. (partly owned by NNMS and SNMC) produced beryllium products in various forms with an estimated annual combined production capacity of about 20 t/yr of beryllium, mainly in the form of beryllium-copper alloys (McNeil, 2003).

Outlook

The United States is expected to remain self-sufficient with respect to most of its beryllium requirements. In 2003, the United States consumed about 140 t of beryllium in beryllium-bearing ores compared with about 120 t in 2002. At yearend 2003, Brush Engineered Materials reported proven bertrandite reserves in Juab County, UT, of about 6.1 million metric tons with an average grade of 0.267% beryllium. This represents about 16,200 t of contained beryllium compared with about 16,300 t in 2002. Proven reserves were reported to be sufficient for about another 100 years of operation based on average production levels in recent years. Approximately 87% of the beryllium is recovered from the ore during the extraction process. As of 2001, the company owned approximately 95% of its proven mineral reserves (Brush Engineered Materials Inc., 2004, p. 25).

Beryllium alloys, primarily beryllium-copper, are expected to remain the dominant form of consumption for beryllium. Demand for beryllium-copper products for undersea communications equipment and pipe products for the oil and gas industry was expected to increase. Beryllium-aluminum alloys containing up to about 65% beryllium, compared with beryllium-copper alloys containing about 2% beryllium, may stimulate demand in applications such as aerospace and computers. Beginning in 2003, annual world beryllium consumption was forecast to increase by about 2% per year (Roskill Information Services Ltd., 2001, p. 1-5, 120-123).

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TABLE 1
SALIENT BERYLLIUM MINERAL STATISTICS

(Metric tons of beryllium metal equivalent)

	1999	2000	2001	2002	2003
United States, beryllium-containing ores:					
Mine shipments	200	180	100	80	85
Imports for consumption, beryl[1]	1	--	19	10	9
Consumption, reported	260	240	170	120	140
Yearend stocks	20	115	100	90	45
World, production[1]	248	226	145	126 r	132

rRevised. -- Zero.
[1]Based on a beryllium metal equivalent of 4% in beryl.

TABLE 2
BERYLLIUM IN GOVERNMENT INVENTORIES AS OF DECEMBER 31, 2003

(Metric tons of beryllium content)

			National Defense Stockpile inventory	
Material	Stockpile goal[1]	Disposal authority	Uncommitted	Committed
Beryllium ore	--	227	227	34
Beryllium-copper master alloy	--	40	40	1
Beryllium metal:				
Vacuum-cast	--	86	86	(2)
Hot-pressed powder	45	110	155	(2)

-- Zero.
[1]Goal effective as of December 28, 2001.
[2]About 35 tons of beryllium metal committed for sale/pending shipment.

Source: Defense National Stockpile Center.

TABLE 3
BERYLLIUM PRICES AT YEAREND 2003

(Dollars per pound unless otherwise specified)

Material		Price
Beryl ore		(1)
Beryllium vacuum-cast ingot, 98.5% pure, in lots up to 1,000 pounds		$325-350 [2]
Beryllium metal powder, 99% pure		350-400 [3]
Beryllium-copper master alloy	per pound of contained Be	160
Beryllium-copper alloy		9.95
Beryllium-copper cast ingot		6.40
Beryllium-copper in rod, bar, wire		9.85 [2]
Beryllium-copper in strip		8.90 [2]
Beryllium-aluminum alloy, in lots up to 100 pounds; 62% Be, 38% Al		260 [2]
Beryllium oxide powder, in 10,000-pound lots		100 [2]

[1]The Metal Bulletin published price for beryl ore was discontinued in October 2001 at a range of $75 per short ton unit to $80 per short ton unit of contained beryllium oxide.
[2]The price was discontinued in February 2002.
[3]The price was discontinued in February 2003.

Sources: American Metal Market, Brush Wellman, Inc., Metal Bulletin, and Platts Metals Week.

TABLE 4
U.S. EXPORTS OF BERYLLIUM ALLOYS, WROUGHT OR UNWROUGHT, AND WASTE AND SCRAP, BY COUNTRY[1, 2]

(Gross weight)

	2002		2003	
Country	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
Canada	17,400	$497	16,000	$413
France	3,540	853	4,540	668
Germany	21,700	1,230	7,620	807
Japan	92,900	1,950	206,000 [3]	7,280 [3]
Netherlands	8,510	357	3,690	308
Singapore	1,040	1,710	8,210	3,560
United Arab Emirates	300	95	137	315
United Kingdom	2,350	1,410	12,800	4,530
Other	17,300 [r]	1,110 [r]	9,910	869
Total	165,000	9,210	269,000	18,800

[r]Revised.
[1]Consisting of beryllium lumps, single crystals, powder; and beryllium rods, sheets, and wire.
[2]Data are rounded to no more than three significant digits; may not add to totals shown.
[3]All or part of these data have been referred to the U.S. Census Bureau for verification.

Sources: U.S. Census Bureau and U.S. Geological Survey.

TABLE 5
U.S. IMPORTS FOR CONSUMPTION OF BERYLLIUM ORE, METAL, AND COMPOUNDS[1]

(Gross weight)

	2002		2003	
Material	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
Beryllium-containing ores	274,000	$182	237,000	$128
Beryllium-copper master alloy	108,000	1,170	20,000	200
Beryllium oxide and hydroxide	20	5	25	6
Beryllium, unwrought and waste and scrap	125,000	2,060	153,000	2,930

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

Sources: U.S. Census Bureau and U.S. Geological Survey.

TABLE 6
WORLD ANNUAL BERYL PRODUCTION CAPACITY, DECEMBER 31, 2003[1]

(Metric tons of beryllium content)

Continent and country	Capacity
North America, United States[2]	360
Africa:	
Madagascar	4
Mozambique	5
Rwanda	3
South Africa	3
Total	15
Asia, China	75
Europe:	
Kazakhstan	8
Portugal	3
Russia	70
Total	81
South America, Brazil	4
Grand total	535

[1]Includes capacity at operating plants as well as at plants on standby basis.
[2]Includes bertrandite ore.

TABLE 7
BERYL: ESTIMATED WORLD PRODUCTION, BY COUNTRY [1, 2]

(Metric tons of gross weight)

Country[3]	1999	2000	2001	2002	2003
Brazil	11 [4]	13 [4]	12	12	12
Kazakhstan	100	100	100	100	100
Madagascar[5]	20	2 [4]	1 [4]	1	1
Mozambique	--	19 [r, 4]	1 [4]	54 [r, 4]	78
Portugal	4	4	5	5	5
Russia	1,000	1,000	1,000	1,000	1,000
United States, mine shipments[6]	5,070	4,510	2,480	1,970	2,100
Zambia	7	7	7	7	7
Total	6,210	5,660 [r]	3,610	3,150 [r]	3,300

[r]Revised. -- Zero.
[1]World totals, U.S. data, and estimated data are rounded to no more than three significant digits; may not add to totals shown.
[2]Table includes data available through June 11, 2004.
[3]In addition to the countries listed, China produced beryl, and Bolivia may also have produced beryl, but available information is inadequate to formulate reliable estimates of production.
[4]Reported figure.
[5]Includes ornamental and industrial products.
[6]Includes bertrandite ore, calculated as equivalent to beryl containing 11% beryllium oxide.