USGS
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2010 Minerals Yearbook

LITHIUM

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

October 2012

LITHIUM

By Brian W. Jaskula

Domestic survey data and tables were prepared by Susan M. Weaver, statistical assistant, and the world production table was prepared by Lisa D. Miller, international data coordinator.

In 2010, lithium consumption in the United States was estimated to be 1,100 metric tons (t) of contained lithium, 15% less than the consumption in 2009 and 52% less than in 2008. Although reports indicated that lithium end-use markets for batteries, ceramics and glass, grease, and other industrial applications increased in 2010 from those of 2009, downstream lithium compound producers in the United States may have continued to operate from inventories of lithium compounds in 2010 instead of importing new material. Imports of lithium compounds into the United States in 2010 were similar to those of 2009 but were considerably lower than the average since 1998. Exports of lithium compounds increased to levels seen before the economic downturn that started in late 2008. Actual lithium consumption in the United States may have been greater than the 1,100 t estimated, but no data were available to support a higher estimate. Lithium carbonate consumed in industrial applications and used as a raw material for other lithium compounds in the United States was produced at a domestic brine operation in Nevada and imported from Argentina and Chile.

Lithium has historically been mined from two distinct sources—continental brines and hard rock ore. Chile was the world's leading producer of lithium carbonate, with production from two lithium brine operations on the Salar de Atacama in the Andes Mountains. Concentrated brines were processed at two lithium carbonate plants in Antofagasta. In the United States, production continued at a lithium brine operation with an associated lithium carbonate plant in Silver Peak, NV. Lithium carbonate and lithium chloride also were produced from brines from the Salar del Hombre Muerto in the Andes Mountains in Argentina. In China, lithium carbonate was produced from brines from the Zabayu Salt Lake in western Tibet and from the Dongtai and Xitai Salt Lakes in Qinghai Province. China was the only country that produced large quantities of lithium carbonate from concentrates, mostly from imported Australian spodumene. A large percentage of the lithium carbonate produced in South America was exported to the United States for consumption in industrial applications and as feed material for the production of downstream lithium compounds, such as lithium hydroxide monohydrate, lithium metal, and organic lithium compounds. Australia was, by far, the leading producer of lithium mineral concentrates, and Brazil, China, Portugal, and Zimbabwe also produced significant quantities.

Worldwide lithium resource exploration (led predominantly by Australian and Canadian startup companies) increased significantly in recent years. The continental brine and clay resources of Nevada and geothermal brines of California were a major focus of exploration in the United States, as were the pegmatite and oil brine resources of Canada, and the pegmatite resources of Australia. Additionally, Argentina, Bolivia, and Chile saw significant exploration of their continental brines.

Legislation and Government Programs

Under the authority of the American Recovery and Reinvestment Act of 2009 (ARRA Public Law III–5), the U.S. Department of Energy (DOE) awarded $1.5 billion in grants to accelerate the development of U.S. manufacturing and production capacity of batteries for electric-drive vehicles and battery recycling—lithium-ion battery technology figured prominently in the awards (U.S. Department of Energy, 2009b). In 2010, construction began at 20 ARRA-funded battery and component manufacturing facilities, and 8 demonstration projects were initiated which were expected to produce 13,000 hybrid and electric-drive vehicles and 20,000 charging stations nationwide by 2013. The ARRA was expected to be a significant factor in bringing 30 battery and component factories online by 2012, giving the United States the capacity to produce 20% of the world's advanced vehicle batteries. By 2015, U.S. share of worldwide capacity was anticipated to increase to 40% (U.S. Department of Energy, 2010).

As part of its Advanced Technology Vehicles Manufacturing Incentive Program (ATVM), the DOE in 2009 loaned Nissan North America, Inc. $1.6 billion to convert its Smyrna, TN, plant to produce an electric vehicle (EV), the LEAF, and lithium-ion battery packs. Nissan expected to have production capacity of 150,000 vehicles per year in the United States when the LEAF manufacturing facility, which was scheduled to open in 2012, reaches full capacity in 2015. Tesla Motors, Inc. received a $465 million loan from the DOE to build an automobile manufacturing facility in southern California and a facility to assemble lithium-ion battery packs, electric motors, and electric components in Palo Alto, CA. Tesla's EV, the Model S, was scheduled to be produced in 2012. Fisker Automotive, Inc. received $528 million for the development and production of two models of lithium-ion battery powered plug-in hybrid electric vehicles (PHEVs)—the Karma and the Nina. The Karma and Nina were scheduled to be produced beginning in 2011 and 2012, respectively (U.S. Department of Energy, 2009a; U.S. Government Accountability Office, 2011, p. 14–17).

Recycling

As part of the ARRA in 2009, the DOE awarded $9.5 million to California-based battery recycler Toxco, Inc. to construct the first U.S. recycling facility for lithium-ion vehicle batteries. The company has recycled lithium metal and lithium-ion batteries since 1992 at its facility in British Columbia, Canada. Toxco planned to expand its existing facility in Lancaster, OH, which already recycled nickel-metal hydride and lead-acid batteries from hybrid-electric vehicles (HEVs) (Hamilton, 2009). In early 2011, the company planned to begin construction of a 60,000 square-foot expansion to process up to 9 million pounds of lithium-ion battery packs per year (Gearino, 2011).

Production

The U.S. Geological Survey (USGS) collects domestic production data for lithium from a voluntary canvass of the only U.S. lithium carbonate producer. Chemetall Foote Corp. (a subsidiary of the German company Chemetall, which is owned by Rockwood Holdings, Inc., of Princeton, NJ) responded to the survey, representing 100% of total production. Production and stock data were withheld from publication to avoid disclosing company proprietary data (table 1). It is known, however, that production increased in 2010 from that of 2009 owing to increased activity in lithium end-use industries.

Chemetall Foote produced lithium carbonate from brines near Silver Peak, NV. The company's other U.S. lithium operations included a lithium hydroxide plant in Silver Peak; a butyllithium plant in New Johnsonville, TN; and facilities for producing downstream lithium compounds in Kings Mountain, NC. Chemetall Foote's subsidiary in Chile, Sociedad Chilena de Litio Ltda., produced lithium carbonate, lithium chloride, and lithium hydroxide from a brine deposit.

FMC Corp.'s Lithium Division produced a full range of downstream compounds, lithium metal, and organic lithium compounds at its facility in Bessemer City, NC. The company met its lithium carbonate and lithium chloride requirements with material produced at its operation in Argentina.

In 2010, Chemetall Foote began expanding the lithium production operations at its Silver Peak and Kings Mountain locations. The Silver Peak expansion included commencement of a well drilling program to double the capacity of Chemetall's lithium carbonate production and a geothermal powerplant installation which was expected to help make the Silver Peak operation self-sufficient for electric power. The well drilling program consists of reworking Chemetall's existing brine production wells, installing new production wells, dredging and expanding the current evaporation pond system, and refurbishing the company's lithium carbonate plant. At Kings Mountain, construction of a battery-grade lithium hydroxide production facility was underway. The lithium hydroxide facility expands an existing Chemetall site that produces lithium salts and lithium metal for primary batteries. Both projects were funded in part by a 2009 DOE award of $28.4 million to expand and upgrade the production of lithium compounds for advanced transportation batteries (Rockwood Holdings, Inc., 2010a, b).

In January, American Lithium Minerals, Inc. acquired the North Borate Hills and South Borate Hills lithium projects in southwestern Nevada. The projects were previously reported by U.S. Borax, Inc. to contain abundant lithium mineralization in a strata-bound formation combined with a claystone unit and volcanic tuff. The company entered into a joint-exploration agreement with Japan Oil, Gas and Metals National Corp. (JOGMEC) in June to advance the Borate Hills projects through the economic prefeasibility stage. JOGMEC was to invest $4 million and would earn a 40% interest in the project (American Lithium Minerals Inc., 2010; Japan Oil, Gas and Metals National Corp., 2010).

In July, Japanese trading company Itochu Corp. acquired a 20% stake in California-based Simbol Materials lithium project and exclusive rights to market Simbol's future products in Asia. Simbol's unique geothermal brine reverse osmosis process, if successful, would eliminate the need for solar evaporation, a lengthy process in more common lithium brine operations. The company's lithium carbonate equivalent (LCE) capacity was initially planned for 16,000 metric tons per year (t/yr) (Industrial Minerals, 2010b).

In October, Rodinia Lithium, Inc. (Vancouver, British Columbia, Canada) staked claims in Clayton Valley, NV, bringing its total claim area to approximately 28,000 hectares in an area with the potential of containing a significant lithium brine resource. The mining claims were adjacent to Chemetall Foote's lithium brine operation (Rodinia Lithium, Inc., 2010b).

In May, Western Lithium Canada Corp. (Vancouver) announced the completion of an independent technical and economic assessment on the second of its five lithium-rich hectorite clay deposits at its Kings Valley, NV, project. The second deposit was approximately seven times larger than the first deposit, and the economic assessment showed an indicated resource of 1,365,000 t LCE and an inferred resource of 650,000 t LCE, both at a cutoff grade of 0.20% lithium. In December, two independent laboratories confirmed the extraction of high-purity 99.5% to 99.9% lithium carbonate from pilot test samples provided by Western Lithium (Western Lithium USA Corp., 2010a, b).

Consumption

Lithium is sold as brines, compounds, metal, or mineral concentrates depending on the end use. Lithium's electrochemical reactivity and other unique properties have resulted in many commercial lithium products. For many years, most lithium compounds and minerals were used in the production of ceramics, glass, and primary aluminum. Growth in lithium battery use and decreased use of lithium in aluminum production has resulted in batteries gaining market share. For 2010, Chilean lithium producer Sociedad Química y Minera de Chile S.A. (SQM) listed the main global markets for lithium products as follows—ceramics and glass, 29%; batteries, 27%; lubricating greases, 12%; continuous casting, 5%; air treatment, 4%; polymers, 3%; primary aluminum production, 2%; pharmaceuticals, 2%; and other uses, 16% (Sociedad Química y Minera de Chile S.A., 2011a, p. 39). Roskill Information Services Ltd. offered different consumption estimates for 2010 but confirmed that ceramics and glass remained the top global market for lithium. Roskill's estimates were ceramics and glass, 30%; batteries, 22%; lubricating greases, 12%; air treatment, 5%; metallurgical, 4%; polymers, 4%; primary aluminum production, 2%; pharmaceuticals, 2%; and other uses, 19% (Orocobre Ltd., 2011). The "other uses" category represented several smaller end uses that may have included alloys, construction, dyestuffs, industrial bleaching and sanitation, pool chemicals, and specialty inorganics (FMC Corp., 2008). Domestic end uses for lithium materials may not directly correspond to worldwide consumption, but the data necessary for making more reliable estimates were not available.

If lithium concentrates were included in lithium consumption estimates, the leading use of lithium in the United States likely was in ceramics and glass manufacturing processes. No lithium concentrates, however, were produced in the United States for direct application in ceramics and glass manufacture, and import statistics do not specifically identify lithium ore imports, making it difficult to accurately estimate end uses.

China, Japan, and the Republic of Korea have historically dominated the small to mid-sized lithium-ion battery manufacturing market, accounting for approximately 98% of the market in 2010. Notably in 2010, the Japanese market research firm, the Institute of Information Technology (IIT), reported that the Republic of Korea had overtaken Japan (the primary lithium-ion battery producer since 1991) as the leading manufacturer of lithium-ion batteries. IIT estimated that by 2011, 38.5% of lithium-ion battery production would be concentrated in the Republic of Korea and 38.4% in Japan. Lithium's natural properties make it one of the most attractive battery materials of all the elements. In 2010, lithium-ion batteries accounted for 76% of the portable rechargeable battery market worldwide (Brown, 2011). Worldwide, rechargeable lithium batteries powered most cellular telephones and laptop computers, as well as many heavy-duty power tools. Automakers were working on lithium batteries for HEVs, PHEVs, and EVs.

Addition of lithium carbonate to aluminum potlines lowers the melting point of the cryolite bath, allows a lower operating temperature for the cells, increases the electrical conductivity, and decreases bath viscosity. U.S. primary aluminum production and U.S. lithium consumption for aluminum production saw no change in 2010 from that of 2009. Aluminum production stabilized after cutbacks were made during 2008 and 2009 in response to a significant drop in the price of aluminum in the second half of 2008 (Bray, 2011).

Additional information concerning other lithium end uses can be found in the lithium chapter of the 2006 U.S. Geological Survey Minerals Yearbook, volume I, Metals and Minerals.

Prices

Customs values for lithium carbonate imports to the United States were used as an indication of the trends in lithium pricing, although they never exactly reflected the producers' prices for lithium carbonate. In 2010, the average customs unit value for imported lithium carbonate was $4.35 per kilogram, 4% lower than that of 2009. The average customs unit value for imported lithium hydroxide was $4.95 per kilogram, 17% lower than that of 2009. The average unit value of exported lithium carbonate was 16% lower than in 2009 but 33% higher than the average unit value of imported carbonate. The average unit value of exported lithium hydroxide was 13% lower than in 2009 but 26% higher than the average unit value of imported hydroxide. This suggests that the material exported from the United States was higher quality lithium carbonate and lithium hydroxide than that which was imported.

As a result of the 2009 downturn in the lithium market, SQM reduced its lithium carbonate and lithium hydroxide prices by 20% in January 2010. Industry experts reported that by yearend, SQM was selling lithium carbonate for approximately $4.70 per kilogram. Chemetall and FMC most likely reduced prices in 2010 as well, but price data were not available (Sylvester, 2011).

In January, Australian spodumene producer Talison Lithium Ltd. increased glass-grade spodumene (5% lithium oxide) prices by 10% to $380 to $430 per metric ton. At yearend, free-on-board West Virginia glass-grade spodumene (5% lithium oxide) was reported to be selling for $390 to $435 per metric ton (Moores, 2009; Industrial Minerals, 2010a).

Foreign Trade

In 2010, total exports of lithium compounds from the United States increased by 53% compared with those of 2009. About 32% of all U.S. exports of lithium compounds went to Japan, while 16% went to Germany, and 11% went to Belgium. The remainder was divided among many other countries (table 2).

Imports of lithium compounds into the United States increased by 4% in 2010 compared with those of 2009. Of the 10,600 t of lithium compounds imported, 70% came from Argentina, 28% from Chile, and the remainder from several other countries (table 3). This was the second consecutive year that most lithium imports originated from Argentina, rather than Chile. Lithium concentrates from Australia and Zimbabwe may have entered the United States, but because these materials have no unique import code, no import data were available.

World Review

Worldwide production and consumption of lithium increased considerably in 2010. The major lithium producers reported a 30% to 50% increase in sales volumes from that of 2009, and lithium end-use markets for batteries, ceramics and glass, grease, and other industrial applications all increased. World lithium production (excluding U.S. production) was estimated to be 28,100 t of lithium contained in minerals and compounds in 2010, an increase of 44% from that of 2009, and 6% more than that of 2008. Gross weight production figures for lithium carbonate, lithium chloride, lithium hydroxide, and lithium mineral concentrates are listed in table 4. Argentina, Chile, China, and the United States were the leading producers of brine-based lithium carbonate. Significant quantities of lithium compounds and concentrates also were produced in Australia, Brazil, Portugal, and Zimbabwe. Canada, Congo (Kinshasa), Namibia, Russia, Rwanda, and South Africa have produced concentrates in the past. Several brine operations were under development in Argentina; spodumene mining operations were under development in Australia, Canada, and Finland; and a jadarite mining operation was under development in Serbia. Pegmatites containing lithium minerals have been identified in Afghanistan, Austria, France, India, Ireland, Mozambique, Spain, Sweden, and Zaire, but economic conditions have not favored development of the deposits. Lithium has been identified in subsurface brines in Afghanistan, Bolivia, and Israel. Companies in France, Germany, Japan, the Republic of Korea, Russia, Taiwan, and the United Kingdom produced downstream lithium compounds from imported lithium carbonate.

World lithium consumption was estimated by SQM to be 23,500 t of lithium contained in minerals and compounds in 2010, an increase of approximately 42% from SQM's consumption estimate of 2009 (Sociedad Química y Minera de Chile S.A., 2011a, p. 40). A different accounting of total world lithium consumption was reported by Chemetall and Roskill Information Services, both of which indicated consumption to be 22,600 t of lithium contained in minerals and compounds in 2010, an increase of approximately 22% from Roskill's consumption estimate of 2009 (Aul, 2011, p. 6; Robert Baylis, Division Manager, Roskill Information Services, Ltd., oral commun., January 20, 2011). The difference in consumption figures most likely reflected differing estimations of consumer drawdown of lithium inventory.

Total lithium consumption growth averaged 5.5% per year between 2000 and 2010, while lithium consumption in batteries increased on average 20% per year during the same timeframe. Using the Chemetall/Roskill figure for total lithium consumption and Roskill's recent research that estimated the lithium chemical market to be about 75% of total lithium consumption, an estimated 17,000 t of lithium was consumed in chemicals and the remainder as mineral concentrates in the ceramics and glass industry in 2010 (Baylis, 2010b, p. 5).

As of 2008 (the latest year with available data), China and Europe were estimated to be the largest consumers of lithium in the world, at 29% and 28% of total consumption, respectively. Other consumers included Japan, 18%; North America, 13%; the Republic of Korea, 5%; India, 3%; South America, 2%; Russia, 1%; and other, 1% (Roskill Information Services Ltd., 2009, p. 155).

Argentina.—FMC has operated its facility at the Salar de Hombre Muerto since 1998. Initially designed to produce about 12,000 t/yr of lithium carbonate and about 5,500 t/yr of lithium chloride, FMC's lithium chloride production has been as high as 8,800 t. FMC's lithium carbonate production capacity was 17,000 t/yr in 2010, and capacity expansion plans were announced to increase lithium carbonate production capacity to 23,000 t/yr by the end of 2011 (Moores, 2010a). Production of lithium carbonate in 2010 was estimated to be 10,000 t, an increase of 18% from that of 2009. Production of lithium chloride was estimated to be 6,500 t, an increase of 49% from that of 2009. Market research firm Global Business Reports estimated FMC's total 2010 LCE output to be slightly higher, at 17,500 t (Tejerina and Falcó, 2010, p. 68).

In December, The Sentient Group's Rincon Lithium Ltd. commissioned its lithium operation at the Salar del Rincón in Salta Province and produced its first lithium carbonate. The company expected to have commercial quantities in the market by 2011. The operation was designed to produce 10,000 t/yr of lithium carbonate, 4,000 t/yr of lithium hydroxide, and 3,000 t/yr of lithium chloride (Industrial Minerals, 2010c).

During 2010, Australian exploration company Orocobre Ltd. conducted a definitive feasibility study on its Olaroz lithium project at the Salar de Olaroz in northwestern Argentina; results were expected in early 2011. A previous scoping study indicated the potential to develop an operation with production of 15,000 t/yr of lithium carbonate. In January, Orocobre established a joint venture with Japanese trading house Toyota Tsusho Corp. Toyota Tsusho, a key supplier to Toyota Motor Corp. and several large Asian technology companies including Panasonic Corp. and Sanyo Electric Co., Ltd., anticipated using the joint venture as a means to secure low-cost lithium for its automotive and battery industry partners (Industrial Minerals, 2010f; Orocobre Ltd., 2011, p. 9).

In December, Canadian exploration company Lithium Americas Corp. completed an independent technical and economic assessment of its Cauchari-Olaroz Salars project on the Puna plateau in northwestern Argentina. The economic assessment reported a measured resource of 2,884,000 t LCE and an indicated resource of 2,420,000 t LCE. Lithium Americas expected to complete a preliminary economic assessment in early 2011. Earlier in 2010, the company entered into strategic investment agreements with Canadian car parts manufacturer Magna International Inc. and Japan's Mitsubishi Corp. The companies purchased 13.3% and 4.1%, respectively, of Lithium Americas' common shares in an effort to secure low-cost lithium supplies for their respective company's hybrid and electric-drive vehicle batteries (Hoffman and Keenan, 2010; Lithium Americas Corp., 2011, p. 3–4).

In June, Canadian-based resource company Lithium One Inc. established a joint venture with the Republic of Korea's government-owned mining company Korea Resources Corp. (KORES) to develop Lithium One's Sal de Vida lithium brine project at the Salar del Hombre Muerto. KORES was to receive a 30% interest in the project by funding and delivering a definitive feasibility study, which was expected by yearend 2011 (Lithium One Inc., 2011, p. 3).

In January, Rodinia Lithium acquired three lithium deposits in Salta, Argentina—Salar de Diabillos, Salar de Centenario, and Salar de Ratones. An initial mineral resource estimate of the Salar was expected in early 2011 (Rodinia Lithium Inc., 2010a; 2011).

Australia.—Talison Lithium produced about 25% of global lithium supply from its deposit in Western Australia, which reportedly is the largest spodumene deposit in the world (Department of Mines and Petroleum, 2010, p. 50). The company reported spodumene production of approximately 295,000 t in 2010, an increase of 50% from that of 2009 (Department of Mines and Petroleum, 2011, p. 21). Talison produced two types of lithium concentrate—chemical grade, which is primarily used for conversion into lithium chemicals for applications including lithium batteries, and technical grade, a low iron concentrate which is used directly in the manufacture of ceramics, glass, and heat-proof cookware.

In the wake of China's electric vehicle developments and the resulting expansion of Chinese lithium chemical production, Talison reported in 2010 that 75% of its spodumene concentrate was sold primarily to chemical companies in China, with the remaining 25% sold worldwide to ceramics and glass manufacturers. This was in stark contrast to 2009, when spodumene concentrate sales were divided evenly between ceramic and glass production and chemical conversion (Industrial Minerals, 2010e). The Stage 1 expansion of Talison's chemical grade lithium concentrate production capacity was completed in December, increasing its total lithium concentrate production capacity to 320,000 t/yr. Stage 2 was expected to be completed in 2012, bringing total production capacity to 740,000 t/yr (Talison Lithium, Ltd., 2011).

In October, Galaxy Resources Ltd. commenced lithium concentrate production at its Mount Cattlin spodumene operation, near Ravensthorpe in Western Australia. The Mount Cattlin plant has a lithium concentrate production capacity of 137,000 t/yr. Production from this operation was to supply a lithium carbonate plant in Jiangsu Province, China. (Platts Metals Week, 2010).

In April, Reed Resources Ltd. and its Australian joint-venture partner Mineral Resources Ltd. completed a resource estimate of its Mount Marion lithium project in Western Australia. The study showed the deposit to contain a resource of 8.9 million metric tons (Mt) grading 1.4% lithium oxide, for a total of 128,000 t of contained lithium oxide. Reed anticipated producing battery-grade lithium carbonate beginning in 2011, with a 17,000-t/yr production capacity (Reed Resources Ltd., 2011, p. 12–14).

Bolivia.—Bolivia's undeveloped Salar de Uyuni is the largest salt flat in the world, with an area of more than 11,000 square kilometers and vast lithium resources. In August, Bolivia and the Republic of Korea agreed to a partnership to develop Bolivia's lithium deposits and other resources. In December, Bolivia also agreed to a partnership with Japan to develop Bolivia's lithium resources, as well as a geothermal powerplant project (Kosich, 2010). In 2009, New World Resource Corp. announced that it had acquired the Pastos Grandes brine property in southwestern Bolivia and initiated a brine sampling program. In 2010, the company was drill testing and sampling the third site in an approximate eight-site drill program, with results expected in early 2011 (New World Resource Corp., 2010).

Canada.—In March, Canada Lithium Corp. completed an independent mineral resource assessment on its Quebec Lithium Project. The assessment reported a measured resource of 6.89 Mt grading 1.10% lithium oxide, and an indicated resource of 24.74 Mt grading 1.11% lithium oxide. A 15,000-t/yr LCE production goal was set for 2013. An updated independent mineral resource assessment of the Quebec Lithium Project was published in October, the results of which were under review in 2011. In 2009, Canada Lithium signed a marketing agreement with Mitsui and Co. Ltd. of Japan for exclusive rights to market the company's lithium in China, Japan, and the Republic of Korea (Canada Lithium Corp., 2010a, p. 10; b; 2011).

Channel Resources Ltd. initiated a brine sampling program on its Fox Creek lithium/potash brine project in Alberta from Polaris Capital Ltd. An earlier study of the area by the Government of Alberta indicated potentially economic concentrations of lithium in the aquifer, comparable with those of the brine found in Clayton Valley, NV. As of November, Channel was working to optimize processes to extract lithium and other elements from brine already being produced as a byproduct from a large group of natural gas wells on the Fox Creek permit (Channel Resources Ltd., 2010a; b, p. 2–4).

In November, Lithium One completed an independent mineral resource assessment on its James Bay lithium project in Quebec. The assessment showed an indicated resource of 11.75 Mt grading 1.3% lithium oxide, and an inferred resource of 10.47 Mt grading 1.2% lithium oxide. In December, Lithium One formed a joint venture with Galaxy Resources under which Galaxy Resources would initially acquire 20% of the James Bay project for $3 million. Galaxy Resources could then earn up to 70% through the completion of a definitive feasibility study (Lithium One, Inc., 2010a, b).

Chile.—With a reported 26% of the world lithium market, SQM revenues from its lithium products increased as a result of robust market activity. Sales volume, at 32,400 t, was 52% higher than in 2009, and the value of sales increased by 28% to $150.8 million. SQM's lithium carbonate production capacity was 43,500 t/yr, and its lithium hydroxide production capacity was 6,000 t/yr in 2010 (Sociedad Química y Minera de Chile S.A., 2011a, p. 40, 59; b, p. 12).

Total lithium carbonate production capacity for Chemetall Foote's operations in Chile and the United States increased to 33,000 t/yr in 2010. Chemetall produced an estimated 23,000 to 25,000 t of lithium carbonate in 2010, mostly from its operation in Chile. The company planned to increase production capacity to 40,000 t/yr by 2015 and 50,000 t/yr by 2020. Further increases to 65,000 t/yr would depend on market conditions. In addition, Chemetall planned to increase lithium hydroxide production capacity, currently estimated to be 5,000 t/yr, to 10,000 t/yr by 2015 and 15,000 t/yr by 2020, depending on market conditions. The company used lithium carbonate from Chile as feedstock for some of its downstream chemical production in Germany, Taiwan, and the United States (Aul, 2011, p. 11; Desormeaux, 2011).

In July, Talison Lithium acquired Salares Lithium Inc., giving Talison control of the prospective Salares 7 Project (composed of seven brine lakes) in Chile's Atacama Desert. Talison planned to develop the project to produce battery-grade lithium carbonate (Industrial Minerals, 2010e).

China.—China was the only country that continued to produce large quantities of lithium carbonate from both domestic and imported spodumene. Domestic lithium mineral concentrates were thought to be low grade and were most likely used in glass and ceramic applications. Higher grade spodumene concentrates imported from Australia were generally used in the production of battery-grade lithium carbonate. Lithium minerals were estimated to contain 35% of China's lithium reserves, while lithium brines were estimated to contain the remaining 65% of the reserves (Baylis, 2009, p. 6–7, 11, 13; Roskill Information Services Ltd., 2009, p. 89–91).

In 2010, it was estimated that China's domestic brine-based lithium operations produced between 8,000 t and 10,000 t LCE of technical grade lithium carbonate and lithium hydroxide. China imported approximately 12,000 t LCE of brine-based lithium carbonate, lithium chloride, and concentrated brine from Argentina and Chile. China's total imports from hard rock lithium sources reached approximately 18,000 t LCE (Industrial Minerals, 2011).

The Tibet Lithium New Technology Development Co. had operated a 5,000-t/yr lithium carbonate plant at the Zabayu Salt Lake in western Tibet since 2005, with production capacity expected to increase to 20,000 t/yr. CITIC Guoan Lithium Science & Technology Co., Ltd.'s 35,000-t/yr lithium carbonate plant was brought online in 2007 at the Taijinaier Salt Lake in Qinghai Province and was the largest lithium carbonate plant in

China. In 2010, CITIC opened a 5,000 t/yr battery-grade lithium carbonate plant in Xitai, Qinghai Province. Qinghai Salt Lake Industry Group Co., Ltd. operated a 3,000-t/yr lithium carbonate plant at the Dongtai Salt Lake in Qinghai Province. Production capacity was expected to increase to 20,000 t/yr. Qinghai Salt Lake Lanke Lithium Industry Co., Ltd. completed construction of a 10,000-t/yr lithium carbonate/lithium chloride project in the Chaerhan Salt Lake zone in Qinghai Province. Production was scheduled to commence in 2012 (Tahil, 2007, p. 10, 13; Baylis, 2009, p. 11; Baylis, 2010a, b, p. 19).

Galaxy Resources commenced construction of its Jiangsu Lithium Carbonate Project in Jiangsu Province. Spodumene mined from Galaxy Resources' Mount Cattlin operation in Australia will be shipped to the Jiangsu plant for conversion to battery-grade lithium carbonate. Once complete, the Jiangsu plant was to produce 17,000 t/yr LCE and would supply users across the Asia-Pacific region (Galaxy Resources Ltd., 2010). Galaxy Resources and Mitsubishi signed an agreement in February giving Mitsubishi a significant portion of Galaxy's lithium carbonate production. Galaxy Resources also signed offtake agreements with 13 Chinese lithium battery producers in April for the remainder of its lithium carbonate production (Industrial Minerals, 2010d).

Finland.—In 2008, Norwegian mining company Nordic Mining ASA purchased a controlling stake in Finnish spodumene mining company Keliber Oy. The company then acquired a lithium deposit in the Lantta area of western Finland and planned to establish a 4,000-t/yr lithium carbonate plant. In 2010, Nordic continued with geologic exploration to expand its resource base. When production begins, Nordic was expected to be the first European producer of lithium carbonate from domestic ore (Industrial Minerals, 2008; Nordic Mining ASA, 2010, p. 5).

Japan.—Japan was a leading consumer of lithium compounds and lithium metal. Because Japan has no domestic lithium producers, the country relied heavily on imports. In an effort to mitigate lithium supply risk, Japan's Itochu, JOGMEC, Mitsubishi, Mitsui, and Toyota Tsusho actively partnered with emerging lithium producers worldwide during 2010. In December, the governments of Japan and the Republic of Korea agreed in principal to cooperate jointly in securing lithium supplies (Brown, 2010).

Japanese consumption of lithium compounds was reported by Roskill Information Services to be 18,095 t LCE in 2010, an increase of 36% from that of 2009. Of the 18,095 t total, lithium carbonate accounted for 14,000 t LCE, an increase of 51% from that of 2009. Japanese end-use markets reported strong growth during 2010—production of lithium-ion batteries increased by 33%, ceramics increased by 32%, and continuous casting fluxes increased by 117%. Japanese consumption of lithium metal for use in primary lithium batteries was 180 t in 2010, double that of 2009 (Roskill's Letters from Japan, 2011a, b).

Korea, Republic of.—As part of the effort to secure stable long-term supplies of lithium for its growing automobile, battery, and electronics industries, the Government partnered with key companies in the Republic of Korea, including POSCO and SK Energy Co., Ltd., to acquire lithium from a broad range of sources and countries. In addition to its 2010 joint venture with Lithium One in Argentina and partnership agreement with Bolivia, the Republic of Korea also invested in U.S.-based Pan American Lithium Corp. which owns the rights to 11 salars in Chile and a geothermal project in Mexico. In early 2010, the Government signed an agreement with POSCO and the Korea Institute of Geoscience and Mineral Resources to conduct joint research and build a pilot plant for the commercial production of lithium from sea water. A research facility and offshore plant were scheduled for completion by mid-2011, with lithium extraction to commence in 2012 (Korea.net, 2010; Moores, 2010b; Park, 2011; Watts, 2011).

Serbia.—Jadarite, a mineral species discovered in 2004 by Rio Tinto plc (London, United Kingdom) at Jadar, Serbia, was found to contain a high percentage of lithium oxide. Rio Tinto confirmed that the Jadar deposit could produce battery-grade lithium carbonate and planned to test for additional resources and build a pilot plant beginning in late-2011. The company intended to start lithium carbonate production in 2016 (O'Driscoll, 2011).

Outlook

The percentage of lithium consumption used globally in batteries averaged 20% per year between 2000 and 2010. Demand for lithium-ion batteries (rechargeable) appears to have the greatest potential for growth. Global sales of all rechargeable batteries were expected to total $18.3 billion in 2011, with lithium-ion batteries accounting for 76% of the market. The global market for all rechargeable batteries was forecast to climb to $95 billion by 2020, primarily on anticipated demand for feature-rich, energy intensive cellular "smartphones" and electric vehicles (Brown, 2011). Other lithium end uses were increasing also but at lower rates than batteries. Roskill Information Services Ltd. (2009, p. 156) indicated that annual growth in lithium consumed for pharmaceuticals had averaged 17% from 2000 to 2008, while lithium consumed for continuous casting and greases had averaged 8-year growth rates of 8% and 6%, respectively. Roskill estimated that total world lithium consumption would increase to approximately 27,600 t in 2013, an increase of 22% from Chemetall and Roskill's consumption estimate for 2010 (Baylis, 2010b, p. 13).

Lithium supply security has become a top priority for Asian technology companies. Strategic alliances and joint ventures have been, and are continuing to be, established with lithium exploration companies worldwide to ensure a reliable, diversified supply of lithium for Asia's battery suppliers and vehicle manufacturers. With lithium carbonate being one of the lowest cost components of a lithium-ion battery, the issue to be addressed was not cost difference or production efficiency but supply security attained by acquiring lithium from diversified lithium sources. These measures were taken in 2009 and 2010 by the battery and vehicle companies to alleviate the possibility of future lithium supply disruptions, which could have devastating consequences in a well-established and productive HEV, PHEV, and EV industry.

Research in nanotechnology, the understanding and control of matter at dimensions of approximately 1 to 100 nanometers, has advanced lithium-ion battery technology and further improvements are expected. By altering the nanostructures of the lithium-ion battery's anode and cathode, researchers have been able to increase battery storage capacity, output power, lifespan, and stability, while decreasing the time required to charge the battery (Harrop, 2008). Used in power tools, nanotechnology has enabled lithium-ion batteries to provide power surges of up to 10 times that of conventional lithium-ion batteries (Bullis, 2008). In hybrid vehicles, power surges from lithium-ion batteries enable a vehicle to accelerate faster than with other batteries of the same size (Pontin, 2007). A promising new technology, the lithium-air battery, may be capable of delivering 5 to 10 times more energy density than today's best lithium-ion technology, effectively rivaling the energy density of petroleum. Development of lithium-air battery technology is still in its infancy, however, and commercial production could be 10 to 20 years away (Rahim, 2010).

Increased use of larger lithium-ion batteries can be attributed in part to use in heavy-duty power tools because lithium-ion batteries are replacing nickel-cadmium batteries in power tools. According to a leading manufacturer of power tools, 70% of all cordless power tools in Europe were powered by lithium-ion batteries in 2009. The manufacturer expected lithium-ion power tools to account for 90% of the cordless power tool market by 2011 (Hartung, 2010).

Most global automobile manufacturers have announced plans to use lithium-ion batteries in current and future generations of HEVs, PHEVs, and EVs. Vehicles with lithium-ion batteries from companies such as BYD Co., Ltd., Daimler AG, General Motors Co., Hyundai Group, Mitsubishi Motors, Nissan Motor Co., Ltd., Tesla Motors, Inc., and Volkswagen Group were introduced in 2010. Major automobile manufacturers also formed partnerships with established battery manufacturers to build battery plants for hybrid and electric-drive vehicles and begin mass production of lithium-ion batteries.

The worldwide market for lithium-ion batteries used in transportation was expected to increase to approximately $8 billion by 2015 from $876 million in 2010, largely fueled by government subsidies and incentives. Asian lithium-ion batteries were forecast to comprise 53% of the $8 billion market by 2015 (Pike Research, 2010a).

The successful use of lithium-ion batteries in HEVs, PHEVs, and EVs could greatly increase demand for lithium. As consumption and prices rise, spodumene and other lithium resources that had been considered uneconomic might once again yield economically feasible raw materials for the production of lithium carbonate. New lithium mineral operations under development throughout the world in 2009 and 2010, specifically built to produce battery-grade lithium carbonate, demonstrated a renewed interest in lithium exploration and development.

Various countries worldwide were establishing national alternative energy policies which have the potential to significantly increase lithium demand. Market research firm Pike Research anticipated that Asia, North America, and Western Europe would be at the forefront of adopting utility-scale energy storage systems which would play a large role in the electricity grids of the future, both for long-duration storage as well as short-duration ancillary services. These energy storage systems would be the downstream beneficiaries of the widespread research and innovation on lithium-ion battery development for the transportation sector. Of several energy storage technologies competing within the short-duration ancillary services market, Pike Research indicated that advanced lithium-ion batteries hold the greatest potential. The firm forecast that lithium-ion batteries would capture approximately 70% of the ancillary services market worldwide by 2019, with revenue approaching $4.7 billion (Pike Research, 2010b, c).

In addition to energy storage systems, several other potential growth areas could significantly increase lithium demand by 2020. Lithium used in the form of large-scale solar thermal working fluids in solar thermal power applications and as a working material for passive control mechanisms in nuclear reactor applications could offer substantial opportunities for future lithium growth (Lee and Hykawy, 2011).

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TABLE 1
SALIENT LITHIUM STATISTICS[1]

(Metric tons of contained lithium)

	2006	2007	2008	2009	2010
United States:					
Production	W	W	W	W	W
Exports[2]	1,500	1,440	1,450	919	1,410
Imports[2]	3,260	3,140	3,160	1,890	1,960
Consumption[e]	2,500	2,400	2,300	1,300	1,100
Rest of world, production[3]	24,300	25,400	26,500 [r]	19,500 [r]	28,100

[e]Estimated. [r]Revised. W Withheld to avoid disclosing company proprietary data.
[1]Data are rounded to no more than three significant digits.
[2]Compounds. Source: U.S. Census Bureau.
[3]Mineral concentrate and lithium carbonate.

TABLE 2

U.S. EXPORTS OF LITHIUM CHEMICALS, BY COMPOUND AND COUNTRY[1]

Compound and country	2009 Gross weight (metric tons)	2009 Value[2] (thousands)	2010 Gross weight (metric tons)	2010 Value[2] (thousands)
Lithium carbonate:				
Australia	1 r	$6 r	1	$14
Canada	157	662	27	117
China	8	28	376	1,650
Germany	576	3,970	677	3,750
India	37	238	56	421
Korea, Republic of	80	514	71	450
Kuwait	42	831	--	--
Mexico	14 r	83 r	21	74
United Kingdom	53	241	35	128
Other	27 r	142 r	89	639
Total	995	6,710 r	1,350	7,240
Lithium carbonate, U.S.P.:[3]				
Australia	13	75	1	10
India	6	166	9	230
United Kingdom	(4)	9	--	--
Other	11	76	6	435
Total	30	326	16	675
Lithium hydroxide:				
Argentina	65	556	87	750
Australia	64	478	63	464
Belgium	--	--	951	4,660
Canada	90	438	157	912
China	37	345	103	658
Colombia	63	521	46	334
Egypt	73	493	102	679
Germany	397	2,490	676	3,440
India	81	436	340	1,720
Japan	1,870	14,200	2,700	20,000
Korea, Republic of	249	1,750	203	1,250
Mexico	68	322	264	988
Netherlands	99	535	(4)	13
Peru	6	40	16	116
Russia	63	348	210	990
Saudi Arabia	89	742	79	481
Singapore	21	318	52	320
South Africa	77	690	49	505
Taiwan	56	357	291	1,830
Thailand	155	933	274	1,490
United Arab Emirates	--	--	100	572
United Kingdom	673	4,380	152	927
Venezuela	78	704	8	96
Vietnam	24	180	16	110
Other	10	347	21	261
Total	4,400	31,600	6,960	43,600

[r]Revised. -- Zero.

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

[2]Free alongside ship values.

[3]Pharmaceutical-grade lithium carbonate.

[4]Less than ½ unit.

Source: U.S. Census Bureau.

TABLE 3

U.S. IMPORTS FOR CONSUMPTION OF LITHIUM CHEMICALS BY COMPOUND AND COUNTRY[1]

Compound and country	2009 Gross weight (metric tons)	2009 Value[2] (thousands)	2010 Gross weight (metric tons)	2010 Value[2] (thousands)
Lithium carbonate:				
Argentina	6,220	$29,700	7,360	$32,400
Chile	2,900	11,400	2,080	8,640
China	107	454	48	179
Other	26	269	9	37
Total	9,250	41,900	9,500	41,300
Lithium hydroxide:				
Chile	510	3,070	915	4,540
China	306	1,440	99	504
Germany	13	526	--	--
India	28	188	--	--
Japan	15	81	1	41
Norway	21	54	33	57
United Kingdom	37	201	20	109
Other	2	30	2	48
Total	932	5,580	1,070	5,300

-- Zero.

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

[2]Customs value.

Source: U.S. Census Bureau.

TABLE 4

LITHIUM MINERALS AND BRINE: WORLD PRODUCTION, BY COUNTRY[1, 2]

(Metric tons)

Country[3]	2006	2007	2008	2009	2010[e]
Argentina:					
Lithium carbonate	8,228	8,863	9,984	8,450 r	10,000
Lithium chloride	8,336	8,828	7,800	4,350 r	6,500
Australia, spodumene	222,101	192,277	239,528	197,482 r	295,000
Brazil, concentrates	8,585	7,991	8,000 e	8,000	8,000
Canada, spodumene[e, 4]	22,500	22,500	22,000	10,000	--
Chile:					
Lithium carbonate from subsurface brine	46,241	51,292	48,469	25,154	48,500
Lithium chloride	1,166	4,185	4,362	2,397	4,400
Lithium hydroxide	3,794	4,160	4,050	2,987	4,050
China, carbonate[e]	15,000	16,000	17,500	20,000	21,000
Portugal, lepidolite	28,497	34,755	34,888 r	37,359 r	40,600
United States, subsurface brine	W	W	W	W	W
Zimbabwe, amblygonite, eucryptite, lepidolite, petalite, and spodumene[e]	30,000	30,000	25,000	20,000	23,500

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

[1]Table includes data available through May 19, 2011.

[2]Estimated data are rounded to no more than three significant digits.

[3]In addition to the countries listed, other nations may produce small quantities of lithium minerals, but output is not reported, and no valid basis is available for estimating production levels.

[4]Based on all Canada's spodumene concentrates (Tantalum Mining Corp. of Canada Ltd.'s Tanco property).