



2015 Minerals Yearbook

LITHIUM [ADVANCE RELEASE]

LITHIUM

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In the United States, one lithium brine operation with an associated lithium carbonate plant 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. In 2015, lithium consumption in the United States was estimated to be 2,000 metric tons (t) of contained lithium, the same as that in 2014, and 11% greater than that in 2013 (table 1). Increased U.S. consumption in 2014 and 2015 was primarily the result of increased demand for lithium-based battery, ceramic and glass, grease, pharmaceutical, and polymer products in the United States. In 2015, the gross weight of lithium compounds imported into the United States increased by 29% and the gross weight of exports increased by 24% from those in 2014. Argentina and Chile were the principal sources of imported lithium carbonate, lithium chloride, and lithium hydroxide (table 3).

World lithium production in 2015 (excluding U.S. production) was estimated to be 30,800 t of lithium contained in minerals and compounds, about the same as that in 2014. World lithium production increased by an average of 4% per year from 2005 through 2015 (fig. 1). World lithium consumption was estimated to be approximately 33,300 t of lithium contained in minerals and compounds, an increase of 7% from that of 2014. More than 50% was consumed by countries within Asia. World lithium consumption increased by an average of 7% per year from 2005 through 2015 (fig. 1). The average unit values of lithium carbonate and lithium hydroxide imports increased slightly and by 9%, respectively, from those of 2014. In the last quarter of 2015, spot lithium carbonate prices in China increased by 200% from those of the third quarter, exceeding \$18,000 per ton, based on an acute, but likely temporary, shortage of imported mineral concentrates from Australia (Asian Metal Inc., 2015). The spot prices continued increasing into 2016. The rest of the world experienced more modest spot price increases owing to more diversified sources of lithium.

Lithium historically has been mined from two distinct sources—continental brines and hard-rock minerals. In Chile, the world's leading producer of lithium carbonate, lithium was recovered from two brine operations on the Salar de Atacama in the Andes Mountains. Concentrated brines were transported to Antofagasta, on the coast of Chile, and processed at two lithium carbonate plants, one lithium chloride plant, and one lithium hydroxide plant. 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. Australia was, by far, the leading producer of lithium mineral concentrates. Brazil, China, Portugal, and Zimbabwe also produced significant quantities of lithium

concentrates, most of which were used directly in the production of ceramics and glass. China was the only country that produced large quantities of lithium carbonate and lithium hydroxide from mineral concentrates, mostly from spodumene imported from Australia. In China, lithium carbonate was also produced from brines from the Zabayu Salt Lake in western Tibet and from the Dongtai and Xitai Salt Lakes in Qinghai Province.

Worldwide lithium resource exploration has increased significantly in recent years. A major focus of exploration in the United States was the continental brine and clay resources of Nevada, the oil field brines of Arkansas, and the geothermal brines of California. Brine resources of Argentina, Bolivia, Chile, and China; pegmatite resources of Australia, Austria, Brazil, Canada, China, Czech Republic, Finland, Germany, the Republic of Korea, Serbia, Spain, and Zimbabwe; oil brine resources of Canada; and the clay resources of Mexico were also explored for recoverable lithium.

Lithium is sold as brines, compounds, metal, or mineral concentrates depending on the end use. Lithium's low atomic mass, low coefficient of thermal expansion, high electrochemical reactivity, and other unique properties resulted in many commercial lithium products. 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 most heavy-duty power tools. Automakers were developing and improving lithium batteries for electric vehicles (EVs), hybrid-electric vehicles (HEVs), and plug-in hybrid-electric vehicles (PHEVs). Rechargeable lithium batteries were also being used in electrical grid storage applications.

Legislation and Government Programs

In 2014, the Defense Logistics Agency Strategic Materials, U.S. Department of Defense, began to acquire selected lithium battery materials for the National Defense Stockpile (NDS). The Annual Materials Plan for fiscal year 2016, which represented the maximum quantities of lithium material that could be acquired from October 1, 2015, through September 30, 2016, was 300 kilograms (kg) for lithium-cobalt oxide and 1,080 kg for lithium-nickel-cobalt-aluminum oxide (Defense Logistics Agency Strategic Materials, 2015). Calendar yearend NDS inventories were 241 kg of lithium-cobalt oxide and 690 kg of lithium-nickel-cobalt-aluminum oxide.

Production

The U.S. Geological Survey (USGS) collected domestic production data for lithium from a voluntary canvass of the only U.S. lithium carbonate producer, Rockwood Lithium Inc., which was acquired by (and became a subsidiary of)

Albemarle Corp. of Baton Rouge, LA, in January 2015. Production and stock data collected from Rockwood Lithium were withheld from publication to avoid disclosing company proprietary data. The company's 6,000-metric-ton-per-year (t/yr) Silver Peak facility was expected to supply lithium carbonate for an additional 20 years at 2015 production levels (Albemarle Corp., 2016a, p. 4).

Albemarle operated a 5,000-t/yr battery-grade lithium hydroxide production facility in Kings Mountain, NC, that used Rockwood Lithium's lithium carbonate as feedstock. The company's other downstream lithium operations in the United States included a plant for producing specialty lithium products in New Johnsonville, TN, and facilities for producing lithium compounds in Kings Mountain. Albemarle's other global lithium operations were a brine extraction operation in Chile's Salar de Atacama; lithium carbonate and lithium chloride plants in La Negra, Chile; a butyllithium, lithium chloride, and specialty chemical-metal plant in Langelshelm, Germany; and a butyllithium plant in Taichung, Taiwan (Albemarle Corp., 2016a, p. 24–26).

Albemarle owns a 49% interest in Australia's Talison Lithium Pty Ltd., a spodumene producer with a 110,000-t/yr lithium carbonate equivalent (LCE) production capacity (Talison Lithium Pty Ltd., 2012, p. 40). Sichuan Tianqi Lithium Industries, Inc., a subsidiary of Chengdu Tianqi (Group) Co., Ltd. (China) owns the remaining interest in Talison. The 2014 acquisition of Talison provided Albemarle with access to another significant lithium reserve, raw material diversity in the form of brines and mineral concentrates, and the flexibility to quickly ramp up production when necessary (Albemarle Corp., 2016a, p. 4). Albemarle was the world's leading producer of lithium in 2015, with an estimated 54,000 t of LCE from its operations in Australia and Chile (Servicio Nacional de Geología y Minería, 2016, p. 82–83).

In September, Albemarle announced its intention to add up to 50,000 t/yr of mineral conversion capacity to increase output of its battery-grade lithium carbonate and lithium hydroxide. The new plant would source spodumene from its jointly owned operation in Australia and was expected to be operational in 2020. Feasibility studies were underway to determine potential sites, including several locations in the United States and Asia (Albemarle Corp., 2015).

FMC Lithium, a division of FMC Corp. (Philadelphia, PA), produced a full range of downstream inorganic lithium compounds, lithium metal, and organic lithium compounds at its facility in Bessemer City, NC. The company sourced its lithium carbonate and lithium chloride from its brine operation in Argentina. FMC's other global lithium operations included a butyllithium facility in Zhangjiagang, China; a butyllithium-organometallic compound facility in Bromborough, United Kingdom; and an organolithium compound facility in Patancheru, India (Schneberger, 2015, p. 61).

In 2012, Western Lithium USA Corp. (Canada) completed a National Instrument 43–101-compliant prefeasibility study of lithium-rich hectorite clay deposits at its King's Valley, NV, project. The study reported that lithium carbonate could be produced at a rate of 26,000 t/yr within 4 years after the initial plant startup. In 2015, the company continued to collect design

data for a definitive feasibility study to demonstrate the viability of extracting high-purity lithium from a hectorite deposit on a commercial scale. In September, Western Lithium completed a merger with Lithium Americas Corp. (Canada), owner of the Cauchari-Olaroz Lithium Project on the Puna Plateau in northwestern Argentina, with Lithium Americas becoming a wholly owned subsidiary of Western Lithium (Western Lithium USA Corp., 2015a, b).

Lithium resource exploration in the United States has increased significantly in recent years in anticipation of increasing demand for lithium-ion batteries and the recent rise in lithium prices. Approximately 30 mining claims (mostly in Nevada) were in the early exploration stage by junior mining companies (Roskill Information Services Ltd., 2016, p. 104).

Recycling

In 2015, lithium battery recycling projects were in operation or under development in Belgium, Germany, Japan, and the United States. As part of the American Recovery and Reinvestment Act of 2009 (ARRA, Public Law III–5), the U.S. Department of Energy awarded \$9.5 million to California-based battery recycler Retriev Technologies Inc. to construct the first U.S. recycling facility for lithium-ion vehicle batteries. The company has been recycling lithium batteries at its facility in Trail, British Columbia, Canada, since 1993. In 2015, Retriev's new facility in Lancaster, OH, designed to process up to 4,000 t/yr of lithium-ion battery packs, began operation (U.S. Department of Energy, 2013, p. 59–60; Retriev Technologies Inc., 2016).

Consumption

In 2015, the main global markets for lithium products were estimated to be batteries, 39%; ceramics and glass, 30%; lubricating greases, 8%; continuous casting mold flux powders, 5%; polymer production, 5%; air treatment, 3%; and other uses, 10% (Roskill Information Services Ltd., 2016, p. 109). Other uses may have included agrochemicals, aluminum alloys, cement and concrete additives, dyes and pigments, industrial bleaching and sanitation products, organic synthesis, pharmaceuticals, pool chemicals, and welding (Albemarle Corp., 2016b). Sufficient data to make reliable estimates of U.S. consumption were not available.

In 2015, EVs, HEVs, and PHEVs accounted for approximately 25% of the global lithium-ion battery market by volume; cellular telephones and smartphones, 19%; portable computers, 16%; tablets, 16%; electric bicycles, 5%; power tools, 3%; household devices, 2%; and other uses, 14% (Deutsche Bank AG, 2016, p. 46). Global lithium-ion battery consumption increased by an average of 23% per year from 2010 through 2015, reaching an estimated 60 gigawatt hours (GWh) in 2015 from 21 GWh in 2010 (1 GWh is the equivalent of consuming 1 billion watts for 1 hour) (Roskill Information Services Ltd., 2016, p. 138). The global market for rechargeable lithium-ion batteries was valued at \$9.4 billion in 2015, and the global market for nonrechargeable lithium batteries was valued at \$1.3 billion (BCC Research LLC, 2016).

About 85% of the world's active lithium-ion battery cell production capacity was in Asia owing to longstanding public and private investments in lithium-ion battery technology by consumer electronics companies and governments. More than 50% of fully commissioned capacity was in China; Japan and the Republic of Korea had 15% and 20%, respectively. Although lithium-ion battery cell production capacity for all end uses in the United States was small compared with that in those three countries, it was a leader in automotive-specific lithium-ion battery production capacity, accounting for 20% of worldwide capacity in 2015 (Chung and others, 2016, p. 1–2; Ralph, 2016).

In 2015, new EV and PHEV sales increased to 550,570 vehicles worldwide, a 69% increase from 325,090 vehicles sold worldwide in 2014, with China (38%), Europe (35%), and the United States (21%) accounting for 94% of the market. EV and PHEV sales in China and Europe increased by 183% and 106%, respectively, from those of 2014, and EV and PHEV sales in the United States decreased by 4%. In 2015, for the first time, more EVs and PHEVs were sold in China and Europe, each, than were sold in the United States (International Energy Agency, 2016, p. 36).

In 2014, electric car manufacturer Tesla Motors, Inc. (Palo Alto, CA) began construction of a large-scale lithium-ion battery plant outside of Sparks, NV. By yearend 2015, the first portion of the facility was complete, and some product assembly began. The factory's planned battery cell production capacity of 35 gigawatt hours per year (GWh/yr) was expected to require 15,000 to 25,000 t/yr of lithium hydroxide to produce 500,000 lithium-ion vehicle batteries per year by 2020. An additional 15 GWh of battery cells were to be purchased from other manufactures, eventually bringing Tesla's total battery pack production capacity to 50 GWh/yr (Tesla Motors, Inc., 2015; 2016, p. 9).

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 2015, the average customs unit value for imported lithium carbonate was \$4.54 per kilogram, slightly higher than that of 2014. The average customs unit value for imported lithium hydroxide was \$6.94 per kilogram, 9% higher than that of 2014. The average unit value of exported lithium carbonate in 2015 was \$6.84 per kilogram, 16% lower than that of 2014. The average unit value of exported lithium hydroxide was \$8.13 per kilogram, 11% higher than that of 2014. The average unit values of exported lithium carbonate and lithium hydroxide in 2015 were 51% and 17% higher, respectively, than the average unit values of imported carbonate and hydroxide. This suggests that the materials exported from the United States were higher quality than those that were imported. Import values mostly reflect companies importing their own materials at cost for further processing.

At yearend 2015, Industrial Minerals (2015) reported that the U.S. import price for lithium carbonate (large contracts, delivered to the continental United States) was \$6,200 to \$7,000 per metric ton. The U.S. import price for lithium hydroxide (56.5% to 57.5% lithium hydroxide; large contracts, packed in drums

or bags) delivered to Europe or the United States was \$8,000 to \$9,000 per metric ton. The U.S. import price for glass-grade spodumene (5% lithium oxide; cost, insurance, and freight) was \$460 to \$500 per metric ton. The U.S. import price for greater than 7.5% lithium oxide spodumene (cost, insurance, and freight) was \$770 to \$850 per metric ton.

In the last quarter of 2015, owing to a shortage of imported spodumene from Australia, spot lithium carbonate prices in China increased by 200% from that of the third quarter, exceeding \$18,000 per metric ton by the end of December (Asian Metal Inc., 2015). The rest of the world experienced more modest spot price increases owing to supplies available from more diversified lithium sources. In October, FMC increased prices for lithium carbonate, lithium chloride, lithium hydroxide, and all other lithium products except specialty organic products by 15%. Specialty organic products, which include all grades of butyllithium, increased by \$3.50 per kilogram on a contained-lithium basis (FMC Corp., 2015). Sociedad Química y Minera de Chile S.A. (SQM) reported that average prices for its lithium products increased by more than 10% from those of 2014 (Industrial Minerals, 2016, p. 30).

Foreign Trade

In 2015, total exports of lithium compounds, by gross weight, from the United States increased by 24% compared with those of 2014. About 62% of all United States exports of lithium compounds went to Japan, 17% went to Germany, and 5% went to Canada (table 2). Lithium hydroxide accounted for 87% of the total lithium exports in 2015, and lithium carbonate accounted for the remaining 13% of total exports. Exports of lithium hydroxide increased by 22% in 2015 compared with those of 2014, whereas exports of lithium carbonate increased by 47% in 2015.

Imports of lithium compounds, by gross weight, into the United States increased by 29% in 2015 compared with those of 2014. About 49% came from Argentina and 48% from Chile (table 3). Lithium concentrates from Australia and Zimbabwe may have entered the United States, but these materials have no unique import code, and disaggregated import data were not available.

World Review

World lithium production in 2015 (excluding U.S. production) was estimated to be 30,800 t of lithium (164,000 t of LCE) contained in minerals and compounds, about the same as than that in 2014 (table 1). Estimates for global lithium production capacity range from about 49,000 to 53,000 t/yr of lithium (260,000 to 280,000 t/yr of LCE). Two of the three leading producing countries, Argentina and Australia, increased lithium production by 5% and 6%, respectively, from that of 2014; Chile decreased lithium production by 9%. 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. Australia, Brazil, China, Portugal, and Zimbabwe were the leading producers of lithium minerals. Additional brine operations

were under development in Argentina, Bolivia, Chile, China, and the United States; new spodumene mining operations were under development in Australia, Canada, China, and Finland; a jadarite mining operation was under development in Serbia; and a lithium-bearing clay mining operation was under development in Mexico. Pegmatites containing lithium minerals also have been identified in Afghanistan, Austria, Congo (Kinshasa), France, India, Ireland, Mozambique, and Sweden, 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.

Market analyst Deutsche Bank reported that lithium compounds accounted for an estimated 86% of global lithium products, and the direct market for mineral concentrates accounted for the remaining 14%. Battery- and technical-grade lithium carbonate accounted for approximately 50% of lithium products; battery- and technical-grade lithium hydroxide accounted for approximately 20%; lithium chloride, butyllithium, lithium metal, and other accounted for 5%, 5%, 3%, and 3%, respectively (Deutsche Bank AG, 2016, p. 85).

In 2015, global lithium consumption exceeded global lithium production by an estimated 2,500 t of contained lithium (13,300 t of LCE). Global lithium consumption for batteries, ceramics and glass, grease, polymers, and other industrial applications increased; lithium consumption for air treatment, metallurgical powders, and primary aluminum production decreased. An estimated 33,300 t of lithium (177,300 t of LCE) contained in minerals and compounds was consumed worldwide in 2015, a 7% increase from the estimate for 2014. China was the leading consumer of lithium minerals and compounds, accounting for 40% of worldwide consumption; Europe consumed 21%; Japan and the Republic of Korea, 11% each; North America, 8%; India, 2%; Russia, 1%; and others, 6% (Roskill Information Services, 2016, p. 108, 112). Worldwide lithium consumption figures varied considerably for the year depending on the source of information, with estimates ranging from 30,000 to 37,000 t (FMC Corp., 2015, p. 7; Deutsche Bank AG, 2016, p. 1; Orocobre Ltd., 2016, p. 9).

According to USGS estimates, total global lithium consumption increased by an average of 7% per year from 2005 through 2015. According to Roskill Information Services (2016, p. 108), lithium consumption for rechargeable batteries increased at an average rate of 18% per year from 2000 through 2015.

Argentina.—Production of lithium carbonate in 2015 was 14,100 t, an increase of 21% from that of 2014, and production of lithium chloride was 5,850 t, a decrease of 21% from that of 2014. FMC produced 12,400 t of lithium carbonate and 5,850 t of lithium chloride at its 23,000-t/yr facility, which has been operating since 1998, on the Salar de Hombre Muerto in Catamarca Province (Merriman, 2015, p. 13–14; McCormick, 2016, p. 33).

In 2015, Australia's Orocobre Ltd. began commercial production at its joint-venture Olaroz Lithium Project [Orocobre (66.5%), Toyota Tsusho Corp. (25%), the government of Jujuy Province (8.5%)] at the Salar de Olaroz in northwestern Argentina. Orocobre produced 1,730 t of combined battery- and

technical-grade lithium carbonate in 2015. Production capacity was 17,500 t/yr of battery-grade lithium carbonate. Owing to the low magnesium-to-lithium ratio in its brine, the lithium content required for processing brine to lithium carbonate was lower than average (0.7% lithium instead of the more typical 6% lithium); Orocobre's brine evaporation process was expected to take approximately 8 months compared with 18 months for lithium operations in Chile. Production was intended to supply automotive and other battery markets (James Calaway, Chairman, Orocobre Ltd., oral commun., June 17, 2015; Calaway, 2016, p. 4).

Enirgi Group Corp. (Canada) developed proprietary technology to produce lithium directly from nonconcentrated brine at the Salar del Rincón in Salta Province. The technology was expected to reduce processing time from the conventional 18 months to less than 24 hours as well as to increase the lithium recovery rate. The company planned to construct a 50,000-t/yr LCE plant (Enirgi Group Corp., 2014). In 2015, a preliminary feasibility study of the Salar del Rincón was completed showing a measured and indicated resource of approximately 680,000 t of contained lithium. A definitive feasibility study was expected in 2016 (Deutsche Bank AG, 2016, p. 126).

In 2015, exploration company Lithium Americas Corp. (Canada), owner of the Cauchari-Olaroz Lithium Project on the Puna Plateau in northwestern Argentina, became a wholly owned subsidiary of Canada's Western Lithium USA Corp. (Western Lithium USA Corp., 2015a, b). In 2014, Lithium Americas agreed to install POSCO's (Republic of Korea) 200-t/yr LCE lithium extraction pilot plant at its Cauchari-Olaroz operation. POSCO's lithium extraction technology was expected to reduce the total brine-to-lithium-carbonate-production process to 8 hours with a lithium recovery rate of greater than 80%, compared with the typical 50% of traditional evaporation technology. Lithium Americas planned to build its project in two stages with each stage consisting of a 20,000-t/yr LCE facility. At yearend 2015, Western Lithium reported minimal exploration and development activity on the property, because the focus had been on incorporating POSCO's lithium extraction technology into the project (Lithium Americas Corp., 2014, p. 4; Western Lithium USA Corp., 2016, p. 15).

Australia.—In 2015, Talison Lithium Pty Ltd., a subsidiary Sichuan Tianqi Lithium (China) and Albemarle, produced an estimated 43% of the global lithium production from its deposit in Western Australia, which reportedly was the largest spodumene deposit in the world. Talison produced two types of lithium concentrate: chemical-grade lithium concentrate (6% lithium oxide content), which is primarily used for conversion into lithium chemicals for applications including lithium batteries, and technical-grade lithium concentrate (5% to 7.5% lithium oxide content), which is a low-iron concentrate that is used directly in the manufacture of ceramics, glass, and heat-proof cookware. Talison's lithium concentrate production capacity was 740,000 t/yr, equivalent to approximately 110,000 t/yr of lithium carbonate, or 21,000 t of contained lithium (Talison Lithium Pty Ltd., 2012, p. 11–12, 29).

Talison previously reported that 100% of its chemical-grade lithium concentrate was sold to China, and its 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 (Talisson Lithium Pty Ltd., 2012, p. 11–12). In 2012, Talison was the source of about 80% of the lithium consumed in China (Wheatley, 2012, p. 21).

At yearend 2015, Neometals Ltd. (formerly Reed Resources Ltd.) began construction of the mining and processing facilities at its Mount Marion lithium project in Western Australia. The operation was jointly owned by Neometals, 45%; Mineral Resources Ltd., 30%; and Ganfeng Lithium Co. Ltd., 25%. Ganfeng, a lithium carbonate and lithium hydroxide producer in China, entered into a long-term offtake agreement with Neometals for 100% of the spodumene produced for a 3-year period. A 2012 prefeasibility study indicated that the Mount Marion lithium project could support a production capacity of 10,000 t/yr of lithium hydroxide and 8,800 t/yr of lithium carbonate. Neometals also began a definitive feasibility study on its proprietary process to produce 15,000 to 20,000 t/yr of battery-grade lithium hydroxide directly from spodumene concentrates (Reed Resources Ltd., 2014; Neometals Ltd., 2016).

In September, Galaxy Resources Ltd., which ceased lithium concentrate production in 2012 at its 137,000-t/yr Mount Cattlin spodumene concentrate operation near Ravensthorpe, Western Australia, entered into an agreement with General Mining Corp. whereby General Mining would acquire 50% of the Mount Cattlin operation with the goal of restarting production in 2016. General Mining would have exclusive rights to sell up to 100% of the spodumene concentrate to China, the Republic of Korea, Taiwan, and Vietnam for 4 years (Perks, 2016).

Lithium resource exploration in Australia has increased significantly. Junior mining companies were in the early exploration stage at more than 30 separate locations, and a few companies were completing preliminary feasibility studies (Roskill Information Services, 2016, p. 66–67).

Bolivia.—Bolivia's undeveloped Salar de Uyuni is the largest salt flat in the world, with an area of about 11,000 square kilometers containing vast lithium resources. In 2013, Bolivia began operations at a 480-t/yr lithium carbonate pilot plant at the Salar de Uyuni. In 2015, the Government of Bolivia announced it would invest approximately \$620 million over a 3-year period to advance its lithium carbonate plant from pilot phase to industrial production of lithium and potassium (Fox News Latino, 2015).

Canada.—Nemaska Lithium Inc. continued development of its Whabouchi Mine and lithium hydroxide-lithium carbonate plant in Quebec. Production capacity was anticipated to be 28,000 t/yr of lithium hydroxide and 3,000 t/yr of lithium carbonate using a proprietary membrane electrolysis process to produce high-purity lithium hydroxide directly from spodumene concentrate. The new technology was expected to reduce processing costs by using electricity to replace caustic soda and by eliminating the production, handling, and disposal of sodium sulfate. Nemaska expected to begin phase I construction of a 500-t/yr lithium hydroxide demonstration plant in the first quarter of 2016 to be completed by the fourth quarter of 2016 (Nemaska Lithium Inc., 2016).

Lithium resource exploration in Canada has increased significantly. Junior mining companies were in the early exploration stage at more than 35 separate locations, and several

companies were working on preliminary feasibility studies (Roskill Information Services, 2016, p. 74–75).

Chile.—In 2015, Chile reported production of 50,400 t of lithium carbonate, a decrease of 8% from that of 2014; 2,070 t of lithium chloride, a decrease of 31% from that of 2014; and 3,890 t of lithium hydroxide, a decrease of 7% (Servicio Nacional de Geología y Minería, 2016, p. 82–83). SQM, which accounted for 26% of global lithium chemicals sales, sold 38,700 t of LCE, slightly less than in 2014, most likely owing to a temporary suspension of operations after unusually heavy rainfall in the Atacama Desert in March. Despite the slight decrease in production, SQM's value of sales increased by 8% to \$223 million. In 2015, the company's lithium products were distributed throughout the world, with 67%, by value of sales, going to Asia; 21% to Europe; 11% to North America; and 1% to Central America and South America. SQM's lithium carbonate production capacity was 48,000 t/yr in 2015, and its lithium hydroxide production capacity was 6,000 t/yr (Benchmark Mineral Intelligence, 2015a; Sociedad Química y Minera de Chile S.A., 2016, p. 23–24).

In 2015, Albemarle began the commissioning process of its new 20,000-t/yr lithium carbonate plant in La Negra, which increased its total lithium carbonate production capacity in Chile to 47,000 t/yr. The new plant was scheduled to begin commercial production in 2016 (McCormick, 2015, p. 12). Lithium chloride production capacity for Albemarle's operation in Chile was 4,500 t/yr. Albemarle used lithium carbonate and lithium chloride from its operations in Chile as feedstock for some of its downstream chemical production in France, Germany, Taiwan, and the United States (Albemarle Corp., 2016a, p. 4).

China.—China was the only country that continued to produce large quantities of lithium carbonate and lithium hydroxide from domestic and imported mineral concentrates. Lithium mineral deposits were estimated to contain 22% of China's lithium reserves, and lithium brines were estimated to contain the remaining 78%. In 2015, China produced an estimated 10,700 t of LCE from domestic sources (6,100 t from brines and 4,550 t from spodumene and lepidolite), a 6% increase from 10,100 t in 2014 (Roskill Information Services Ltd., 2016, p. 83). Spodumene-based production capacity of China's mineral producers was 19,900 t/yr of LCE; lepidolite-based, 3,250 t/yr; and brine-based, 15,200 t/yr. China's spodumene and lepidolite production was mostly within Sichuan Province but also took place in Hunan Province, Jiangxi Province, and Xinjiang Uyghur Autonomous Region (David Merriman, Senior Analyst, Roskill Information Services Ltd., written commun., July 30, 2015). In 2015, total lithium consumption in China was reported to be 70,300 t of LCE, a 13% increase from 62,000 t of LCE in 2014 (Lowry, 2015; Roskill Information Services Ltd., 2016, p. 112). Another source reported that China consumed as much as 86,700 t of LCE in 2015 (Hao and others, 2017, p. 104).

The rapid expansion of China's spodumene-based lithium carbonate and lithium hydroxide production facilities in recent years has significantly affected the global lithium supply chain and enabled spodumene-sourced lithium, the majority mined by Talison in Australia, to account for approximately one-half of the world's lithium-chemical supply since 2012.

In 2015, China's spodumene-based capacity was reported to be 82,500 t/yr of LCE, although only 49,500 t of LCE was produced (60% capacity utilization) owing to Sichuan Tianqi restricting supply of its Talison-sourced spodumene to the lithium carbonate and lithium hydroxide plants (Roskill Information Services Ltd., 2016, p. 85).

Beginning in October, lithium carbonate and lithium hydroxide spot prices began to increase greatly in China. The Government of China increased its support of the use of lithium-ion batteries for electric vehicles, with special emphasis on their use in electric buses. This exacerbated the acute short-term shortage of spodumene from Australia to China's lithium carbonate and lithium hydroxide plants (Economist, The, 2016).

Several expansion projects were planned or underway in China. Qinghai Lanke Lithium Industry Co., Ltd. operated a 5,000-t/yr lithium carbonate-lithium chloride project in the Chaerhan Salt Lake Zone in Qinghai Province and a 200-t/yr lithium carbonate 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 these operations to 17,000 t/yr and 10,000 t/yr of LCE, respectively. CITIC Guoan Lithium Science & Technology Co., Ltd. operated a 5,000-t/yr lithium carbonate plant at West Taijiner Salt Lake in Qinghai Province with plans to expand capacity to 20,000 t/yr. Tibet Mineral Development Co., Ltd. operated a 5,000-t/yr lithium carbonate-lithium hydroxide project at the Zabayu Salt Lake in western Tibet with plans to expand to 18,000 t/yr (David Merriman, Senior Analyst, Roskill Information Services Ltd., written commun., July 30, 2015).

Japan.—Consumption of all lithium compounds in Japan in 2015 increased to an estimated 20,900 t of LCE, 24% greater than the 16,800 t of LCE consumed in 2014, owing primarily to increased demand for lithium-ion battery cathodes and electrolytes. Japan's consumption of lithium carbonate increased by 14% to 12,500 t of LCE, and consumption of lithium hydroxide increased by 38% to 7,920 t of LCE owing to Tesla's use of lithium hydroxide rather than lithium carbonate for its lithium-ion cathode. Chile accounted for 78% of Japan's lithium carbonate imports, and the United States accounted for 71% of Japan's lithium hydroxide imports. Japan's lithium metal consumption increased by 46% to 120 t owing to greater demand for primary lithium battery anodes (Roskill's Letter from Japan, 2016).

Mexico.—At yearend 2015, Canada's Bacanora Minerals Ltd. completed a mineral resource estimate update for its Sonora Lithium Project in Sonora, which consisted of 10 mining concessions about 200 kilometers south of Arizona. Mineralization on the concessions consisted of lithium-bearing clays localized in lake basins. The mineral resource estimate update focused on 7 of the 10 concessions, which were reported as the La Ventana concession and the El Sauz-Fleur concessions. The La Ventana concession had an indicated clay resource of 141 million metric tons (Mt) ranging between 1,500 and 3,500 parts per million (ppm) lithium, with a resource of 1.9 Mt of LCE. The El Sauz-Fleur concessions had an indicated clay resource of 223 Mt with lithium content ranging between 1,100 and 4,300 ppm lithium, with a resource of 3.1 Mt of LCE (Bacanora Minerals Ltd., 2016, p. 7).

Outlook

In 2015, Orocobre and lithium market analysts Deutsche Bank, Global Lithium LLC, Roskill, and Stormcrow Capital developed forecasts of world lithium consumption levels in 2020 that ranged from 230,000 to 360,000 t/yr of LCE and averaged approximately 300,000 t/yr of LCE. Average annual growth in world lithium consumption from 2015 through 2020 was expected to be between 9.5% and 14% (Deutsche Bank AG, 2016, p. 138; Mining Journal, 2016; Orocobre Ltd., 2016, p. 12; PGI Intelligence Ltd., 2016; Roskill Information Services, 2016, p. 8).

In 2016, Australia was expected to continue to lead the world in lithium mine production. Galaxy Resources and Neometals were on track to begin commercial mineral production in 2016, joining Talison in spodumene output and increasing the mineral's contribution to total lithium supply.

In batteries, rechargeable lithium-ion batteries continue to have the greatest potential for growth. Worldwide lithium consumption for lithium-ion batteries in vehicle transportation applications is expected to increase by 36% per year from 2015 through 2020, from 11 GWh in 2015 to 54 GWh in 2020 (Chung and others, 2016, p. 12). Owing to the potentially large demand for lithium hydroxide needed by Tesla at its factory in Nevada, FMC and Albemarle were considering construction of new lithium hydroxide plants (Benchmark Mineral Intelligence, 2015b).

Lithium supply security has become a top priority for technology companies in Asia. Strategic alliances and joint ventures have been and continue to be established with lithium exploration companies worldwide to ensure reliable, diversified supplies 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 of concern is not price, but rather supply security.

Most global automobile manufacturers have announced plans to use lithium-ion batteries in current and future generations of EVs, HEVs, and PHEVs. In 2016, new vehicle models with lithium-ion batteries are to be introduced into the United States by companies such as Bavarian Motor Works AG (BMW); BYD Co., Ltd.; Daimler AG (Mercedes-Benz); Ford Motor Co.; General Motors Co.; Mitsubishi Motors; Tesla Motors, Inc.; and Volkswagen Group. Major automobile manufacturers formed partnerships with established battery manufacturers to build battery plants for EVs and HEVs and to begin mass production of automotive lithium-ion batteries.

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 production, prices for lithium compounds are likely to increase, and other lithium resources that had been uneconomic might become economic as lithium carbonate prices increase. New lithium mineral operations under development throughout the world, which were specifically designed to produce battery-grade lithium carbonate and lithium hydroxide, demonstrate the potential economic viability of these resources.

Various countries worldwide are establishing national alternative energy policies that have the potential to substantially increase lithium demand. It is anticipated that countries in Asia,

North America, and Western Europe would be at the forefront of adopting utility-scale energy storage systems that would become integral components of electrical grids for long-duration storage as well as short-duration ancillary services. China, in particular, is expected to become the leading 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 are thought to hold the greatest potential, capturing approximately 70% of the global ancillary services market by 2019. Worldwide revenue from sales of lithium-ion batteries for use in utility-scale energy storage systems is expected to increase to nearly \$6 billion in 2020 from \$72 million in 2012 (Pike Research, 2010; Oyama, 2011).

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TABLE 1
SALIENT LITHIUM STATISTICS¹

(Metric tons of contained lithium)

	2011	2012	2013	2014	2015
United States:					
Production	W	W	870 ²	W	W
Exports ³	1,310	1,300	1,230	1,420	1,790
Imports ³	2,850	2,760	2,210	2,120	2,750
Consumption ^e	2,000 ⁴	2,000 ⁴	1,800	2,000 ⁴	2,000 ⁴
Rest of world, production ⁵	29,300 ^r	30,700 ^r	28,600 ^r	30,800 ^r	30,800 ^e

^eEstimated. ^rRevised. W Withheld to avoid disclosing company proprietary data.

¹Data are rounded to no more than three significant digits.

²Source: Rockwood Holdings, Inc., 2014, 2013 annual report: Rockwood Holdings, Inc., p. 16.

³Compounds. Source: U.S. Census Bureau.

⁴Rounded to one significant digit to avoid disclosing company proprietary data.

⁵Mineral concentrate, lithium carbonate, lithium chloride, and lithium hydroxide.

TABLE 2
U.S. EXPORTS OF LITHIUM CHEMICALS, BY COMPOUND AND COUNTRY¹

Compound and country	2014		2015	
	Gross weight (metric tons)	Value ² (thousands)	Gross weight (metric tons)	Value ² (thousands)
Lithium carbonate:				
Australia	10	\$75	11	\$82
Bangladesh	19	45	11	40
Belgium	6	53	16	76
Bolivia	28	305	26	94
Brazil	--	--	4	42
Canada	31	168	27	129
China	--	--	12	42
Ecuador	--	--	10	194
Germany	706	4,140	1,180	6,910
India	6	36	16	58
Korea, Republic of	30	157	--	--
Mexico	49	558	33	118
Singapore	3	23	6	47
Other	15	75	3	42
Total	904	5,630	1,350	7,880
Total lithium content	170	XX	255	XX
Lithium carbonate, U.S.P.:³				
India	69	2,240	41	1,230
Korea, Republic of	--	--	38	381
Other	8 ^r	103 ^r	6	351
Total	77	2,340	85	1,960
Total lithium content	14	XX	16	XX
Lithium hydroxide and oxide:				
Argentina	127	1,410	128	1,960
Australia	45	379	16	132
Bahamas	--	--	9	43
Belgium	441	2,830	364	2,630
Canada	398 ^r	1,720	516	2,280
Chile	10	67	20	135
China	136	1,020	74	615
Colombia	69	493	29	206
Ecuador	16	193	1	3
Egypt	58	424	102	767
Germany	400	2,530	648	4,090
India	31	217	16	127
Japan	5,140	38,100	6,590	55,100
Korea, Republic of	80	660	96	824
Mexico	68	635	86	773
Peru	14	100	10	68
Russia	40	274	--	--
Saudi Arabia	85	528	36	228
Singapore	20	148	44	396
South Africa	3	312	2	214
Taiwan	76	604	138	1,250
Tanzania	--	--	9	60
Thailand	266	1,940	160	1,410
Trinidad and Tobago	5 ^r	50	3	32
United Kingdom	12	252	1	71
Venezuela	40	371	120	1,310
Vietnam	8	66	--	--
Other	5 ^r	249 ^r	2	217
Total	7,590 ^r	55,600	9,220	74,900
Total lithium content	1,240	XX	1,520	XX

^rRevised. XX Not applicable. -- Zero.

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

²Free alongside ship values.

³Pharmaceutical-grade lithium carbonate.

Source: U.S. Census Bureau.

TABLE 3
U.S. IMPORTS FOR CONSUMPTION OF LITHIUM CHEMICALS, BY COMPOUND AND COUNTRY¹

Compound and country	2014		2015	
	Gross weight (metric tons)	Value ² (thousands)	Gross weight (metric tons)	Value ² (thousands)
Lithium carbonate:				
Argentina	3,350	\$15,100	7,290	\$34,200
Canada	10	21	10	25
Chile	5,940 ^r	26,300 ^r	5,510	23,400
China	283	861	71	196
Italy	--	--	13	41
Other	-- ^r	-- ^r	(3)	13
Total	9,580 ^r	42,300 ^r	12,900	57,900
Total lithium content	1,800	XX	2,420	XX
Lithium carbonate, U.S.P.:⁴				
India	48	1,090	29	765
Italy	(3)	9	2	9
Total	48	1,100	31	774
Total lithium content	9	XX	6	XX
Lithium hydroxide and oxide:				
Chile	1,730	11,000	1,580	11,100
China	133	937	230	1,820
Germany	(3)	14	4	33
Japan	25 ^r	123 ^r	7	42
Korea	(3)	4	80	97
Norway	18	38	3	7
Romania	--	--	34	185
Russia	--	--	21	150
United Kingdom	11	62	2	117
Other	(3)	3 ^r	2	22
Total	1,920	12,200	1,960	13,600
Total lithium content	316	XX	324	XX

^rRevised. XX Not applicable. -- Zero.

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

²Customs value.

³Less than ½ unit.

⁴Pharmaceutical-grade lithium carbonate.

Source: U.S. Census Bureau.

TABLE 4
LITHIUM MINERALS AND BRINE: WORLD PRODUCTION, BY COUNTRY^{1,2}

(Metric tons, gross weight)

Country ³	2011	2012	2013	2014	2015 ⁶
Argentina, subsurface brine:					
Lithium carbonate	10,024	10,535	9,248	11,698	14,137 ⁴
Lithium chloride	4,605	4,297	5,156	7,370	5,848 ⁴
Australia, spodumene	421,391	456,921	415,000 ^r	463,000 ^r	490,000
Brazil, concentrates	7,820	7,084	7,982	8,519	8,500
Chile, subsurface brine:					
Lithium carbonate	59,933	62,002	52,358	55,074	50,418 ⁴
Lithium chloride	3,864	4,145	4,091	2,985	2,069 ⁴
Lithium hydroxide	5,800	5,447	4,197	4,194	3,888 ⁴
China, lithium carbonate equivalent ^{6,5}	11,300	10,000	11,200	10,100	10,700
Portugal, lepidolite	37,534	20,698	19,940	17,459	17,120 ⁴
United States, carbonate	W	W	4,600 ⁶	W	W
Zimbabwe, amblygonite, eucryptite, lepidolite, and petalite ⁶	48,000 ⁴	53,000 ⁴	50,000 ^r	50,000 ^r	50,000

⁶Estimated. ^rRevised. W Withheld to avoid disclosing company proprietary data.

¹Includes data available through March 23, 2017.

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

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

⁴Reported figure.

⁵Produced from subsurface brine and concentrates.

⁶Source: Rockwood Holdings, Inc., 2014, 2013 annual report: Rockwood Holdings, Inc., p. 16.

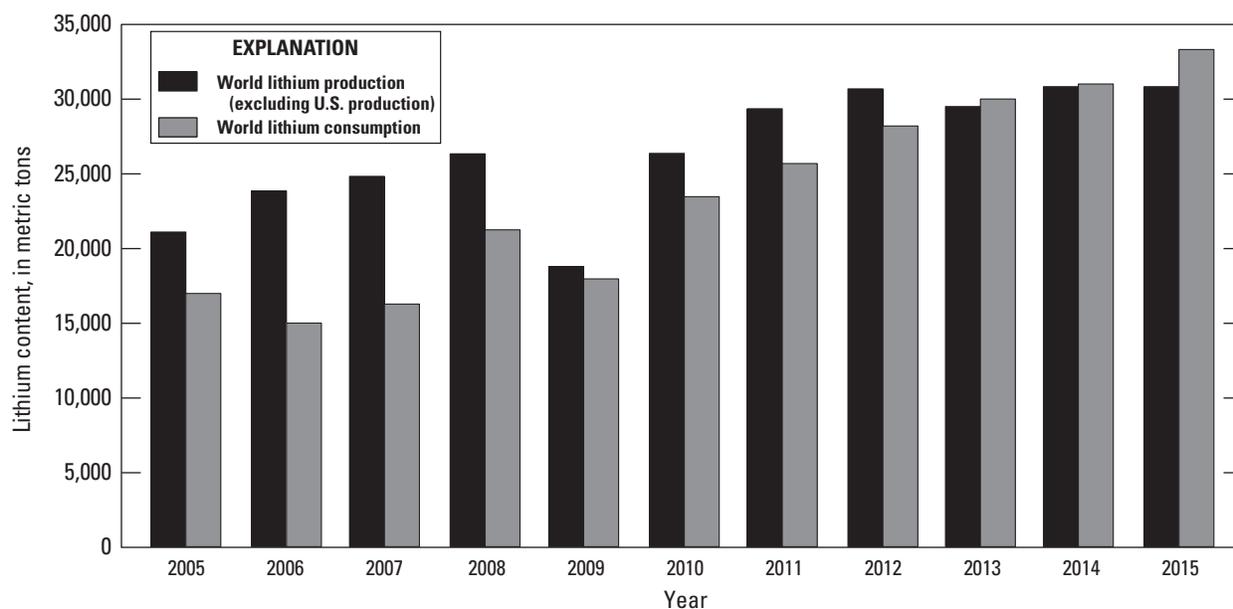


Figure 1. Estimated world lithium production (excluding U.S. production) and consumption.