BORON

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Boron produced domestically during 2001 totaled 536,000 metric tons (t) of boron oxide valued at $506 million (table 1). The most common minerals of commercial importance in the United States were colemanite, kernite, tincal, and ulexite (table 2). Boron compounds and minerals sold were produced by surface and underground mining, in situ, and from brine. U.S. consumption of minerals and compounds amounted to 347,000 t of boron oxide (table 3). Boron products are priced and sold based on the boron oxide content, which varies by ore and compound, and on the absence or presence of sodium and calcium (table 4). Boron exports totaled 306,000 t (table 5). Boron imports consisted primarily of borax, boric acid, colemanite, and ulexite (tables 1, 6). Turkey and the United States were the world's largest producers of boron (table 7).

The glass industry, which remained the largest domestic market for boron production in 2001, accounted for 78% of boron consumption. Insulation-grade glass fibers accounted for an estimated 48% of domestic consumption; textile-grade glass fibers, 20%; boron sold to distributors, 8%; borosilicate glasses, 6%; soaps and detergents, 6%; enamels, frits, and glazes, 4%; and other uses, 8%.

Legislation and Government Programs

The U.S. Department of Energy (DOE) plans to store spent nuclear fuel encased in a boron-containing glass inside stainless steel containers underground at Yucca Mountain, NV, beginning in 2009. The DOE was required by law to begin accepting spent fuel by January 31, 1998 (Chemical & Engineering News, 2000). A major concern of critics is that the materials would be shipped through major cities, including Washington, DC, and Baltimore, MD, and the casks containing the radioactive material would be a ready-made "dirty bombs." One of the problems involved is to maintain the secrecy of the schedules and routes of the 175 shipments per year.

The U.S. Department of Commerce determined in January that Canada's Co-Steel Lasco Inc. and Brazil's Gerdau MRM Steel Inc. have been shipping carbon plate steel into the United States without paying duties for more than 8 years by adding an extremely minute amount of boron (0.0008% by weight) to the carbon plate steel. The boron did not affect the character of the steel but did make it chemically different from the carbon plat steel that was subject to duties. In the huge U.S. market for steel, most of the metal comes in legally, but there is a steady, lucrative and damaging business in smuggling. Dozens of traders used falsified documents and various tricks to regularly smuggle hundreds of thousands of tons of steel into the country (Matthews, 2001).

In 1990, the desert tortoise was listed by the Fish and Wildlife Service of the U.S. Department of the Interior as threatened. The status affects mining operations, such as boron, that are found in the desert tortoise habitat. In the last decade, two shell diseases have been identified and described in desert tortoises. In one disease, the plates or scutes that cover the bone on tortoise shells discolor, lighten, and flake; in the second, parts of the shell die or necrose. In one turtle population studied, 85% of the population declined in a 6-year period. Tortoises require about 15 to 25 years to reach sexual maturity, and young adult females lay fewer eggs than larger, older females. The cause for the shell diseases is being researched (Berry, 2001).

The Federal Railroad Administration of the U.S. Department of Transportation solicited proposals for the construction of a magnetic levitation (maglev) train to be built with funds approved by the Transportation Equity Act for the 21st Century. Maglev is an advanced transportation technology in which magnetic forces lift, propel, and guide a vehicle over a specially designed guide way. Boron is used in the superconducting and other high-intensity magnets of this system. By using state-of-art electric power and control systems, maglev would reduce the need for many mechanical parts, thereby minimizing resistance and permitting excellent acceleration and cruising speeds of about 386 kilometers per hour (km/hr) (240 miles per hour) or more. Since passage of the High-Speed Ground Transportation Act of 1965, a number of maglev system concepts had undergone research and development in the United States. The Federal Government had appropriated $1 billion to explore and construct a maglev segment of rail in various locations in the United States. The Federal Government declared Pittsburgh and the Baltimore-Washington areas the finalists in a nationwide competition to build what could be the first commercial high-speed magnetic levitation train in the world (Federal Railroad Administration, 2001§[1]).

In January, the Secretary of Transportation announced the selection of two east coast maglev projects for further consideration for federal maglev construction funding. The Southern California Association of Governments prepared a business plan that outlines a strategy for deploying a 92-mile high-speed maglev system in southern California (California Maglev Project, 2002§).

The Consumer Product Safety Commission (CPSC) began rulemaking to improve the fire safety of mattresses. Boric acid is used in cotton mattresses as a fire retardant. Mattress and bedding fires are one of the leading causes of injuries and were second to upholstered furniture in the number of fire-related deaths in 1998. During that year, mattresses or bedding items were the first to ignite in about 18,100 residential fires that resulted in 390 deaths and 2,160 injuries brought to hospital

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

emergency rooms. From 1994 though 1998, over three-quarters of the deaths related to mattress and bedding fires ignited by candles, lighters, and matches were caused by children under the age of 15. Researchers at the National Institute for Standards and Technology were researching an effective fire-retardant performance and screening test (Giles, 2001).

In July 1960, four B-25 bombers crashed while dropping borates on forest fires near Magic Mountain in southern California. The U.S. Department of Agriculture's Forest Service banned the B-25 from fire bombing operations. As a result, a B-25 plane with Federal Aviation Administration registration number N10564 was selected for a series of flight tests conducted at Edwards Air Force Base, CA. In 1985, the B-25 landed at Dulles Airport in northern Virginia and became part of the Smithsonian Institution's National Air and Space Museum exhibits. The aircraft will be on display at the new USAR-Hazy Center opening in 2003 (Smithsonian Institution, 2002§).

Production

Domestic data for boron were derived by the U.S. Geological Survey from a voluntary survey of 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. Of the four operations to which a survey request was sent, all responded, representing 100% of the total boron produced (tables 1, 3).

More than 200 minerals contain boric oxide, but only a few were of commercial significance (table 2). Four minerals comprised almost 90% of the borates used by industry–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 from 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. Reported employment was 110 employees (Business.com, [undated]§).

In 2000, IMC Global Inc. announced the opening of new corporate headquarters in Lake Forest, IL. IMC Chemicals, formerly headquartered in Overland Park, KS, operated the Trona and the Westend plants at Searles Lake in San Bernardino County. IMC Chemicals produced refined sodium borate and boric acid as a coproduct of soda ash and sodium sulfate from the mineral-rich lake brines. A series of closed systems circulated brines in the upper unit salt layer of the lake to increase the borax grade to a theoretical 1.45%. The brine was processed at the Westend plant and circulated back to the upper salt layer. IMC Global continued to divest a controlling share of IMC Chemicals, and another group of investors were considering purchasing the Searles Valley facilities at yearend.

U.S. Borax Inc., a wholly owned subsidiary of London based the Rio Tinto plc, mined borate ores at Boron, CA, by open pit methods and transported the ores to the surface via a conveyor. At Boron, reserves containing the minerals kernite and tincal were reportedly in excess of 100 million metric tons (Mt) (Baele, 2000, p. 29). Production was reported to be 570,000 t during 2000 compared with 543,000 t in 1999 (Rio Tinto plc, 2000, p. 8). The stripping ratio was more than 36:1, and the quantity of stripped overburden was projected to reach 100 Mt in 2000. During 2000, it was necessary to remove a layer of overburden between 107 meters (m) and 198 m thick to access the ore. As the mine advanced to the east and southeast, that overburden layer was projected to gradually increase to 366 m in thickness. A 32-t groundslide on the north slope of the pit in 1999 was the initiative for construction of less steep benches, starting at the top of the existing 17 benches. The 91-m-thick ore contains four zones. The upper layer of borax overlies three layers of borax and kernite (Garrett, 2000). 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 in the port of Los Angeles for international distribution. U.S. Borax's human resources include 1,600 men and women, worldwide. California employees include 1,100 people working in Boron, where the principal mine and refinery are located; Wilmington, with a refinery and shipping terminal; Valencia, with the global headquarters; and Owens Lake, with a trona mine that supplies raw material to the Boron refinery. Multiyear labor agreements were negotiated at U.S. Borax's U.S. operations that will provide additional operational flexibility and efficiency (Rio Tinto plc, 2002, p. 12).

Cogeneration plants, which are part of the boron-processing facilities at Boron, produced 100 megawatts (MW) of electricity, 85 MW of which are sold to Southern California Edison. One-third of the electricity used at the site goes to operate pollution control equipment. Another cost saving practice was a daily tire pressure check, which would increase tire life by 40%. An environmentally sound practice blended engine oil with diesel fuel to dispose of oil and increase engine life by 20% (Garrett, 2000).

A new $10 million plant at Boron was projected to be able to process more than 1,400 metric tons per day of dry pond material containing 300,000 metric tons per year (t/yr) of high-quality feed (25% boron oxide) for the sodium borate process. Before 1985, thickened clays and muds were sent to storage ponds along with plant liquid effluents containing low levels of borax. The clays contain low levels of pyrrhotite, a paramagnetic iron sulfide mineral that is attracted to powerful, rare-earth magnets (Mining Engineering, 2000).

U.S. Borax's Owens Lake operation allowed the company to ensure control of its trona supply used in the borate refining process. Trona provided a cost-effective source of carbonates, which helped reduce scaling in the processing equipment. Owens Lake was the third largest trona deposit in the United States.

The 849 employees at the Boron mine processed about 3 million metric tons per year of ore. Two new safety programs were instituted. A safety management audit training program trained employees to observe work practices and encouraged feedback. It transitioned from a top-down model enforcement to bottom-up participation. A second program installed video cameras on the trucks to eliminate drivers' blind spots. The primary goal was to improve safety (Craig, 2000).

The Gerstley Borate Mine near Boron, CA, was closed in 2000 owing to environmental and safety factors that made continued operation potentially dangerous for the miners. Less than 1,000 t/yr were mined, primarily for pottery. Glaze recipes containing Gerstley borate were developed in the 1950s for its ability to impart mottled, varied opacity effects to the fired glaze surface. This was because the two primary minerals in the ore melt at different temperatures; ulexite melts at 835°C (1,535°F) and colemanite at 900°C (1,652° F). The mineral colemanite offered the best choice for a substitution (Zamek, 2000§).

Fort Cady Minerals Corp. used an in situ process near Hector, CA, to produce a product containing 48% boron oxide. Because it is chemically precipitated, this product has advantages in the consistency of its chemical composition, namely, high boron oxide content, low impurities, and a consistent physical size. The product contained 25% calcium oxide, 0.8% sulfur, 0.1% chloride, 0.08% iron, and less than 1 part per million arsenic. In situ extraction required that wells be drilled 427 m (1,400 feet) into the ore body. A solution of dilute sulfuric acid was injected into wells in the borate ore. The boron-enriched solution was pumped to the surface and then reacted with lime to precipitate a pure calcium borate product. The product was dried and packaged.

Consumption

World consumption of borates was estimated to be as follows: insulation, fiberglass, textile fiberglass, and heat-resistant glass (41%); ceramic and enamel frits and glazes (13%); detergents, soaps, and personal care products (12%); agricultural micronutrients (6%).

Glass fiber thermal insulation, primarily used in new construction, was a large area of demand for borates and was the principal insulating material used in the construction industry. Composed of very thin fibers spun from molten glass, fiberglass traps and holds air. Typically, between 4% and 5% of boron oxide is incorporated in its formulation 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 glass fiber uses a borosilicate (e-glass) formulation 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% boron oxide.

Borosilicate glass can withstand extreme temperature ranges, such as bakeware that goes from the oven to the freezer or lamps that go from room temperature to blistering hot. Borosilicate glass is important for many lamps, such as the lava lamps now celebrating 34 years in production. The first lava lamp was designed in 1963 by English engineer Edward Craven Walker. Haggerty Enterprises, Inc., in Chicago, manufacturers the lamp in North America. Kimble/Kontes makes the borosilicate glass for the lava lamp and also for pharmaceutical uses (BoraxPioneer, 2001b).

With the advent of more stringent environmental regulations in the United States, many traditional treatments to protect homes from insect infestation have been banned. Borate-treated building components with ground line barriers and the services of professional pest control operators protect wooden components throughout the house. While homes could be built out of a material that termites do not eat and that does not attract decay fungi, trees have the ability to absorb carbon dioxide and emit oxygen, which makes wood the only building material that has a positive impact on the environment (Bhatia, 2001).

U.S. Borax teamed with Osmose Inc., which was the leading chemical supplier to the wood preservation industry, and L-P Corp., which was the world's largest producer of oriented strand board. Osmose provided borate-treated lumber through its many licenses, and L-P Corp. incorporated borates into some structural panel products. U.S. Borax would supply Tim-bor® Industrial, which is disodium octaborate tetrahydrate, for lumber and plywood, and Composibor®, which is zinc borate, for engineered wood products (Bhatia, 2001).

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 postharvest to provide adequate nutrition as buds begin to develop. During 2000, 18,628 t of boron micronutrients was applied on crops compared with 20,398 t in 1999. The largest U.S. region of use was in the west north-central, which used 8,297 t (Terry and Kirby, 2001, p. 37).

Boron is a trace element that is essential to human health and behavior. Evidence continues to mount that boron may reduce either the symptoms or incidence of arthritis. Researchers have discovered a relationship between the amount of boron in soil and drinking water and the incidence of arthritis in a population. Arid areas have been found to have the highest concentrations of boron in the drinking water and soil. In post menopausal females, who are magnesium deficient, it has been demonstrated that 3 milligrams per day (mg/d) of boron added to the diet result in improvements in calcium and magnesium retention, elevations in circulation serum concentrations of testosterone, and elevations in circulating serum concentrations of a form of estrogen. Similar improvements can also be seen in vitamin D deficient postmenopausal females. No recommended daily allowance has been established for boron in humans at this time; however, females are recommended to take 2.0 mg/d (Schauss, [undated]§).

Transportation

In 2001, U.S. Borax ranked as the primary bulk shipper in California with a fleet of 800 railcars. Almost all U.S. Borax's bulk product was shipped in North America via rail. The Boron mine is served solely by the Burlington Northern Santa Fe (BNSF) railroad. A transload was set up in Cantil, CA, about 64 kilometers (km) (40 miles) northwest of Boron, which is served by Union Pacific Railroad. Trucks of product from boron are driven to Cantil and loaded into dedicated railcars. These cars are shipped to customers by Union Pacific Railroad.

Ocean transport was from the port of Wilmington, CA, where U.S. Borax had the only remaining privately owned berth in the harbor. It ranked as the largest exporter of high-value dry bulk products and among the top 10 shippers of ocean containers out of the ports of Los Angeles and Long Beach, CA. In 2001, the equivalent of more than 8,000 6.1-m (20-foot) containers was shipped to nearly 100 countries (Docks, 2002).

Products destined for Europe were shipped from the bulk terminal in Wilmington, CA, to a company-owned facility in the port of Rotterdam using handymax vessels of about 45,000-short-ton dead weight capacity. The vessels have been supplied by Japanese shipping company “K” for more than 20 years. Holds in smaller vessels also are used to transport bulk borates to company facilities in Spain and to contracted warehouses in Monfalcone, Italy, and Port Klang, Malaysia. Borax Group also maintains secondary stock points that include Germany, Norway, Austria, Ukraine, Taiwan, and the Republic of South Korea (Docks, 2002).

Antwerp, Belgium, which had the most central port location in Europe, 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. The decision to import material 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 had 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, the Baltic, the Black, and the Mediterranean Seas and the Atlantic Ocean. In 1992, the 170-km canal linking the Main River to the Danube River was opened in Germany.

The Trona railway connected to Southern Pacific Railroad between Trona and Searles Station and provided a dedicated line with access to national rail systems for the borate and soda ash markets. Cross country rail shipments are more cost effective than the use of U.S. flag shipping lines, which are required by the Merchant Marine Act of 1920, known as the Jones Act, for shipping on all U.S. waterways and goods moved between U.S. ports.

Prices

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

World Review

Argentina.—Borax Argentina S.A., which was a subsidiary of Rio Tinto plc, was the country’s leading producer of borates (table 6). Borax Argentina mined borates at three deposits in Salta and Jujuy Provinces. 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. The clay overburden averages 50 m and typically overlies 30 to 40 m of ore. About 100,000 t/yr ore was trucked from the mine to a rail terminal at Packets, 120 km north of Tincalayu, and loaded on trains of 11 cars, each with a 30-t capacity. A drilling program was completed to verify a new borate resource (Industrial Minerals, 2002). Borax Argentina has 198 employees working at the mines and refinery. The Tincalayu mine is at an altitude of 4,100 m. Energy was supplied by two generation plants that produced 146,000 kilowatts per month (Rio Tinto Borax, [undated]§).

Borax Argentina announced the completion of a drilling program that outlined new borate resources at the Tincalayu mine. Borax does not plan to increase production as a result of the reclassification of reserves. The Tincalayu operations had a capacity of 477,000 t/yr. Other operations included 108,000 t/yr capacity of hydroboracite and colemanite at the Sijes mine and 30,000 t/yr of ulexite from Porvenir (Industrial Minerals, 2001a).

Borax Argentina also mined ulexite of Ordovician Age at Salar Cauchari in Puma Province. Reserves were estimated to be 1.5 Mt of 19% boron oxide (Salar Cauchari, [undated]§).

The newest producer was Procesadora de Boratos Argeninos S.A. (owned by Ferro Corp. and Canadian JEM Resources & Engineering, Inc.). The project was purchased in 1999 from S.R. Minerals Ltd., which was an affiliate of Smokey River Coal Ltd., a Canadian coal producer. Tincal and ulexite mined at Loma Blanca were processed with magnetic separation and then calcined at Palpalá. A range of calcined and noncalcined products were produced containing 35% to 60% boron oxide. Production was about 3,000 metric tons per month (O’Driscoll, 2001).

Norquímica S.A. was one of the few surviving boric acid manufacturers in Argentina. Ulexite was raked on the surface of the salars in Salta Province, spread out to dry, and trucked to the company’s plant in Salta for concentrating. A portion of the ulexite concentrate is used as feed for the boric acid plant, where it is reacted with sulfuric acid.

Admiralty Resources NL, through its subsidiary Argentina Diamonds Ltd., completed due diligence on the Rincon project. The project comprises 53 mining tenements covering 410 square kilometers located in northwestern Argentina. The deposit contains borate, cesium-rubidium, lithium, magnesium, and potash (Admiralty Resources NL, 2001§).

The origin of the La Puna borate deposit was studied to explain the occurrence of playa-lake deposits and the formation of Neogene borate deposits. The Neogene includes the Miocene and Pliocene epochs of the late Cenozoic era. Vulcanism reached its greatest intensity worldwide during the Miocene epoch. There are no continental exogenous (as a result of weathering and/or metamorphic contact) borate deposits known in the world older than Miocene. The deposits and occurrences of exogenous borate in Argentina are restricted to the Puna Geologic Province, specifically to the Northern Puna and the eastern border of the Southern Puna and constitute the greatest reserves in South America and the third largest in the world, after those of Turkey and the United States. The borate-bearing section of the Tincalayu mine represents a deposition in a lake. The generation of the deposits directly related to the evolution of a geothermal system linked to the development of a volcano complex. The largest deposit of the Argentine Puna is in the Sijes District and is composed of hydroboracite and colemanite with smaller amounts of ulexite and inyoite along a

30-km-long belt. Lomo Blanca, the fourth largest borax deposit in the world, is still largely unknown owing to a lack of drill holes. The main borate bodies of the Quaternary are the salar deposits. All the borate deposits of the Puna are interpreted as being directly or indirectly related to thermal springs. An arid or semiarid climate is important for the mechanism of evaporation which aids the process of supersaturation and precipitation of the mineralized solutions. Closed basins that contain small, shallow lakes are necessary for the formation of significant deposits. The grade of borate deposits is directly related to the concentration of the thermal waters, and their dilution is a function of the size of the lake bed (Alonso, 1999, p. 141, 143, 161-163).

The sedimentologic and diagenetic aspects of the sediments of the Sijes Formation formed by evaporation were studied. These were the largest known hydroboracite reserves in the world and were located in the Monte Amarillo member of the Sijes Formation. Hydroboracite is the primary mineral, although it is replaced by gypsum under certain sedimentary conditions. The boron source of the deposit seems to be related to the volcanic/hydrothermal activity in the central Andes during the Miocene (Alonso and Orti, 2000§).

Bolivia.—Borate production was from companies that mined ulexite from Government concessions around Salar de Uyuni in the Bolivian Altiplano. Cia. Minera Tierra S.A. had large ulexite concessions near the Chilean border and produced dried and washed grades for export. Reserves were on the order of 5.5 Mt of boron oxide. In addition to ulexite, Tierra produced boric acid and in 1999 and exported 12,500 t worldwide. The operation employed 250 in Bolivia and 45 in Chile.

On August 28, Bolivian, Chilean, and United States antidrug authorities descended on Tierra and its Chilean sulfuric acid supplier, Alco Ltda. Thirteen executive staff and employees were arrested. In December, the Bolivian executives were released, but the seven Chilean employees were detained. The charge was based on 7,000 to 15,000 t of sulfuric acid allegedly being diverted from the production of boric acid to the illegal cocaine processing plants in the Chapare District of Bolivia. The volume of sulfuric acid in question represented about 35% of Tierra's consumption in the production of boric acid. Judgement on the case in Bolivia was expected to begin in March 2001 (O'Driscoll, 2001).

The case, the first of its kind, highlighted potential problems that could arise with industrial minerals companies that need to consume or process predetermined precursors, such as soda ash or sulfuric acid. These commodities were recognized by antidrug agencies as being at the same level as controlled substances in narcotics culture (O'Driscoll, 2001). In February, Bolivian authorities permitted Tierra SA to reopen its boric acid plant, which had been closed pending a court case. Production resumed in April (Industrial Minerals, 2002).

The Pampa borax deposit, which was owned by Champagne Miner Rio Grande S.A., had ulexite ore with a boron oxide content of between 30% and 34% and 1.7 Mt of proven reserves. The deposit included nine concessions comprising 4,480 mining claims and was located in Nor Lapis Province south of the Salar de Uyuni.

Chile.—Quimica e Industrial del Borax Ltda. (Quiborax) mined ulexite from Salar de Surire, which was the largest ulexite deposit in the world. Reserves were estimated to be 1,500 t. The deposit was located at an altitude of 4,250 m in Monumento Natural de Surire, a national park. Production in 2000 was 380,000 t of crude ulexite. The ore was trucked to the El Aguila production facility north of Arica. Some of the ulexite was dried and sold, and the balance was reacted with sulfuric acid to produce 36,000 t of 98% to 99.9% boric acid. The majority of production was exported through the port of Arica.

Quiborax's other plants included a new granulated ulexite plant, which produced agricultural ulexite ranging between 10% to 13% boron oxide, and another special ulexite plant, which produced different types of boron product ranging between 30% to 45% boron oxide for specific market requirements (O'Driscoll, 2001).

Champagne Minera Salar de Atacama was 100% owned by Sociedad Quimica y Minera de Chile S.A. (SQM). A large integrated facility was scheduled to begin production of 16,000 t/yr of boric acid as a byproduct of potassium sulfate production. SQM was reported to be purchasing boric acid for resale until the plant could begin boric acid production. SQM also produced ulexite from reserves in excess of 7 Mt boron oxide content at Salar de Ascotán and Salar de Carcote (O'Driscoll, 2001).

China.—More than 80% of the country's borates resources were in Liaoning and Jilin Provinces. The ores were primarily metamorphic deposits containing ascharite, a magnesium borate. Other production was from playa lakes in Qinghai where borate minerals, such as ulexite, hydroboracite, and borax, were produced from brines near the Qinghai-Tibet plateau (O'Driscoll, 2001).

Shanghai planned to be the world's first city to build a commercial maglev train using boron-based magnets (Denver Post Newspaper in Education, 2001§).

India.—Submarginal borax reserves occur in the Puga Valley districts of Jammu and Kashmir. In Rajasthan State, the bitterns from Lake Sambhar were reported to contain about 0.5% borax.

Italy.—Rio Tinto Borax appointed Milan-based Novaria Chemicals as its exclusive distributor of its Firebrake range of fire retardant polymer additives in the Italian market. Novaria provided expertise in the storage, handling, and distribution of plastic additives (Chemical Market Reporter, 2001).

Russia.—In August 1999, Russia's sole borates producer, JSC Bor, was reorganized and renamed JSC Energomash-Bor in response to a move by Russian power equipment supplier JSC Energomash to become more involved in the borates business. In mid-2000, Energomash-Bor was preparing its second boric acid production line for commissioning, following a 9-month closure. The company also tested a nitrate method of processing datolite ore, which may permit a savings in power consumption. The refurbished plant was expected to double boric acid production and increase output of other boron products to between 100,000 and 140,000 t/yr (O'Driscoll, 2001).

Major repairs took place from September to November at the Bor plant at a cost of $1 million. In the boric acid plant, solution pipelines were repaired, a tail pipeline was installed, and a flotation cell and packing lines were reconstructed. In the boron products plant, a mother liquor pipeline was installed, the repair of the calcium borate rotary dryer was completed, and a multicyclone was replaced with a battery cyclone to decrease calcium borate dust emission. Bor increased production of boric acid to an estimated 50,000 t/yr with 170,000 t of boron products (Industrial Minerals, 2001c).

On October 30, the new Land Code of Russia came into force; it represented a significant reform owing to sanction and encouragement given to the creation of private ownership rights to land, including ownership rights to foreigners. The full provisions of the Land Code apply only to certain nonagricultural land that constitutes approximately 2% of Russia's land surface by the use of a Russian subsidiary entity. (Moore, 2002).

Turkey.—Turkey's boron operations were under the control of Eti Holding AS, formerly Etibank, through its subsidiary Eti Boron Inc. Boron production was managed by five operations, four of which were integrated mine and plant facilities and one was a plant facility. Additional capacity was planned for startup in 2002 with a 160,000-t/yr plant for borax pentahydrate at Kirka and in 2003 with a 100,000-t/yr boric acid facility at Emet (O'Driscoll, 2001).

U.S. imports of borates by port were reported for 1994 through 1998. The boron materials were found in a category of inorganic chemicals coming from Turkey. The data show the quantity and customs value of harmonized codes for boron, boric acid, refined borax, refined anhydrous borax, and sodium perborate (Oregon State University, 2001§).

United Kingdom.—Rio Tinto Borax was dedicated to the mining, refining, and marketing of borates. Rio Tinto Borax produced more than a Mt of product each year from ore bodies in the United States and Argentina, employing 1,700 people worldwide. As a miner and refiner, Borax managed the environmental, social, and economic impact of its operations, applying the same standards at each location. These activities were classified under the headings of safety and stewardship.

The 2001 Rio Tinto Borax social and environment report described efforts to measure and improve how company practices and products contribute to a sustainable future. The wide range of issues involved in supplying nearly half the world's demand for refined borates called for a comprehensive system to ensure that operations and products contribute to sustainable development. Borax believed its contribution to sustainable development to be that its operations have low environmental impact and make a positive social contributions; that its borate products enhance standards of living and contribute to economic development; and that borates measure up favorably to most substitute products. To aid the mining industry in progressing toward sustainable development, the Industrial Minerals Association was formed as an industry association. In addition, a number of the world's largest mining companies established the Global Mining Initiative as a case for mining as a positive factor towards sustainable development. This was projected to lead to a major conference on mining and sustainable development in 2001 (Edbrooke, 2000). The three principal goals adopted to guide the company are as follows: economic, environmental, and social. These goals require maximizing utilization of resources while minimizing environmental impacts of the operation; protecting the safety and health of employees, contractors, neighboring communities, and the public by prevention; raising safety consciousness and instituting systems to make the workplace safer; and enhancing the human potential and well-being of communities and employees by measuring and improving quality of life now and beyond the life of the operation. Sustainable development required Borax to assess and address the principal goals and to involve experts outside the company in the process (U.S. Borax, Inc., 2002).

Borax Europe Ltd., a subsidiary of Rio Tinto Borax, was involved in a court case against one of its former employees over an alleged breach of confidentiality. The case involved a graph that was placed on the personal website of the former employee. The company claimed that the graph disclosed information that was confidential to the company. At the August hearing, the employee voluntarily agreed not to disclose any confidential information and to return the material used to Borax Europe (Industrial Minerals, 2001b).

Current Research and Technology

Millennium Cell plc of Eatontown, NJ, was developing a chemical storage technology based on sodium borohydride. A clear aqueous solution of about 30% sodium borohydride is exposed to a proprietary catalyst to yield hydrogen and sodium borate byproducts, resulting in a milky solution of spent fuel. Millennium Cell is forming a joint development with Rohm and Haas Co., a major sodium borohydride supplier, to come up with a better process by closing the loop in the stream and recycling the sodium borate back to sodium borohydride. Millennium Cell stated its storage density rivals liquid hydrogen at about 63 grams per liter (Tullo, 2001).

In August, Millennium Cell and Air Products and Chemicals, Inc., signed an agreement to jointly develop technology for converting sodium borates to sodium borohydride. Millennium Cell invented and developed a process called Hydrogen on Demand™ that safely generates pure hydrogen or electricity from environmentally friendly raw material. In the process, the energy potential of hydrogen is carried in the chemical bonds of sodium borohydride, which releases hydrogen or produces electricity in the presence of a catalyst (Minich and George, 2001).

Millennium Cell has a patented design for boron-based longer-life batteries. The reaction is very energetic, and the components are very light in weight. Millennium Cell is also developing prototype batteries for titanium diboride. Boron-based batteries are potentially several times better than the currently used zinc batteries. Boron-based batteries can last twice as long as traditional batteries (Millennium Cell, [undated]§).

All the chemicals required by the DaimlerChrysler AG "Natrium" Town and Country minivan powered by a fuel cell technology are naturally occurring—water, borax, and hydrogen. Older, commercially available fuel cells transport hydrogen through a phosphoric acid medium and tend to be large and heavy, restricting their use to stationary generators. Hydrogen derived from sodium borohydride is the most promising of all energy carriers. Its energy density is high, making it a very efficient source of power. It is entirely free from carbon monoxide, which can damage fuel cells. It is efficient, clean, abundant, and renewable. The vehicle has a range of 480 km (300 miles) and a top speed of 130 km/hr (80 miles per hour). DaimlerChrysler expected to have its first fuel cell in buses in 2002 and in passenger cars in 2004 (Grenville-Robinson, 2002).

Physicists at Aoyama-Gakuin University, Japan, announced that magnesium diboride became superconductive when cooled to or below 39 K. This range of superconductivity is 16 K higher than any other simple metallic compound. The possibility is that magnesium-diboride-based material may be able to carry more current than the copper oxide superconductors. Furthermore, magnesium diboride may need to be cooled not with liquid helium as conventional superconductors but rather by electrical refrigeration (Dagani, 2001).

A senior scientist at Haldor Topsoe Research Laboratories, Lyngby, Denmark, prepared a barium-promoted boron nitride catalyst to synthesize ammonia. The catalyst was prepared from boron nitride crystals and aqueous solutions of ruthenium nitroso nitrate and barium hydroxide (Chemical & Engineering News, 2001).

Carboranes, the new class of boron compounds that contain both boron and carbon in their cage structures, are much more stable than the simpler boron hydrides. Carboranes are stable in air and can be heated without decomposing. They resist attack by strong acids (BoraxPioneer 2001a).

Boron is a problematic impurity for the production of magnesia used as a high-quality refractory material where a high hot strength is required. Boron occurs in seawater partly as nondissociated boric acid and partly as borate ions. During the magnesia precipitation process, boron is absorbed onto the magnesia. Studies examine the possibility of producing a high-purity precipitate of magnesium using reduced levels of magnesium hydroxide rinsing agent. Recycling provides for conserving the rinsing agent, although the magnesium hydroxide precipitate should be rinsed with fresh alkalized distilled water in order to obtain the final magnesium oxide product purity (Martinac and others, 2001).

The U.S. Department of Energy's Ames Laboratory in Ames, IA, studied a boron-aluminum-magnesium alloy with a hardness nearly equal to that of diamond. Diamond wears quickly when cutting steel owing to chemical reaction between the carbon in the diamond and the iron in the workpiece. Also, the new alloy cuts without getting hot reportedly because of the fine grain size and the complex crystal structure (Advanced Materials & Processes, 2002).

Two research teams independently reported the development of iridium catalyst systems using a direct route to organoboron reactants, avoiding the need to first generate intermediate reactions. The iridium catalyst systems can be used under mild, solventless reaction conditions and provide significantly higher catalytic turnover rates than rhodium, palladium, and other metals. The principal factor that enables the one-pot transformations is the extremely high selectivity of the iridium boryl catalysts for C-H activations (Ritter, 2002).

The triennial meeting on boron chemistry was planned for August 2002 in Moscow, Russia. The meeting provides an international forum for presentations in various field of boron chemistry. The goals of the conference are to assess the state-of-the-art in boron chemistry, to encourage newcomers to the field, and to give experts fresh motivation for future development (Chemistry International, 2001).

Outlook

The demand for boron in the United States is expected to remain strong. New applications in gypsum board and strong demand in the glass industry are expected to increase consumption. Boron compounds and chemicals can reduce energy use in the processing of many products. This may become an important sector if energy costs continue to rise. Although South America has large reserves of boron minerals, location, infrastructure, and processing problems have delayed significant production. The world production amounts for Turkey in table 7 do not accurately reflect production because some ore that was once exported is now being consumed as boron products for sale to Asia and Europe. World demand is expected to grow, primarily in the glass industry.

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TABLE 1
SALIENT STATISTICS OF BORON MINERALS AND COMPOUNDS 1/

(Thousand metric tons and thousand dollars)

	1997	1998	1999	2000	2001
United States:					
Sold or used by producers:					
Quantity:					
Gross weight 2/	1,190	1,170	1,220	1,070	1,050
Boron oxide (B_2O_3) content	604	587	618	546	536
Value	$580,000	$486,000	$630,000	$557,000	$506,000
Exports: 3/					
Boric acid: 4/					
Quantity	92	106	107	119	85
Value	$60,500	$54,600	$56,700	$64,400	$47,000
Sodium borates:					
Quantity	473	453	370	413	221
Value	$169,000	$146,000	$180,000	$136,000	$91,700
Imports for consumption:					
Borax:					
Quantity	54 5/	14 3/	8 3/	1 3/	1 3/
Value	$17,000	$5,160	$2,840	$716	$642
Boric acid:					
Quantity	26 5/	23 3/	30 3/	39 3/	56 3/
Value	$11,800 e/	$12,500	$14,000	$17,500	$21,700
Colemanite:					
Quantity	44 5/	47 5/	42 5/	26 5/	35 5/
Value	$13,000 e/	$13,900	$13,100	$7,410	$9,790
Ulexite:					
Quantity	157 5/	170 5/	178 5/	127 5/	109 5/
Value	$31,400	$34,000	$35,700	$31,800	$21,800
Consumption, B_2O_3 content	403	NA	416	360	347
World, production	4,580 r/	4,570 r/	4,460 r/	4,660 r/	4,620 e/

e/ Estimated. r/ Revised. NA Not available.
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 (HTS) codes 2840.19.0000, 2840.30.0000, and 2840.20.0000.
5/ Source: Journal of Commerce Port Import/Export Reporting Service.

TABLE 2
BORON MINERALS OF COMMERCIAL IMPORTANCE 1/

Mineral	Chemical composition	Boron oxide weight percentage
Boracite (stassfurite)	$Mg_6B_{14}O_{26}C_{12}$	62.2
Colemanite	$Ca_2B_6O_{11}$•$5H_2O$	50.8
Datolite	$CaBSiO_4$•OH	24.9
Hydroboracite	$CaMgB_6O_{11}$•$6H_2O$	50.5
Kernite (rasortie)	$Na_2B_4O_7$•$4H_2O$	51.0
Priceite (pandermite)	$CaB_{10}O_{19}$•$7H_2O$	49.8
Probertite (kramerite)	$NaCaB_3O_9$•$5H_2O$	49.6
Sassolite (natural boric acid)	H_3BO_3	56.3
Szaibelyite (ascharite)	$MgBO_2$•20H	41.4
Tincal (natural borax)	$Na_2B_4O_7$•$10H_2O$	36.5
Tincalconite (mohavite)	$Na_2B_4O_7$•$5H_2O$	47.8
Ulexite (boronatrocalcite)	$NaCaB_5O_9$•$8H_2O$	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	2001
Agriculture	12,700
Borosilicate glasses	19,600
Enamels, frits, glazes	13,000
Fire retardants:	
Cellulosic insulation	8,760
Other	1,650
Insulation-grade glass fibers	166,000
Metallurgy	--
Miscellaneous uses	4,460
Nuclear applications	--
Soaps and detergents	21,000
Sold to distributors, end use unknown	29,200
Textile-grade glass fibers	70,400
Total	347,000

-- Zero.

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 PER METRIC TON 1/

	Price	
Product	December 31, 2000	December 31, 2001
Borax, technical, anhydrous, 99%, bulk, carload, works 2/	$637	$637
Borax, technical, anhydrous, 99%, bags, carload, works 2/	846	846
Borax, technical, granular, decahydrate, 99%, bags, carload, works 2/	378	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, works 2/	376	376
Boric acid, technical, granular, 99.9%, bags, carload, works 2/	834	834
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	1,996	1,996
Colemanite, Turkish, 42% B_2O_3, ground to a minus 70-mesh, free on board (f.o.b.) railcars, Kings Creek, SC 3/	270-290	270-290
Ulexite, Chilien, 38% B_2O_3, ground to a minus 6-mesh, f.o.b railcars, Norfolk, VA e/	200	200

e/ Estimated.

1/ U.S. 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. Prices are rounded.

2/ Chemical Market Reporter, v. 261, no. 1, January 2002, p. 23.

3/ Industrial Minerals, no. 412, January 2002, p. 78.

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

	2000			2001		
	Boric acid 2/		Sodium	Boric acid 2/		Sodium
	Quantity	Value	borates 3/	Quantity	Value	borates 3/
Country	(metric tons)	(thousands)	(metric tons)	(metric tons)	(thousands)	(metric tons)
Australia	2,290	$1,090	5,600	2,250	$1,030	5,360
Belgium	--	--	(4/)	--	--	(4/)
Brazil	5,140	1,930	1,070	4,820	1,810	1,260
Canada	4,410	2,930	42,100	5,150	3,320	43,900
Colombia	195	184	2,940	138	139	2,310
France	--	--	1	114	75	12
Germany	1,020	731	3	200	135	8
Hong Kong	121	66	181	41	25	30
India	19	13	337	74	50	(4/)
Indonesia	577	315	5,190	624	334	4,100
Israel	5	4	(4/)	5	4	7
Japan	15,600	11,800	26,400	17,700	11,800	48,500
Korea, Republic of	9,810	5,740	17,900	11,800	6,290	13,400
Malaysia	2,210	1,290	7,730	2,950	1,570	2,420
Mexico	3,670	2,300	28,000	4,290	2,680	18,600
Netherlands	36,800	19,100	194,000	4,610	3,090	32,700
New Zealand	342	151	2,300	280	118	2,460
Philippines	19	15	2,010	38	27	1,300
Singapore	506	289	559	235	150	291
South Africa	--	--	39	169	113	4
Spain	11,700	3,790	43,400	3,750	1,420	12,000
Taiwan	11,700	6,150	8,880	12,700	6,350	5,880
Thailand	1,840	1,010	6,010	1,460	813	4,200
United Kingdom	188	162	109	528	354	47
Venezuela	213	205	362	178	185	355
Other	11,100	5,180	18,300	11,400	5,070	21,300
Total	119,000	64,400	413,000	85,500	47,000	221,000

-- 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/

	2000		2001	
	Quantity	Value 2/	Quantity	Value 2/
Country	(metric tons)	(thousands)	(metric tons)	(thousands)
Argentina	59	$40	263	$161
Belgium	2	5	1	4
Bolivia	2,530	982	222	71
Canada	--	-- r/	--	--
Chile	14,900	6,140	17,500	6,840
France	20	63	13	43
Georgia	--	--	--	--
Germany	21	37	11	6
Italy	5,010	3,210	1,290	1,390
Japan	8	14	35	84
Peru	1,500	618	3,000	1,220
Russia	839	368 r/	1,650	759
Turkey	14,300	6,000	32,000	11,100
United Kingdom	--	--	22	13
Total	39,200	17,500	55,900	21,700

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 7
WORLD PRODUCTION OF BORON MINERALS, BY COUNTRY 1/ 2/

(Thousand metric tons)

Country	1997	1998	1999	2000	2001 e/
Argentina	423	277 r/	245 r/	580 e/	500
Bolivia (ulexite)	12	7	7	35	34
Chile (ulexite)	171	280	325	338 r/	338
China 3/	136	137	110 e/	145 r/ e/	150
Germany (borax) e/	1	1	1	1	1
Iran (borax) 4/	(5/) e/	2	4	4 e/	4
Kazakhstan e/	30	30	30	30	30
Peru	47 r/	22 r/	15 r/	9 r/	9
Russia e/ 6/	1,000	1,000	1,000	1,000	1,000
Turkey e/ 7/	1,569 8/	1,650	1,500 r/	1,450 r/	1,500
United States 9/	1,190	1,170	1,220	1,070	1,050
Total	4,580 r/	4,570 r/	4,460 r/	4,660 r/	4,620

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, 2002.
3/ Boron oxide (B_2O_3) equivalent.
4/ Data are for years beginning March 21 of that stated.
5/ Less than 1/2 unit.
6/ Blended Russian datolite ore that reportedly grades 8.6% B_2O_3.
7/ Concentrates from ore.
8/ Reported figure.
9/ Minerals and compounds sold or used by producers, including both actual mine production and marketable products.