Boron

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Boron, a nonmetal, has atomic number 5 and is in periodic group 13. Elemental boron is a dark brown powder in the amorphous form and a yellowish-brown hard, brittle solid in the monoclinic crystalline form. Elemental boron is marketed in grades from 90% to 99% purity. Borax is a white crystalline substance chemically known as sodium tetraborate decahydrate and found in nature as the mineral tincal. Boric acid is a white, colorless crystalline solid sold in technical national formulary and special quality grades as granules or powder. Boron oxide is a colorless hard, brittle, solid resembling glass that is ground and marketed most often under the name anhydrous boric acid.

Boron ore produced domestically during 2003 totaled 1.15 million metric tons (Mt) valued at $591 million (table 1). The percentages in this chapter are based on unrounded numbers while the numbers in the tables are rounded to three significant figures. The boric acid content was 560,000 metric tons (t). The most common minerals of commercial importance in the United States were colemanite, kernite, tincal, and ulexite (table 2). Boron compounds and minerals were produced by surface and underground mining and from brine. U.S. consumption of minerals and compounds amounted to 348,000 t of boric acid (table 3). Boron products are priced and sold based on the boric oxide content, which varies by ore and compound, and on the absence or presence of sodium and calcium (table 4). Boron compounds exported by producers were boric acid (69,600 t) and sodium borate (131,000 t) (tables 1, 5). Boron imports consisted primarily of borax, boric acid, colemanite, and ulexite (tables 1, 5-6). Turkey and the United States were the world's largest producers of boron minerals (table 7).

The glass industry, which remained the largest domestic market for boron production in 2003, accounted for 75% of boron consumption. Insulation-grade glass fibers accounted for an estimated 45% of domestic consumption; textile-grade glass fibers, 19%; boron sold to distributors, 10%; borosilicate glasses, 6%; fire retardants, 4%; miscellaneous, 4%; soaps and detergents, 4%; agriculture, 3%; enamels, frits, and glazes, 3%; and other uses, 2%.

Legislation and Government Programs

Magnetic levitation (maglev) is an advanced transportation technology in which magnetic forces lift, propel, and guide a vehicle on a specially designed guideway. Boron is used in the superconducting and other high-intensity magnets in this system. By using state-of-the art electric power and control systems, the maglev system would reduce the need for many mechanical parts, thereby minimizing resistance and permitting improved acceleration compared with conventional modes of transportation and cruising speeds of about 385 kilometers per hour (km/hr) (240 miles per hour) or more. The Baltimore, MD, to Washington, DC, maglev project is a 63-kilometer (km) (29-mile) project linking Camden Yard in Baltimore (a sports complex and center for recreation and tourism) and Baltimore-Washington International Airport to Union Station in Washington. This project has been under study since 1994. It would provide residents and visitors to Washington with an airport only 15 minutes from Union Station. The project is visualized as the initial stage of a high-speed maglev system that would serve the Northeast Corridor between Boston, MA, and Charlotte, NC. The Pittsburgh, PA, maglev project is an 87-km (54-mile) project linking Pittsburgh Airport to Pittsburgh and its eastern suburbs. This project has been under study since 1990. The project was intended to be the first stage of a system that would eventually provide high-speed intercity service to Cleveland, OH, on the west and Philadelphia, PA, on the east. In addition to the two projects selected for further study by the U.S. Department of Transportation, Congress has continued to fund further planning for projects between Las Vegas, NV, and Anaheim, CA, and in the Los Angeles area of California. Funding for all four projects totaled $4.5 billion in 2003 and $4.8 billion in 2004 (Federal Railroad Administration, 2004§[1]).

In the 2003 State of the Union Address, the President announced a $1.2 billion initiative to reverse America's growing dependence on foreign oil by developing the technology for commercial hydrogen-powered fuel cells to power businesses, cars, homes, and trucks with no pollution or greenhouse gases. The funding was good news for boric acid producers. DaimlerChrysler Corp. introduced the Natrium, a minivan that uses a fuel cell based on boron.

In October 2003, the U.S. Consumer Product Safety Commission (CPSC) voted unanimously to expand its regulatory proceedings to develop a possible Federal standard for upholstered furniture flammability performance. Zinc borate is a fire retardant material that could be used to meet the proposed standard. The standard would address the risk of residential fires ignited by cigarettes and/or by small open flames, such as candles, lighters, and matches. Reducing residential fires is a major goal at the CPSC (U.S. Consumer Product Safety Commission, 2003§).

Production

Domestic data for boron were derived by the U.S. Geological Survey from a voluntary survey of four U.S. operations. The majority of boron production continued to be from Kern County, CA, with the balance from San Bernardino and Inyo Counties, CA. All four operations to which a survey request was sent

[1]References that include a section mark (§) are found in the Internet References Cited section.

responded, representing 100% of the total boron produced and consumed (tables 1, 3).

More than 200 minerals contain boric oxide, but only a few were of commercial importance (table 2). Four minerals comprised almost 90% of the borates used by industry worldwide; they are the sodium borates borax and kernite, the calcium borate colemanite, and the sodium-calcium borate ulexite. These minerals were extracted primarily in California and Turkey and to a lesser extent in Argentina, Bolivia, Chile, China, and Peru. American Borate Co. mined small amounts of colemanite and ulexite-probertite underground at the Billie Mine in Death Valley, CA. The ore was transported to Lathrop Well, NV, for processing. Storage and grinding facilities were at Dunn, CA. Export was primarily to the Asian markets.

Fort Cady Minerals Corp. used an in situ process near Hector, CA, to produce a product that contained 48% boron oxide. During 2003, the plant was idle but product in storage was being marketed. The company had hired consultants to assess the market for derivatives and whether additional downstream plants should be built to market boron compounds and that assessment was ongoing during 2003.

IMC Chemicals (a subsidiary of IMC Global Inc.) produced borax, soda ash, and related products on Federal and private land from Searles Lake, CA. Searles Lake is a closed structural basin filled with alluvium and lacustrine evaporates of Quaternary age. A flat area overlies two separate salt structures that contain borates and other salts in the form of brines. In March 2004, IMC Global sold IMC Chemicals to Sun Capital Partners, Inc. of Boca Raton, FL. Sun Capital purchased the soda ash and boron chemicals operations in Searles Valley, CA. As a result of the sale, the company changed its name to Searles Valley Minerals, Inc. IMC's specialty borates plant in Lardellero, Italy, was purchased by Tuscan Stars GSA, LLC and some of its affiliates. IMC Global retained about 20% equity interest in IMC Chemical.

U.S. Borax, Inc. (a wholly owned subsidiary of London, United Kingdom-based Rio Tinto plc) mined borate ores at Boron, CA, by open pit methods and transported the ores to a storage area by trucks. The ore was processed into sodium borate or boric acid products in the refinery complex adjacent to the mine. An onsite plant also produced anhydrous sodium borate and boric oxide. Refinery products were shipped by railcar or truck to North American customers or to the U.S. Borax Wilmington, CA, facility at the Port of Los Angeles for international distribution. In addition to its refinery and shipping terminal in Wilmington, CA, U.S. Borax has its global headquarters in Valencia, CA, and its Owens Lake, CA, trona mine supplies raw material to the Boron, CA, refinery. Multiyear labor agreements that will provide additional operational flexibility and efficiency were negotiated at U.S. Borax's U.S. operations. U.S. Borax reported achieving a 12% increase in the boric acid plant productivity by equipment upgrades and maintenance improvements at the Boron plant. Fresh water usage was reduced by 7% (Taylor, 2003). U.S. Borax's Owens Lake operation allowed the company to ensure control of the trona supply used in the borate refining process. Trona provided a cost-effective source of carbonates, which helped reduce scaling in the processing equipment.

Environment

The U.S. Environmental Protection Agency (EPA) recognized U.S. Borax for voluntary environmental excellence. All borax sites in California joined the Nation's top 300 public and private facilities as members of the EPA's National Environmental Performance Track Program. Performance Track membership required companies to maintain an environmental management system of regulatory compliance, performance improvement, and public outreach. Performance improvements must be above and beyond what is required by local, State, or Federal laws (Rio Tinto Borax, 2003).

Consumption

Glass is an amorphous solid that has cooled to rigidity without crystallizing. Glass can be found formed in nature from volcanoes or lightening strikes. Boron is one of four elements (boron, germanium, phosphorus, and silicon) able to form glass but one of thousands of compounds that can be made into glass. Boron compounds are used in bakeware (commonly marketed as Pyrex) and laboratory equipment because they impart the ability to the glass to expand and contract without breaking (Gilman, 2003, p. 27; Stentiford, 2004, p. 55).

Boron is used to make ceramic frits and glazes. Formulations of some frits and glazes can contain concentrations of borates as high as 25%, and the entire market accounts for more than 13% of global borate demand. All ceramic glazes and the frits often used to create them are glasses (supercooled liquids). Glass retains the structural arrangements of a liquid, but the rates of change of volume with temperature are the same as those found in crystalline solids. A frit is a calcined mixture of sand and fluxes ready to be melted to form glass. The process of fritting (melting the soluble materials with silica) renders these ingredients insoluble, remaining on the surface through firing. Frits have the following advantages when used as part of a glaze composition: greater homogeneity, the use of soluble compounds, which are rendered insoluble; the removal of gaseous constituents; and the maturing of glaze formulations at lower temperatures. The raw frit materials, such as alumina, boron, potassium, silica, sodium, and zirconium, are milled to produce a homogeneous mixture. A glaze is used to cover pottery with a vitreous substance, which is fixed by melting. The glaze can be aesthetically appealing, resistant to abrasion, easier to clean, chemically durable, impervious to liquids and gases, and enhance mechanical strength (Cook, 2003; Stentiford, 2004, p. 54-55).

The use of borates in the manufacturing process for ceramic tile can reduce firing-cycle and temperature requirements, lowering the energy needed for manufacturing the tile, thus lowering costs. Borates increase the dry mechanical strength of unfired tiles between 30% and 80%, thereby lowering handling losses and saving money, which can be passed on to consumers as lower prices (Chemical Market Reporter, 2003b).

Glass-fiber thermal insulation, primarily used in new construction, was a large end use for borates and was a major insulating material used in the construction industry. Composed of very thin fibers spun from molten glass, fiberglass insulation traps and holds air. Typically, between 4% and 5% of boron oxide is incorporated in the manufacturing of thermal insulation to aid melting, to inhibit devitrification, and to improve the aqueous durability of the finished product.

Borates also were used in a range of products made from high-tensile-strength glass fiber materials. The process of producing the glass fiber uses a borosilicate formulation (E-glass) that is continuously drawn through platinum alloy bushings into continuous 9- to 20-micrometer diameter filaments. Calcium aluminoborosilicate (E-glass or textile fiberglass) typically contains between 6% and 10% boric oxide.

Boron carbide is used in military personnel body armor. Modern attack helicopters, such as the Apache, Blackhawk, Cobra, and other models, are fitted with boron carbide panels that fortify floors, seats, walls, and other parts of the cockpit to protect crews from gunfire. Similar protection is found on C-17 and C-141 cargo planes and other military aircraft. Tiles made from boron carbide are used in the U.S. Army's Stryker and other light-armor vehicles (Jacoby, 2003).

Albemarle Corp. was a producer of boron-based cocatalysts, which are important activators for metallocene catalyst systems, for the production of propylene and ethylene polymerization, and many contain fluorinated groups. Production of pentafluorophenyl intermediates needed to produce organoboron cocatalysts were only produced in Japan and Russia prior to Albemarle's back integration into production (Albemarle Corp., 2003§). Boron is 1 of 16 nutrients essential to all plants. It is essential to plant growth and can be applied as a spray and incorporated in fertilizer, herbicides, and irrigation water. Boron applied in May and June can be combined with calcium. For early season apples, boron can be applied post-harvest to provide adequate nutrition when buds begin to develop for blooming the next growing season. In the crop year ending June 30, 2003, 9,380 t (10,300 short tons) of boron micronutrients was applied on crops compared with 5,980 t (6,590 short tons) in crop year 2002. The largest consuming U.S. region in 2002 and 2003 was the Pacific, which used 2,790 t (3,080 short tons) and 4,460 t (4,920 short tons), respectively (Terry and Kirby, 2003, p. 37; 2004, p. 37).

Boron is necessary in plant reproduction, controlling flowering, pollen production, germination, and fruit development. Boron fertilizers can quadruple corn yields and increase cotton yields by more than 227 kilograms per acre (500 pounds per acre). Boron deficiencies in crops are found primarily in soils low in organic matter and in acid, sandy soils in humid regions. Soils with low organic matter content usually require more frequent fertilizations at lower application rates. The availability of boron increases when the soil pH is more than 6.5. Warm moist soils with adequate aeration are most favorable to boron availability (Fertilizer International, 2003).

Twenty boron chemicals and minerals were listed in the Pesticide Action Network's pesticides database that included boron and compounds from barium metaborate to ulexite (Orme and Kegley, 2003§).

Until 2001, sodium perborate consumed more than one-third of the peroxide used in the manufacture of inorganic chemicals. The use has declined because of environmental concerns about boron in wastewater. Sodium percarbonate can substitute for sodium perborate in laundry products (Kirschner, 2004).

Callery Chemical Division of Mine Safety Appliances Co., a leading manufacturer of elemental boron, was being acquired by BASF Corp. (the North American affiliate of BASF AG of Germany) (Oil & Gas Journal, 2004§).

Transportation

The Trona railway, connected to the Southern Pacific railroad between Trona and Searles Stations, provided a dedicated line with access to the national rail systems for the borate and soda ash markets. Cross-country rail shipments are more cost effective in the United States than the use of ocean transportation. The use of U.S.-flag shipping lines was required by the Merchant Marine Act of 1920 (the Jones Act) for shipping on all U.S. waterways and for moving goods between U.S. ports.

Almost all U.S. Borax bulk products were shipped in North America by rail. The Boron Mine is served solely by the Burlington Northern Santa Fe Railroad. In order to connect to another rail line, a transload or transfer point was set up in Cantil, CA, which is served by the Union Pacific Railroad. Trucks of product from Boron are driven to Cantil, about 64 km (40 miles) northwest of Boron, CA, and loaded into dedicated railcars to be shipped to customers.

Prices for rail haulage depended on a number of factors including the ability of customers to load and unload efficiently, the ability to use whole unit trains, and the ability to supply their own railcars. The recent increase in fuel prices is another factor affecting cost with carriers passing on surcharges to customers. Boron material generally moves in closed hopper railcars to avoid loss through wind or agglomeration (Moore, 2003).

Transportation cost comparisons by L.G. Everist, Inc. for aggregates comparing cost in dollars per metric ton per kilometer were as follows: ship, 0.007; barge, inland, 0.175; barge, ocean, 0.023; rail, manifest, 0.088; rail, unit train, 0.058; and truck 0.190. Dollars per short ton per mile were as follows: ship, 0.005; barge, inland, 0.12; barge, ocean, 0.016; rail, manifest, 0.06; rail, unit train, 0.04; and truck 0.13 (Everist, 2004).

Ocean transport of U.S. Borax products was from the Port of Wilmington, CA, where the company had a privately owned berth in the harbor. Products destined for Europe were shipped from the bulk terminal in Wilmington to a company-owned facility in the Port of Rotterdam, Netherlands; the vessels have been supplied by the Japanese shipping company "K" for more than 20 years. Smaller vessels also are used to transport bulk borates to company facilities in Spain and to contracted warehouses. Borax Group also maintains secondary stock points that include Austria, Germany, Norway, the Republic of Korea, Taiwan, and Ukraine. The most centrally located U.S. Borax port location in Europe in Antwerp, Belgium, had access to 188 major European cities. The industrial minerals market in Europe was characterized by high volumes of imported materials, mostly forwarded through the industrialized areas of Belgium, France, Germany, and the Netherlands for destinations in Central Europe, such as Austria, the Czech Republic, and Slovenia. A decision to import borates was based on the geographic location, the range of service needed, and prices.

U.S. Borax used barges to ship borates from Rotterdam, Netherlands, to customers in Belgium, Eastern Europe, France, Germany, and countries even farther away. Barges were the most efficient and reliable method of transporting goods in Europe, which has a 25,000-km network of navigable canals and rivers. Most of the large industrial areas could be reached by barge on waterways that link parts of the North, Baltic, Black, and Mediterranean Seas and the Atlantic Ocean. A 170-km canal operated in Germany linked the Main River to the Danube River.

Prices

Prices of boron minerals and compounds produced in Chile, Turkey, and the United States are listed in table 4.

World Review

Argentina.—In 2003, Argentina was the leading producer of boron minerals in South America. Borax Argentina S.A. (a subsidiary of Rio Tinto plc) was the country's leading producer of borates and exported to the United States (tables 6, 7). Borax Argentina mined borates at four deposits—Tincalayu and Sijes in Salta Province, at more than 4,270 meters (m) (14,000 feet) above sea level, and two dry lake beds, Salars Cauchari and Diabillo in Jujuy Province at 3,370 m. Yacimiento de Boroato El Porvenir at the Salar Cauchari produces ulexite that grades 37% boron oxide. The Tincalayu Mine, originally developed in 1976, was Argentina's largest open pit operation and measured 1.5 km long, 500 m wide, and 100 m deep. Commercial borates mined were colemanite, hydroborocite, kernite, tincal, and ulexite. The clay overburden averages 50 m and typically overlies 30 to 40 m of ore. Rio Tinto Borax invested $2.6 million to establish a new boric-acid plant near the Campo Quijano, Salta refinery. Construction began in August 2002, and the plant was in production in August 2003. Tailings from the company's ulexite concentration operation were used as feedstock to supply 8,000 t of boric acid production. The new plant achieved a 7% reduction in fresh water usage compared with 2002 (Keefe, 2003).

Other borate producers in the Province of Juyuy included Processadora de Boratos Argentina S.A. (owned by Ferro Corp. and Canadian JEM Resources & Engineering, Inc.), which produced borates from 2-m thick layers of tincal and ulexite interbedded with clay and lenses of inyoite; Cia Minera Gavenda S.A., which produced borates at the La Inundada Mine at Salar Cauchari from layers of ulexite up to 1-m thick that grade between 11% and 35% boron oxide; and Triboro S.A., which operated the Irene Mine where ulexite was mined that contained between 11% and 35% boron oxide. In addition, other producers were Coop. de Borateros, Viento Blanco S.R.L., Ramiro Matinez, and Moncholi y Guijarro.

A prefeasibility study was completed on Argentina Diamonds Ltd.'s Rincon project in the Saltar Province. The project was located at an altitude of 3,700 m on the Rincon Salar, close to the Chilean border. Commodities evaluated were boron (300 parts per million), cesium and rubidium, lithium, magnesium, and potash (Andreani, 2003§).

Australia.—Boron Molecular Ltd. of Melbourne, was a leading company in the synthesis of organoboron compounds. The company has seven patents using Suzuki's coupling reaction. Organoborons are used in medicinal chemistry, such as boron-neutron capture therapy (BNCT), which can be used in the treatment of malignant brain tumors by selectively delivering boron-10 nuclei to tumor cells. When the boron-10 captures neutrons from radiation, helium and lithium ions form that result in cell death in the surrounding tissue. Therapeutic amounts of a boron-rich compound can be delivered to tumor cells that can be selectively absorbed by tumor cells, thus increasing the capture of neutrons and resulting in the death of tumor cells (Freemantle, 2002; Chemical Market Reporter, 2003a).

Bolivia.—Boron minerals mined in the Uyuni area are shipped to Chile by rail to be processed. In December 2003, miners who wanted the processing to take place in Bolivia protested for 2 days (Travis, 2003§). In July, 2 years after antidrug authorities arrested 13 executive staff and employees of Tierra S.A., a sentence was handed down. The executive president was sentenced to serve 12 years in jail. The former administrative manger was sentenced to 8 years, and the former Tierra lawyer, 4 years. The proprietor of the mining concession also received 4 years (Botey, 2003§). The principal mining concession is ulexite from the Kapina Mine, which is located 65 km from Apachete in the province of South Lipez, formerly mined by Tierra was now under the Bolivian Government (Tierra S.A., 2003§).

China.—A large number of the borate deposits in China are found in magnesium-rich, iron-poor carbonates within tourmaline-bearing leptynite (metamorphosed equivalents of evaporates enclosed within volcanic tuffs) deposits in Liaoning and Jilin Provinces. Evidence indicates that the borates are metamorphosed nonmarine evaporates that formed in shallow, wide playa lakes where magnesium-rich brines precipitated salts in the basin centers (Peng and Palmer, 2002, p 93-108).

India.—Borax Morarji Ltd. (a subsidiary of Dharamsi Morarji Chemicals Ltd.), Raj Industries Ltd., and Indo-Borax & Chemicals Ltd. are the major producers of borates in India. Production has shifted from the manufacturer of borax decahydrate from imported Turkish ulexite to value-added products. The Finance Ministry issued an antidumping duty on imports of borax decahydrate originating in or exported from China and Turkey effective June 10, 2003. Chinese and Turkish producers were reported to have 70% of the borax decahydrate market in India, which was estimated to be 16,000 metric tons per year (t/yr) (Mitra, 2003§).

Italy.—Societa Chimica Larderello closed its technical-grade boric-acid plant that was estimated to have produced between 50,000 and 60,000 t/yr during 2002 (Taylor, 2003). Boric acid purchased on the world market was being used to feed the purified-grade boric-acid facility.

Russia.—JSC Bor was the only producer of boron compounds in Russia. The majority of output was exported. In 1998, Energomashkorporatsiya acquired control over Bor, after which Bor's debt grew. Bor earned a small profit for the first time in many years during the first half of 2003. In September, shareholders appealed to the arbitration court to file bankruptcy.

International prices for boron have declined during recent years to $400 per metric ton, while the cost for raw material, electric power, and transport service increased. It was estimated that Bor will need Rubl.5 billion during 2004 to 2008 to maintain and renovate the existing facilities. Upgrading of existing facilities and construction of new capacity will require up to Rub1.9 billion. Bor was seeking a new owner and investor (JSC Publishing Company Zolotoy Rog, 2003§).

Turkey.—Turkey was the largest producer of boron ore in the world and was expanding plant capacity to produce boron compounds. The new Government elected on November 23, 2002, planned to increase the mining of reserves, provide affordable and reliable power, and increase exports of processed mineral products. The prospecting and operating licenses of publicly owned agencies and enterprises will be transferred to the private sector. Boron will not be privatized, but the Government planned to establish the Boron Research Institute to develop Turkey's exports of processed boron. The institute was expected to develop a fiberglass industry and other industries to make use of boron derivatives (Schmidt-Whitely and Loehman, 2003).

Boron mines and reserves were nationalized in 1978 and have been controlled exclusively by Government-owned Eti Bor (a subsidiary of Eti Holding, Inc. formerly known as Eti Bank). Eti Holding was established in 1935 to develop the country's natural resources. Criticism of how Government money was invested in borates included the creation of a 4,100 m canal to divert a river in the Bigadic mining area in order to make an underground mine into an open pit operation. Transforming the underground mine into an open pit involved the removal of 4 million cubic meters of overburden. The mine capacity is now between 400,000 and 500,000 t/yr; however, sales are less than 120,000 t/yr (Buehler, 2003). Total exports of boron concentrate for 2002 were reported to be 244,660 t valued at $52,467,000 (Yildiz, 2003§).

Turkey has an estimated 29.1% share of the worldwide borate market. Annual boric acid production capacity was 100,000-t/yr at the new plant at Emet, 85,000-t/yr at a plant at Bandirma, and 35,000-t/yr at a plant at Kirka. A 48,000-t/yr borax pentahydrate plant, a 65,000-t/yr borax decahydrate plant, and a 10,000-t/yr anhydrous borax plant were located at Kirka. Other capacity included a 22,000-t/yr sodium perborate tetrahydrate and a 9,000-t/yr sodium perborate monohydrate plant at Bandirma. Borate mine capacity was available at Bigadic (180,000 t/yr of colemanite), Emet (660,000 t/yr of colemanite), and Mustafa Kemalpasa (480,000 t/yr of colemanite and ulexite). In addition, 800,000 t/yr of tincal was produced at Kirka (Industrial Minerals, 2003).

Current Research and Technology

Diamonds having a perfect carbon crystal lattice without defects or substitutions are colorless. Such diamond has a large band gap—meaning that the energy required to free an electron so it can move through the diamond lattice is high—and therefore is an excellent electrical insulator. But replacing some of the carbon atoms in the diamond lattice with boron—an impurity that produces the pretty blue color in some rare diamonds, including the famed Hope Diamond—transforms diamond into a p-type semiconductor. That's because boron has only three outer-shell electrons and can make only three of four bonds that carbon normally does in the diamond lattice. The result is a missing electron or "hole" that can move freely through the crystal, allowing the diamond to conduct positive charge. Boron-doped diamond, which is normally a semiconductor, turns into a superconductor at low temperatures. Synthetic diamond containing about 3% boron becomes a superconductor at 4 K. Superconducting diamond could be useful for surgical blades with sensors that measure properties of the surrounding tissue. Another use could be the direct electrical detection of the binding of complementary deoxyribose nucleic acid (DNA) strands to the DNA-labeled diamond surface directly; the detection is done by measuring the change in electrical properties of the diamond film, thus eliminating the need for labor- and time-intensive labeling steps required by other biosensing methods. Boron-doped diamond could be used to fabricate diamond-base electronic devices that could resist heat and chemical attack. Diffusion of other light elements, such as boron, calcium, or lithium, might also be used to alter corundum colors. Most synthetic diamond is grown by methods that use high-pressure, high-temperature growth chambers. Better control of impurities is possible using a low-pressure technique called chemical vapor deposition (CVD) where the carbon is deposited from a very pure gas. CVD allows the production of a wider variety of colored diamond by varying the gas composition. A combination of spectroscopy and photoluminescence spectroscopy can be used to distinguish the CVD gems from naturally occurring ones (Chemical & Engineering News, 2004b; Yarnell, 2004).

A University of South Florida medical study confirmed that borates can control dust mites, the predominant cause of asthma attacks in children. Borates are already approved for household use in cleaners, fertilizers, insecticides, and insulation, so benefits to millions of asthma and allergy suffers could be immediate. In a 6month study of 100 Tampa, FL, houses, researchers applied disodium octaborate tetrahydrate (DOT) in an odor-free, stain-free solution. The study showed the DOT was effective in killing the dust mites and controlling their reemergence for 6 months (Makely, 2004§).

Studies at the Physical Chemistry Institute at the Technical University of Freiberg, Germany, reported on the properties of borazane (BH_3NH_3), which is a potential hydrogen source. Borazane is a stable nontoxic solid with high hydrogen content. Hydrogen can be released in quantities of up to 15% by mass through direct thermal decomposition of the solid or by catalytic decomposition of aqueous borazane solutions. These properties have attracted Opel (a subsidiary of General Motors Corp.) to support the research in an effort to find a suitable method for hydrogen generation for use in fuel-cell-powered car (Jacoby, 2004).

A team at the University of Florida demonstrated that borate minerals help stabilize ribose synthesized under alkaline conditions. In the absence of borate, a mixture of pentoses, including ribose, turns brown and degrades after an hour of incubation. When the mixture is incubated in the presence of borate minerals, the solution does not degrade over an extended period. The researchers believe that their results support prebiotic formation of ribose (Chemical & Engineering News, 2004a). Ribose regulates production of adenosine triphosphate, the source of cellular energy. When the body's oxygen-carrying capacity decreases, tissue can be damaged. Ribose aids the body in producing cellular energy in low-oxygen conditions more efficiently, allowing the body more energy for recovery, delivery of nutrients, and growth and repair of tissue, such as in professional athletes training to improve performance or individuals struggling with muscle and cardiovascular diseases (Essense-of-Life, LLC, 2003§).

Water in California was contaminated by boron, perchlorates, and trihalomethane. One method for removal of the contaminants is an ion-exchange resin system that uses two towers that alternate between water processing and resin regeneration. In the regeneration cycle, salt or acid is added for a reverse ionic exchange. Resins are also being applied in tandem with reverse-osmosis membrane filtration. Reverse osmosis is effective in removing up to 99% of most contamination (Mullin, 2002).

Outlook

Historically, the housing market has been a large consumer of boron minerals, notably for fiberglass insulation. Increased usage of ceramic tiles in kitchens and bathrooms will keep demand in the enamels, frits, and glazes end use strong in the short term and will increase as the overall size of the market for ceramic products grows (Stentiford, 2004). The boron industry is directly affected by the health of the glass industry. Sales of boron for glass consumption included borosilicate glass, enamels, insulation-grade glass fibers, and textile-grade glass fibers, represented 74.5% of domestic demand and decreased by 1% in 2003. Demand as a fertilizer will remain high. Imports of boron chemicals from Turkey are expected to grow because manufactured Turkish boron derivatives are expected to increase and supplies of boron minerals to diminish from the market as the country produces more value-added products. New plants for boric acid and sodium borate that are to come onstream may cause prices for boron derivatives to decline. Some automobile manufacturers have been replacing metal parts with reinforced fiberglass plastic parts to reduce weight and increase the efficiency of gasoline consumption. The demand for energy-efficient nonpolluting cars could cause increased demand for borates in fuel cells. A prototype car using a sodium borohydride fuel cell was displayed during 2003. The vehicle had a range of 480 km and a top speed of 130 km/hr. A prototype battery for titanium diboride has potential to be superior to traditional zinc batteries. Titanium diboride batteries could last twice as long as traditional carbon-zinc batteries.

New technology could create a large demand for boron chemicals. New uses in fuel cells for automobiles also have the potential for creating strong demand. A new process in paper mills that recycles boron chemicals can reduce the effort needed to meet environmental requirements and can lower production costs.

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TABLE 1
SALIENT STATISTICS OF BORON MINERALS AND COMPOUNDS[1]

(Thousand metric tons and thousand dollars)

	1999	2000	2001	2002	2003
United States:					
Sold or used by producers:					
Quantity:					
Gross weight[2]	1,220	1,070	1,050	1,050	1,150
Boron oxide (B_2O_3) content	618	546	536	518	560
Value	630,000	557,000	506,000	513,000	591,000
Exports:[3]					
Boric acid:[4]					
Quantity	107	119	85	84	70
Value	56,700	64,400	47,000	44,600	36,400
Sodium borates:					
Quantity	370	413	221	150	131
Value	180,000	136,000	91,700	63,100	55,400
Imports for consumption:					
Borax:					
Quantity[3]	8	1	1	(5)	(5)
Value	2,840	716	642	94	19
Boric acid:					
Quantity[3]	30	39	56	49	47
Value	14,000	17,500	21,700	18,500 r	19,000
Colemanite:					
Quantity[6]	42	26	35	32	24
Value	13,100	7,410	9,790	8,960	6,960
Ulexite:					
Quantity[6]	178	127	109	125	80
Value	35,700	31,800	21,800	25,000	16,000
Consumption, B_2O_3 content	416	360	347	359	348
World, production	4,470 r	4,550 r	4,730 r	4,550 r	4,800 e

[e]Estimated. [r]Revised.
[1]Data are rounded to no more than three significant digits.
[2]Minerals and compounds sold or used by producers, including actual mine production, and marketable products.
[3]Source: U.S. Census Bureau.
[4]Includes orthoboric and anhydrous boric acid. Harmonized Tariff Schedule of the United States codes 2840.19.0000, 2840.30.0000, and 2840.20.0000.
[5]Less than 1/2 unit.
[6]Source: Journal of Commerce Port Import/Export Reporting Service.

TABLE 2
BORON MINERALS OF COMMERCIAL IMPORTANCE

Mineral[1]	Boron oxide (B_2O_3) Chemical composition	Weight percentage
Boracite (stassfurite)	$Mg_3B_7O_{13}Cl$	62.2
Colemanite	$Ca_2B_6O_{11}\cdot 5H_2O$	50.8
Datolite	$CaBSiO_4OH$	24.9
Hydroboracite	$CaMgB_6O_{11}\cdot 6H_2O$	50.5
Kernite (rasortie)	$Na_2B_4O_7\cdot 4H_2O$	51.0
Priceite (pandermite)	$CaB_{10}O_{19}\cdot 7H_2O$	49.8
Probertite (kramerite)	$NaCaB_3O_9\cdot 5H_2O$	49.6
Sassolite (natural boric acid)	H_3BO_3	56.3
Szaibelyite (ascharite)	$MgBO_2OH$	41.4
Tincal (natural borax)	$Na_2B_4O_7\cdot 10H_2O$	36.5
Tincalconite (mohavite)	$Na_2B_4O_7\cdot 5H_2O$	47.8
Ulexite (boronatrocalcite)	$NaCaB_5O_9\cdot 8H_2O$	43.0

[1]Parentheses include common names.

TABLE 3
U.S. CONSUMPTION OF BORON MINERALS AND COMPOUNDS,
BY END USE[1, 2]

(Metric tons of boron oxide content)

End use	2002	2003
Agriculture	12,900	11,000
Borosilicate glasses	19,300	22,000
Enamels, frits, glazes	12,700	11,800
Fire retardants:		
Cellulosic insulation	9,790	12,700
Other	1,480	1,230
Insulation-grade glass fibers	178,000	158,000
Metallurgy	39	14
Miscellaneous uses	6,010	14,600
Soaps and detergents	20,900	15,400
Sold to distributors, end use unknown	29,100	33,700
Textile-grade glass fibers	69,300	67,800
Total	359,000	348,000

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

[2]Includes imports of borax, boric acid, colemanite, and ulexite.

TABLE 4
YEAREND PRICES FOR BORON MINERALS AND COMPOUNDS[1]

(Dollars per metric ton)

Product	Price, December 31, 2002	Price, December 31, 2003
Borax, technical, anhydrous, 99%, bulk, carload, works[2]	637	900-930
Borax, technical, anhydrous, 99%, bags, carload, works[2]	846	846
Borax, technical, granular, decahydrate, 99%, bags, carload, works[2]	340-380	378
Borax, technical, granular, decahydrate, 99.5%, bulk, carload, works[2]	374	374
Borax, technical, granular, pentahydrate, 99.5%, bags, carload, works[2]	426	426
Borax, technical, granular, pentahydrate, 99.5%, bulk, carload, work[2]	376	400-425

See footnotes at end of table.

TABLE 4--Continued
YEAREND PRICES FOR BORON MINERALS AND COMPOUNDS[1]

(Dollars per metric ton)

Product	Price, December 31, 2002	Price, December 31, 2003
Boric acid, technical, granular, 99.9%, bags, carload, works[2]	834	836
Boric acid, technical, granular, 99.9%, bulk, carload, works[2]	788	788
Boric acid, United States Borax & Chemical Corp., high-purity anhydrous, 99% boron oxide (B_2O_3), 100-pound-bags, carlots[2]	1,996	1,996
Colemanite, Turkish, 42% B_2O_3, ground to a minus 70-mesh, f.o.b. railcars, Kings Creek, SC[3]	270-290	270-290
Ulexite, Chilean, 38% B_2O_3, ground to a minus 6-mesh, f.o.b railcars, Norfolk, VA[e]	200	200

[e]Estimated.

[1]U.S. free on board (f.o.b.) plant or port prices per metric ton of product. Other conditions of final preparation, transportation, quantities, and qualities not stated are subject to negotiation and/or somewhat different price quotations. Values have been rounded to the nearest dollar.

[2]Source: Chemical Market Reporter, v. 264, no. 1, January 6, 2003, p. 23; v. 265, no. 1, January 2, 2004, p. 16.

[3]Source: Industrial Minerals, no. 424, January 2003, p. 66; no. 436, January 2004, p. 68.

TABLE 5
U.S. EXPORTS OF BORIC ACID AND REFINED SODIUM BORATE COMPOUNDS, BY COUNTRY[1]

	2002			2003		
	Boric acid[2]		Sodium	Boric acid[2]		Sodium
Country	Quantity (metric tons)	Value (thousands)	borates[3] (metric tons)	Quantity (metric tons)	Value (thousands)	borates[3] (metric tons)
Australia	2,980	$1,360	5,700	2,120	$929	4,780
Belgium	--	--	531	--	--	61
Brazil	5,810	2,090	1,950	2,950	1,210	3,010
Canada	5,760	3,730	44,000	4,990	3,270	45,700
China	16,300	6,860	14,400	11,800	4,950	20,800
Colombia	173	119	2,130	5	4	2,270
France	115	53	7	--	--	1
Germany	178	264	13	1,660	786	10
Hong Kong	197	99	449	614	339	395
India	--	--	40	--	--	434
Indonesia	800	400	994	550	323	457
Israel	--	--	19	--	--	4
Italy	1	3	5,440	32	47	2,400
Japan	21,500	13,500	28,200	17,500	10,700	17,900
Korea, Republic of	12,400	5,950	11,600	11,400	5,420	9,130
Malaysia	1,470	1,030	5,080	518	415	4,280
Mexico	3,060	1,920	7,280	1,350	883	3,780
Netherlands	--	--	23	11	7	2
New Zealand	410	164	2,500	164	57	2,040
Philippines	29	18	1,010	34	22	979
Singapore	597	311	825	697	371	612
South Africa	--	--	(4)	--	--	(4)
Taiwan	9,140	4,750	4,850	9,770	4,520	4,600
Thailand	2,470	1,300	5,970	2,730	1,430	3,900
United Kingdom	53	135	13	81	243	2
Venezuela	158	162	336	56	54	179
Vietnam	192	90	1,670	57	27	887
Other	612	329	4,720	523	306	2,170
Total	84,400	44,600	150,000	69,600	36,400	131,000

-- Zero.

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

[2]Harmonized Tariff Schedule of the United States (HTS) code 2810.00.0000.

[3]HTS codes 2840.19.0000, 2840.30.0000, and 2840.20.0000.

[4]Less than 1/2 unit.

Source: U.S. Census Bureau.

TABLE 6

U.S. IMPORTS FOR CONSUMPTION OF BORIC ACID, BY COUNTRY[1]

Country	2002 Quantity (metric tons)	2002 Value[2] (thousands)	2003 Quantity (metric tons)	2003 Value[2] (thousands)
Argentina	524	$277	704	$305
Australia	2	4	11	15
Bolivia	2,100	824	2,940	1,250
Chile	22,600	7,800	20,500	7,070
China	37	49	107	184
Czech Republic	1	4	--	--
France	12	23	30	62
Germany	41	24	37	40
India	12	22	36	71
Italy	1,140	1,390	1,160	1,210
Japan	1	9	70	62
Korea, Republic of	--	--	72	26
Netherlands	5	11	--	--
Peru	2,270	873	3,690	1,440
Russia	8,520	3,110	8,370	3,530
Turkey	11,200	4,030	9,450	3,650
United Kingdom	17	16	38	68
Other	--	--	78	30
Total	48,600 r	18,500 r	47,300	19,000

-- Zero.

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

[2]U.S. customs declared values.

Source: U.S. Census Bureau.

TABLE 7

BORON MINERALS: WORLD PRODUCTION, BY COUNTRY[1, 2]

(Thousand metric tons)[r]

Country	1999	2000	2001	2002	2003[e]
Argentina	245	513	634	510	545 [3]
Bolivia, ulexite	15	41	32	33 r	34 [3]
Chile, ulexite	325	338	328	431 r	500
China[e, 4]	110	145	150	145	130
Germany, borax[e]	1	1	1	1	1
Iran, borax[5]	4	4	3 r	2 r	3
Kazakhstan[e]	30	30	30	30	30
Peru	15	9	9	7 r	9 [3]
Russia[e, 6]	1,000	1,000	1,000	1,000	1,000
Turkey[7]	1,504 r	1,402 r	1,493 r	1,346 r	1,400
United States[8]	1,220	1,070	1,050	1,050	1,150 [3]
Total	4,470 r	4,550 r	4,730 r	4,550 r	4,800

[e]Estimated. [r]Revised.

[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 May 20, 2004.

[3]Reported figure.

[4]Boron oxide (B_2O_3) equivalent.

[5]Data are for years beginning March 21 of that stated.

[6]Blended Russian datolite ore that reportedly grades 8.6% B_2O_3.

[7]Concentrates from ore.

[8]Minerals and compounds sold or used by producers, including both actual mine production and marketable products.