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LITHIUM

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Lithium

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In 2012, lithium consumption in the United States was estimated to be about 2,000 metric tons (t) of contained lithium, the same as that in 2011 and about 80% greater than that in 2010. The increase in U.S. consumption in 2011 and 2012 relative to 2010 was primarily the result of increased demand for lithium-based air treatment, battery, ceramic and glass, grease, metallurgical, pharmaceutical, and polymer products in the United States. Net imports of lithium compounds into the United States in 2012 decreased by about 5% from those in 2011, and were nearly 15% lower than those in 2008. In the United States, one lithium brine operation with associated lithium carbonate and lithium hydroxide plants operated in Silver Peak, NV. Domestic and imported lithium carbonate, lithium chloride, and lithium hydroxide were consumed directly in industrial applications and used as raw materials for downstream lithium compounds. Argentina and Chile were the principal sources of imported lithium carbonate, lithium chloride, and lithium hydroxide. World lithium production in 2012 (excluding U.S. production) was estimated to be 36,600 t of lithium contained in minerals and compounds, an increase of 8% from that of 2011.

Lithium historically has been mined from two distinct sources—continental brines and hard rock minerals. Chile, the world's leading producer of lithium carbonate, recovered lithium from two brine operations on the Salar de Atacama in the Andes Mountains. Concentrated brines were transported to and processed at two lithium carbonate plants, one lithium chloride plant, and one lithium hydroxide plant in Antofagasta, on the Chilean coast. Lithium carbonate and lithium chloride also were produced from brines from the Salar del Hombre Muerto in the Andes Mountains in Argentina. A large percentage of the lithium carbonate produced in South America was exported to the United States. 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 mineral concentrates, mostly from imported Australian spodumene. Australia was, by far, the leading producer of lithium mineral concentrates, but Brazil, China, Portugal, and Zimbabwe also produced significant quantities, most of which is used directly in the production of ceramics and glass.

Worldwide lithium resource exploration (led predominantly by Australian and Canadian startup companies) has 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, significant exploration was conducted in Argentina, Bolivia, and Chile for continental brines.

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. Rockwood Lithium Inc. (a subsidiary of 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.

Rockwood Lithium produced lithium carbonate and lithium hydroxide from brines near Silver Peak, NV. In 2012, the company continued to make progress on a well drilling program designed to double Rockwood's lithium carbonate equivalent (LCE) production capacity to 6,000 metric tons per year (t/yr). The expansion included a geothermal powerplant that was expected to help make Silver Peak self-sufficient in electric power.

In 2012, Rockwood opened its new 5,000-t/yr battery-grade lithium hydroxide production facility in Kings Mountain, NC. The lithium hydroxide facility expanded an existing Rockwood site that produced lithium salts and lithium metal for primary (nonrechargeable) batteries. Rockwood also opened its Global Technical Center at Kings Mountain, which offered expanded facilities for engineers and technicians to develop new lithium compounds for alternative transportation, energy storage, and other applications. Rockwood's Kings Mountain and Silver Peak plant expansions were funded in part by a $28.4 million grant from the U.S. Department of Energy (DOE), as part of the American Recovery and Reinvestment Act of 2009 (ARRA Public Law III–5).

The company's other lithium operations included a butyllithium plant in New Johnsonville, TN, facilities for producing downstream lithium compounds in Kings Mountain, and lithium carbonate and lithium chloride production from a brine operation in Chile (formally Sociedad Chilena de Litio Ltda.) (Rockwood Holdings, Inc., 2012a, p. 2; U.S. Department of Energy, 2012).

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. The company commissioned a metal distillation unit in Bessemer City to supply high-purity lithium metal to battery and metal alloy producers and was building a new lithium hydroxide plant. FMC sourced its lithium carbonate and lithium chloride from its operation in Argentina (FMC Corp., 2012d, p. 8).

Simbol Materials LLC began operating a high-purity lithium carbonate pilot plant in California in 2011. The company announced plans to begin construction of a commercial 16,000-t/yr-LCE facility in California in early 2013, and startup of the facility was expected by 2014. Simbol's geothermal brine reverse-osmosis process, if successful, would eliminate the need for solar evaporation, a lengthy process used in traditional lithium brine operations (Industrial Minerals, 2013b).

Recycling

In 2012, lithium battery recycling projects were under development in Belgium, Germany, Japan, and the United States. As part of the ARRA, 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 began recycling lithium metal and lithium-ion batteries in 1992 at its facility in British Columbia, Canada, and recycled nickel-metal hydride and lead-acid batteries from hybrid-electric vehicles (HEVs) at its plant in Lancaster, OH. At yearend 2012, the lithium-ion recycling plant adjacent to its facility in Lancaster was 75% complete. The new facility was designed to process up to 4,000 t/yr of lithium-ion battery packs (Gearino, 2011; U.S. Department of Energy, 2013, p. 59–60). In 2012, Umicore Group opened a dismantling facility for rechargeable automotive batteries in Maxton, NC. The dismantling facility breaks down the battery packs before shipping the components to Belgium for recycling (Umicore Group, 2013, p. 12).

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. As a result of growth in lithium battery use and a reduction in the use of lithium in aluminum production, batteries have gained market share. For 2012, according to one estimate, the main global markets for lithium products were batteries, 35%; ceramics and glass, 26%; lubricating greases, 13%; metallurgy, 8%; air conditioning, 4%; polymers, 3%; medical applications, 3%; and other uses, 8% (Desormeaux, 2013, p. 13). Other uses may have included alloys, cement and concrete, dyestuffs, industrial bleaching and sanitation, pool chemicals, and specialty inorganics (FMC Corp., 2008). Another source, however, calculated that ceramics and glass remained the top global lithium market in 2012 with 35% market share, and batteries accounted for 29% of the market (Robert Baylis, general and division manager, Roskill Information Services, Ltd., written commun., May 14, 2013). Data to make reliable estimates of U.S. consumption were not available.

Lithium's properties make it one of the most attractive battery materials of all the elements. Worldwide, rechargeable lithium batteries powered most cellular telephones and laptop computers, as well as many heavy-duty power tools. Automakers were developing and improving lithium batteries for electric vehicles (EVs), HEVs, and plug-in hybrid electric vehicles (PHEVs).

The Portable Rechargeable Battery Association reported that the number of lithium-ion cells produced worldwide increased to 4.4 billion in 2012, a 450% increase from 800 million cells made in 2002 (Seetharaman, 2013). The global lithium-ion battery market had revenues of $11.7 billion in 2012. Consumer applications (cameras, cellular telephones, computer tablets, laptop computers, etc.) accounted for 64% of the revenues; industrial applications (aerospace and defense, energy storage, industrial tools, medical devices, etc.) accounted for 22%; and automotive applications (EVs, HEVs, PHEVs, and electric bicycles) accounted for 14%. Although the consumer segment accounted for the highest revenues in 2012, the industrial and automotive segments increased at a faster pace. The greatest share of consumer and industrial revenues came from North America, and China led in automotive revenues (Tohani, 2013).

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, 74% of new cordless power tools produced in 2012 were powered by lithium-ion batteries, up from only 26% in 2007 (Müller, 2013).

In 2012, China, Japan, and the Republic of Korea accounted for 85% to 90% of global lithium-ion battery production. Germany, Switzerland, and the United States were among other countries producing lithium-ion batteries (Tohani, 2013). According to a Japanese market research firm, the Republic of Korea overtook Japan (the leading lithium-ion battery producer since 1991) in 2011 to become the leading manufacturer of lithium-ion batteries (Sung-Mi, 2012).

In 2011, Alcoa Inc. developed a third-generation aluminum-lithium alloy that could contribute to lighter, less costly, and more corrosion resistant airplanes compared with those using composite alternatives. The alloy reduced density by up to 7% in critical structural components. In May, as part of a plan to expand its aluminum lithium production capacity and capabilities, Alcoa began construction of a new $90 million facility adjacent to its Lafayette, IN, plant with a capacity to produce more than 20,000 t/yr of aluminum lithium. Alcoa also began expanding aluminum lithium capacity at its Technical Center in Alcoa Center, PA, and Alcoa's Kitts Green plant in the United Kingdom (Chai, 2011; Alcoa Inc., 2013, p. 17).

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 in 2012 remained near the level in 2011. Aluminum production and respective lithium use remained well below the 2008 level following cutbacks in response to a significant drop in the price of aluminum in the second half of 2008 (Bray, 2013).

Prices

Customs values for U.S. imports of lithium carbonate and lithium hydroxide were used as an indication of the trends in lithium pricing; producer pricing was not available for lithium carbonate or lithium hydroxide. In 2012, the average customs unit value for imported lithium carbonate was $4.22 per kilogram, 9% higher than that of 2011. The average customs unit value for imported lithium hydroxide was $6.45 per kilogram, 42% lower than that of 2011. The 2011 lithium hydroxide unit value of $11.12 per kilogram, however, was unusually high, most likely owing to either intercompany transfers between foreign and U.S. subsidiaries of the same company or incorrect data reported to the U.S. Census Bureau. The average unit value of exported lithium carbonate in 2012 was $6.25 per kilogram, 6% lower than that of 2011. The average unit value of exported lithium hydroxide was $7.85 per kilogram, 19% higher than that of 2011. The average unit value of exported lithium carbonate in 2012 was 48% higher than the average unit value of imported carbonate. The average unit value of exported lithium hydroxide in 2012 was 22% 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.

In 2012, Rockwood Lithium increased prices for all of its lithium salt products, including lithium carbonate and lithium hydroxide, by $1,000 per metric ton. The company also increased butyllithium prices by 4% to 6% (Rockwood Holdings, Inc., 2012b, c). FMC increased prices of its lithium salt products (including lithium carbonate, lithium chloride, and lithium hydroxide) by as much as $1,000 per metric ton. FMC also increased butyllithium and specialty organic product prices by 8%, and lithium metal prices by 10% (FMC Corp., 2012b, c). Sociedad Química y Minera de Chile S.A. (SQM) reported an 8% increase in its lithium carbonate price (Michael J. Harrison, analyst, First Analysis Securities Corp., written commun., March 6, 2013).

Galaxy Resources Ltd. reported that the battery-grade lithium carbonate price in China averaged $6,750 per metric ton, a 17% increase from 2011. China's technical-grade lithium carbonate averaged $6,450 per metric ton. The lithium hydroxide price increased by 15% to $6,600 per metric ton in 2012 (Galaxy Resources, Ltd., 2012a, p. 36).

Australian spodumene producer Talison Lithium Ltd. increased chemical-grade and technical-grade lithium concentrate prices by 15% during the first half of 2012, with a further price increase of 10% for chemical-grade concentrates during the second half of 2012. The company reported its average price of lithium concentrates sold during the last 6 months of 2012 was $361 per metric ton. Talison also reported that prices would increase between 10% and 15% for its chemical-grade and technical-grade lithium concentrates during the first half of 2013 (Talison Lithium Ltd., 2012b, p. 3; 2013, p. 4, 8). At yearend, the U.S. import price for glass-grade spodumene [(5% lithium oxide), cost, insurance, and freight] was $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 United States was $6,500 to $7,500 per metric ton (Industrial Minerals, 2013a).

Foreign Trade

In 2012, total exports of lithium compounds from the United States decreased slightly compared with those of 2011. About 52% of all U.S. exports of lithium compounds went to Japan, 17% went to Germany, and 7% went to Belgium (table 2).

Imports of lithium compounds into the United States decreased by 3% in 2012 compared with those of 2011. Of the 14,900 t of lithium compounds imported, 59% came from Chile and 38% 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 2012. Two major lithium producing countries, Chile and Australia, increased lithium production by 9% and 8%, respectively, from that of 2011. World lithium production in 2012 (excluding U.S. production) was estimated to be 36,600 t of lithium contained in minerals and compounds, an increase of 8% from that of 2011 (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, China, Portugal, and Zimbabwe. Several brine operations were under development in Argentina, Bolivia, and Chile; spodumene mining operations were under development in Australia, Canada, China, and Finland; and a jadarite mining operation was under development in Serbia. Pegmatites containing lithium minerals also have been identified in Afghanistan, Austria, France, India, Ireland, Mozambique, Spain, Sweden, and Zaire, but have not been developed. Lithium also has been identified in subsurface brines in Afghanistan and Israel. Companies in China, France, Germany, Japan, the Republic of Korea, Russia, Taiwan, the United Kingdom, and the United States 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 Roskill Information Services (2013a) to be 28,200 t of lithium contained in minerals and compounds in 2012, an increase of approximately 9% from Roskill's consumption estimate of 2011. Capacity utilization among the current lithium producers was estimated to be greater than 80% (Norris, 2012, p. 16).

Total lithium consumption growth averaged 6.4% per year from 2000 through 2012. Based on estimated total lithium consumption and an estimated lithium chemical market share of total consumption of about 75%, an estimated 21,200 t of lithium was consumed in chemicals and the remainder as mineral concentrates used in the ceramics and glass industry in 2012. One Chilean lithium producer estimated global lithium chemical consumption to be 23,500 t (Baylis, 2010, p. 5; Sociedad Química y Minera de Chile S.A., 2013b, p. 17).

In 2011 (the latest year for which data were available), China was estimated to be the leading consumer of lithium with 33% of total world consumption—an increase of 5% from China's 28% share of world lithium consumption in 2009. In 2012, China, Japan, and the Republic of Korea consumed 60% of the world's lithium, and Europe and North America consumed 24% and 9%, respectively. China was expected to consume almost 50% of worldwide lithium by 2020 (Merriman, 2012, p. 5, 9; Roskill Information Services Ltd., 2013b).

Argentina.—Production of lithium carbonate in 2012 was 10,600 t, and production of lithium chloride was 4,300 t. FMC has operated its facility at the Salar de Hombre Muerto since 1998. It was initially designed to produce about 12,000 t/yr of lithium carbonate and about 5,500 t/yr of lithium chloride. In 2012, FMC's lithium carbonate production capacity increased to 23,000 t/yr. Heavy rains in Argentina during the first quarter, however, diluted the lithium brines in the solar evaporation ponds, and poor evaporative conditions during Argentina's winter reduced lithium production during the third quarter (FMC Corp., 2012a).

At yearend 2010, The Sentient Group's ADY Resources Ltd. (previously Rincon Lithium Ltd.) commissioned its lithium operation at the Salar del Rincón in Salta Province. 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. In 2012, the company produced approximately 300 t of lithium carbonate and made its first commercial shipments. Feasibility studies were also conducted in 2012 to determine phased production capacity expansions during a 20-year period (Watts, 2010a; Clarke, 2012b; Patel, 2013).

The Australian exploration company Orocobre Ltd. began constructing its Olaroz Lithium Project at the Salar de Olaroz in northwestern Argentina at yearend 2012. Construction was expected to be completed in 2014. A definitive feasibility study indicated the project could support a production rate of 17,500 t/yr of battery-grade lithium carbonate (Orocobre Ltd., 2012). 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 definitive feasibility study of its Cauchari-Olaroz Lithium Project on the Puna plateau in northwestern Argentina. The feasibility study indicated proven and probable reserves sufficient to operate at a production rate of up to 40,000 t/yr of LCE for 40 years, which would include an initial 5-year ramp-up period. The company planned to build the project in two stages, with each stage consisting of a 20,000-t/yr LCE facility. The second stage, which would require a second definitive feasibility study, was not expected to commence until 2018. 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 companies' hybrid and electric-drive vehicle batteries (Lithium Americas Corp., 2012, p. 4).

In 2012, Australia's Galaxy Resources Ltd. acquired Canadian-based resource company Lithium One Inc., including 70% of its Sal de Vida lithium brine project at the Salar del Hombre Muerto. The remaining 30% of the Sal de Vida project was owned by the Republic of Korea's LG International Corp., GS Caltex Corp., and Government-owned mining company Korea Resources Corp. (KORES). Lithium One's previous preliminary economic assessment of the Sal de Vida project indicated the operation could produce 25,000 t/yr lithium carbonate. A definitive feasibility study of the project was expected by early 2013 (Galaxy Resources Ltd., 2013, p. 12).

Rodinia Lithium completed a prototype production well and drilling program for its Salar de Diabillos lithium deposit in Salta. A feasibility study was expected in 2013 (Clarke, 2013). The company's initial mineral resource estimate for the lithium deposit 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 (Elliott, 2011).

Australia.—Talison Lithium produced about 34% of global lithium supply from its deposit in Western Australia, which reportedly is the largest spodumene deposit in the world. The company reported spodumene production of 399,000 t in 2012, an increase of 12% from that of 2011 (Talison Lithium, Ltd., 2013, p. 6, 8). Talison produced two types of lithium concentrate—chemical grade (6% lithium oxide content), which is primarily used for conversion into lithium chemicals for applications including lithium batteries, and technical grade (5% to 7.5% lithium oxide content), 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 40% (by weight) going to China, 37% to Europe, 13% to North America, and 7% to Japan (Talison Lithium, Ltd., 2012a, p. 11–12). Talison was the source of 80% of the lithium consumed in China (Wheatley, 2012, p. 21).

The stage 2 expansion of Talison's chemical-grade lithium concentrate production capacity was completed and commissioned in 2012. The expansion more than doubled existing production capacity, which increased to 740,000 t/yr from 315,000 t/yr of 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., 2012a, p. 15, 29).

In December, Windfield Holdings Pty. Ltd. [a wholly owned subsidiary of Chengdu Tianqi (Group) Co., Ltd. (Chengdu, China)] entered into a definitive agreement with Talison to acquire all of the shares in Talison that it did not already own for approximately $832 million. In March 2013, Tianqi completed its acquisition of Talison. Tianqi, which previously purchased approximately 40% of Talison's chemical-grade lithium concentrate and was the sole distributor in China of Talison's technical-grade lithium concentrate, announced it would pursue additional markets in Asia and worldwide for Talison's lithium concentrate (Chengdu Tianqi (Group) Co., Ltd., 2012a, b; Diniz, 2013).

In July, Galaxy Resources Ltd. halted lithium concentrate production at its 137,000-t/yr Mount Cattlin spodumene operation, near Ravensthorpe, Western Australia, to reduce its spodumene stocks. The company announced that continued ramp up of its lithium carbonate plant in Jiangsu Province, China, resulted in a build up of the Mount Cattlin operation's spodumene inventory to levels equivalent to 12 months of supply of feedstock for the Jiangsu Plant. Galaxy produced 48,700 t of lithium concentrate in 2012 (Galaxy Resources Ltd., 2012b, p. 5).

Belgium.—Development work continued at Umicore's pilot 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 Toyota Motor Europe to recycle spent lithium-ion battery packs for two new Toyota models—the Prius+™ and the Prius Plug-in Hybrid™—sold in Europe (Recycling International, 2012; Umicore Group, 2013, p. 12).

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 containing vast lithium resources. In July, a Korean consortium consisting of KORES, POSCO, SK Innovation Co., and LG Chemical Ltd. established a joint venture with COMIBOL, Bolivia's state-owned mining corporation, for the production of lithium cathodes, a key component of Li-ion batteries. As part of the agreement, COMIBOL was to provide materials for the Li-ion batteries, including lithium, manganese, and nickel, and the Korean consortium was to provide the manufacturing technology (The Korea Times Co., 2012). By yearend, Bolivia's first lithium carbonate pilot plant had been constructed at the Salar de Uyuni (Pistilli, 2013b).

Canada.—Canada Lithium Corp. commissioned an open pit mine and a processing plant at its Quebec Lithium Project near Val d'Or, Quebec. Full production from the 20,000-t/yr lithium carbonate processing plant was expected by yearend 2013 (Canada Lithium Corp., 2012). The company signed a 5-year lithium carbonate offtake agreement with Chinese commodity trader Tewoo-EDRC for a minimum commitment of 12,000 t/yr of battery-grade lithium carbonate. The first delivery was scheduled for 2013. The 5-year agreement included a provision for the formation of a joint venture to be incorporated as Tewoo Quebec Lithium Co. Ltd. Canada Lithium also signed a 3-year lithium carbonate offtake agreement with Japan's Marubeni Corp. for a minimum commitment of 5,000 t/yr, starting with 2,000 t/yr in 2013 (Lismore, 2012; 2013).

In 2012, Nemaska Lithium Inc. completed a second preliminary economic assessment on its Whabouchi mine and lithium hydroxide/carbonate plant in Quebec. The assessment showed a measured resource of 10.2 million metric tons (Mt) grading 1.53% lithium oxide, and an additional indicated resource of 9.4 Mt grading 1.45% lithium oxide. A production rate of 213,000 t/yr spodumene concentrate grading 6% lithium oxide was anticipated, and the plant was expected to produce up to 20,700 t/yr of lithium hydroxide and 10,000 t/yr of lithium carbonate. Nemaska developed a proprietary membrane electrolysis process which would produce lithium hydroxide directly from spodumene concentrate. The new technology was expected to reduce processing costs by replacing the use of caustic soda with electricity, as well as eliminating the production, handling, and disposal of sodium sulfate. The company expected to commission a 500-t/yr phase I lithium hydroxide demonstration plant in early 2014 (Nemaska Lithium Inc., 2012a, b; Pistilli, 2013a).

In 2012, Galaxy Resources completed the acquisition of Lithium One's James Bay lithium project in Quebec, and anticipated the results of a definitive feasibility study by early 2013 (Clarke, 2013). The James Bay project was expected to include a mine, a processing plant, and a 17,000-t/yr battery-grade lithium carbonate plant (Lithium One Inc., 2011).

Chile.—With a reported 35% share of the world lithium chemicals market, SQM's revenues from its lithium products increased as a result of robust market activity, mainly driven by the rechargeable battery and lubricating grease markets. Its sales of 45,700 t of LCE, was 12% higher than that in 2011, and the value of sales increased by 21% to $222 million. The company's lithium products were distributed throughout the world, with 64% going to Asia and Oceania; 24% to Europe, the Middle East, and Africa; 10% to North America; and 2% to other regions in 2012. SQM's lithium carbonate production capacity was 48,000 t/yr in 2012, and its lithium hydroxide production capacity was 6,000 t/yr. The company also began engineering work for a lithium carbonate production capacity expansion to 68,000 t/yr (Clarke, 2013; Sociedad Química y Minera de Chile S.A., 2013a, p. 31; 2013b, p. 14; 2013c, p. 3).

Total lithium carbonate production capacity for Rockwood Lithium's operations in Chile and the United States was 33,000 t/yr in 2012. Rockwood produced an estimated 30,000 t of lithium carbonate and its derivates in 2012, mostly from its operation in Chile. Sales of lithium products was 3.9% higher than that in 2011 owing to increased selling prices and increased volumes of lithium carbonate sold for use in battery applications and lithium specialties, but partially offset by decreased sales of technical grade lithium carbonate. The company announced plans to construct a 20,000-t/yr lithium carbonate plant in La Negra. The new facility, expected to be completed by 2014, would increase Rockwood's worldwide lithium carbonate production capacity to more than 50,000 t/yr. In addition, Rockwood planned to increase its worldwide lithium hydroxide production capacity, estimated to be greater than 5,000 t/yr, to more 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, India, Taiwan, and the United States. Rockwood's lithium compounds and value added lithium specialty products were distributed throughout the world, with 43% (by sales) going to Europe, the Middle East, and Africa; 27% to Asia; 19% to North America; and 11% to Latin America in 2012 (Haber, 2013, p. 3, 27; Rockwood Holdings, Inc., 2013a, p. 7, 30; 2013b, p. 11).

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 joint venture with POSCO Canada Ltd. to build a pilot plant that would recover lithium and other elements including boron, calcium, magnesium, and potassium using a proprietary direct extraction technology developed by POSCO. The 20-t/yr high-purity lithium carbonate pilot plant was installed in December in Copiapo, Chile (Pistilli, 2013c).

China.—China was the only country that continued to produce large quantities of lithium carbonate from domestic and imported spodumene concentrates. 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).

As of 2011, the latest year for which data were available, China produced an estimated 13,100 t of LCE from combined domestic brine and mineral production (Merriman, 2012, p. 11). China's brine producers accounted for 4,530 t of LCE, approximately one-third of the country's lithium production. Only 13% of China's 34,000-t/yr LCE brine-based production capacity was used in 2011 (Clarke, 2013). Qinghai Lanke Lithium Industry Co., Ltd. operated a 10,000-t/yr lithium carbonate-lithium chloride project in the Chaerhan Salt Lake Zone in Qinghai Province and a 200-t/yr LCE pilot project (with Qinghai Salt Lake Industry Group Co., Ltd.) in the East Taijiner Salt Lake Zone. Qinghai Lanke planned to expand production capacity of both operations to a total of 16,500 t/yr of LCE. CITIC Guoan Lithium Science & Technology Co., Ltd. operated a 20,000-t/yr lithium carbonate plant at West Taijiner Salt Lake in Qinghai Province with production capacity expected to expand to 30,000 t/yr of LCE. Tibet Mineral Development Co., Ltd. operated a 3,750-t/yr lithium carbonate plant at the Zabayu Salt Lake in western Tibet with production capacity planned to expand to 18,000 t/yr of LCE (Merriman, 2012, p. 16–17).

China's mineral producers accounted for 8,570 t of LCE, approximately two-thirds of the country's domestic lithium production in 2011 (Clarke, 2013). China's spodumene production was mostly within Sichuan Province, but also took place in Hunan, Jiangxi, and Xinjiang Provinces.

By yearend 2012, owing to China's increasing demand for lithium, the country's capacity to produce lithium compounds from spodumene was estimated to have increased to 125,600 t/yr of LCE, an increase of 140% from 52,500 t/yr of LCE in 2011 (Clarke, 2013). China produced 49,000 t of LCE from domestic and imported spodumene feedstock in 2011 and relied on imports for approximately 70% (Merriman, 2012, p. 13).

In March, Galaxy Resources officially opened its lithium carbonate plant in Jiangsu Province, and by yearend, had produced 1,200 t of technical-grade lithium carbonate and 290 t of battery-grade lithium carbonate. The Jiangsu plant was designed to produce 17,000 t/yr of LCE and supply users across the Asia-Pacific region. Galaxy also initiated a feasibility study to assess building a 5,000-t/yr battery-grade lithium hydroxide plant (Galaxy Resources, Ltd., 2013, p. 4, 7).

Germany.—At yearend 2011, Rockwood Lithium GmbH (previously Chemetall GmbH) commissioned a recycling pilot plant for lithium-ion batteries in Langelsheim, Germany. The German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety contributed $8.2 million toward the $20.6 million cost of the pilot plant (Kanter, 2011).

Japan.—JX Nippon Mining & Metals Co. completed construction of a commercial-scale recycling plant for lithium-ion batteries in Tsuruga City, Japan. Plant processing capacity was reported to be 10 metric tons per month of lithium carbonate (JX Nippon Mining & Metals Corp., 2012).

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 several companies, including POSCO and SK Energy Co., Ltd., to acquire lithium from a broad range of sources and countries. In February, POSCO announced that its Research Institute of Industrial Science and Technology had developed a technology to directly extract lithium from brines that eliminated the need for natural evaporation and reduced the lithium processing time from 12 months to less than 1 month. The lithium recovery rate also rose from approximately 50% to more than 80%. The demonstration was performed on brine obtained from Bolivia's Salar de Uyuni. POSCO planned to use its new technology to build direct extraction plants worldwide in association with lithium brine producers (Jiyoon, 2012).

Outlook

World lithium consumption forecasts to 2015 and 2020 were projected by numerous lithium producers and many leading lithium market analysts. On average, their conclusions indicated that world lithium consumption was likely to increase to approximately 190,000 t/yr of LCE by 2015 and to 280,000 t/yr of LCE by 2020 (Clarke, 2012a). From 2012 to 2017, average annual growth in world lithium consumption was expected to be approximately 11% (Baylis, 2013, p. 23). New lithium producers were expected to supply approximately 25% of the lithium required by 2020 (Baylis and Chegwidden, 2012, p. 29).

Annual growth in lithium consumed globally for batteries averaged 21% per year between 2000 and 2012. Demand for rechargeable lithium-ion batteries continues to have the greatest potential for growth. The lithium-ion battery market was expected to increase by 200% by 2017, the equivalent of an additional 90,000 t of LCE (Baylis, 2013, p. 26). The global market for lithium-ion batteries was forecast to reach $9 billion by 2015, with potential to exceed $50 billion by 2020 (Schrader, 2012). Other lithium end uses were projected to increase 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.

A new technology, the lithium-air battery, may be capable of substantially increasing the energy density of lithium batteries, effectively rivaling the energy density of petroleum. Although development of lithium-air battery technology is still in its infancy, a coalition of U.S. national laboratories and commercial partners led by International Business Machines Corp. anticipated having a laboratory prototype battery ready by 2013, a scaled-up prototype capable of powering a car ready by 2015, and commercial batteries in production within a decade (Fogg, 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 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 light duty vehicles was forecast to increase to approximately $22 billion by 2020 from $1.6 billion in 2012. As manufacturing efficiencies improve, the cost of lithium-ion batteries was expected to decrease by more than one-third by 2017 (Pike Research, 2012; Navigant Research, 2013).

The successful use of lithium-ion batteries in EVs, HEVs, and PHEVs could greatly increase consumption of lithium. If the rate of 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 potential 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 become integral components of electricity grids in the future, 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 could be the 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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TABLE 1
SALIENT LITHIUM STATISTICS[1]

(Metric tons of contained lithium)

	2008	2009	2010	2011	2012
United States:					
Production	W	W	W	W	W
Exports[2]	1,450	919	1,410	1,310	1,300
Imports[2]	3,160	1,890	1,960	2,850	2,760
Consumption[e]	2,300	1,300	1,100	2,000 [3]	2,000 [3]
Rest of world, production[4]	27,200 [r]	20,300 [r]	28,200 [r]	34,000 [r]	36,600

[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]Rounded to one significant figure to avoid disclosing company proprietary data.
[4]Mineral concentrate, lithium carbonate, lithium chloride, and lithium hydroxide.

TABLE 2
U.S. EXPORTS OF LITHIUM CHEMICALS, BY COMPOUND AND COUNTRY[1]

	2011		2012	
Compound and country	Gross weight (metric tons)	Value[2] (thousands)	Gross weight (metric tons)	Value[2] (thousands)
Lithium carbonate:				
Bangladesh	9	$33	19	$45
Belgium	150	1,130	12	113
Canada	93	415	23	140
China	9	31	51	367
Denmark	41	303	--	--
Dominican Republic	7	25	14	49
Germany	657	3,540	810	4,920
India	61	329	41	163
Japan	1	4	37	194
Korea, Republic of	101	486	20	133
Mexico	(4)	10	10	40
Pakistan	101	619	--	--
Singapore	--	--	17	82
United Kingdom	11	48	--	--
Other	16 r	120 r	10	67
Total	1,260	7,090	1,060	6,310
Lithium carbonate, U.S.P.:[3]				
Canada	--	--	8	50
India	45	1,280	44	1,130
Israel	2	54	2	63
Japan	19	216	--	--
Mexico	(4)	107	132	129
United Kingdom	--	--	11	166
Other	3	105 r	3	67
Total	69	1,770	201	1,600
Lithium hydroxide:				
Argentina	99	615	96	660
Australia	53	380	54	446
Belgium	467	2,070	496	2,980
Canada	162	980	230	1,350
Chile	3	34	19	101
China	119	749	82	613
Colombia	49	346	64	494
Egypt	73	469	73	523
Germany	574	3,210	468	3,050
India	20	107	43	359
Japan	3,380	25,400	3,990	32,800
Korea, Republic of	264	1,720	132	1,100
Mexico	396	1,260	39	495
Peru	12	92	20	162
Russia	41	242	--	--
Saudi Arabia	41	252	36	245
Singapore	38	264	66	706
South Africa	34	418	2	206
Taiwan	223	1,470	281	2,010
Thailand	304	1,770	206	1,390
Turkey	--	--	5	408
Venezuela	--	--	12	132
Vietnam	44	292	8	64
Other	14 r	154 r	10	270
Total	6,410	42,300	6,440	50,500

[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	2011 Gross weight (metric tons)	2011 Value[2] (thousands)	2012 Gross weight (metric tons)	2012 Value[2] (thousands)
Lithium carbonate:				
Argentina	6,430	$24,800	5,620	$23,900
Chile	7,210	26,400	7,250	29,400
China	801	4,160	299	1,650
Japan	(3)	17	29	80
Other	15	58 r	--	3
Total	14,400	55,400	13,200	55,100
Lithium carbonate, U.S.P.:[3]				
India	19	517	34	740
Italy	(3)	4	--	--
Total	19	522	34	740
Lithium hydroxide:				
Chile	652	7,130	1,450	9,460
China	32	182	115	682
Finland	19	88	6	31
Germany	14	942	(3)	5
Japan	10	109	(3)	3
Norway	22	38	15	33
United Kingdom	46	374	49	274
Other	5	36	3	84
Total	800	8,890	1,640	10,600

r Revised. -- Zero.

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

[2] Custom value.

[3] 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]	2008	2009	2010	2011	2012e
Argentina, subsurface brine:					
Lithium carbonate	10,000 r	8,600 r	11,200 r	10,000 r	10,600 4
Lithium chloride	7,800	4,400	6,800 r	4,600 r	4,300 4
Australia, spodumene	239,528	197,482	295,000	421,396	456,921 4
Brazil, concentrates	14,460	15,929	15,733	7,820 r	7,500 p
Canada, spodumene[e, 5]	22,000	10,000	--	--	--
Chile, subsurface brine:					
Lithium carbonate	48,469	25,154	44,025	59,933	65,000
Lithium chloride	4,362	2,397	3,725	3,864	4,200
Lithium hydroxide	4,050	2,987	5,101	5,800 e	6,500
China, carbonate[e, 6]	17,500	20,000	21,000	22,000	24,000
Portugal, lepidolite	34,888	37,359	40,109 r	37,534 r	37,500
United States, subsurface brine	W	W	W	W	W
Zimbabwe, amblygonite, eucryptite, lepidolite, petalite, and spodumene[e]	50,000 r	50,000 r	47,000 r, 4	48,000 r, 4	53,000 4

e Estimated. p Preliminary. r Revised. W Withheld to avoid disclosing company proprietary data. -- Zero.

[1] Table includes data available through July 9, 2013.

[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] Reported figure.

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

[6] China produces lithium carbonate from subsurface brine and concentrates.