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LITHIUM

By Brian W. Jaskula

Domestic survey data and tables were prepared by Annie Hwang, statistical assistant.

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 2016, lithium consumption in the United States was estimated to be 3,000 metric tons (t) of elemental lithium (table 1), primarily owing to demand for lithium-based battery, ceramic and glass, grease, pharmaceutical, and polymer products. In 2016, the gross weight of lithium compounds imported into the United States increased by 13% and the gross weight of exports decreased by 15% from those in 2015. Argentina, Chile, and China were the principal sources of imported lithium carbonate, and Chile, China, and Russia were the principal sources of imported lithium hydroxide (table 3).

World lithium production in 2016 (excluding U.S. production) was estimated to be 38,000 t of lithium contained in minerals and compounds, about 23% higher than that in 2015. World lithium production increased at a compound annual growth rate (CAGR) of 5% per year from 2006 through 2016 (fig. 1). World lithium consumption was estimated to be approximately 36,700 t of lithium contained in minerals and compounds, an increase of 10% from that of 2015. More than 60% was consumed by countries within Asia. World lithium consumption increased at a CAGR of 9% per year from 2006 through 2016 (fig. 1). The average unit values of lithium carbonate (including pharmaceutical grade) and lithium hydroxide imports increased by 8% and by 32%, respectively, from those of 2015. Spot lithium carbonate prices in China increased by 300% from those of mid-2015, exceeding $25,000 per metric ton during the first half of 2016, as the result of an acute, but likely temporary, shortage of imported mineral concentrates from Australia (Asian Metal Inc., 2016a). The rest of the world experienced more modest spot price increases owing to supplies available from 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. Exploration in the United States has focused on the continental brine and clay resources of Nevada, the spodumene resources of North Carolina, 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, China, Czechia, Finland, Germany, the Republic of Korea, Serbia, Spain, and Zimbabwe; pegmatite and oil brine resources of Canada; and the clay resources of Mexico were also being 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

National Defense Stockpile.—In 2014, the Defense Logistics Agency Strategic Materials, an agency of the 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 2017, which represented the maximum quantities of lithium material that could be acquired from October 1, 2016, through September 30, 2017, was 600 kilograms (kg) for lithium-cobalt oxide and 2,160 kg for lithium-nickel-cobalt-aluminum oxide (Defense Logistics Agency Strategic Materials, 2016). At yearend 2016, the NDS held 450 kg of lithium-cobalt oxide and 1,150 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. (a subsidiary of Albemarle Corp. of Charlotte, NC). 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 2016 production levels (Albemarle Corp., 2017b, 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; lithium carbonate and lithium hydroxide plants in Meishan and Xinyu, China; a butyllithium, lithium chloride, and specialty chemical and metal plant in Langelsheim, Germany; and a butyllithium plant in Taichung, Taiwan (Albemarle Corp., 2017b, p. 23–25).

Albemarle owns a 49% interest in Australia's Talison Lithium Pty Ltd., a spodumene producer with a 95,000-t/yr lithium carbonate equivalent (LCE) production capacity (Roskill Information Services Ltd., 2016a, p. 66). 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 was the world's leading producer of lithium in 2016, with an estimated 62,000 t of LCE produced from its operations in Australia and Chile (Roskill Information Services Ltd., 2017a, p. 10).

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. In 2016, FMC announced plans to triple its production capacity of lithium hydroxide to 30,000 t/yr by 2019. To help support the hydroxide expansion, FMC announced a supply agreement to source 8,000 t/yr of lithium carbonate from Canada's Nemaska Lithium Inc. beginning in mid-2018 (FMC Corp., 2017, p. 7, 18).

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., 2016a, p. 104). In 2016, lithium exploration expenditures totaled $20.9 million in Nevada, an increase of 127% from $9.2 million in 2015. Lithium exploration accounted for 7% of all exploration expenditures in Nevada (Botkin, 2017).

Recycling

In 2016, lithium battery recycling projects were in operation or under development in Belgium, Canada, 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. (formerly Toxco 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. Retriev's new facility in Lancaster, OH, designed to process up to 4,000 t/yr of lithium-ion battery packs, began operation in 2015 (U.S. Department of Energy, 2013, p. 59–60; Retriev Technologies Inc., 2016).

Consumption

In 2016, the global markets for lithium products were estimated to be batteries, 43%; ceramics and glass, 28%; lubricating greases, 7%; polymer production, 5%; continuous casting mold flux powders, 4%; air treatment, 3%; and other uses, 10% (Roskill Information Services Ltd., 2017a, p. 9). 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., 2017a). Sufficient data to make reliable estimates of U.S. consumption were not available.

In 2015 (latest data available), EVs, HEVs, and PHEVs accounted for approximately 25% of the global lithium-ion battery market by volume; cellular telephones and smartphones, 19%; laptop computers, 16%; computer tablets, 16%; electric bicycles, 5%; power tools, 4%; household devices, 2%; and other uses, 13% (Deutsche Bank AG, 2016, p. 46). Global lithium-ion battery consumption increased by an average of 22% per year from 2010 through 2016, reaching an estimated 70 gigawatthours (GWh) in 2016 from 21 GWh in 2010 (1 GWh is the equivalent of consuming 1 billion watts for 1 hour) (Roskill Information Services Ltd., 2016a, p. 138; 2017b).

About 85% of the world's 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 (Chung and others, 2016, p. 1–2; Ralph, 2016).

In 2016, new EV and PHEV sales increased to 773,000 vehicles worldwide, a 40% increase from 550,570 vehicles sold worldwide in 2015, with China (45%), Europe (29%), and the United States (20%) dominating the market. EV and PHEV sales in China, Europe, and the United States increased by 85%, 13%, and 36%, respectively, from those of 2015 (International Energy Agency, 2016, p. 36; EV-Volumes.com, 2017).

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. The company officially opened the facility in July 2016 to begin limited battery pack assembly, although construction of the facility was only 14% complete. The factory's planned battery cell production capacity of 35 GWh per year 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 (Benchmark Mineral Intelligence, 2016, p. 46; Tesla Motors, Inc., 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 2016, the average customs unit value for imported lithium carbonate was $4.92 per kilogram, 8% higher than that of 2015. The average customs unit value for imported lithium hydroxide was $9.16 per kilogram, 32% higher than that of 2015. The average unit value of exported lithium carbonate in 2016 was $7.74 per kilogram, 13% higher than that of 2015. The average unit value of exported lithium hydroxide was $8.93 per kilogram, 10% higher than that of 2015. The average unit values of exported lithium carbonate and lithium hydroxide in 2016 were 57% higher and 3% lower, respectively, than the average unit values of imported carbonate and hydroxide. This suggests that domestic lithium carbonate exports were of a higher quality than imports. Import values mostly reflect companies importing their own materials at cost for further processing.

At yearend 2016, Industrial Minerals (2016) reported that the U.S. import price for lithium carbonate (large contracts, delivered to the continental United States) was $10,000 to $16,000 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 $14,000 to $20,000 per metric ton. The import price for glass-grade spodumene (5% lithium oxide; cost, insurance, and freight) to Asia was $350 to $410 per metric ton. The import price for greater than 7.5% lithium oxide spodumene (cost, insurance, and freight) to Asia was $755 to $780 per metric ton.

Spot lithium carbonate prices in China increased by 300% from those of mid-2015, exceeding $25,000 per metric ton during the first half of 2016, based on an acute, but likely temporary, shortage of imported mineral concentrates from Australia (Asian Metal Inc., 2016a). The rest of the world experienced more modest spot price increases owing to supplies available from more diversified sources of lithium. Battery-grade lithium metal (99.9% Li) prices in China averaged $121,600 per metric ton at yearend 2016, a 43% increase from that of yearend 2015 (Asian Metal Inc., 2016b). In October, FMC increased prices by 10% for its specialty organic products, which include all grades of butyllithium (FMC Corp., 2016). Sociedad Química y Minera de Chile S.A. (SQM) reported that average prices for its lithium products increased by more than 80% from those of 2015 (Sociedad Química y Minera de Chile S.A., 2017, p. 23). The average prices for Sichuan Tianqi's lithium carbonate and lithium hydroxide increased by 147% and 178%, respectively, from those of 2015 (Li, 2017).

Foreign Trade

In 2016, total exports of lithium compounds, by gross weight, from the United States decreased by 15% compared with those of 2015. About 54% of all United States exports of lithium compounds went to Japan, 18% went to Germany, and 5% went to Canada (table 2). Lithium hydroxide accounted for 87% of the total lithium exports in 2016, and lithium carbonate accounted for the remaining 13% of total exports. Exports of lithium carbonate and lithium hydroxide decreased by 20% and 14%, respectively, in 2016 compared with those of 2015.

Imports of lithium compounds, by gross weight, into the United States increased by 13% in 2016 compared with those of 2015. About 63% came from Argentina and 33% 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 2016 (excluding U.S. production) was estimated to be 38,000 t of lithium (202,000 t of LCE) contained in minerals and compounds, 23% higher than that in 2015 (table 1). Global lithium production capacity was estimated to be 58,000 t/yr of lithium (310,000 t/yr of LCE). Two leading producing countries, Argentina and Chile, increased lithium production by 60% and 46%, respectively, from that of 2015. 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.

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 2016, global lithium consumption for air treatment, batteries, ceramics and glass, grease, metallurgical powders, polymers, and other industrial applications increased; lithium consumption for primary aluminum production remained about the same. An estimated 36,700 t of lithium (195,000 t of LCE) contained in minerals and compounds was consumed worldwide in 2016, a 10% increase from the estimate for 2015. China was the leading consumer of lithium minerals and compounds, accounting for 40% of worldwide consumption as reported by Roskill; Europe consumed 21%; Japan and the Republic of Korea, 11% each; North America, 8%; India, 2%; Russia, 1%; and others, 6% (Roskill Information Services Ltd., 2016a, p. 108, 112; 2017a, p. 9).

According to USGS estimates, total global lithium consumption increased at a CAGR of 9% from 2006 through 2016. According to Roskill Information Services Ltd. (2016a, p. 108; 2017a, p. 9), lithium consumption for rechargeable batteries increased at a CAGR of 19% from 2010 through 2016.

Argentina.—Production of lithium carbonate in 2016 was estimated by the USGS to be 25,500 t, an increase of 80% from that of 2015, and production of lithium chloride was 6,000 t, a 3% increase. FMC produced an estimated 13,500 t of lithium carbonate and 6,000 t of lithium chloride at its 26,000-t/yr LCE facility, which has been operating since 1998, on the Salar de Hombre Muerto in Catamarca Province. Orocobre Ltd. produced 11,845 t of lithium carbonate 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. Production capacity was 17,500 t/yr of battery-grade lithium carbonate (Orocobre Ltd., 2016, p. 18; 2017b, p. 3).

Chile's two lithium producers, SQM and Albemarle, entered into joint ventures with junior mining companies in Argentina. In March, SQM reached a 50–50 joint venture agreement with Lithium Americas Corp. to develop the Cauchari-Olaroz Lithium Project on the Puna plateau in northwestern Argentina. The two companies are updating Lithium Americas' 2012 definitive feasibility study of the project and expect a production capacity of 50,000 t/yr LCE built in two stages of 25,000 t/yr each. Construction was expected to commence during the first half of 2017 (Sociedad Química y Minera de Chile S.A., 2016). In September, Albemarle entered into an agreement with Bolland Minera S.A. for the exploration and acquisition rights to the Salar de Antofalla, a lithium resource within Catamarca Province (Albemarle Corp., 2017b, p. 4).

POSCO (Republic of Korea) signed a lithium supply contract with Argentina's Lithea Inc., owner of the mining rights to the Pozuelo Salt Lake in Salta Province, and began construction of a 2,500-t/yr lithium processing plant. POSCO's lithium extraction technology was expected to reduce the total brine-to-lithium-carbonate-production process from the conventional 18 months to 8 hours with a lithium recovery rate of greater than 80%, compared with the typical 50% recovery from traditional evaporation technology (Steel Wire, The, 2016).

Enirgi Group Corp. (Canada) developed proprietary technology to produce lithium directly from nonconcentrated brine at the Salar del Rincon in Salta Province. The technology was expected to reduce processing time from the conventional 18 months to less than 24 hours as well as increase the lithium recovery rate. The company planned to construct a 50,000-t/yr LCE plant. In 2016, a definitive feasibility study of the Salar del Rincon was completed showing probable reserves of approximately 230,000 t of elemental lithium (Enirgi Group Corp., 2014, 2016).

Australia.—In 2016, Talison Lithium Pty Ltd. (a subsidiary of Sichuan Tianqi Lithium and Albemarle Corp.) produced an estimated 70,000 t of LCE from its Greenbushes spodumene deposit in Western Australia. Talison's lithium concentrate production capacity was 740,000 t/yr, equivalent to approximately 95,000 t/yr of LCE, or 17,900 t/yr of contained lithium. The production capacity gradually decreased to 95,000 t/yr of LCE in 2016 from 110,000 t/yr of LCE in 2012 owing to lower grade ore being mined. Sichuan Tianqi and Albemarle announced plans to increase production capacity of the Greenbushes Mine to 160,000 t/yr of LCE. No timescale for the expansion was given (Roskill Information Services Ltd., 2016a, p. 66; 2016b, p. 5; 2017a, p. 10).

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, resumed commercial operation in late 2016, producing approximately 10,000 t of lithium concentrate. Mount Cattlin's spodumene ore reserves as of September 2010 graded 1.04% lithium oxide (Galaxy Resources Ltd., 2017).

Neometals Ltd. began commercial spodumene production at its Mount Marion lithium project in Western Australia in late 2016, producing approximately 6,000 t of lithium concentrate. Mount Marion's estimated spodumene resources at October 21, 2016, graded 1.37% lithium oxide. Neometals also continued the 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 (Neometals Ltd., 2016, 2017).

China's Sichuan Tianqi Lithium Industries announced it would build a 24,000-t/yr lithium hydroxide plant in Kwinana, Western Australia, with plant commissioning expected in late 2018. The spodumene concentrate would be sourced from Tianqi's subsidiary, Talison Lithium (Thomson Reuters, 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 Ltd., 2016a, p. 66–67).

Canada.—Nemaska continued development of its Whabouchi Mine and lithium hydroxide-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 continued phase I construction of its 500-t/yr lithium hydroxide demonstration plant, with the first shipment of lithium hydroxide expected in early 2017 (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 Ltd., 2016a, p. 74–75).

Chile.—Based on 2016 exports, Chile produced approximately 67,300 t of lithium carbonate, an increase of 34% from that of 2015; 1,600 t of lithium chloride, a decrease of 23% from that of 2015; and 6,000 t of lithium hydroxide, an increase of 54%. Chile also produced and exported approximately 7,200 t of lithium chloride brine (Lowry, 2017). SQM, which accounted for 27% of global lithium chemicals sales, sold 49,700 t of LCE in 2016, an increase of 28% from that of 2015. SQM's value of sales increased by 131% to $515 million owing to an upturn in both sales volumes and lithium prices. In 2016, the company's lithium products were distributed throughout the world, with 72%, by value of sales, going to Asia; 19% to Europe; 8% to North America; and 1% to Central America and South America. SQM's lithium was recovered from its brine operation at the Salar de Atacama and processed into lithium carbonate and lithium hydroxide in Antofagasta. SQM's lithium carbonate production capacity was 48,000 t/yr in 2016, and its lithium hydroxide production capacity was 6,000 t/yr. Owing to rapidly increasing demand for lithium hydroxide from electric vehicle battery manufacturers, SQM announced it would increase its lithium hydroxide capacity to 13,500 t/yr by yearend 2017 (Sociedad Química y Minera de Chile S.A., 2017, p. 22–23).

In 2016, Albemarle began ramping up production at 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. 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., 2017b, p. 23–24).

In February, the Government of Chile approved Albemarle's request to increase its lithium production quota at the Salar de Atacama to 70,000 t/yr of lithium compounds over a 27-year period. In December, Albemarle amended its agreement with the Government to increase its lithium production quota to 80,000 t/yr of lithium compounds over the same period (Albemarle Corp., 2017b, p. 4).

China.—China was the only country that commercially produced 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 2016, China produced an estimated 12,200 t of LCE from domestic sources, a 14% increase from 10,700 t in 2015 (Roskill Information Services Ltd., 2017a, p. 10). 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 2016, total lithium consumption in China was estimated by the USGS to be 81,000 t of LCE, a 15% increase from that of 2015. 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 of which was mined by Talison in Australia, to account for approximately one-half of the world's lithium compound production since 2012.

In December, Albemarle acquired the lithium carbonate and lithium hydroxide production facilities and supporting businesses of China-based Jiangxi Jiangli New Materials Science and Technology Co. Ltd. The facilities, located in Jiangxi and Sichuan Provinces, processed material from the Greenbushes Mine and had a total lithium compound production capacity of 15,000 t/yr. Albemarle also began expansion work at the facilities to add 20,000 to 25,000 t/yr of lithium hydroxide capacity by 2018 (Patel, 2017).

Outlook

In 2016, Orocobre and lithium market analysts Global Lithium LLC and Roskill developed forecasts of world lithium consumption levels in 2020 that ranged from 270,000 to 320,000 t/yr of LCE and averaged approximately 300,000 t/yr of LCE. The CAGR in world lithium consumption from 2016 through 2020 is expected to be between 8.5% and 14% (Lowry, 2016; Orocobre Ltd., 2017a, p. 18; Roskill Information Services Ltd., 2017a, p. 9).

In anticipation of robust electric vehicle battery demand, vigorous efforts were underway by battery companies worldwide to construct new large-scale lithium-ion battery plants or to expand existing facilities. LG Chem's Holland, MI, lithium-ion battery plant is expected to triple its annual capacity to 3 GWh within several years. A new large-scale battery plant in Poland and two large-scale plant expansions in the Republic of Korea are expected to have a total combined annual capacity of 28 GWh by 2020. In China, nine large-scale battery plants are being built or expanded, and are expected to have a total annual capacity of 108 GWh by 2020, giving China more than 60% of the world's lithium-ion battery production capacity (Benchmark Minerals, 2016, p. 46; Desjardins, 2017).

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 or lithium hydroxide 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 either started incorporating or 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 U.S. market 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 HEVs and EVs 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 viable sources for lithium carbonate raw materials. 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 could 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).

References Cited

Albemarle Corp., 2017a, Application areas: Baton Rouge, LA, Albemarle Corp. (Accessed April 18, 2017, at http://www.albemarle-lithium.com/applications/.)

Albemarle Corp., 2017b, Form 10–K—2016: U.S. Securities and Exchange Commission, 122 p. (Accessed April 18, 2017, via http://investors.albemarle.com/phoenix.zhtml?c=117031&p=irol-reportsannual.)

Asian Metal Inc., 2016a, Chinese lithium carbonate prices level off: Beijing, China, Asian Metal Inc., June 3. (Accessed January 23, 2017, via http://www.asianmetal.com.)

Asian Metal Inc., 2016b, Lithium market summary December 19–23: Beijing, China, Asian Metal Inc., December 26. (Accessed January 23, 2017, via http://www.asianmetal.com.)

Benchmark Mineral Intelligence, 2016, The lithium ion supply chain: Benchmark Mineral Intelligence, September, p. 44–61. (Accessed February 19, 2017, at https://s1.q4cdn.com/337451660/files/doc_articles/2016/161214-Benchmark-approved-for-distribution-Lithium-ion-supply-chain.pdf.)

Botkin, Ben, 2017, Demand for lithium a potential boon for Nevada: Las Vegas [NV] Review Journal, February 25. (Accessed February 27, 2017, at https://www.reviewjournal.com/news/politics-and-government/nevada/demand-for-lithium-a-potential-boon-for-nevada/.)

Chung, Donald, Elgqvist, Emma, and Santhanagopalan, Shriram, 2016, Automotive lithium-ion cell manufacturing—Regional cost structures and supply chain considerations: U.S. Department of Energy, 20 p. (Accessed June 9, 2016, at http://www.nrel.gov/docs/fy16osti/66086.pdf.)

Defense Logistics Agency Strategic Materials, 2016, Annual materials plan for FY 2017 for possible acquisition of new NDS stocks: Fort Belvoir, VA, Defense Logistics Agency Strategic Materials, October 3, 1 p. (Accessed November 20, 2016, at http://www.dla.mil/Portals/104/Documents/StrategicMaterials/Announcements/3118%20FY17%20AMP_ACQ.pdf.)

Desjardins, Jeff, 2017, China leading the charge for lithium-ion megafactories: Vancouver, British Columbia, Canada, Visual Capitalist, February 17. (Accessed February 21, 2017, at http://www.visualcapitalist.com/china-leading-charge-lithium-ion-megafactories/.)

Deutsche Bank AG, 2016, Lithium 101: Frankfurt, Germany, Deutsche Bank AG, May, 176 p. (Accessed August 10, 2016, at http://resourceswire.com/wp-content/uploads/2016/05/Lithium-Report-May-2016.pdf.)

Enirgi Group Corp., 2014, Enirgi Group validates revolutionary new proprietary lithium extraction technology: Toronto, Ontario, Canada, Enirgi Group Corp. press release, October 29, 2 p. (Accessed November 4, 2014, at http://www.enirgi.com/wp-content/uploads/2015/04/News-Release-10-29-2014-Enirgi-Group-Validates-Proprietary-Lithium-Extraction-Technology.pdf.)

Enirgi Group Corp., 2016, Enirgi Group announces positive results of definitive feasibility study for Salar del Rincón Lithium Project: Toronto, Ontario, Canada, Enirgi Group Corp. press release, July 7, 13 p. (Accessed September 12, 2016, at http://www.enirgi.com/wp-content/uploads/2016/07/Enirgi-Group-Accounces-Positive-Results-of-Definitive-Feasibility-Study-for-Salar-Del-Rincon-Lithium-Project.pdf.)

EV-volumes.com, 2017, Global plug-in sales for 2016: Stockholm, Sweden, EV-volumes.com. (Accessed April 26, 2017, at http://www.ev-volumes.com/country/total-world-plug-in-vehicle-volumes/.)

FMC Corp., 2016, FMC Corporation announces butyllithium price increase: Philadelphia, PA, FMC Corp. press release, September 12. (Accessed September 12, 2016, at http://phx.corporate-ir.net/phoenix.zhtml?c=117919&p=RssLanding&cat=news&id=2201028.)

FMC Corp., 2017, Annual report—2016: Philadelphia, PA, FMC Corp., February, 98 p. (Accessed April 21, 2017, at https://materials.proxyvote.com/Approved/302491/20170228/CMBAR_312270.PDF.)

Galaxy Resources Ltd., 2017, First lithium concentrate shipment from recommissioned Mt. Cattlin operations: Ardross, Western Australia, Australia, Galaxy Resources Ltd. press release, January 3, 4 p. (Accessed January 4, 2017, at http://www.galaxyresources.com.au/media/announcements/43f3418970f1v2.pdf.)

Industrial Minerals, 2016, IM's December price movements: Industrial Minerals, December 23. (Accessed January 30, 2017, via http://indmin.com.)

International Energy Agency, 2016, Global EV outlook 2016—Beyond one million electric cars: Paris, France, International Energy Agency, 45 p. (Accessed October 2, 2016, at https://www.iea.org/publications/freepublications/publication/Global_EV_Outlook_2016.pdf.)

Li, Albert, 2017, The ins and outs of China's lithium industry: Industrial Minerals, April 27. (Accessed April 28, 2017, via http://indmin.com.)

Lowry, Joe, 2016, New lithium supply & demand forecast: LinkedIn, October 8. (Accessed May 10, 2017, at https://www.linkedin.com/pulse/new-lithium-supply-demand-forecast-joe-lowry.)

Lowry, Joe, 2017, 2016 lithium exports from South America: Twitter posting of March 1. (Accessed March 5, 2017, at https://twitter.com/globallithium/status/837007362133278720.)

Nemaska Lithium Inc., 2016, Nemaska Lithium provides progress report on mine site and phase 1 plant: Quebec City, Quebec, Canada, Nemaska Lithium Inc. press release, December 12. (Accessed January 10, 2017, at http://www.nemaskalithium.com/en/investors/press-releases/2016/c9777810-db09-4d48-9b81-239e4eac0efb/.)

Neometals Ltd., 2016, Mount Marion lithium project update: West Perth, Western Australia, Australia, Neometals Ltd. press release, December 22, 1 p. (Accessed January 3, 2017, at http://www.neometals.com.au/reports/693-20161222ASXMtMarionShippingUpdate.pdf.)

Neometals Ltd., 2017, Quarterly activities report for the quarter ended 31 December 2016: West Perth, Western Australia, Australia, Neometals Ltd., 12 p. (Accessed February 5, 2017, at http://www.neometals.com.au/reports/695-QADec2016Final.pdf.)

Orocobre Ltd., 2016, Annual report 2016: Brisbane, Queensland, Australia, Orocobre Ltd., October, 138 p. (Accessed May 10, 2017, at http://www.orocobre.com/news/mdocs-posts/annual-report-2016/.)

Orocobre Ltd., 2017a, Macquarie Australia conference presentation: Brisbane, Queensland, Australia, Orocobre Ltd., presentation, 24 p. (Accessed May 10, 2017, via https://www.orocobre.com/investor-centre/presentations/.)
Orocobre Ltd., 2017b, Quarterly report of operations for the period ended 31 December 2016: Brisbane, Queensland, Australia, Orocobre Ltd., 12 p. (Accessed May 10, 2017, at http://www.orocobre.com/news/mdocs-posts/quarterly-report-period-ending-jan-2017/.)
Oyama, Satoru, 2011, Smart grids spur massive demand for lithium ion batteries: El Segundo, CA, iSuppli Corp. press release, September 23. (Accessed January 18, 2012, at https://technology.ihs.com/389385/smart-grids-spur-massive-demand-for-lithium-ion-batteries.)
Patel, Kasia, 2017, Albemarle buys Chinese lithium salts production assets: Industrial Minerals, January 3. (Accessed January 10, 2017, via http://indmin.com.)
Pike Research, 2010, Lithium ion batteries to lead the market for short-duration energy storage ancillary services: Boulder, CO, Navigant Consulting, Inc. press release, September 13. (Accessed September 15, 2010, at http://www.navigantresearch.com/newsroom/lithium-ion-batteries-to-lead-the-market-for-short-duration-energy-storage-ancillary-services.)
Ralph, Julia, 2016, The rise of lithium—Demand set to surge: London, United Kingdom, CRU Group, April 14. (Accessed May 23, 2016, at http://rockstone-research.com/index.php/en/news/385-The-Rise-Of-Lithium:-Demand-Set-To-Surge.)
Retriev Technologies Inc., 2016, Electric and hybrid vehicles: Anaheim, CA, Retriev Technologies Inc. (Accessed June 30, 2016, at http://www.retrievtech.com/batteries/electric-and-hybrid-vehicles.)
Thomson Thomson Roskill Information Services Ltd., 2016a, Lithium—Global industry, markets and outlook to 2017 (13th ed.): London, United Kingdom, Roskill Information Services Ltd., June, 386 p.
Roskill Information Services Ltd., 2016b, November 2016 quarterly review: London, United Kingdom, Roskill Information Services Ltd., no. 2, November, 13 p.
Roskill Information Services Ltd., 2017a, February 2017 quarterly review: London, United Kingdom, Roskill Information Services Ltd., no. 3, February, 12 p.
Roskill Information Services Ltd., 2017b, Lithium-ion batteries—Market development and the impact on raw materials: London, United Kingdom, Roskill Information Services Ltd. news release, January 26. (Accessed January 27, 2017, at https://roskill.com/news/lithium-ion-batteries-market-development-impact-raw-materials/.)
Sociedad Química y Minera de Chile S.A., 2016, SQM reports earnings for the six months ended June 30, 2016: Santiago, Chile, Sociedad Química y Minera de Chile S.A. press release, August 24, 9 p. (Accessed August 26, 2016, at http://s1.q4cdn.com/793210788/files/doc_financials/2016/q2/PR_2Q16_ing_FINAL.pdf.)
Sociedad Química y Minera de Chile S.A., 2017, Annual report—2016: Santiago, Chile, Sociedad Química y Minera de Chile S.A., April, 382 p. (Accessed May 2, 2017, at http://s1.q4cdn.com/793210788/files/doc_financials/2016/annual/Memoria-Anual-2016_ing_final.pdf.)
Steel Wire, The, 2016, POSCO expands lithium manufacturing business: The Steel Wire, Pohang, Republic of Korea, POSCO, February 18. (Accessed August 8, 2016, at http://globalblog.posco.com/posco-expands-lithium-manufacturing-business/.)
Tesla Motors, Inc., 2016, Form 10–K—2015: U.S. Securities and Exchange Commission, 82 p. (Accessed June 30, 2016, at https://www.sec.gov/Archives/edgar/data/1318605/000156459016013195/tsla-10k_20151231.htm.)
Thomson Reuters, 2016, China's Tianqi Lithium to build $300 million plant in Australia: Thomson Reuters, September 6. (Accessed September 8, 2016, at http://www.reuters.com/article/tianqi-lithium-australia-idUSL3N1BI2PW.)
U.S. Department of Energy, 2013, FY 2012 progress report for energy storage R&D: U.S. Department of Energy. (Accessed April 17, 2013, at http://energy.gov/eere/vehicles/fy-2012-progress-report-energy-storage-rd.)

GENERAL SOURCES OF INFORMATION

U.S. Geological Survey Publications

Historical Statistics for Mineral and Material Commodities in the United States. Data Series 140.
Lithium. Ch. in Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply, Professional Paper 1802, 2017.
Lithium. Ch. in Mineral Commodity Summaries, annual.
Lithium. International Strategic Minerals Inventory Summary Report, Circular 930–I, 1990.
Lithium (Li). Ch. in Metal Prices in the United States Through 2010, Scientific Investigations Report 2012–5188, 2013.
Lithium Resources and Requirements by the Year 2000. Professional Paper 1005, 1976.

Other

Lithium. Ch. in Minerals Facts and Problems, U.S. Bureau of Mines Bulletin 675, 1985.
Lithium. U.S. Bureau of Mines Information Circular 9102, 1986.

TABLE 1
SALIENT LITHIUM STATISTICS[1]

(Metric tons of contained lithium)

	2012	2013	2014	2015	2016
United States:					
Production	W	870 [2]	W	W	W
Exports[3]	1,300	1,230	1,420	1,790	1,520
Imports[3]	2,760	2,210	2,120	2,750	3,140
Consumption[e]	2,000 [4]	1,800	2,000 [4]	2,000 [4]	3,000 [4]
Rest of world, production[5]	30,700	28,600	30,800	30,800	38,000

[e]Estimated. W Withheld to avoid disclosing company proprietary data.
[1]Table includes data available through September 12, 2017. Data are rounded to no more than three significant digits.
[2]Source: Rockwood Holdings, Inc., 2014, 2013 annual report: Rockwood Holdings, Inc., p. 16.
[3]Compounds. Source: U.S. Census Bureau.
[4]Rounded to one significant figure to avoid disclosing company proprietary data.
[5]Mineral concentrate, lithium carbonate, lithium chloride, and lithium hydroxide.

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

	2015		2016	
Compound and country or locality	Gross weight (metric tons)	Value[2] (thousands)	Gross weight (metric tons)	Value[2] (thousands)
Lithium carbonate:				
Australia	11	$82	10	$73
Bangladesh	11	40	11	38
Belgium	16	76	5	40
Bolivia	26	94	--	--
Canada	27	129	52	227
China	12	42	--	--
Ecuador	10	194	--	--
Germany	1,180	6,910	903	5,340
India	16	58	42	284
Mexico	33	118	(3)	3
Other	12 r	133 r	15	148
Total	1,350	7,880	1,040	6,150
Total Li content	255	XX	195	XX
Lithium carbonate, U.S.P.:[4]				
Canada	--	--	13	60
India	41	1,230	57	1,940
Korea, Republic of	38	381	10	391
Mexico	(3)	22	16	16
Other	6	329 r	13	316
Total	85	1,960	108	2,720
Total Li content	16	XX	20	XX
Lithium hydroxide:				
Argentina	128	1,960	204	1,750
Australia	16	132	30	278
Bahamas, The	8 r	43	10	39
Belgium	364	2,630	325	2,390
Canada	516	2,280	428	1,850
Chile	20	135	10	67
China	74	615	140	1,460
Colombia	29	206	23	222
Egypt	102	767	116	1,010
Germany	648	4,090	757	5,230
India	16	127	45	599
Japan	6,570 r	54,900 r	4,920	46,100
Korea, Republic of	96	824	142	1,600
Mexico	86	773	76	807
Peru	10	68	12	127
Saudi Arabia	36	228	72	483
Singapore	44	396	49	604
Taiwan	138	1,250	342	3,110
Tanzania	9	60	--	--
Thailand	160	1,410	166	1,790
United Kingdom	1	71	18	167
Venezuela	120	1,310	--	--
Other	10 r	466 r	23	870
Total	9,200 r	74,800 r	7,910	70,600
Total Li content	1,520	XX	1,300	XX

[r]Revised. XX Not applicable. -- Zero.
[1]Table includes data available through September 12, 2017. 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 OR LOCALITY[1]

	2015		2016	
Compound and country or locality	Gross weight (metric tons)	Value[2] (thousands)	Gross weight (metric tons)	Value[2] (thousands)
Lithium carbonate:				
Argentina	7,290	$34,200	10,500	$54,000
Canada	10	25	4	28
Chile	5,490 r	23,300 r	4,670	21,000
China	71	196	333	1,060
Italy	13	41	5	29
United Kingdom	(3)	2	10	31
Other	(3)	10 r	(3)	2
Total	12,900	57,800 r	15,600	76,100
Total Li content	2,420	XX	2,920	XX
Lithium carbonate, U.S.P.:[4]				
India	29	765	16	508
Italy	2	9	--	--
Total	31	774	16	508
Total Li content	6	XX	3	XX
Lithium hydroxide:				
Canada	2	13	4	24
Chile	1,580	11,100	830	6,830
China	230	1,820	127	1,490
Japan	7	39 r	(3)	14
Korea	80	97	1	20
Norway	3	7	--	--
Romania	34	185	45	248
Russia	21	150	266	3,010
United Kingdom	2	117	1	28
Other	4 r	43 r	2	20
Total	1,960	13,600	1,280	11,700
Total Li content	324	XX	211	XX

[r]Revised. XX Not applicable. -- Zero.
[1]Table includes data available through September 12, 2017. Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Customs value.
[3]Less than ½ unit.
[4]Pharmaceutical-grade lithium carbonate.

Source: U.S. Census Bureau.

TABLE 4
LITHIUM MINERALS AND BRINE: WORLD PRODUCTION, BY COUNTRY OR LOCALITY[1]

(Metric tons, gross weight)

Country or locality[2]	2012	2013	2014	2015	2016
Argentina, subsurface brine:					
Lithium carbonate	10,535	9,248	11,698	14,137	25,500
Lithium chloride	4,297	5,156	7,370	5,848	6,000
Australia, spodumene	456,921	415,000	463,000	490,000	560,000
Brazil, concentrates	7,084	7,982	8,519	8,500	8,500
Chile, subsurface brine:					
Lithium carbonate	62,002	52,358	55,074	50,418	67,300
Lithium chloride	4,145	4,091	2,985	2,069	1,600
Lithium hydroxide	5,447	4,197	4,194	3,888	6,000
China, lithium carbonate equivalent[e, 3]	10,000	11,200	10,100	10,700	12,200
Portugal, lepidolite	20,698	19,940	17,459	17,120	25,800
United States, lithium carbonate	W	4,600 [4]	W	W	W
Zimbabwe, amblygonite, eucryptite, lepidolite, and petalite	53,000	50,000 [e]	50,000 [e]	50,000 [e]	50,000

[e]Estimated. W Withehld to avoid disclosing proprietary data.
[1]Includes data available through May 2, 2017. All data are reported unless otherwise noted. U.S. data and estimated data are rounded to no more than three significant digits.
[2]In addition to the countries listed, other nations may have produced small quantities of lithium minerals, but available information was inadequate to make reliable estimates of output.
[3]Produced from subsurface brine and concentrates.
[4]Source: Rockwood Holdings, Inc., 2014, 2013 annual report: Rockwood Holdings, Inc., p. 16.

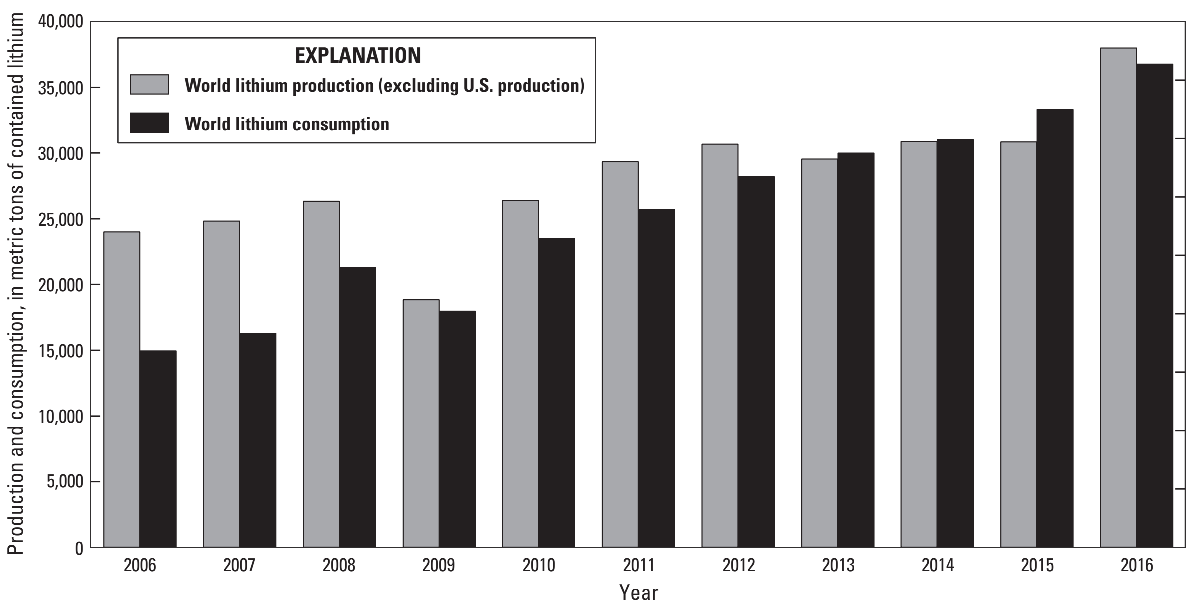

Figure 1. Estimated world lithium production (excluding U.S. production) and consumption from 2006 through 2016.