science for a changing world

2008 Minerals Yearbook

BORON

U.S. Department of the Interior
U.S. Geological Survey

October 2010

Boron

By Marc A. Angulo

Domestic survey data and tables were prepared by Cheryl J. Crawford, statistical assistant, and the world production table was prepared by Lisa D. Miller, international data coordinator.

U.S. consumption of minerals and compounds reported in boron oxide continued to increase in 2008, but has been withheld to avoid disclosing company proprietary data (table 1). Turkey and the United States were the world's leading producers of boron minerals (table 6). World production of boron minerals increased slightly in 2008 to an estimated 4.35 million metric tons (Mt) compared with 4.22 Mt in 2007 (excluding U.S. production). Boron compounds exported by producers were boric acid [303,000 metric tons (t)] and sodium borate (519,000 t) (tables 1, 4). Boron imports consisted primarily of borax, boric acid, colemanite, and ulexite (tables 1, 5). 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 3).

Elemental boron is a nonmetal with atomic number 5 that is marketed in grades from 90% to 99% purity. Borax, one of the most important boron minerals for industrial use, is a white crystalline substance chemically known as sodium tetraborate decahydrate and found in nature as the mineral tincal. Boric acid, also known as orthoboric acid or boracic acid, is a white, colorless crystalline solid containing 56% boron oxide (B_2O_3) and sold in technical national formulary and special quality grades as granules or powder. Boron oxide is a colorless, hard, brittle, glassy solid that is ground and marketed most often under the name anhydrous boric acid. Colemanite (hydrated calcium borate), kernite (hydrated sodium borate), tincal, and ulexite (hydrated sodium calcium borate) were the minerals of most commercial importance in the United States (table 2).

Production

Although there are more than 200 minerals that contain boron, only a few were of commercial importance (table 2). Boron compounds and minerals were produced by surface and underground mining and from brine. Four minerals make up 90% of the borates used by industry worldwide: 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. The largest colemanite and ulexite deposits in the world are located in Turkey.

Domestic data for boron were derived by the U.S. Geological Survey from a voluntary survey of two U.S. producers—Rio Tinto Group's U.S. Borax Inc. and Searles Valley Minerals, Inc. (SVM). Both companies responded; however, data were withheld to avoid disclosing company proprietary data (table 1).

The calcium borate mine in Newberry Springs, CA, owned and operated by Fort Cady Minerals Corp., has been idle since February 2003. According to the State of California Department of Conservation, the Newberry Springs mine was under partial reclamation in 2008, but Elementis Specialties Inc. was considering its purchase for future mining operations. Fort Cady Minerals Corp. was in the process of acquiring county planning approval to mine borates near Hector, CA (California Historic Route 66 Association, 2007).

The Billie Mine, the last active mining operation in Death Valley National Park, CA (owned by American Borate Company), closed in 2008 (National Park Service, 2008). American Borate Co. continued to import Turkish ulexite and colemanite, which was processed in plants in Chesapeake, VA, and Blacksburg, SC, through Industrial Minerals Co. (American Borate Company, 2005; Industrial Minerals Inc., 2007).

SVM produced borax and boric acid from brines pumped from several salt layers, up to 100 meters (m) deep, in Searles Lake, located near Trona in San Bernardino County, CA. SVM selectively pumps the brines from several of the salt layers and refines them in their plants in Trona. These brines supply other commercial salts in addition to sodium borates and boric acid.

Rio Tinto Borax (a wholly owned subsidiary of United Kingdom-based Rio Tinto Minerals) mined borate ores containing tincal and kernite at Boron, CA, by open pit methods, and the ores were transported by truck to a storage area. This property was the world's leading producer of refined borate products, processing the borate ore 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 Rio Tinto Borax, Wilmington, CA, facility at the Port of Los Angeles for international distribution. Specialty borate products are made at Borax's Wilmington plant and shipping facility located at the Los Angeles harbor.

Consumption

The first reported use of borax was as a flux or bonding agent by Arabian gold and silversmiths in the eighth century, but current research suggests Babylonians may have used it 4,000 years ago. Today, there are more than 300 end uses for borates, but more than three-quarters of the world's supply is sold into five end uses, with new uses continuing to be found each year. The distribution of borates by end use in 2008 was glass, 61%; ceramics, 14%; detergent, 7%; fertilizer, 6%; and other, 12% (Garrett, 1998; Hamilton, 2006; Eti Maden AS, 2008, p. 83).

In 2008, U.S. imports for consumption of colemanite, borax, boric acid, and ulexite were 156,000 t, which was 16% less than the 186,000 t imported in 2007. In 2008, total U.S. consumption of all boron products increased by 3% compared with that of 2007.

The form in which boron is consumed has changed in recent years. The use of beneficiated ores like colemanite has declined following concerns over arsenic content. Consumers have moved towards the use of refined borates or boric acid that have a lower hazardous material content.

Agriculture.—Boron is one of seven micronutrients essential to plant nutrition. Studies show that boron is essential for plant uptake of calcium, magnesium, manganese, phosphorus, and zinc. It influences the transport of nutrients through plant membranes, which directly correlates into improved fruit development, germination, plant reproduction, and pollen production. Normal plant leaves typically contain 25 to 100 parts per million boron with 1 kilogram per hectare of boron (1 pound per acre) in soil being adequate to maintain these levels. Domestic consumption in fertilizers was estimated to be 2%. Since borax is water soluble, boron fertilizers can be delivered through sprays or irrigation water and does not require chemical treatment. U.S. boron deficiencies in crops are found primarily in the Atlantic coastal plains, Great Lakes region, and coastal Pacific Northwest where soils tend to be acidic, leached, coarse sandy, or organic in nature. Excessive boron fertilization on the other hand can cause crop toxicity, which studies suggest is more often caused by higher boron levels in irrigation water than those in soil (Troeh, 2005, p. 489).

Ceramics.—Ceramics comprise the second largest application of borates after glass. Borates are an important component in ceramic glazes and enamels, increasing thermal, chemical, and wear resistance for ceramic products. Borax and colemanite are used in ceramics primarily as fluxing agents, with borax being utilized in higher temperature, and colemanite in lower temperature firings. Borates are also used in technical ceramics, an industry with implications in aerospace, ballistics, electronics, and medicine, which observed strong growth over the past decade. Boron carbide is a key ingredient in lightweight ceramic armor, the use of which has caused increased United States and European consumption of boron carbide during the past few years (Industrial Minerals, 2008b).

Detergents and Soaps.—Borates have been used as oxygen-base bleaching agents, enzyme stabilizers, alkaline buffers, and water softeners in detergents and soaps. Two borates, sodium perborate and perborate tetrahydrate, have primarily been used as oxidizing bleaching agents since they contain true peroxygen bonds. Hydrogen peroxide, a very effective bleaching agent, is produced when sodium perborate undergoes hydrolysis when in contact with water. Since hydrogen peroxide cannot be effectively incorporated into detergents, sodium perborate acts as its carrier (Rio Tinto Borax, 2005).

However, sodium perborate requires hot water to undergo hydrolysis, and concerns have emerged over excessive boron levels in waterways owing to sodium perborate in detergents. Sodium percarbonate, a more unstable compound containing pseudoperoxidates, has been used as a substitute primarily in Europe since it produces hydrogen peroxide at lower temperatures. This switch has affected boron consumption considerably.

Ferroboron.—Ferroboron (FeB) is a binary alloy of iron with boron content between 17.5% and 24% and is the lowest cost boron additive for steel and other ferrous metals. On average, the steel industry consumes more than 50% of the ferroboron produced annually (Eti Holding Inc., 2003). Boron steel, containing around 0.008% ferroboron, possesses a higher strength and lighter weight than that of average high-strength steel, making it the ideal material in the manufacturing of safe and fuel efficient automobiles. Boron steel had been found primarily in luxury European automobiles, being incorporated into the dash-cross member, door strengthening beam, and bumper reinforcement. However, auto manufacturers have announced the use of boron steel in future, lower priced vehicles (Ford Motor Co., 2008; Watson, 2008).

Boron is also utilized in aluminum castings to refine the grain; in copper-base alloys and high-conductance copper, as a degasifier; and in the nonferrous metals industry, generally as a deoxidizer. In the semiconductor industry, small, carefully controlled amounts of boron are added as a doping agent to germanium and silicon to modify electrical conductivity. Applications also include the manufacturing of neodymium-iron-boron magnets, consuming nearly 10% of the ferroboron produced annually (Eti Holding Inc., 2003).

Fire Retardants.—Zinc borate was used in plastics as a multifunctional boron-base fire retardant with applications in a variety of plastics and rubber compounds. Zinc borate is mainly used in flexible and rigid polyvinyl chloride formulations partly substituting for antimony trioxide. It is increasingly used as a component of halogenated and halogen-free formulations in epoxies, nylons, polyolefins, rubber, and thermoplastic polyesters. Boric acid is used in cellulose insulation and wood as a fire retardant. Boric acid is also found in flame-retardant barrier materials for inexpensive cotton mattresses (U.S. Environmental Protection Agency, 2005).

Glass.—As in previous years, the glass industry remained the leading domestic market for boron production. Boron is used as an additive in glass to reduce thermal expansion, improve strength, chemical resistance and durability, and provide resistance against vibration, high temperature, and thermal shock. Boron is also used as a fluxing agent, reducing the viscosity of glass during formation to improve manufacturing. Depending on the application and quality of the glass, borax, boric acid, colemanite, ulexite, and sodium borates are typically used.

Insulation and textile fiberglass represents the largest single use of borates worldwide. Fiberglass is a material made from fibers of glass usually 6 to 9 nanometers (nm) in diameter, produced by heating glass to a molten state with uniform viscosity, extruding fibers from orifices in platinum bushings, spraying the fibers with a binder, and winding the fibers onto a spool. End uses for fiberglass are corrosion-resistant, heat-resistant, and high-strength fabrics, insulation, reinforcement, and sound absorption. The incorporation of borates into fiberglass greatly improves quality, establishing a product that is strong, lightweight, and thermal and chemical resistant (Garrett, 1998).

Borosilicate refers to glass with boric oxide content between 5% and 30%. The boron content in borosilicate imparts many valuable properties to the glass, such as increased mechanical strength, low coefficient of thermal expansion, and resistance to chemical attack and thermal shock. As such, borosilicate glass was used on the National Aeronautics and Space

Administration Space Shuttle Orbiter thermal protection tiles to dissipate temperatures of 3,000° F (1,650° C) experienced during atmospheric reentry (National Aeronautics and Space Administration, 1989). Typically borosilicate glass has a composition of 70% silica, 10% boron oxide, 8% sodium oxide, 8% potassium oxide, and 1% calcium oxide. After Corning Glass Works introduced Pyrex® in 1915, it became a synonym for borosilicate glass. However, since 1998, Pyrex® kitchen brand is no longer made of borosilicate but of soda-lime glass.

Demand for boron glass was driven by the construction industry, which saw decreased U.S. activity in 2008. On the other hand, consumption of boron glass in high-tech applications increased in 2008, particularly in the manufacturing of circuit boards, computer screens, and flat screen televisions (Tran, 2008).

Other.—Borates are a part of the starch adhesive formulation for corrugated paper and paperboard and a peptizing agent in the manufacture of casein- and dextrin-based adhesive. Borate treated wood is used in the construction of homes to protect against wood destroying organisms. Borate treated wood has been used successfully for more than 50 years in New Zealand and for a decade in Hawaii—specifically to combat highly destructive termites. Borates prevent fungal decay and are deadly to carpenter ants, roaches, and termites.

Boron fiber is a monofilament almost 125 to 140 nm in diameter comprising elemental boron, typically produced under chemical vapor deposition of boron trichloride with tungsten wire acting as the catalyst. Owing to its high strength and hardness, boron fiber was used in the construction of the horizontal and vertical stabilizers and rudders of the F-14 and F–15 fighter and B–1 bomber aircrafts. The lower production cost and the higher availability associated with carbon fiber has limited boron fiber's use in modern aviation structural components. However, boron fiber has proven to be more advantageous than carbon fibers when used as a repair material for structural defects. Boron fiber does not produce a galvanic couple with aluminum, thus eliminating the threat of corrosion at the repair site. Boron fiber possesses the ideal electrical conductivity for the use of the eddy-current nondestructive inspection method, the preferred means of verifying structural integrity of repairs (Baker and others, 2004, p. 597).

Various boron compounds are used in nuclear powerplants to control neutrons produced during nuclear fission. The isotope boron-10 in particular possesses a high propensity for absorbing free neutrons, producing molecules of lithium and alpha particles after absorbing neutrons. Control rods composed of boron carbide are lowered into a nuclear reactor to control the fission reaction by capturing neutrons. Boric acid is used in the cooling water surrounding nuclear reactors to absorb escaping neutrons (Ceradyne Inc., 2009).

There is growing evidence that boron plays an important role in human health, but the available data are not conclusive. However, the adult mean intake of boron from supplemental vitamins is approximately 0.14 milligrams per day (Otten and others, 2006, p. 543).

Borazine and polyborazylene can be used as precursor chemicals to boron nitride coatings and composites. Boron nitride can also be found in large quantities in cosmetics owing to its low coefficient of friction and lack of toxicity. It has been shown to be an ideal alternative to talcum powder, which studies show may be linked to ovarian cancer (Emsley, 2004, p. 259). Boric acid has applications in cosmetics, pharmaceuticals, and toiletries. Borates are also added to brake fluids, fuel additives, lubricants, metalworking fluids, and water treatment chemicals. Boron oxide inhibits corrosion.

Transportation and Distribution

Almost all U.S. borates were shipped in North America by rail. Prices for rail haulage depended on a number of factors, including the ability of customers to load and unload efficiently, the ability to use unit trains and to supply one's own railcars, and fuel prices.

SVM owns the Trona Railway, a 50-kilometer (km) (31-mile) shortline railroad that connects to the Southern Pacific Railroad between Trona and Searles Stations in California. The Trona Railway provides a dedicated line with access to the national rail system for the borate, soda ash, and sodium sulfate markets.

The Boron Mine (owned by Rio Tinto Borax) at Boron, CA, 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. Truckloads of product from Boron are driven to Cantil, about 64 km (40 miles) northwest of Boron and loaded into dedicated railcars to be shipped to customers.

Rio Tinto Borax utilized a privately owned berth located in the Port of Wilmington, CA, for ocean transportation of borate products. Products destined for Europe were shipped from the bulk terminal in Wilmington to a company-owned facility in the Port of Rotterdam, Netherlands, to company facilities in Spain, and to contracted warehouses. Borax Group also maintains secondary stock points in Austria, Germany, the Republic of Korea, Norway, Singapore, Taiwan, and Ukraine. The most centrally located Rio Tinto Borax port location in Europe was Antwerp, Belgium. 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, including Austria, the Czech Republic, and Slovenia. A decision to import borates was based on the geographic location, the range of service needed, and prices.

Rio Tinto Borax used barges to ship borates from Rotterdam to customers in Belgium, Eastern Europe, France, and Germany. Barges were the most efficient and reliable method of transporting goods throughout Europe because waterways provide an ideal, low-cost linkage between large industrial areas and the Baltic, Black, Mediterranean, and North Seas and the Atlantic Ocean.

Imports from South America and Turkey entered into the United States principally through the ports of Charleston, SC, and Houston, TX.

Prices

Yearend prices of boron minerals and compounds produced in the United States are listed in table 3. Prices for borates have been flat for the past few years, reflecting competition in the marketplace and a balance between supply and demand. Table 4 lists the free alongside ship values for U.S exports of boric acid and quantities of boric acid and refined sodium borate compounds exported to various countries. The Netherlands received the largest amount of both boric acid and sodium borates from the United States owing to the fact that U.S. Borax has one of its main facilities located in the Port of Rotterdam, which received products from its U.S. facility in California.

World Review

Argentina.—Argentina was the leading producer of boron minerals in South America in 2008 (table 6). Borate deposits are located primarily in the Puna region, which includes the northwestern tip of Argentina, the southeastern corner of Peru, the southwestern corner of Bolivia, and the northeastern edge of Chile. Recent increased demand in Asia and North America for borate use in ceramics and glass increased production of Argentine borates, boric acid in particular. However, future foreign mine investments appeared to be stagnating with the lifting of tax exemptions for mineral exports in 2007, creating a 5% to 10% export duty (Industrial Minerals, 2007a).

Rio Tinto Minerals–Argentina (formally Borax Argentina S.A.), the country's leading producer of borates, operated open pit mines at Porvenir in Jujuy Province and at Sijes and Tincalayu in Salta Province. These operations produced colemanite, hydroborocite, kernite, tincal, and ulexite at a rate of 100,000 metric tons per year (t/yr) (Industrial Minerals, 2009). Located at 4,100 m (13,400 feet) above sea level, the Tincalayu Mine was Argentina's largest open pit operation. The deposit consisted primarily of borax ore, with rare occurrences of ulexite and 15 other borates. Rio Tinto also produced refined borate ores and boric acid at refineries in Campo Quijano, Sijes, and Tincalayu in Salta Province and Porvenir in Jujuy Province.

Minera Santa Rita S.R.L. (MSR) operated mines in Catamarca, Jujuy, and Salta Provinces and operated a processing plant in Campo Quijano, which produced granular deca- and pentahydrate borax, technical-grade boric acid powder, and various grades and sizes of the natural boron minerals. MSR refined more than 50,000 t/yr of borates and was expected to refine 75,000 t/yr through the investment in a flow bed system, a device that more efficiently dries boric acid. MSR has also announced a permanent supply agreement with Sulphaar S.R.L. to furnish sulphuric acid for the Campo Quijano plant (Santa Rita Mining Co., 2007).

Other borate producers in the Province of Juyuy included Procesadora de Boratos Argentina S.A. (PBA), Cía Minera Gavenda S.A., and Triboro S.A. PBA mined borates from the Loma Blanca mineral deposit located in the northeast Puna region and operated a processing facility located in Palpala, Jujuy, with a capacity of 50,000 t/yr. Cía Minera Gavenda produced borates at the Inundada Mine at Salar Cauchari which is a calcium-depleted ulexite playa with boron oxide content between 11% and 35%. Triboro mined ulexite from the Irene Mine which also contains boron oxide at a grade of between 11% and 35%. Manufacturas Los Andes S.A. and Ulex S.A. were other producers in Argentina, with capacities of 4,800 t/yr and 50,000 t/yr, respectively. Numerous smaller companies mine ulexite on an intermittent basis from salars in the Altiplano of the Andes (Tran, 2008).

Bolivia.—The most important Bolivian borate deposits, mined primarily by small cooperatives, are located in the Altiplano of the Andes and contain ulexite with associate tincal. A dispute in 2006 between the Bolivian Government and Chilean industrial minerals producer Química e Industrial del Bórax Limitada (Quiborax) over mining concessions resulted in the blockade of the Ferroviaria Andina railway used by Quiborax to transport borates between Bolivia and Chile and the withdrawal of concessions to mine the Salar de Uyuni salt flats for ulexite. The Bolivian mining agency, Corporación Minera de Bolivia (COMIBOL), was seeking to develop the Salar de Uyuni salt flats for future borate production with the intent to produce 20,000 t/yr of boric acid (Industrial Minerals, 2006a, 2009).

Chile.—In 2008, Chile was the second leading producer of boron minerals in South America (table 6). The Chilean borate producers were all located in the northeastern edge of Chile, which contains one the world's largest deposits of ulexite. The largest producers, Quiborax, mines 450,000 t/yr of crude ulexite and processes up to 80,000 t/yr of boric acid and 40,000 t/yr of granular ulexite (Tran, 2008).

Chile's National Forestry Corp. (CONAF) requested that Quiborax halt all operations in the protected natural reserve salt flat of Salar de Surire owing to encroachment on important flamingo nesting sites. A 1989 presidential decree prohibited any mining activity within 3,000 m of nesting sites. CONAF also requested the National Environmental Commission (CONAMA) demand that Quiborax perform an environmental impact study (U.S. Agency for International Development, 2008).

China.—China possessed more than 100 borate deposits in 14 Provinces with 20 to 30 private borate producers in 2008. The northeastern Province of Liaoning and the western Province of Qinghai accounted for more than 80% of the resources, mostly in the form of borax decahydrate and boric acid. The resources were largely consumed domestically, although there are some exports to neighboring countries. Chinese boron consumption increased in 2008 driven by demand from the ceramic and domestic glass industry. In 2008, China became the world's leading consumer of ceramic raw materials (Industrial Minerals, 2008a).

India.—India relied entirely on imports of borates from China, Turkey, and the United States to fulfill its domestic needs. Borate products that are refined in India include boric acid, boron carbide, ferroboron, and sodium perborate. The leading producer of refined borates was Indo Borax & Chemical Ltd., which operated borax and boric acid plants in Pithampur, Madhya Pradesh, northeast of Mumbai.

Kazakhstan.—The Satimola borates deposit in western Kazakhstan was under development by Borates PLC of the United Kingdom. The deposit is about 220 km from the Caspian Sea port of Atyrau and 210 km from the railhead at Makat. Solution mining appears to be the most cost-effective method of mining. The project was expected to produce 75,000 t/yr of boric acid, 50,000 t/yr of ulexite-hydroboracite concentrates, and 25,000 t/yr of anhydrous boric acid. Sodium borates also could be produced if a local source of trona can be found (Industrial Minerals, 2006c).

Russia.—There are three known boron deposits in Russia, but only the Bor deposit in Primorsk is mined. Russian borates were primarily exported to consumers in China, Japan, and the Republic of Korea, with only 10% being consumed domestically. The sole producer, Bor Mining Chemical Co., had a production capacity of 120,000 t/yr boric acid which accounted for 92% of their total production. In January, the company announced the completion of a high-purity boron trichloride production plant, which was expected to increase production capacity (Tran, 2008).

Serbia.—Rio Tinto Minerals was awarded the concession in December 2005 for the Piskanja borate deposit in southern Serbia (Industrial Minerals, 2006b). However, Erin Ventures Inc. contended that it held a joint venture contract with Elektroprevreda, the Serbian national power corporation, for development of the deposit and was seeking monetary compensation and property rights. The Serbian Ministry of Mining and Erin Ventures had agreed to discuss a possible settlement (Erin Ventures Inc., 2009).

Turkey.—The main borate producing areas of Turkey are Bigadic, Emet, Kestelek, Kirka, and Sultancayiri, all controlled by Eti Maden AS, the Turkish state-owned mining company. Production of refined borates increased during the past few years owing to continued investment in new refineries and technologies. As a result, Eti Maden increased exports of boric acid to Asian consumers for use in ceramics and glass (Rio Tinto plc, 2009).

The 2002 decision by the Swedish Government to classify borates as toxic may lead to two far-reaching ramifications: loss of export revenues and denial of admission into the European Union (EU). Nearly 25% of export revenues generated from borates come from Europe. The Turkish Government reportedly contended that sales would plummet if harsher regulations against borates were enacted throughout Europe. Such regulations would need to be approved through the EU Council. Turkey planned to take the matter to the World Trade Organization's Dispute Settlement Body if such regulations were enacted, but feared retaliation against their entry into the EU (Daly, 2008).

Outlook

Fire Retardants.—Worldwide flame retardants consumption was expected to increase between 4% and 5% from 2009 to 2012. The forecast growth will be in response to environmental concerns regarding halogen retardants and higher demand in automotive applications. The highest increase in use of halogen-free flame retardants was expected to be in China, with an expected increase of greater than 13% during this period. A smaller increase was expected to take place in Western Europe, and in the United States the anticipated increase could be between 9% and 11%. The average global annual growth rate for halogen-free flame retardants was greater than 10%, compared with 5% for the general flame retardants market (Industrial Minerals, 2007b).

Glass.—Since the U.S. demand for boron glass greatly depends on the construction industry, the outlook for this sector appeared to stagnate owing to the 2008 housing credit crisis. Glass producers were predicting not to gain or lose additional business and were pointing to signs of an economic rebound for future market stability. The decline in boron consumption by the construction industry was predicted to be offset by increased growth in fiberglass and high-tech sectors. Europe and emerging markets are requiring higher building standards, which directly correlates to higher consumption of insulation fiberglass. Global demand for liquid-crystal display televisions was expected to double by 2012. Consumption of borates used in high-tech applications was expected to increase by 13% in Europe and 10% in North America by 2012 (Tran, 2008).

Other.—Research into boron use in nanotechnology is progressing rapidly, with studies constructing more stable forms of boron nanotubes and developing more efficient fabrication techniques. Boron nanotubes were expected to overtake carbon nanotubes as the ideal material in nanoengineering, since boron nanotubes can be configured as electrical conductors, a property not inherent to carbon nanotubes (Battersby, 2008; Oku, 2008, p. 335–350).

Boron neutron capture therapy (BNCT), conceptualized as early as the 1930s by the biophysicist G.L. Locher, is an experimental radiation technique for destroying tumor cells, which clinical trials have shown holds promise for the treatment of head and neck cancer. BNCT relies on the concept that boron-10 irradiated with low-energy thermal neutrons yields alpha particles and lithium-7 ions. By injecting patients with boron-10 containing tumor-seeking compounds, researchers have illustrated the disintegration of tumor cells while leaving adjacent normal cells unaffected. BNCT requires that a steady neutron beam be applied to the tumor cells, thus reducing the types of cancers that can be treated and the availability of the treatment. Only tumors located away from bone structures are ideal candidates for BNCT, since obstructions limit the exposure of neutrons to the tumor site. Presently, epithermal neutrons can only be produced in a nuclear reactor, limiting the availability of BNCT to large research facilities and keeping it out of reach of smaller oncology departments (Massachusetts Institute of Technology, 2009).

Boron-treated wood is becoming more widely used throughout the United States, especially in the southern States. Borates interfere with termites' metabolic pathways when ingested through feeding or grooming, effectively killing them. Borate has been so successful that the Southern Building Code Congress has determined that homes built with borate-treated framing lumber do not need to be ground-poisoned. Costs are about 30% higher than comparable building products (Old House Journal, 2007).

To create more demand for its product, Turkey launched a promotional campaign for boron by seeking out new areas of use for the mineral. The Boron Institute of Turkey continues to sponsor multiple projects by Turkish universities and research centers. The successful projects so far include adding boric acid to porcelain floor tiles as well as adding boron in the production of fortified cement, doubling cement quality and lifespan. Other successful projects include use as bone reinforcement for laying hens; as a fertilizer for hazelnut, kiwi, sugar beet, and tomato farming; in the production of fuel cells that are 100 times structurally stronger than ordinary cells while remaining environmentally friendly; in the production of environmentally friendly batteries; as an additive to boost the traction and elongation capacity of steel; and in the treatment of breast and prostate cancer (Today's Zaman, 2008).

With the increase in government involvement and funding into "greener" policies, a greater importance has been placed on the development of alternative automotive power sources. The use of fuel cells has for decades been a viable solution, but commercially did not come to true fruition until recently with the greater use of lithium-ion batteries. Sodium tetrahydroborate is a principle component in direct borohydride fuel cells (DBFC), which have been successfully produced for several small scale uses. Although considered a hydrogen fuel cell, DBFC differs from traditional hydrogen fuel cell in that hydrogen is produced as the waste product (exhaust) with sodium tetrahydroborate and water being the input fuels. This design is advantageous since hydrogen can be stored and then reused as the input fuel for another hydrogen fuel cell (Moores, 2008).

References Cited

American Borate Company, 2005, [untitled]: Virginia Beach, VA, American Borate Company. (Accessed July 20, 2009, at http://www.americanborate.com/.)

Baker, A., Dutton, S., and Kelly, D., 2004, Composite materials for aircraft structures (2d ed.): Reston, VA, American Institute of Aeronautics and Astronautics, 597 p.

Battersby, Stephen, 2008, Boron nanotubes could outperform carbon: New Scientist, January 4. (Accessed September 12, 2009, at http://www.newscientist.com/article/dn13143-boron-nanotubes-could-outperform-carbon.)

California Historic Route 66 Association, 2007, Newberry Springs, California fact sheet: Azusa, CA, California Historic Route 66 Association, October. (Accessed July 20, 2009, at http://www.route66ca.org/traveler/towns/11newber/factsht.html.)

Ceradyne Inc., 2009, Boron products: Costa Mesa, CA, Ceradyne Inc. (Accessed August 3, 2009, at http://www.ceradyneboron.com/about/boron-products.aspx.)

Daly, J.C.K., 2008, Turkey and EU in trade row over boron: Washington, DC, The Jamestown Foundation, November 12. (Accessed November 18, 2008, at http://jamestown.org/edm/article.php?article_id=2373528.)

Emsley, John, 2004, Vanity, vitality and virility—The science behind the products you love to buy: New York, NY, Oxford University Press, 259 p.

Erin Ventures Inc., 2009, Serbian lawsuit and boron property settlement discussions continue: Victoria, Ontario, Canada, Erin Ventures Inc., June 19. (Accessed September 4, 2009, at http://www.erinventures.com/news/news190609.html.)

Eti Holding Inc., 2003, Pre-feasibility report summaries of boron carbide, boron nitride, ferroboron, frit and glaze, textile glass fibre, zinc borate: Ankara, Turkey, Eti Holding Inc., 23 p.

Eti Maden AS, 2008, Annual report 2008: Ankara, Turkey, Eti Maden AS, 83 p.

Ford Motor Co., 2008, Ford Flex hits safety pinnacle with 5-star ratings: Dearborn, MI, Ford Motor Co. press release, August 5. (Accessed September 9, 2009, at http://www.ford.com/about-ford/news-announcements/press-releases/press-releases-detail/pr-ford-flex-hits-safety-pinnacle-28812.)

Garrett, D. E. 1998, Preface, in Borates—Handbook of deposits, processing, properties, and use: San Diego, CA, Academic Press, p. xi–xiv.

Hamilton, S., 2006, Boron: Mining Engineering, v. 58, no. 6, June, p. 21–22.

Industrial Minerals, 2006a, Quiborax dispute update: Industrial Minerals, no. 464, May, p. 13.

Industrial Minerals, 2006b, Rio Tinto looks to Serbian borates: Industrial Minerals, no. 462, March, p. 14.

Industrial Minerals, 2006c, Satimola borates: Industrial Minerals, no. 462, March, p. 101.

Industrial Minerals, 2007a, Argentina invokes 10% mineral export tax: New York, NY, Industrial Minerals, December 14. (Accessed August 24, 2009, via http://www.indmin.com.)

Industrial Minerals, 2007b, Mineral flame retardants, still burning bright: Industrial Minerals, no. 479, August, p. 52.

Industrial Minerals, 2008a, Serving China's ceramics: Industrial Minerals, no. 488, May, p. 35.

Industrial Minerals, 2008b, Technical ceramics take off: Industrial Minerals, no. 495, December, p. 66.

Industrial Minerals, 2009, Minerals in the mist: Industrial Minerals, no. 498, March, p. 40.

Industrial Minerals Inc., 2007, [untitled]: Industrial Minerals Inc. (Accessed July 20, 2009, at http://www.iminco.com/.)

Massachusetts Institute of Technology, 2009, The basics of boron neutron capture therapy: Cambridge, MA, Massachusetts Institute of Technology. (Accessed July 21, 2009, at http://web.mit.edu/nrl/www/bnct/info/description/description.html.)

Moores, Simon, 2008, Fuel for thought—Fuel cell mineral potential reviewed: Industrial Minerals, no. 488, May, p. 44.

National Aeronautics and Space Administration, 1989, Orbiter thermal protection system: Houston, TX, National Aeronautics and Space Administration, February. (Accessed August 20, 2009, at http://www-pao.ksc.nasa.gov/kscpao/nasafact/tps.htm.)

National Park Service, 2008, Death Valley National Park, Mining in Death Valley: U.S. Department of the Interior, July 6. (Accessed July 20, 2009, at http://www.nps.gov/deva/naturescience/mining-in-death-valley.htm.)

Oku, Takeo, 2008, Formation of gold and iron nanowires in carbon and boron nitride nanotubes, *in* Xue, X., ed., Nanowire research progress: New York, NY, Nova Science Publishers, Inc., p. 335–350.

Old House Journal, 2007, Better ways to lasting wood: Little Rock, AR, Old House Journal, September. (Accessed August 22, 2008, at http://www.oldhousejournal.com/Better_Ways_to_Lasting_Wood/magazine/1314.)

Otten, J.J., Hellwig, J.P., and Meyers, L.D., eds., 2006, Dietary reference intakes—The essential guide to nutrient requirements: Washington, DC, Institute of Medicine of the National Academies Press, 543 p.

Rio Tinto Borax, 2005, Bleaching with sodium perborate: Boron, CA, Rio Tinto Borax, 2005. (Accessed August 18, 2009, at http://www.borax.com/detergents/bleaching.html.)

Rio Tinto plc, 2009, Rio Tinto announces underlying earnings of $10.3 billion—Up 38 per cent: London, United Kingdom, Rio Tinto plc., February 12, 38 p.

Santa Rita Mining Co., 2007, Santa Rita Mining Co. (Accessed August 24, 2009, via http://www.santaritasrl.com/.)

Today's Zaman, 2008, Turkey finds new uses for abundant boron reserves: Istanbul, Turkey, Today's Zaman, September 12, 5 p. (Accessed September 12, 2008, at http://todayszaman.com/.)

Tran, Alison, 2008, Borates, as seen on TV: Industrial Minerals, no. 489, June, p. 30.

Troeh, F.R., and Thompson, L.M., 2005, Soils and soil fertility: Ames, IA, Blackwell Publishing, 489 p.

U.S. Environmental Protection Agency, 2005, Considerations for selecting a replacement for pentaBDE *of* Furniture flame retardancy partnership—Environmental profiles of chemical flame-retardant alternatives for low-density polyurethane foam: U.S. Environmental Protection Agency, v. 1, September, p. 5.1–5.6.

U.S. Agency for International Development, 2008, Chile forestry officials halt mining to protect flamingos: U.S. Agency for International Development Resource Management Portal, October. (Accessed September 4, 2009, at http://rmportal.net.)

Watson, Len, 2008, Boron steel in vehicles—Implications of HSLA/UHSS and boron steels for rescuers: Halstead, United Kingdom, ResQmed Ltd., August, 7 p. (Accessed July 28, 2009, at www.resqmed.com/BoronSteel1.pdf.)

GENERAL SOURCES OF INFORMATION

U.S. Geological Survey Publications

Boron. Ch. in Mineral Commodity Summaries, annual.

Evaporites and Brines. Ch. in United States Mineral Resources, Professional Paper 820, 1973.

Other

Boron. Ch. In Mineral Facts and Problems, U.S. Bureau of Mines, Bulletin 675, 1985.

European Borates Association.

Industrial Minerals Association-North America.

TABLE 1

SALIENT STATISTICS OF BORON MINERALS AND COMPOUNDS[1]

(Thousand metric tons and thousand dollars)

	2004	2005	2006	2007	2008
United States:					
Sold or used by producers:					
Quantity:					
Gross weight[2]	1,210	1,150	W	W	W
B_2O_3 content	637	612	W	W	W
Value	626,000	713,000	W	W	W
Exports:[3]					
Boric acid:[4]					
Quantity	61	183	221	248	303
Value	34,900	96,800	126,000	124,000	165,000
Sodium borates:					
Quantity	135	308	393	446	519
Value	60,200	110,000	138,000	146,000	192,000
Imports for consumption:					
Borax:[3]					
Quantity	(5)	1	2	1	1
Value	62	319	701	647	566
Boric acid:[3]					
Quantity	49	52	85	67	50
Value	20,300	22,500	34,900	27,500	26,200
Colemanite:					
Quantity[6]	21	31	25	26	30
Value	6,070	8,900	7,260	7,640	8,880
Ulexite:					
Quantity[6]	110	103	131	92	75
Value	21,900	31,000	39,200	27,600	22,600
Consumption, B_2O_3 content	385	W	W	W	W
World, production[7]	4,960	4,950 [r]	3,760 [r]	4,220 [r]	4,350 [e]

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data.

[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, 2840.20.0000, and 2840.30.0000.

[5]Less than ½ unit.

[6]Source: Journal of Commerce Port Import/Export Reporting Service.

[7]United States production withheld from world production in 2006, 2007, and 2008 to avoid disclosing company proprietary data.

TABLE 2
BORON MINERALS OF COMMERCIAL IMPORTANCE

Mineral[1]	Chemical composition	B_2O_3, 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 indicate common names.

TABLE 3
YEAREND PRICES FOR BORON MINERALS AND COMPOUNDS[1, 2]

(Dollars per metric ton)

Product	2007	2008
Borax, anhydrous, 25-kilogram bags	1,678–1,798	1,223–1,310
Borax, decahydrate	340–380	340–380
Borax, decahydrate, granular	799–899	582–655
Borax, pentahydrate	400–430	400–430
Borax, pentahydrate, granular	599–699	437–509
Boric acid, granular	699–799	509–582
Colemanite, Turkish lump, 40%-42% boron oxide (B_2O_3)	270–290	270–290
Ulexite, Lima, 40% B_2O_3	250–300	490–520

[1]As of December 31 of year stated.

[2]U.S. free on board 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.

Source: Industrial Minerals, no. 483, December 2007, p. 76; no. 495, December 2008, p. 88.

TABLE 4

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

	2007			2008		
	Boric acid[2]		Sodium	Boric acid[2]		Sodium
	Quantity	Value[3]	borates[4]	Quantity	Value[3]	borates[4]
Country	(metric tons)	(thousands)	(metric tons)	(metric tons)	(thousands)	(metric tons)
Australia	2,520	$1,270	7,070	3,100	$1,690	7,750
Belgium	45	31	31	64	129	265
Brazil	1,990	1,150	866	1,840	1,970	4,060
Canada	4,350	3,150	40,300	4,210	3,090	38,100
China	50,200	24,700	88,100	73,400	37,900	109,000
Colombia	242	199	5,150	347	383	6,240
France	7,960	5,370	679	12,700	7,860	514
Germany	1,410	2,010	17	357	851	12
Hong Kong	1,520	752	21	2,060	1,050	125
India	1,470	525	19,700	1,890	941	26,200
Indonesia	921	468	1,820	1,690	966	3,140
Italy	--	--	1,440	1	3	240
Japan	29,700	17,600	26,100	33,900	21,400	26,600
Korea, Republic of	25,600	13,800	15,500	35,500	19,500	17,600
Malaysia	1,630	858	50,900	2,140	1,110	64,200
Mexico	3,200	1,890	10,600	5,360	3,770	13,500
Netherlands	54,900	21,300	127,000	55,000	26,600	121,000
New Zealand	403	208	1,430	717	397	1,530
Philippines	117	89	1,400	105	82	1,910
Singapore	1,500	1,070	619	1,750	1,200	801
Spain	16,500	5,970	24,600	24,500	11,200	41,500
Taiwan	31,300	15,400	4,290	32,700	17,300	5,560
Thailand	3,830	2,120	6,600	4,700	2,650	8,830
United Kingdom	60	58	72	55	77	16
Venezuela	71	83	479	63	104	522
Vietnam	1,380	677	2,810	1,380	772	3,240
Other	4,960	2,970	9,160	3,300	2,010	17,300
Total	248,000	124,000	446,000	303,000	165,000	519,000

-- 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]Free alongside ship valuation.

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

Source: U.S. Census Bureau.

TABLE 5

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

	2007		2008	
Country	Quantity (metric tons)	Value[2] (thousands)	Quantity (metric tons)	Value[2] (thousands)
Argentina	--	--	112	$95
Bolivia	7,210	$2,860	2,480	1,830
Chile	12,800	5,140	6,650	4,430
China	268	472	222	141
France	738	1,230	716	1,210
Germany	13	34	35	51
India	181	187	275	289
Italy	954	1,370	1,310	1,550
Japan	56	124	13	30
Peru	1,510	651	2,170	1,760
Russia	1	6	--	--
Turkey	43,000	15,100	35,900	14,600
United Kingdom	270	284	216	218
Other	21 r	44 r	5	18
Total	67,000	27,500	50,100	26,200

[r]Revised. -- 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 6

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

(Thousand metric tons)

Country	2004	2005	2006	2007	2008[e]
Argentina	821	633	534	670 r, 3	786 3
Bolivia, ulexite	68	63	50 r	80 r	56 p, 3
Chile, ulexite	594	461	460	528	583 3
China[e, 4]	135	140	145	145	140
Iran, borax[5]	2	2 e	2 e	2	2
Kazakhstan[e]	30	30	30	30	30
Peru	10	120 r	191 r	234 r	350 3
Russia[e, 6]	500	400	400	400	400
Turkey[7]	1,588	1,953	1,948	2,128 3	2,000
United States[8]	1,210	1,148 r	W	W	W
Total	4,960	4,950 r	3,760 r	4,220 r	4,350

[e]Estimated. [p]Preliminary. [r]Revised. W Withheld to avoid disclosing company proprietary data, not included in total.

[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 August 24, 2009.

[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.