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BORON

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Boron

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U.S. consumption of minerals and compounds reported in boron oxide continued to increase in 2010 but quantities are 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 in 2010 to an estimated 4.08 million metric tons (Mt) compared with 3.76 Mt in 2009 (excluding U.S. production). The United States exported 264,000 metric tons (t) of boric acid and 423,000 t of sodium borate in 2010, an increase from the 171,000 t of boric acid and 417,000 t of sodium borates exported in 2009 (tables 1, 4). Boron imports consisted primarily of borax, boric acid, colemanite, and ulexite (tables 1, 5).

Elemental boron is a metalloid with limited commercial applications. The main applications were as a doping agent in the manufacture of semiconductors and as an ignition source in airbags. The global consumption rate of elemental boron was estimated to be 15 metric tons per year (t/yr). Boron compounds, chiefly borates, are commercially important; therefore, boron products are priced and sold based on boric oxide content (B_2O_3), which varies by ore and compound, and on the absence or presence of sodium and calcium (table 2). Borax, one of the most important boron minerals for industrial use, is a white crystalline substance chemically known as sodium tetraborate decahydrate and is found in nature as the mineral tincal. Boric acid, also known as orthoboric acid or boracic acid, is a white, colorless crystalline solid sold in technical, national formulary, and special quality grades as granules or powder. 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

Four minerals make up 90% of the borates used by industry worldwide: the sodium borates tincal and kernite, the calcium borate colemanite, and the sodium-calcium borate ulexite. Borate deposits are associated with volcanic activity and arid climates, and the largest borate deposits are located in the Mojave Desert of the United States, the Alpide belt in southern Asia, and the Andean belt of South America. As a result, most borates were extracted primarily in California and Turkey and to a lesser extent in Argentina, Bolivia, Chile, China, and Peru. Boron compounds and minerals were produced by surface and underground mining and from brine.

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).

SVM, acquired by the Indian company Nirma in 2007, produced borax and boric acid from brines containing potassium and sodium borates that were extracted from three salt layers, up to 100 meters (m) deep, in Searles Lake, located near Trona in San Bernardino County, CA. SVM's Trona and Westend plants refined the brines, producing anhydrous, decahydrate, and pentahydrous borax. These brines also supplied other commercial salts in addition to sodium borates and boric acid. The Trona plant has a reported capacity of 27,500 t/yr B_2O_3, and the Westend plant has a reported capacity of 82,300 t/yr B_2O_3.

Rio Tinto Borax (a wholly owned subsidiary of United Kingdom-based Rio Tinto Minerals) mined mainly tincal and kernite at Boron, CA, by open pit methods, and the ore was transported by truck to a storage area. The tincal had an average grade of 25.3% B_2O_3 and the kernite had an average grade of 31.9% B_2O_3. Boric acid and refined sodium borates were produced at an onsite processing plant. Refined borate products were shipped by railcar or truck to North American customers or to the company's Wilmington, CA, facility and exported from the Port of Los Angeles. Specialty borate products were made at the Wilmington plant. According to a Securities and Exchange Commission report filed by Rio Tinto Borax, the company produced 483,000 t of borates in 2010, an 18% increase from the 411,000 t reported in 2009 (Rio Tinto plc, 2011, p. 80).

As part of a divestment program in September 2007, Rio Tinto Minerals put Rio Tinto Borax on sale. In July 2009, the company canceled the sale because bidders had not offered the valuation of the asset (Industrial Minerals, 2009c). In May, a labor agreement reached by Rio Tinto Borax and the employees' labor union, International Longshore & Warehouse Union, effectively ended a 3-month strike at the borate mine in Boron. During the strike, operations were manned by temporary employees and 170 unaffected worked (Watts, 2010). In January 2011, Rio Tinto declared force majeure on sales of its sodium borate products owing to disruptions at its Boron Mine in Boron, CA, caused by heavy rain storms in late December 2010. Although 2010 production from Rio Tinto's California and Argentina mines increased by 18% from that of 2009, production during the fourth quarter 2010 decreased by 20% from that of the third quarter 2010 (O'Driscoll, 2011b).

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 and distributed for five end uses (Garrett, 1998; Hamilton, 2006).

In 2010, U.S. imports for consumption of borax, boric acid, colemanite, and ulexite were 101,000 t, a 5% increase from 96,000 t imported in 2009. In 2010, total U.S. apparent consumption of all boron products increased by 6% compared with that of 2009.

Agriculture.—Fertilizers represented the third largest application of borates. Boron was the most widely used micronutrient, applied primarily to promote fruit and seed production. Boron fertilizers were mostly sourced from borax, boric acid, and calcium borate owing to their high water solubility; thus, boron fertilizers can be delivered through sprays or irrigation water. Domestic consumption of boron fertilizers was estimated to be approximately 2% of total U.S. fertilizer consumption.

Boron is essential for plant uptake of primary and secondary nutrients, such as calcium, manganese, magnesium, 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 of boron, with 1 kilogram per hectare of boron (1 pound per acre) in soil being adequate to maintain these levels. U.S. boron deficiencies in crops are found primarily in the Atlantic coastal plains, Great Lakes region, and the 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 suggested was more often caused by higher boron levels in irrigation water than those in soil (Troeh and Thompson, 2005, p. 489).

Ceramics.—Ceramics comprise the second largest application of borates after glass, accounting for 10% of world consumption. Borates play an important role in ceramic glazes and enamels, increasing chemical, thermal, and wear resistance. Borax and colemanite are used in ceramics primarily as fluxing agents, with borax being used in higher temperature, and colemanite in lower temperature firings. Borates are also used in technical ceramics, an industry with applications in aerospace, ballistics, electronics, and medicine, which experienced strong growth during the past decade. The amount of B_2O_3 used in glazes varies between 8% and 24% and the amount used in enamels is between 17% and 32% by weight.

Boron carbide is a key ingredient in lightweight ceramic armor, the use of which created increased United States and European consumption of boron carbide during the past few years. Small arms protective inserts, used by the U.S. military, are boron carbide ceramic plates inserted into Kevlar flak jackets to protect against high-velocity projectiles (Industrial Minerals, 2008b).

A new calcined borate, known as E4972, was developed to replace conventional frits used in ceramic glazes. Frits were incorporated into glazes to obtain the appropriate technical and aesthetic properties under short firing of ceramics. E4972 possesses a low solubility, which enables its use in glaze formation (Industrial Minerals, 2009a).

Detergents and Soaps.—The use of borates in detergents and soaps represented the fourth largest market, accounting for 4% of world consumption. Borates were incorporated into laundry detergents, soaps, and other cleaning products because they can be used as alkaline buffers, enzyme stabilizers, oxygen-based bleaching agents, and water softeners. Two borates, sodium perborate and perborate tetrahydrate, were used as oxidizing bleaching agents because they contain true peroxygen bonds. Hydrogen peroxide, a very effective bleaching agent, is produced when sodium perborate undergoes hydrolysis while in contact with water. Because hydrogen peroxide cannot be effectively incorporated into detergents, sodium perborate acts as its carrier (Rio Tinto Borax, 2005). Sodium perborate, however, requires hot water to undergo hydrolysis, and concerns have emerged over excessive boron levels in waterways owing to sodium perborate in detergents. Sodium percarbonate has been used as a substitute primarily in Europe because it produces hydrogen peroxide at lower temperatures. This substitution has affected boron consumption.

Ferroboron.—Ferroboron (FeB) is a binary alloy of iron with a 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, p. 8). Boron steel, containing nearly 0.008% ferroboron, possesses a higher strength and lighter weight than that of average high-strength steel, and is a useful material in the manufacturing of safe and fuel efficient automobiles.

Ferroboron was used in the production of cast iron, neodymium-iron-boron (Nd-Fe-B) magnets, and steel. Nd-Fe-B magnets consumed nearly 10% of the ferroboron produced annually (Eti Holding Inc., 2003, p. 8). Nd-Fe-B magnets possess the highest strength of all magnets and were used in computer hard drives, guidance systems, and wind turbines (Moores, 2010). Ferroboron was also utilized in aluminum castings to refine grain-size; in copper-base alloys and high-conductance copper as a degasifier; and in the nonferrous metals industry, generally as a deoxidizer.

Fire Retardants.—Borates were incorporated into various materials, such as cellulosic insulation, textiles, and timber, to impart flame retardant properties to the materials. Boric acid was incorporated into wood flame-retardants to inhibit the transfer of combustible vapors and reduce the effective heat of combustion, resulting in reduced flame spread. Zinc borate was used in plastics as a multifunctional boron-based 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.

Glass.—The principle market for borates in 2010 was glass, representing approximately 60% of global borate consumption. 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 represented the largest single use of borates worldwide, at 45% of world consumption. 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 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. Past application of borosilicate ranged from Pyrex® kitchenware to the thermal protection tiles on the National Aeronautics and Space Administration Space Shuttle Orbiter.

Other.—Boron fiber is a monofilament about 125 to 140 nanometers 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 (Baker and others, 2004, p. 249).

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., 2011).

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 a useful alternative to talcum powder, which studies show may be linked to ovarian cancer (Emsley, 2004, p. 15–17). 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. Both U.S. producers had rail fleets dedicated to the exclusive transportation of their products. Small shipments of borates were shipped by rail or truck in specialty bags, usually of 2,100-pound capacity. Prices for rail haulage depended on 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 owned 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 provided a dedicated line with access to the national rail system for the borate, soda ash, and sodium sulfate markets. Nearly 80% of output was transported by rail to domestic consumers and to the ports of Long Beach and San Diego in California for export.

The Boron Mine was 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, served by the Union Pacific Railroad. Trucks of product from Boron were 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 Los Angeles, 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, company facilities in Spain, or contracted warehouses. 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 borate products 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 mode of transportation 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.

More than 65% of boric acid and sodium borate imports entered the United States through the ports of Norfolk, VA, and Philadelphia, PA. More than 87% of total exports of boron compounds and minerals left the United States through the ports of Los Angeles, CA, and Houston-Galveston, TX.

Prices

Yearend prices of boron minerals and compounds produced in the United States are listed in table 3. Prices for borates remained relatively unchanged from 2009 to 2010. The decrease in price observed from 2008 to 2009 reflected an imbalance between supply and demand created by the economic downturn observed beginning in the fourth quarter of 2008. The stabilization of prices from 2009 to 2010 may be an indicator that equilibrium between supply and demand was obtained during this period. 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.

Foreign Trade

The United States remained a net exporter of boron compounds and minerals in 2010, with net exports totaling 592,000 t, a 19% increase from the 498,000 t in 2009. Exports of boron compounds and minerals increased by 17% to 687,000 t in 2010. In 2010, China received the largest amount of sodium borates and boric acid from the United States owing to increased consumption of borates used in the Chinese glass and ceramic industries. Imports of 101,000 t in 2010 was a 6.3% increase from that of 2009. The sharp decrease in imports of ulexite in 2010 is primarily attributed to a 27,000 t decrease in shipments from Turkey.

World Review

Argentina.—Argentina became the leading producer of boron minerals in South America in 2010 (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 border of Chile. Recent increased demand in Asia and North America for borate use in ceramics and glass led to increased production of Argentine borates, boric acid in particular.

Borax Argentina S.A. (a subsidiary of Rio Tinto Minerals), 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 t/yr (Industrial Minerals, 2009b). 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, 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. Lithium Americas Corp. entered into an agreement with Borax Argentina to extract subsurface lithium and borate brines from the salt lake at Jujuy Province. The company contends that the brine has the correct composition to be economically viable (Industrial Minerals, 2009e). The company produced 18,000 t of borates in 2010, a 38% increase from the 13,000 t reported in 2009 but a 5% decrease from the 19,000 t produced in 2008 (Rio Tinto plc, 2011, p. 80).

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 exports 97% of its products to 28 countries through the port of Buenos Aires and by land to Brazil. MSR refined more than 50,000 t/yr of borates and was expected to refine 75,000 t/yr after the investment in a "flowing 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 sulfuric acid for the Campo Quijano plant (Santa Rita Mining Co., 2011).

Bolivia.—The most important Bolivian borate deposits, mined primarily by small cooperatives, are located in the Altiplano of the Andes and contain ulexite with associated tincal. The Bolivian mining agency, Corporación Minera de Bolivia (COMIBOL), was seeking to develop the Salar de Uyuni salt flats for future borate production. COMIBOL planned to establish a $5 million borate pilot plant on the deposit to determine full-scale feasibility. A full-scale boric acid plant would be expected to produce 20,000 t/yr (Industrial Minerals, 2006, 2009c; Moores, 2009).

Chile.—In 2010, Chile was the second leading producer of boron minerals in South America (table 6). The 504,000 t of boron minerals produced in 2010 was a 17% decrease from that of 2009. The Chilean borate producers were all located on the northeastern border of Chile, which contains one the world's largest deposits of ulexite. The largest producer, Quimica e Industrial del Borax Ltda. (Quiborax), mined 450,000 t/yr of crude ulexite and produced up to 80,000 t/yr of boric acid and 40,000 t/yr of granular ulexite (Tran, 2008).

China.—China possessed more than 100 borate deposits in 14 Provinces. The northeastern Province of Liaoning and the western Province of Qinghai accounted for more than 80% of the resources, mostly in the form of sassolite and tincal. Chinese boron resources are of low quality, averaging about 8.4% B_2O_3, in comparison to the Turkish and United States reserves, which average about 26% to 31% and 25.3% to 31.9% B_2O_3, respectively. Apparent consumption of borate in China increased by 7% per year between 2000 and 2009 fueled by the glass and ceramic industries, but domestic production remained relatively consistent during this period. To maintain this high level of consumption and moderate level of production, China became more import reliant on borate products originating from Russia, South America, Turkey, and the United States (Industrial Minerals, 2008a; Baylis, 2010, p. 5).

The Chinese government was considering closing a loophole that gives a 5% tax rebate on the export of alloys in attempts to curtail misuse of the rebate. Some carbon steel mills added small amounts of boron, nearly 0.0005% by weight, to pass the steel off as an alloy in order to collect the rebate. This practice may have given these mills as much as a 20% pricing advantage on their products (Metal Bulletin, 2011).

India.—Although deposits of borates were identified in India, the country was reliant on imports of borates from China, Turkey, and the United States to fulfill domestic needs. Borate products produced 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.

Serbia.—Erin Ventures Inc. (Victoria, British Columbia, Canada) entered into a binding agreement with the Serbian state-owned coal mining company, JP PEU, for joint development of the Piskanja borate deposit in southern Serbia. Additionally, Erin Ventures was seeking monetary compensation totaling $15 million from Elektroprevreda, the Serbian national power corporation, over an alleged 1997 breach of contract in the development of the Piskanja deposit. The deposit had an estimated resource of 7.5 Mt averaging 36% to 39% B_2O_3 (O'Driscoll, 2010, 2011a).

Rio Tinto Minerals held a license to the Jadar borate lithium deposit 150 km north of the Piskanja deposit and planned further exploration drilling in 2010. Initial drilling revealed an inferred resource of 114 Mt with a 13.1% B_2O_3 and 1.8% Li_2O grade. The company expected to produce borate by 2015 (Industrial Minerals, 2009d; O'Driscoll, 2010, 2011a).

Turkey.—The main borate producing areas of Turkey, all controlled by the state-owned mining company Eti Maden AS, are Bigadic (colemanite and ulexite), Emet (colemanite), Kestelek (colemanite, probertite, and ulexite), and Kirka (tincal). Production of refined borates increased during the past few years owing to continued investment in new refineries and technologies. Eti Maden planned to expand its share in the world boron market from 36% to 39% by 2013, increasing sales to $1 billion by expanding its production facilities and product range. In 2009, Turkey exported 4 Mt of borates valued at $104 million (Today's Zaman, 2009; Uyanik, 2010).

Since 2007, the Turkish government has granted 110 million Turkish lira (about $64 million) to 317 proposals in support of the Industry-University Project (SAN-TEZ). SAN-TEZ was implemented to develop boron-related technologies that might lead to increased consumption of Turkish borates (Today's Zaman, 2010).

Outlook

Consumption of borates is expected to increase, spurred by strong demand in the Asian and South American agriculture, ceramic, and glass markets. World consumption of borates was projected to reach 2.0 Mt B_2O_3 by 2014, compared with 1.5 Mt B_2O_3 in 2010 (Roskill Information Services Ltd., 2010, p. 167; O'Driscoll, 2011a).

Europe and emerging markets are requiring higher building standards, correlating to increased consumption of insulation fiberglass. Domestic demand for fiberglass was dominated by the construction industry, which saw decreased U.S. activity in 2009 owing to the global economic downturn. With a projected sluggish economic recovery in the construction industry, demand for fiberglass, which increased at a rate of 5% annually between 2000 and 2008, was expected to continue to increase but at a slower rate (Roskill Information Services Ltd., 2010, p. 179). Demand for boron based fertilizers was expected to rise owing to increased demand for food and biofuel crops. Higher crop prices have enabled farmers to invest more capital in advanced farming techniques and higher-grade fertilizers. Consumption of borates by the ceramics industry was expected to shift away from Europe to Asia, which accounted for 60% of world demand in 2010.

Research into boron use in nanotechnology is progressing rapidly. More stable forms of boron nanotubes have been constructed, and more efficient fabrication techniques have been developed. In 2009, a team of material scientists created the first high-quality, uniformly crystalline boron nitride nanotubes in large quantities (EurekAlert, 2010). The first successful measurement of the strength of boron nitride nanotubes was performed in 2010, adding to high expectations for potential applications (Nanowerk, 2010). Boron nanotubes were expected to overtake carbon nanotubes as the ideal material in nanoengineering because boron nanotubes can be configured as electrical conductors, a property not inherent to carbon nanotubes (Battersby, 2008; Oku, 2008).

The use of boron nitrate in neutron-emitting nuclear material detectors may increase owing to scientific advances. Conventional neutron-emitting nuclear material detectors use helium-3 gas to detect neutrons emitted from nuclear reactive material. The problem with these detectors lies in their large irregular size and the decreasing supply of helium-3. Detectors using boron nitrate are smaller in size, and availability of boron nitrate is greater (Jean, 2010).

Consumption of boron nitride is expected to increase owing to the development of high-volume production techniques coupled with the creation of new technologies. The properties intrinsic to cubic boron nitride, such as hardness (second only to diamond), high thermal conductivity, and oxidation resistance make it an ideal material in a variety of emerging applications. Hexagonal boron nitride was used in additives, ceramics, and intermetallic composites, imparting thermal shock resistance, improved machinability, and reduction of friction. Pyrolytic boron nitride is finding rapid acceptance in molecular beam epitaxy crucibles and furnace hardware owing to its high tensile strength and its anisotropic nature (Lelonis, 2007).

The European Chemical Agency has declared the use of boric acid in the development of photographs to pose no health risk to consumers with the proper handling of the chemicals. This ruling was considered to have wider implications for the use of borates used in other applications, such as in the ceramic and glass industries (Industrial Minerals, 2010a).

Chinese Nd-Fe-B magnet production is expected to increase 25% per year through 2014, driven by an increase in high-technology applications. With boron content in Nd-Fe-B magnets averaging 18% to 22%, the Chinese boron industry was investigating ways to expand the use of boron from its low-grade deposits through more efficient and effective processes (Industrial Minerals, 2010b).

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TABLE 1

SALIENT STATISTICS OF BORON MINERALS AND COMPOUNDS[1]

(Thousand metric tons and thousand dollars)

	2006	2007	2008	2009	2010
United States:					
Sold or used by producers:					
Quantity:					
Gross weight[2]	W	W	W	W	W
B_2O_3 content	W	W	W	W	W
Value	W	W	W	W	W
Exports:[3]					
Boric acid:[4]					
Quantity	221	248	303	171	264
Value	126,000	124,000	165,000	109,000	170,000
Sodium borates:					
Quantity	393	446	519	417	423
Value	138,000	146,000	192,000	176,000	218,000
Imports for consumption:					
Borax:[3]					
Quantity	2	1	1	(5)	(5)
Value	701	647	566	376	183
Boric acid:[3]					
Quantity	85	67	50	36	50
Value	34,900	27,500	26,200	26,100	30,100
Colemanite:					
Quantity[6]	25	26	30	31	50
Value	7,260	7,640	8,880	8,630	18,400
Ulexite:					
Quantity[6]	131	92	75	28	1
Value	39,200	27,600	22,600	11,300	238
Consumption, B_2O_3 content	W	W	W	W	W
World, production[7]	3,620 r	4,200	4,480 r	3,760 r	4,080 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]U.S. production withheld from world production in 2006–10 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]

(Dollars per metric ton)

Product	Price, December 31, 2008	Price, December 31, 2009	Price, December 31, 2010
Borax, decahydrate, Buenos Aires	560	520	520
Boric acid, Chile	950	800	735
Colemanite, Buenos Aires, 40% boron oxide (B_2O_3)	420–460	370–420	370–420
Ulexite, Buenos Aires, 40% B_2O_3	390–410	350–380	350–380
Ulexite, granular, Chile, 40% B_2O_3	500	400	400
Ulexite, Lima, 40% B_2O_3	490–520	250–300	350–370

[1]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. 495, December 2008, p. 88; no. 507, December 2009, p. 68; no. 519, December 2010, p. 69.

TABLE 4

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

	2009			2010		
	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	3,990	$2,550	9,310	1,780	$1,120	4,330
Belgium	132	172	259	3	11	14
Brazil	448	613	3,300	1,190	1,550	927
Canada	2,970	2,440	27,500	2,530	2,290	27,500
China	26,500	14,500	146,000	59,900	35,000	104,000
Colombia	190	250	3,990	159	210	6,840
France	4,280	5,270	312	120	81	324
Germany	316	532	1	1,380	1,670	1
Hong Kong	--	--	4	--	--	--
India	1,530	1,200	17,400	3,930	2,840	32,300
Indonesia	833	532	4,770	1,340	935	9,630
Italy	--	--	2,400	93	94	1,080
Japan	22,800	16,700	19,500	46,100	32,500	25,300
Korea, Republic of	38,800	21,700	12,700	49,700	27,700	12,700
Malaysia	206	124	32,400	3,340	1,940	25,700
Mexico	6,600	5,350	16,900	6,540	5,240	34,700
Netherlands	23,000	13,200	85,900	38,600	24,200	99,200
New Zealand	361	212	1,930	428	289	2,010
Philippines	54	38	1,360	121	89	1,980
Singapore	847	1,170	578	1,610	2,880	1,050
Spain	3,000	1,700	5,890	1,840	1,080	661
Taiwan	25,100	13,900	2,900	31,200	17,800	3,250
Thailand	2,850	1,620	6,340	3,610	2,210	8,600
United Kingdom	49	71	4	--	--	2
Venezuela	82	198	501	253	2,190	240
Vietnam	3,280	2,040	4,230	2,990	1,940	5,060
Other	2,990	2,620	10,700	5,630	4,270	14,900
Total	171,000	109,000	417,000	264,000	170,000	423,000

-- 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]

Country	2009 Quantity (metric tons)	2009 Value[2] (thousands)	2010 Quantity (metric tons)	2010 Value[2] (thousands)
Argentina	841	$637	1,080	$790
Bolivia	2,440	1,550	4,160	2,330
Chile	6,550	4,390	7,340	4,380
China	125	228	100	162
France	750	1,190	505	657
Germany	21	20	103	100
India	192	257	627	607
Italy	1,110	1,250	1,570	1,600
Japan	82	77	173	111
Peru	1,140	896	2,920	1,850
Russia	4,380	2,920	923	483
Turkey	18,300	12,600	30,000	17,000
United Kingdom	54	54	1	2
Other	46	43	27	39
Total	36,100	26,100	49,500	30,100

[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	2006	2007	2008	2009	2010[e]
Argentina	534	670	786	500 [r]	600
Bolivia, ulexite	39 [r]	64	56	86 [r]	97 [3]
Chile, ulexite	460	528	583	608	504 [3]
China[e, 4]	145	145	140	145	150
Iran, borax[e, 5]	2	2 [3]	1 [r, 3]	1 [r]	2
Kazakhstan[e]	30	30	30	30	30
Peru	191	234	350	187	293 [3]
Russia[e, 6]	400	400	400	400	400
Turkey[7]	1,819 [r]	2,128	2,139 [r]	1,800 [r, e]	2,000
United States[8]	W	W	W	W	W
Total	3,620 [r]	4,200	4,480 [r]	3,760 [r]	4,080

[e]Estimated. [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, 2011.

[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.