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LITHIUM

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LITHIUM

By Joyce A. Ober

Domestic survey data and tables were prepared by Hoa Phamdang, statistical assistant, and the world production table was prepared by Regina R. Coleman, international data coordinator.

In 2005, lithium consumption in the United States was estimated to be 2,500 metric tons (t) of contained lithium, nearly 32% more than the estimate for 2004 and 79% more than in 2003. Increased U.S. consumption likely is a result of a general improvement in the domestic economy that created additional consumption in most industrial uses and significantly increased demand for lithium in battery applications. Lithium compounds consumed in the United States were produced at a single domestic operation in Nevada and imported from Argentina and Chile.

Chile has been the world's leading producer of lithium carbonate since 1997, the year that it first surpassed the United States in production. Production in Chile was from two lithium brine operations on the Salar de Atacama in the Andes Mountains and two lithium carbonate plants in Antofagasta. In the United States, production continued at a single lithium brine operation with an associated lithium carbonate plant in Nevada. Lithium carbonate and lithium chloride also were produced from brines from the Salar del Hombre Muerto in the Andes Mountains in Argentina. China was the only country producing large quantities of lithium carbonate from lithium minerals. Australia was, by far, the leading producer of lithium concentrates, but Brazil, Canada, Portugal, and Zimbabwe also produced significant quantities. A large percentage of the lithium carbonate produced in South America was exported to the United States for consumption in industrial applications and as feed material for the production of downstream lithium compounds, such as lithium hydroxide monohydrate, lithium metal, and organic lithium compounds.

Production

The U.S. Geological Survey (USGS) collects domestic production data for lithium from a voluntary canvass of U.S. operations. The single U.S. lithium carbonate producer, Chemetall Foote Corp. (a subsidiary of the German company Chemetall GmbH), responded to the survey, representing 100% of total production. Production and stock data were withheld from publication to avoid disclosing company proprietary data (table 1).

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

FMC Corp.'s Lithium Division produced a full range of downstream compounds, lithium metal, and organic lithium compounds at its facilities in Bessemer City, NC, and Bayport, TX. FMC met its lithium carbonate requirements with material produced at its Argentine operation and through a long-term agreement with Chilean producer Sociedad Química y Minera de Chile S.A. (SQM) to supply it with lithium carbonate produced at SQM's brine operation. FMC also produced lithium chloride in Argentina in 2005.

Consumption

Lithium is sold as brines, compounds, metal, or mineral concentrates depending on the end use. Lithium's electrochemical reactivity and other unique properties have resulted in many commercial lithium products. For many years, the majority of lithium compounds and minerals were used in the production of ceramics, glass, and primary aluminum, but growth in lithium battery use and decreased use of lithium in aluminum production has resulted in batteries gaining market share and perhaps soon becoming the leading end use for lithium. SQM listed main uses for lithium in 2004 as follows: ceramics and glass, 21%; batteries, 19%; lubricating greases, 16%; pharmaceuticals and polymers, 9%; air conditioning, 8%; primary aluminum production, 6%; and other uses, 21% (Sociedad Química y Minera de Chile S.A., 2005). The "other uses" category represents several smaller end uses including alloys, construction, dyestuffs, industrial bleaching and sanitation, pool chemicals, and specialty inorganics (FMC Corp., 2006§[1]).

In 2005, lithium consumption in the United States was estimated to be 2,500 t of contained lithium, nearly 32% more than the estimate for 2004 and 79% more than in 2003. The recent recovery can be attributed to increased consumption in all end uses except aluminum as a result of the upswing in the domestic economy and increased demand in a few rapidly expanding end uses. Domestic end uses for lithium materials may not directly correspond to worldwide consumption, but the data necessary for making more reliable estimates are not available. Growth areas are believed to be similar globally, but individual markets may differ by location.

If lithium concentrates are included in lithium consumption estimates, the leading use of lithium in the United States may be in ceramics and glass manufacturing processes. No lithium concentrates are produced in the United States for direct application in ceramics and glass manufacture, and import statistics do not specifically identify lithium ore imports, making it difficult to determine definitive end-use estimates. The addition of lithium as lithium carbonate or lithium concentrates to a glass melt lowers the process melting point, reduces the coefficient of thermal expansion and the viscosity, and eliminates the use of more toxic compounds. The production of ceramics and glass was the only commercial use for lithium mineral concentrates. The manufacture of thermal-shock-resistant cookware (pyroceramics) consumed the majority of lithium used in the ceramics and glass industry. Low-iron

[1]References that include a section mark (§) are found in the Internet References Cited section.

spodumene and petalite were sources of the lithium used to improve the physical properties of container and bottle glass, as well as sources of alumina, another important component of glass. Glass manufacturers used lithium in container and bottle glass to produce a lighter weight, thinner walled product. Lithium concentrates are the predominant lithium source for ceramics and glass uses, but lithium carbonate also is used.

Lithium batteries may now be the second ranked end use for lithium and might become the leading end use in the near future. Many major battery manufacturers marketed some type of lithium battery, exploiting the many advantages of lithium batteries compared with older battery technologies. Research and development continued, and innovative rechargeable battery configurations continued to be developed to meet the changing requirements of electronic equipment, such as portable telephones, portable computers, and video cameras. Worldwide, rechargeable lithium batteries power more than 60% of cellular telephones and 90% of laptop computers (FMC Corp., 2006§).

Nonrechargeable lithium batteries offer improved performance compared with alkaline batteries at a slightly higher cost and have been commercially available for more than 10 years. They are used in cameras, electronic games, microcomputers, small appliances, toys, and watches. The military purchases lithium batteries for a variety of applications.

The multipurpose grease industry was an important market for lithium in 2005. Lithium hydroxide monohydrate was the compound used to produce lithium lubricants. Lithium-base greases were favored for their retention of lubricating properties over a wide temperature range; good resistance to water, oxidation, and hardening; and formation of a stable grease on cooling after melting. These greases are used in aircraft, automotive, industrial, marine, and military applications.

Another major end use for lithium compounds was as catalysts and reagents in the production of synthetic rubbers, plastics, and pharmaceuticals. N-butyllithium, an organic lithium compound, was used to initiate the reactions between styrene and butadiene to form abrasion-resistant synthetic rubbers that require no vulcanization. Other organic lithium compounds were used as catalysts for the production of plastics, such as polyethylene. Lithium metal and organic compounds also were used as catalysts in the production of pharmaceuticals, including anticholesterol agents, antihistamines, contraceptives, sleep inducers, steroids, tranquilizers, vitamin A, and other products. Pharmaceutical-grade lithium carbonate was used in the treatment of manic-depressive psychosis, the only treatment approved by the U.S. Food and Drug Administration in which lithium was consumed by the patient.

The use of lithium in primary aluminum production has decreased steadily since 2000 in the United States, as domestic aluminum production declined. Adding lithium carbonate to aluminum potlines lowers the melting point of the cryolite bath, allows a lower operating temperature for the cells, increases the electrical conductivity, and decreases bath viscosity. These factors contribute to increased production without changing any other operating conditions especially in older smelters, like those in North America. Lithium carbonate additions also have the potential environmental benefit of reducing fluorine emissions by 20% to 30% (Chemetall GmbH, undated§).

Small quantities of other lithium compounds were important to many industries. Aircraft manufacturers in several countries sometimes use aluminum-lithium alloys for wing and fuselage skin or for structural members in different types of aircraft to reduce the weight of the aircraft by more than 10%, allowing significant fuel savings during the life of the aircraft. Lithium was being used increasingly as a concrete additive to prevent or mitigate premature deterioration of concrete through alkali silica reactivity, lithium compounds were added to fast-setting cements, floor screeds, joint sealing mortars, and cement based adhesives to accelerate setting and hardening rates (FMC, 2006§; Chemetall GmbH, undated§).

Lithium chloride and lithium bromide were used in industrial air-conditioning and commercial dehumidification systems and in the production of sophisticated textiles. Sanitizers for commercial glassware, public restrooms, and swimming pools contained lithium hypochlorite, as did dry bleaches for commercial laundries. Lithium metal was used as a scavenger to remove impurities from bronze and copper, and anhydrous lithium chloride was used as a component in fluxes for hard-to-weld metals, such as aluminum and steel alloys.

Prices

Lithium pricing became very competitive when SQM entered the market in 1998, and it has been difficult to obtain reliable price information since that time. Companies may announce price hikes, but they are reported relative only to previous prices. Producers negotiate with consumers on an individual basis; price information is not usually reported.

In recent years, customs values for lithium carbonate imports to the United States seemed to be a good indication of the trends in lithium pricing, although they never exactly reflected the producers' prices for lithium carbonate. In 2005, this did not seem to be the case. The average customs unit value for imported lithium carbonate was $1.46 per kilogram, about 15% lower than in 2004; lithium producers, however, reported increased prices for most lithium compounds in contrast to the decreased customs values. Average unit vales of exported lithium carbonate were about the same in 2005 as the previous year and are more than twice those of imported material. This suggests that the material being exported from the United States may be higher quality lithium carbonate than what is imported.

Foreign Trade

In 2005, total exports of lithium compounds from the United States increased slightly compared with those of 2004. About 62% of all U.S. exports of lithium compounds went to China, Germany, Japan, and Russia, all with more than 500 t. The remainder was divided among many other countries (table 2).

Imports of lithium compounds increased by 23% in 2005 as the domestic economy continued to improve. In 2005, 75% of lithium chemical imports came from Chile, 24% came from Argentina, and 1% from other countries (table 3). Lithium concentrates from Australia, Canada, and Zimbabwe may have entered the United States, but because these materials have no unique import code, no import data were available.

World Review

A small number of countries throughout the world produced lithium concentrates and brine. Chile, China, and the United States were the leading producers of lithium carbonate. Significant quantities of lithium compounds and concentrates also were produced in Argentina, Australia, Brazil, Canada, Portugal, Russia, and Zimbabwe. Congo (Kinshasa), Namibia, Rwanda, and South Africa produced concentrates in the past. Production figures for lithium mineral concentrates, lithium carbonate, and lithium chloride are listed in table 4. Pegmatites containing lithium minerals have been identified in Austria, France, India, Ireland, Mozambique, Spain, and Sweden, but economic conditions have not favored development of the deposits. Lithium has been identified in subsurface brines in Bolivia, China, and Israel. Companies in France, Germany, Japan, Taiwan, and the United Kingdom produced downstream lithium compounds from imported lithium carbonate.

Estimates of the total world lithium market averaged 14,100 t of lithium contained in minerals and compounds in 2003, the latest year for which this type of information was available. About 11,300 t of lithium was consumed as compounds, and the remainder, as concentrates (Ebensperger and others, 2005). More recent data were not available, but some estimates on growth can be made based on recent growth rates reported by SQM. That company estimated demand for their lithium materials to have grown by 10% in 2004. Assuming similar growth in 2005 for all lithium compounds consumption, total consumption of lithium in minerals and compounds can be estimated to be about 17,000 t, with nearly 14,000 t in compounds (Sociedad Química y Minera de Chile S.A., 2005).

Argentina.—FMC's Argentine facility at the Salar de Hombre Muerto was designed to produce about 12,000 metric tons per year (t/yr) of lithium carbonate and about 5,500 t/yr of lithium chloride (North American Mineral News, 1998). Production of both compounds reached record levels in 2004, with lithium chloride production surpassing reported capacity. It is not known whether the plant was expanded or if improved efficiencies made the extra production possible.

Admiralty Resources NL of Melbourne, Australia, was considering the development of the Salar de Rincon brine resources in Argentina, expecting to begin producing lithium chloride in 2007. Initial capacity was expected to be about 12,000 t/yr (Admiralty Resources NL, 2005).

Australia.—Sons of Gwalia Ltd. is the leading lithium mineral producer with 60% of world lithium concentrate capacity. It produces spodumene concentrates at the Greenbushes Mine in Western Australia. The company markets products containing 2.2% to 3.5% lithium (Crossley, 2003b). Spodumene concentrates are sold for consumption in ceramics and glass and also are exported to China where it is used in glass and as a raw material for the production of lithium carbonate.

Chile.—With two large brine operations at the Salar de Atacama and their associated lithium carbonate plants, Chile was the leading lithium carbonate producer in the world. Chemetall Foote's plant first produced lithium carbonate in 1984, and current capacity is about 14,500 t/yr. The plant uses this lithium carbonate as feedstock for some of its downstream chemical production in the United States and supplies the operations of its parent company, Chemetall, in Germany and Taiwan (Chemetall GmbH, undated§). SQM completed its first full year of production in 1997 with the capacity to produce about 23,000 t/yr of lithium carbonate (Schmitt, 2001). Both Chilean companies transported concentrated brines from the Salar de Atacama to lithium carbonate plants near Antofagasta.

In 2005, SQM produced at its full capacity of 27,000 t/yr and was working to increase capacity to 40,000 t/yr by 2008. The company reported that its share of the world lithium carbonate market has grown to 40% (Harris, 2005). SQM completed its 6,000-t/yr lithium hydroxide plant in late 2005 (Sociedad Química y Minera de Chile S.A., undated§).

China.—China is the only country that continued to produce large quantities of lithium carbonate from spodumene. China Xinjuang Nonferrous Metals Corporation of Mingyuan produced lithium carbonate from domestic and imported Australian ore (Ebensperger and others, 2005). Additional lithium carbonate was imported into China from Chile and the United States. Lithium brines were believed to be the largest lithium resources in China, containing 80% of the country's reserves (Crossley, 2003a).

China was developing a project to recover lithium carbonate from the brines of the Zabayu salt lake in Tibet. Capacity was expected to be 5,000 t/yr (Chinanews, 2005§). A similar project was being developed by a Canadian company, Sterling Group Ventures, Inc., and its wholly-owned subsidiary Micro Express Holding, Inc. The company signed an agreement with the Beijing Mianping Salt Lake Research Institute to develop another brine deposit to produce lithium carbonate in Tibet. The $30 million operation also is expected to produce 5,000 t/yr of lithium carbonate (Sterling Group Venture, Inc., 2005).

Current Research and Technology

Carbon Dioxide Absorption.—Researchers in Japan discovered a series of lithium-containing oxides that absorb 10 times more carbon dioxide than other carbon dioxide absorbents. The reaction between carbon dioxide and the lithium oxide materials occurs instantaneously at temperatures up to 700º C and is reversed at higher temperatures. Lithium silicate showed great potential because of its large absorption capacity, rapid absorption, effectiveness over a wide range of temperatures and carbon dioxide concentrations, and reusability. This process would be used to remove carbon dioxide from flue gases at powerplants and other facilities that release large quantities of carbon dioxide into the atmosphere, reducing the possible contribution to global warming, thought to be caused, at least in part, by excess carbon dioxide in the atmosphere (Kato and others, 2005).

Hybrid-Electric Vehicles.—In 2005, most hybrid electric vehicles (HEVs) used nickel-metal-hydride batteries, but many experts believed that lithium-ion batteries would power the next-generation of HEVs because they offer advantages in power generation, size, weight, cycle life, and cost. HEVs offer fuel economy improvements of 5% to 35% compared with those of vehicles powered exclusively by internal combustion engines. The U.S. Government funded a research program to develop an abuse-tolerant lithium-ion battery with extended life and improved power-to-weight performance compared with the batteries used in early HEVs (Johnson Controls, Inc., 2006).

Medical Devices.—Lithium batteries have found widespread acceptance in implantable medical devices such as pacemakers and electronic stimulators that help restore function in the brains of people with Parkinson's disease. New technology has made it possible to make batteries smaller and longer lasting. It is expected that soon an implanted lithium battery incorporating organosilicon compounds may be able to be recharged from outside the body. These new batteries are projected to last 12 years (Devitt, 2005§).

Nanotechnology.—Nanotechnology, the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, has made it possible to make rechargeable batteries that can charge and discharge very rapidly, making it reasonable to expect that lithium-ion batteries could be used in many more applications in the near future. Lithium-ion batteries were being considered for power hand tools, flywheel uninterrupted power supplies, and HEVs. This technology makes it possible to completely recharge the batteries in an electric vehicle in about the same time it currently takes to refill the gas tank on a vehicle with an internal combustion engine (Gotcher, 2005).

Thin Film Technology.—The Oak Ridge National Laboratory was developing thin-film lithium batteries and materials for these batteries that withstand a wide range of temperatures from below 0° to 250° C. Thin-film lithium batteries last longer; hold their charge better during storage; recharge faster with no memory effects; can be recharged many times; and can be made much smaller, lighter, and more flexible than more traditional batteries. Because all their components are solid, there are no such potential problems as corrosion, freezing, and leakage. They are more expensive than more common batteries and are not available in standard cell sizes, but they are more attractive for modern technology developments like package tracking systems, "smart cards," and many other innovative devices (Oak Ridge National Laboratory, 2005).

Outlook

Although traditional markets are still important to the lithium industry, batteries are rapidly gaining in importance and could very soon be the major market for lithium materials of all kinds.

The market for lithium batteries has been increasing by more than 20% per year in the past few years. Lithium-ion and lithium-polymer batteries appear to have the greatest potential for growth. First introduced in 1993, the market for these rechargeable batteries was estimated to be $4 billion in 2005 (Chemical & Engineering News, 2006). Most lithium batteries that are sold are the lithium-ion type, but lithium-polymer batteries are gaining in popularity and represent about 10% of the battery market. Lithium-polymer batteries are more attractive to many original equipment manufacturers because they can be constructed in unusual shapes to more easily fit into the devices that they power (Crossley, 2003b).

New developments in lithium battery technology, including the use of nanotechnology that enables very fast charges for rechargeable lithium batteries, hold the potential for large growth. Widespread use of lithium-ion batteries in HEVs could create tremendous demand for lithium in the near future.

Other lithium markets are also growing but at lower rates than batteries. Lithium producers had diverse opinions on what other areas offer the most potential for growth. One producer reported growth in construction uses, especially in fast-setting concrete. Another company experienced its largest growth in the use of organic lithium compounds used as pharmaceutical catalysts. Lithium bromide consumption for air conditioning was reported to be increasing by some producers, but on the decline, especially in the United States, by another. Better estimates of actual markets were not possible because details that closely define these markets were not publicly available.

Most experts, however, agree that lithium batteries hold the greatest promise for expanding the demand for lithium. Established uses in portable devices continue to increase as consumers demand longer lasting, lighter weight, and more reliable power systems. If and when lithium batteries become the accepted battery type for HEVs, demand is likely to expand rapidly. Brine operations can be expected to expand capacity relatively quickly to supply increasing demand. It is possible, however, that if the market grows large enough, lithium minerals may once again be attractive raw materials for lithium carbonate production.

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TABLE 1
SALIENT LITHIUM STATISTICS[1]

(Metric tons of contained lithium)

	2001	2002	2003	2004	2005
United States:					
Production	W	W	W	W	W
Exports[2]	1,480	1,620	1,520	1,690	1,720
Imports[2]	1,990	1,920	2,200	2,910	3,580
Consumption, estimated	1,400	1,100	1,400	1,900	2,500
Rest of world, production[3]	15,400	16,400	19,100	20,300 [r]	20,600 [e]

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

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

Compound and country	2004 Gross weight (metric tons)	2004 Value[2] (thousands)	2005 Gross weight (metric tons)	2005 Value[2] (thousands)
Lithium carbonate:				
Brazil	--	--	77	$1,480
Canada	126	$451	60	219
China	771	2,750	797	2,930
Germany	795	2,380	1,030	2,840
India	63	169	49	182
Japan	634	2,280	1,170	3,100
Korea, Republic of	329	874	38	139
Netherlands	105	378	169	430
Thailand	--	--	148	561
United Kingdom	177	743	242	651
Vietnam	--	--	54	147
Other	168 r	561 r	123	404
Total	3,170	10,600	3,960	13,100
Lithium carbonate, U.S.P.:[3]				
Australia	6	18	51	155
China	668	1,210	144	319
United Kingdom	56	103	21	36
Other	14 r	287 r	17	131
Total	738	1,600	233	641
Lithium hydroxide:				
Argentina	166	642	133	602
Australia	226	810	153	511
Belgium	410	1,260	179	514
Canada	150	609	156	655
China	40	100	180	645
Egypt	83	240	34	128
Germany	701	1,930	931	2,540
India	505	1,430	399	1,580
Japan	1,200	4,570	1,310	5,500
Korea, Republic of	278	1,010	262	1,120
Mexico	190	676	171	626
Netherlands	160	423	210	524
New Zealand	123	762	--	--
Russia	572	1,820	523	1,370
Singapore	107	317	114	454
South Africa	119	325	84	591
Sweden	56	132	95	234
Taiwan	57	272	17	58
Thailand	181	488	215	682
Ukraine	34	92	80	272
United Kingdom	118	651	89	257
Other	310 r	1,480 r	290	1,230
Total	5,780	20,000	5,620	20,100

[r]Revised. -- Zero.
[1]Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Free alongside ship values.
[3]Pharmaceutical-grade lithium carbonate. USP, U.S. Pharmacopeia.

Source: U.S. Census Bureau.

TABLE 3

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

Compound and country	2004 Gross weight (metric tons)	2004 Value[2] (thousands)	2005 Gross weight (metric tons)	2005 Value[2] (thousands)
Lithium carbonate:				
Argentina	4,850	$11,200	4,630	$9,600
Chile	10,500	15,200	14,300	17,700
Other	47	165	39	146
Total	15,400	26,500	18,900	27,500
Lithium hydroxide:				
Chile	--	--	54	172
China	16	38	1	10
Norway	27	45	48	93
United Kingdom	11	59	13	76
Other	10 r	91 r	8	102
Total	64	233	124	453

[r]Revised.

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

[2]Customs value.

Source: U.S. Census Bureau.

TABLE 4

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

(Metric tons)

Country[3]	2001	2002	2003	2004	2005
Argentina:[4]					
Lithium carbonate	-- 5	906 5	2,850	4,970 5	5,000
Lithium chloride	4,512 5	4,729 5	4,700	6,303 5	6,300
Australia, spodumene	79,859 5	79,085 5	124,410 5	118,451 r, 5	120,000
Brazil, concentrates	9,084 5	12,046 5	12,100	12,100	12,100
Canada, spodumene[6]	22,500	22,500	22,500	22,500	22,500
Chile, carbonate from subsurface brine	31,320 5	35,242 5	41,667 5	43,971 r, 5	44,000
China, carbonate	13,000	13,000	13,500	14,000	15,000
Portugal, lepidolite	11,571 5	16,325 5	16,000	16,000	16,000
Russia, minerals not specified[7]	2,000	2,000	2,000	2,200	2,200
United States, subsurface brine	W	W	W	W	W
Zimbabwe, amblygonite, eucryptite, lepidolite, petalite, and spodumene	36,103 5	33,172 5	12,131 5	13,710 r, 5	13,000

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

[1]Table includes data available through March 28, 2006.

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

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

[4]New information was available from Argentine sources, prompting major revisions in how lithium production was reported.

[5]Reported figure.

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

[7]Lithium contained in concentrates and brine. These estimates denote only an approximate order of magnitude; no basis for more exact estimates is available. Other countries from the Commonwealth of Independent States, including Uzbekistan, could have produced or could be producing lithium, but information is not available for estimating production levels.