science for a changing world

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LITHIUM

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Lithium

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In 2011, lithium consumption in the United States was estimated to be 2,000 metric tons (t) of contained lithium, 82% greater than the consumption in 2010 and 54% greater than that in 2009. Increased U.S. consumption was primarily the result of improving market conditions for lithium-based products in the United States. Downstream lithium compound producers also may have built up their inventories of lithium materials. Imports of lithium compounds into the United States in 2011 increased nearly to levels seen before the economic downturn that started in late 2008. Exports of lithium compounds were less than those of 2010 but also remained close to levels seen before the economic downturn. 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 historically has 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, on the Chilean coast. In the United States, production continued at a lithium brine operation with associated lithium carbonate and lithium hydroxide plants 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 inorganic lithium compounds such as lithium hydroxide monohydrate and 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

In an effort to accelerate the development and deployment of advanced vehicle technologies, the U.S. Department of Energy (DOE) announced in 2011 that it awarded $50 million toward the development of electric vehicle (EV) batteries that were expected to significantly exceed existing state-of-the-art technologies in terms of performance and cost. Lithium-ion, lithium metal, and lithium-sulfur battery technologies figured prominently in the awards, which were to be divided among 12 separate projects (U.S. Department of Energy, 2011).

Recycling

Lithium battery recycling projects were under development in the Belgium, Germany, Japan, and the United States in 2011. As part of the American Recovery and Reinvestment Act of 2009 (ARRA Public Law III–5), 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. In 2011, Toxco began construction of a recycling plant adjacent to its existing facility in Lancaster, OH, where the company recycled nickel-metal hydride and lead-acid batteries from hybrid-electric vehicles (HEVs). The new facility was designed to process up to 4 million kilograms of lithium-ion battery packs per year and was expected to begin operations in 2012 (Gearino, 2011; U.S. Department of Energy, 2012, p. 59–60).

Umicore opened a recycling facility for lithium-ion, lithium-polymer, and nickel metal hydride batteries in Hoboken, Belgium. The facility was designed to recover nearly all of the metallic elements in EV and HEV batteries. Umicore also reached an agreement with Tesla Motors, Inc. for Umicore to process Tesla's spent lithium-ion battery packs, recovering several metals and recycling the recovered cobalt into high-grade lithium cobalt oxide, which would then be resold to battery manufacturers (Kanter, 2011; Tesla Motors, Inc., 2011).

At yearend 2011, Chemetall GmbH commenced operations of a recycling pilot plant for lithium-ion batteries in Langelsheim, Germany. The German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety previously awarded Chemetall, as part of a consortium called LithoRec including Volkswagen AG and Audi AG, $8.2 million toward the $20.6 million cost of the pilot plant (Kanter, 2011).

In 2011, JX Nippon Mining & Metals Co. announced plans to open a commercial-scale recycling plant for lithium-ion batteries in 2012 in Tsuruga City, Japan. The plant opening, however, was contingent on additional improvement of the quality of the recovered lithium and reduction of the recycling cost at the plant (Japan Metal Bulletin, 2011). Dowa

Eco-System Co., Ltd. announced in late 2010 that it had begun to recycle used lithium batteries and scrap produced from the lithium-ion battery manufacturing process. The company had the capacity to recycle more than 1,000 metric tons per year (t/yr) of lithium batteries. Dowa also developed a technology to refine high-purity lithium from recycled lithium-ion batteries and was studying the possibility of supplying lithium to battery manufacturers (Dowa Eco-System Co., Ltd., 2010).

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.

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.

In 2011, Chemetall Foote made progress expanding the lithium production operations at its Silver Peak and Kings Mountain locations. The Silver Peak expansion consisted of a well drilling program to double Chemetall's lithium carbonate equivalent (LCE) production capacity to 6,000 t/yr, and a geothermal powerplant installation, which was expected to help make the Silver Peak operation self-sufficient in electric power. The well drilling program consisted 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 5,000-t/yr battery-grade lithium hydroxide production facility was nearly complete. The lithium hydroxide facility expanded an existing Chemetall site that produces lithium salts and lithium metal for primary batteries. Chemetall also began construction of its Global Technical Center at Kings Mountain, which would offer expanded facilities for engineers and technicians to develop new lithium compounds for alternative transportation, energy storage, and other applications (Krause, 2012, p. 16; Rockwood Holdings, Inc., 2012, p. 2).

FMC Corp.'s Lithium Division produced a full range of downstream inorganic compounds, lithium metal, and organic lithium compounds at its facility in Bessemer City, NC. By yearend 2011, the company commissioned a metal distillation unit in Bessemer City to supply high-purity lithium metal to battery and metal alloy markets and made progress toward completing the pre-engineering work for the construction of a new lithium hydroxide plant. FMC met its lithium carbonate and lithium chloride requirements with material produced at its operation in Argentina (FMC Corp., 2012, p. 8).

Simbol Materials LLC (Pleasanton, CA) started operating its high-purity lithium carbonate plant in California. Simbol's LCE capacity, initially 500 t/yr, was expected to increase to 1,500 t/yr by yearend 2012. The company also planned to develop a larger scale lithium carbonate, lithium chloride, and lithium hydroxide operation with a LCE capacity of 16,000 t/yr. 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 (Watts, 2011c).

Albemarle Corp. (Baton Rouge, LA) announced that it developed a unique separation technology to recover lithium from the brine at its Magnolia, AR, bromine operation. The company planned to build a plant with a LCE capacity of 20,000 t/yr, and produce commercial quantities of lithium carbonate by 2013 (Reisch, 2011).

Western Lithium USA Corp. (Vancouver) completed a prefeasibility study of lithium-rich hectorite clay deposits at its King's Valley, NV, project. The study demonstrated that initial lithium carbonate production of 13,000 t/yr could commence in 2015 and could increase to full production of 26,000 t/yr within 4 years after the initial startup, if demand for lithium increased. In October, Western Lithium signed an agreement for the DOE's Argonne National Laboratory to analyze and develop the company's lithium carbonate products for battery applications (Western Lithium USA Corp., 2011; 2012, p. 2).

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 a reduction in use of lithium in aluminum production has resulted in batteries gaining market share. For 2011, Chilean lithium producer Sociedad Química y Minera de Chile S.A. (SQM) listed the main global markets for lithium products as follows—batteries, 33%; ceramics and glass, 26%; lubricating greases, 11%; air treatment, 5%; continuous casting, 4%; polymers, 3%; primary aluminum production, 2%; pharmaceuticals, 2%; chemical processes, 1%; and other uses, 13% (Sociedad Química y Minera de Chile S.A., 2012b, p. 12). The consulting firm signumBOX offered different consumption estimates for 2011 but concurred that batteries may have caught up to, if not surpassed, ceramics and glass as the top global market for lithium. signumBOX's estimates were batteries, 29%; ceramics and glass, 29%; lubricating greases, 14%; continuous casting, 5%; air treatment, 4%; primary aluminum production, 4%; medical, 3%; polymers, 3%; and other uses, 9% (Favre, 2012, p. 4). Roskill Information Services Ltd., however, reported that ceramics and glass still remained the top global lithium market in 2011 with 30% market share, while lithium-ion batteries captured 22% of the market (Baylis, 2012, p. 8). The "other uses" category represented several smaller end uses that may have included alloys, cement and concrete, 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 to make reliable estimates of U.S. consumption by end use 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 96% of the market in 2011. The Japanese market research firm, the Institute of Information Technology (IIT), reported that the Republic of Korea had overtaken Japan (the leading lithium-ion battery producer since 1991) as the leading manufacturer of lithium-ion batteries. For 2011, IIT reported that 40% of lithium-ion battery production was concentrated in the Republic of Korea, 35% in Japan, and 20% in China (Sung-Mi, 2012). Lithium's properties make it one of the most attractive battery materials of all the elements. Lithium-ion batteries accounted for 76% of the rechargeable battery market worldwide (Brown, 2011b). 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 EVs, HEVs, and plug-in hybrid electric vehicles (PHEVs).

Alcoa Inc. (Pittsburgh, PA) announced the development of a third-generation aluminum-lithium alloy that would contribute to lighter and lower cost airplanes compared with those using composite alternatives. The alloy offered superior corrosion resistance and reduced density by up to 7% in critical structural applications (Chai, 2011).

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 increased in 2011 from those of 2010. Aluminum production increased 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, 2012).

Prices

Customs values for lithium carbonate imports to the United States were used as an indication of the trends in lithium pricing; producer pricing was not available for lithium carbonate. In 2011, the average customs unit value for imported lithium carbonate was $3.87 per kilogram, 11% lower than that of 2010. The average customs unit value for imported lithium hydroxide increased markedly to $11.12 per kilogram, more than double that of 2010. The average unit value of exported lithium carbonate was 16% higher than in 2010 and 73% higher than the average unit value of imported carbonate. This suggests that the material exported from the United States was higher quality lithium carbonate than that which was imported. The average unit value of exported lithium hydroxide was 6% higher than in 2010 but 41% lower than the average unit value of imported hydroxide. Given the higher than normal average unit value of imported hydroxide in 2011 compared to its export value, the large imported unit value increase was most likely owing to intercompany transfers between foreign and U.S. subsidiaries of the same company.

In July, Chemetall increased prices by up to 20% for lithium carbonate, lithium hydroxide, lithium chloride, and battery-grade lithium metal (Rockwood Holdings Inc., 2011). Also in July, FMC increased prices by 20% for lithium carbonate, and between 15% and 25% for a range of lithium products including lithium hydroxide, lithium chloride, specialty lithium salts, and battery-grade lithium metal (FMC Corp., 2011).

Technical-grade lithium carbonate in China (domestic use) averaged approximately $5,000 per metric ton in 2011. The price was slightly higher delivered to the United States. Free-on-board technical-grade lithium carbonate from Argentina and Chile averaged approximately $4,000 per metric ton (Baylis, 2012).

Australian spodumene producer Talison Lithium Ltd. reported its average sales price of lithium concentrates sold during the last 6 months of 2011 was $320 per metric ton. Talison also reported that, beginning January 2012, a price increase of 15% would become effective across the company's entire product range (Talison Lithium Ltd., 2012, p. 5, 11). At yearend, United States glass-grade spodumene (5% lithium oxide, cost, insurance, and freight) was reported to be selling for $417 to $463 per metric ton, and lithium hydroxide (56.5% to 57.5% lithium hydroxide, large contracts, packed in drums or bags, delivered to Europe or the United States) was reported to be selling for $6,500 to $7,500 per metric ton (Industrial Minerals, 2012).

Foreign Trade

In 2011, total exports of lithium compounds from the United States decreased by 7% compared with those of 2010. About 44% of all U.S. exports of lithium compounds went to Japan, 16% went to Germany, and 6% went to Belgium (table 2).

Imports of lithium compounds into the United States increased by 44% in 2011 compared with those of 2010. Of the 15,200 t of lithium compounds imported, 52% came from Chile and 42% from Argentina (table 3). 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 in 2011. Two major lithium producing countries, Chile and Australia, reported 33% and 21% increases in lithium production, respectively, from that of 2010. World lithium production (excluding U.S. production) was estimated to be 34,800 t of lithium contained in minerals and compounds in 2011, an increase of 25% from that of 2010, and 77% more than that of 2009 (table 1). 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, Bolivia, and Chile; 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, and Sweden, but economic conditions have not favored development of the deposits. Lithium has been identified in subsurface brines in Afghanistan and Israel. Companies in China, France, Germany, Japan, the Republic of Korea, Russia, Taiwan, and the United Kingdom produced downstream lithium compounds from imported lithium carbonate.

Lithium end-use markets for batteries, ceramics and glass, grease, and other industrial applications all increased. World lithium consumption was estimated by SQM to be 25,700 t of lithium contained in minerals and compounds in 2011, an increase of approximately 9% from SQM's consumption estimate of 2010 (Sociedad Química y Minera de Chile S.A., 2012b). Roskill Information Services estimated slightly higher world lithium consumption of 25,900 t (Baylis, 2012). Different accountings of total world lithium consumption in 2011 were reported by FMC, offering a low estimate of 24,400 t of lithium contained in minerals and compounds, and Talison Lithium, reporting a high estimate of 28,200 t (Koven, 2012; Norris, 2012, p. 13). Capacity utilization among the current lithium producers was estimated by FMC to be greater than 80%, reflecting a relatively tight market between lithium production and consumption in 2011 (Norris, 2012, p. 16).

Total lithium consumption growth averaged 5.6% per year between 2000 and 2011. Using the SQM 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 19,000 t of lithium was consumed in chemicals and the remainder as mineral concentrates in the ceramics and glass industry in 2011 (Baylis, 2010b, p. 5; Favre, 2012, p. 4).

As of 2008 (the latest year with available data), China and Europe were estimated to be the leading 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.—Production of lithium carbonate in 2011 was estimated to be 10,500 t, and production of lithium chloride was estimated to be 6,000 t. 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 2011, and construction was near completion to increase it to 23,000 t/yr (Lismore, 2012b). Heavy snowstorms in Argentina disrupted FMC's mining operations during the second quarter with blocked roads, diluted lithium brines in the solar evaporation ponds, and lowered brine production (Watts, 2011a). The company reported that it sold all of its lithium carbonate production and stocks in 2011 (Lismore, 2012a).

At yearend 2010, 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. In 2011, the company produced an estimated 1,200 t lithium carbonate (Clarke, 2012b). 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 (Watts, 2010a).

The Australian exploration company Orocobre Ltd. completed a definitive feasibility study on its Olaroz lithium project at the Salar de Olaroz in northwestern Argentina. The study indicated the project could support a production rate of 16,400 t/yr of battery-grade lithium carbonate (Orocobre Ltd., 2011). Orocobre previously established a joint venture with Japanese trading firm Toyota Tsusho Corp. to supply low-cost lithium to automotive and battery industry markets (Watts, 2010b).

The Canadian exploration company Lithium Americas Corp. completed a preliminary economic assessment of its Cauchari-Olaroz Salars project on the Puna plateau in northwestern Argentina. The economic assessment indicated a production facility could be built in two phases, with construction of a 20,000-t/yr LCE phase to begin in 2012, and construction of a second 20,000-t/yr LCE phase to begin in 2016. In November, the company built a battery-grade lithium carbonate pilot plant in Canada and began pilot production. After testing of the pilot plant was complete, it would be shipped to the Cauchari-Olaroz project site. Canadian car parts manufacturer Magna International Inc. and Japan's Mitsubishi Corp. previously 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 (Lithium Americas Corp., 2011a, b, c, p. 3–4).

The Canadian-based resource company Lithium One Inc. completed a preliminary economic assessment of its Sal de Vida lithium brine project at the Salar del Hombre Muerto. The economic assessment indicated the operation could produce 25,000 t/yr lithium carbonate. Lithium One had a joint venture with the Republic of Korea's LG International Corp., GS Caltex Corp., and Government-owned mining company Korea Resources Corp. (KORES). The three Korean partners were to share a 30% interest in the project and the right to market the lithium products in China, Japan, and the Republic of Korea in exchange for funding and delivering a definitive feasibility study, which was expected by 2012 (Lithium One Inc., 2011b).

Rodinia Lithium announced an initial mineral resource estimate for the Salar de Diabillos lithium deposit in Salta, which indicated the potential to produce up to 25,000 t/yr of lithium carbonate. This deposit was one of three that the company acquired in early 2010 (Rodinia Lithium Inc., 2010; Elliott, 2011).

Australia.—In 2011, Talison Lithium produced about 32% of global lithium supply from its deposit in Western Australia, which reportedly is the largest spodumene deposit in the world (Wheatley, 2012, p. 21). The company reported spodumene production of 357,543 t in 2011, an increase of 21% from that of 2010 (Talison Lithium, Ltd., 2012, p. 9). 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 that 100% of its chemical-grade lithium concentrate was sold in China. The company's technical-grade lithium concentrate was distributed throughout the world with approximately 50% (by weight) going to Europe, 25% to China, 10% to Japan, and 10% to North America (Talison Lithium, Ltd., 2011a, p. 15–16). Talison supplied 80% of China's lithium demand in 2011 (Wheatley, 2012, p. 21).

The Stage 2 expansion of Talison's chemical-grade lithium concentrate production capacity progressed during 2011. Upon completion of the expansion at the end of 2012, the capacity was to increase to 740,000 t/yr lithium concentrate. The company also planned to build a 20,000-t/yr lithium carbonate plant in Western Australia with plant commissioning expected in 2015 (Talison Lithium, Ltd., 2011b, p. 6).

In 2011, Galaxy Resources Ltd. produced 63,853 t lithium concentrate at its Mount Cattlin spodumene operation, near Ravensthorpe, Western Australia. The Mount Cattlin plant has a lithium concentrate production capacity of 137,000 t/yr. Production from this operation was to supply the company's lithium carbonate plant in Jiangsu Province, China (Tan, 2012, p. 20).

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 2011, a Korean consortium consisting of KORES, POSCO, SK innovation Co., and LG Chemical Ltd. signed a memorandum of understanding with the Government of Bolivia to establish a joint venture for the development of a Bolivian-based lithium battery project (Shim, 2011). Bolivia also signed an agreement with China's CITIC Guoan Group Corp. to explore for lithium in the Salar de Coipasa in southwest Bolivia. CITIC was to finance a study, and upon acceptable results, submit a proposal to establish a joint venture with Bolivia for lithium extraction (Brown, 2011a).

Canada.—Canada Lithium Corp. began construction of an open pit mine and a processing plant at its Quebec Lithium Project. Commissioning of the operation was expected in late 2012, with battery-grade lithium carbonate production at a rate of 20,000 t/yr expected by the end of 2013. Canada Lithium previously 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 indicated that it would target the Asian grid storage market and the generic battery markets (Canada Lithium Corp., 2010, p. 10; Lismore, 2012c).

Nemaska Lithium Inc. completed an independent mineral resource assessment on its Whabouchi lithium deposit in Quebec. The assessment showed a measured resource of 11.3 million metric tons (Mt) grading 1.58% lithium oxide, and an indicated resource of 13.8 Mt grading 1.51% lithium oxide. A preliminary economic assessment of the deposit completed earlier in 2011 indicated a production rate of 202,000 t/yr spodumene concentrate grading 6% lithium oxide. The company also began to develop a process to produce lithium hydroxide directly from spodumene concentrate, which could reduce processing costs by eliminating the need for caustic soda, as well as eliminating the production, handling and disposal of sodium sulfate (Nemaska Lithium Inc., 2012).

Galaxy Resources initiated a definitive feasibility study on Lithium One's James Bay lithium project in Quebec. Lithium One previously formed a joint venture with Galaxy Resources under which Galaxy Resources would initially acquire 20% of the James Bay project for $3 million, and could then earn up to 70% through the completion of a definitive feasibility study. The James Bay project was expected to include a mine, processing plant, and a 17,000-t/yr battery-grade lithium carbonate plant (Lithium One, Inc., 2011a).

Chile.—With a reported 31% of the world lithium market, SQM's revenues from its lithium products increased as a result of robust market activity, mainly driven by the rechargeable battery and ceramics and glass markets. Sales of lithium carbonate and its derivatives, at 40,700 t LCE, was 26% higher than that in 2010, and the value of sales increased by 22% to $183 million. SQM's lithium carbonate production capacity increased to 48,000 t/yr in 2011, and its lithium hydroxide production capacity was 6,000 t/yr. The company's lithium products were distributed throughout the world, with 61% going to Asia and Oceania, 28% to Europe, 10% to North America, and 1% to other regions in 2011 (Sociedad Química y Minera de Chile S.A., 2012a, p. 29).

Total lithium carbonate production capacity for Chemetall Foote's operations in Chile and the United States was 33,000 t/yr in 2011. Chemetall produced an estimated 29,000 to 30,000 t of lithium carbonate and its derivates in 2011, mostly from its operation in Chile. In early 2012, the company announced plans to construct a new 20,000-t/yr lithium carbonate plant in La Negra. The new facility, expected to be completed by yearend 2013, would increase Chemetall's worldwide lithium carbonate production capacity to greater than 50,000 t/yr. Further capacity increases would depend on market conditions. In addition, Chemetall would increase its worldwide lithium hydroxide production capacity, currently estimated to be greater than 5,000 t/yr, to greater than 10,000 t/yr by 2014. The company used lithium carbonate from Chile as feedstock for some of its downstream chemical production in Germany, Taiwan, and the United States (Krause, 2012, p. 15; Rockwood Holdings, Inc., 2012, p. 2, 17).

At its Salares 7 Project in Chile's Atacama Desert, Talison Lithium completed its first shallow reconnaissance drilling program at two of the seven salars. The company planned additional drilling at one of the salars to define a potential lithium mineral resource estimate. Talison's goal was to develop the project to produce battery-grade lithium carbonate (Talison Lithium, Ltd., 2011b, p. 6).

Li3 Energy, Inc. (Lima, Peru) acquired 60% ownership of the Maricunga lithium project at the Salar de Maricunga in northern

Chile. The company formed a strategic partnership with POSCO Canada Ltd. to fund exploration and development of the project, and initiated a brine resource evaluation program shortly thereafter (Saenz, 2012, p. 3).

China.—China was the only country that continued to produce large quantities of lithium carbonate from both domestic and imported spodumene concentrates. 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, and lithium brines were estimated to contain the remaining 65% (Baylis, 2009, p. 6–7, 11, 13; Roskill Information Services Ltd., 2009, p. 89–91).

In 2011, Galaxy Resources estimated that China consumed 54,000 t LCE from domestic production and imports (Tan, 2012, p. 7). It was estimated that 32,000 t LCE of spodumene mineral concentrates were converted to lithium chemicals in 2011 (Baylis, 2012, p. 5). China's mineral conversion capacity was estimated to be 52,500 t/yr LCE, with a capacity increase to 69,500 t/yr LCE expected by yearend 2012 (Clarke, 2012b).

By yearend, Galaxy Resources achieved mechanical completion of its Jiangsu Lithium Carbonate Project in Jiangsu Province. Commercial production of battery-grade lithium carbonate was expected in April 2012. Three shipments of spodumene from Galaxy Resources' Mount Cattlin operation in Australia were shipped to the Jiangsu plant during 2011. The Jiangsu plant was to produce 17,000 t/yr LCE and supply users across the Asia-Pacific region (Tan, 2012, p. 27). Galaxy Resources had an agreement to give Mitsubishi access to a significant portion of Galaxy's lithium carbonate production. Galaxy Resources also signed offtake agreements with 13 Chinese lithium battery producers for the remainder of its lithium carbonate production (Moores, 2010).

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, with production expected in 2012. Other lithium carbonate producers included CITIC Guoan Lithium Science & Technology Co., Ltd., with a 35,000-t/yr lithium carbonate plant at the Taijinaier Salt Lake in Qinghai Province and a 5,000 t/yr battery-grade lithium carbonate plant in Xitai, Qinghai Province; the Tibet Lithium New Technology Development Co., with a 5,000-t/yr lithium carbonate plant at the Zabayu Salt Lake in western Tibet; and Qinghai Salt Lake Industry Group Co., Ltd., with a 3,000-t/yr lithium carbonate plant at the Dongtai Salt Lake in Qinghai Province (Tahil, 2007, p. 10, 13; Baylis, 2009, p. 11; Baylis, 2010a, b, p. 19).

Galaxy signed an agreement with U.S. lithium-ion battery producer K2 Energy Solutions to support the construction of Galaxy's battery plant adjacent to the Jiangsu lithium carbonate plant. K2 Energy would provide Galaxy with battery technology expertise, licensing, and commercial support in establishing battery production. Commissioning of the battery plant was anticipated in early 2013 (Smith and Watts, 2011).

Finland.—Nordic Mining ASA completed a preliminary independent mineral resource assessment of its Lantta and Outovesi lithium deposits. The assessment showed a measured and indicated resource of 1.3 Mt grading 1.08% lithium oxide at the Lantta deposit, and a measured and indicated resource of 289,000 t grading 1.49% lithium oxide at the Outovesi deposit. The company planned to establish a 4,000-t/yr lithium carbonate plant. Upon completion of the plant, Nordic would become the first European producer of lithium carbonate from domestic ore (Industrial Minerals, 2008; Outotec Oyj, 2011, p. 2).

Korea, Republic of.—As part of the effort to secure stable long-term supplies of lithium for its expanding automobile, battery, and electronics industries, the Government partnered with companies, including POSCO and SK Energy Co., Ltd., to acquire lithium from a broad range of sources and countries. The Government had signed an agreement with POSCO and the Korea Institute of Geoscience and Mineral Resources to conduct joint research and to build an offshore pilot plant for the commercial production of lithium from seawater. The pilot plant was completed in 2011 and was expected to produce 30 t/yr of lithium carbonate beginning in 2014, with the goal of producing a total of 100,000 t of lithium carbonate by 2020 (Watts, 2011b).

Russia.—Liotech Ltd. (a joint venture between the Russian Corp. of Nanotechnologies and the Chinese holding company Thunder Sky Ltd.) commissioned one of the world's highest capacity lithium-ion battery facilities in Russia's Novosibirsk region. The facility has the capacity to manufacture 1 million lithium-ion batteries per year, enough to equip 5,000 electric buses. The majority of the batteries initially would be sold to the Chinese market (Elliott, 2012).

Outlook

FMC and SQM anticipated about 10% growth in world lithium consumption for 2012 mostly owing to robust demand from the energy applications markets (Lismore, 2012a; Sociedad Química y Minera de Chile S.A., 2012b, p. 13). World lithium consumption forecasts to 2015 and 2020 were projected by all current lithium producers and many leading lithium market analysts. An aggregate of their conclusions showed world lithium consumption was likely to increase to approximately 190,000 t LCE by 2015, and 280,000 t LCE by 2020. From 2011 to 2020, average annual growth in world lithium consumption was expected to be approximately 9.5% (Clarke, 2012a). Roskill Information Services Ltd. estimated that new lithium producers would supply approximately 25% of the lithium required by 2020 (Baylis and Chegwidden, 2012, p. 29).

Annual growth in lithium consumed globally for batteries averaged 19% per year between 2000 and 2011. Demand for lithium-ion batteries appears to have the greatest potential for growth. The global market for lithium-ion batteries was forecast by Roland Berger Strategy Consultants to reach $9 billion by 2015, with potential to exceed $50 billion by 2020 (Schrader, 2012). Other lithium end uses were increasing also, but at lower rates than batteries.

Lithium supply security has become a top priority for Asian technology companies. Strategic alliances and joint ventures have been, and continue to be, established with lithium exploration companies worldwide to ensure a reliable, diversified supply of lithium for Asia's battery 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. Battery and vehicle companies have taken these measures since 2009 to alleviate the possibility of future lithium supply disruptions, which could have devastating consequences in the EV, HEV, and PHEV 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). Nanotechnology has enabled lithium-ion batteries used in power tools 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, a coalition of U.S. national laboratories and commercial partners led by International Business Machines Corp. anticipated having a full-scale prototype battery ready by 2013, with commercial battery production expected by 2020 (Graham-Rowe, 2012).

Increased use of larger lithium-ion batteries can be attributed in part to the rapid replacement of nickel-cadmium batteries with lithium-ion batteries in heavy-duty power tools. According to Robert Bosch GmbH, a leading manufacturer of power tools, 85% of the cordless power tool market were powered by lithium-ion batteries in 2011, up from only 26% in 2007. Bosch reported that its share of the lithium-ion cordless tool market was 90% (Müller, 2012).

Most global automobile manufacturers have announced plans to use lithium-ion batteries in current or future generations of EVs, HEVs, and PHEVs. Vehicles with lithium-ion batteries from companies such as Bavarian Motor Works AG (BMW), Ford Motor Co., General Motors Co., Honda Motor Co., Ltd., Hyundai Group, Tesla Motors, Inc., Toyota Motor Corp., and Volkswagen Group were expected to be introduced in 2012. Major automobile manufacturers 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 forecast by research consultants Pike Research to increase to approximately $15 billion by 2017 from $2 billion in 2011. As manufacturing efficiencies improve and access to lithium expands, the cost of lithium-ion batteries was expected to decrease by more than one-third by 2017 (Pike Research, 2012).

The successful use of lithium-ion batteries in EVs, HEVs, and PHEVs could greatly increase demand for lithium. If consumption increases faster than supply, prices could increase, and 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 specifically designed to produce battery-grade lithium carbonate, demonstrate the perceived economic viability of these mineral operations.

Various countries worldwide were establishing national alternative energy policies that have the potential to substantially increase lithium demand. It was anticipated that Asia, North America, and Western Europe would be at the forefront of adopting utility-scale energy storage systems that would play a large role in the electricity grids of the future, both for long-duration storage as well as short-duration ancillary services. China, in particular, was expected to become the largest utility-scale energy storage market in the world, with $586 billion in Government funds to be invested by 2020. These energy storage systems would be the downstream beneficiaries of the widespread research and development of lithium-ion batteries for the transportation sector. Of several energy storage technologies competing within the short-duration ancillary services market, advanced lithium-ion batteries were expected to hold the greatest potential, capturing approximately 70% of the ancillary services market worldwide by 2019. Worldwide revenue from sales of lithium-ion batteries for use in utility-scale energy storage systems was expected to increase to nearly $6 billion in 2020, from $72 million in 2012 (Pike Research, 2010; Oyama, 2011).

In addition to energy storage systems, several other potential growth areas could significantly increase lithium demand by 2020. Lithium used in solar power applications and in nuclear reactor applications offer substantial opportunities for future lithium growth (Lee and Hykawy, 2011).

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Roskill Information Services Ltd.

TABLE 1

SALIENT LITHIUM STATISTICS [1]

(Metric tons of contained lithium)

	2007	2008	2009	2010	2011
United States:					
Production	W	W	W	W	W
Exports[2]	1,440	1,450	919	1,410	1,310
Imports[2]	3,140	3,160	1,890	1,960	2,850
Consumption[e]	2,400	2,300	1,300	1,100	2,000
Rest of world, production[3]	25,400	26,700 [r]	19,700 [r]	27,800 [r]	34,800

[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]

	2010		2011	
Compound and country	Gross weight (metric tons)	Value[2] (thousands)	Gross weight (metric tons)	Value[2] (thousands)
Lithium carbonate:				
Bangladesh	9	$32	9	$33
Belgium	15	66	150	1,130
Canada	27	117	93	415
China	376	1,650	9	31
Denmark	--	--	41	303
Germany	677	3,750	657	3,540
India	56	421	61	329
Korea, Republic of	71	450	101	486
Mexico	21	74	(3)	10
Pakistan	4	76	101	619
United Kingdom	35	128	11	48
Other	62 r	479 r	24	148
Total	1,350	7,240	1,260	7,090
Lithium carbonate, U.S.P.:[4]				
India	9	230	45	1,280
Israel	3	61	2	54
Japan	(3)	55	19	216
Other	4 r	329 r	3	212
Total	16	675	69	1,770
Lithium hydroxide:				
Argentina	87	750	99	615
Australia	63	464	53	380
Belgium	951	4,660	467	2,070
Canada	157	912	162	980
China	103	658	119	749
Colombia	46	334	49	346
Egypt	102	679	73	469
Germany	676	3,440	574	3,210
India	340	1,720	20	107
Japan	2,700	20,000	3,380	25,400
Korea, Republic of	203	1,250	264	1,720
Mexico	264	988	396	1,260
Peru	16	116	12	92
Russia	210	990	41	242
Saudi Arabia	79	481	41	252
Singapore	52	320	38	264
South Africa	49	505	34	418
Taiwan	291	1,830	223	1,470
Thailand	274	1,490	304	1,770
United Arab Emirates	100	572	--	--
United Kingdom	152	927	1	22
Vietnam	16	110	44	292
Other	29 r	370 r	16	166
Total	6,960	43,600	6,410	42,300

[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]Less than ½ unit.

[4]Pharmaceutical-grade lithium carbonate.

Source: U.S. Census Bureau.

TABLE 3

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

Compound and country	2010 Gross weight (metric tons)	2010 Value[2] (thousands)	2011 Gross weight (metric tons)	2011 Value[2] (thousands)
Lithium carbonate:				
Argentina	7,360	$32,400	6,430	$24,800
Chile	2,080	8,640	7,210	26,400
China	48	179	801	4,160
Other	9	37	15	75
Total	9,500	41,300	14,400	55,400
Lithium carbonate, U.S.P.:[3]				
India	--	--	19	517
Italy	--	--	(4)	4
Total	--	--	19	522
Lithium hydroxide:				
Chile	915	4,540	652	7,130
China	99	504	32	182
Finland	--	--	19	88
Germany	(4) r	7 r	14	942
Japan	1	41	10	109
Norway	33	57	22	38
United Kingdom	20	109	46	374
Other	2	41 r	5	36
Total	1,070	5,300	800	8,890

[r]Revised. -- Zero.

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

[2]Customs value.

[3]Pharmaceutical-grade lithium carbonate.

[4]Less than ½ unit.

Source: U.S. Census Bureau.

TABLE 4

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

(Metric tons)

Country[3]	2007	2008	2009	2010	2011
Argentina:					
Lithium carbonate	8,863	9,984	8,586 r	11,196 r	10,500 e
Lithium chloride	8,828	7,800	4,400 r	6,832 r	6,000 e
Australia, spodumene	192,277	239,528	197,482	295,000	421,396
Brazil, concentrates	7,991	14,460 r	15,929 r	15,733 r	15,800
Canada, spodumene[e, 4]	22,500	22,000	10,000	--	--
Chile:					
Lithium carbonate from subsurface brine	51,292	48,469	25,154	44,025 r	59,933
Lithium chloride	4,185	4,362	2,397	3,725 r	3,864
Lithium hydroxide	4,160	4,050	2,987	5,101 r	5,800
China, carbonate[e]	16,000	17,500	20,000	21,000	22,000
Portugal, lepidolite	34,755	34,888	37,359	40,600 e	41,000
United States, subsurface brine	W	W	W	W	W
Zimbabwe, amblygonite, eucryptite, lepidolite, petalite, and spodumene[e]	30,000	25,000	20,000	23,500	23,500

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

[1]Table includes data available through May 29, 2012.

[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).