

Earlier this year, President Barack Obama announced that the U.S. Department of Energy would make \$2.4 billion in grants available to U.S. companies for the manufacture and deployment of domestically manufactured batteries and electric vehicles. Bringing down the cost of lithium-ion batteries is key to advancing the deployment of electric vehicles. Yet for sometime debate has raged within the community of scientists working on lithium technology as to whether or not there are sufficient reserves of this metal. In short, oil import dependent states don't want to replace one dependency-oil for the transportation sector-with another in this case lithium if insufficient quantities of this material are available.

Based on data from U.S. National Research Council reports produced over the last 30 years and augmented in the interim by many subsequent discoveries of lithium the fact is that lithium deposits are large. In a report on a major conference on lithium supply and demand held in Chile in January 2009, the conference Chairman stated, "What speakers in the Santiago event demonstrated beyond any reasonable doubt is that lithium resources are large enough to cover any rationally conceivable demand."

Lithium Background: Sources and Science

Current and potential sources of lithium are from pegmatites, continental brines, oilfield and geothermal brines, and jadarite. The lithium contents of various deposits can be expressed in terms of the lithium oxide content (Li₂O) for ores or parts per million (ppm) or milligrams per liter (mg/L) for brines. In tabulating reserves from a variety of sources the weights (tons) are generally quoted as elemental lithium (Li).

Pegmatites

These are coarse grained igneous rocks formed by the crystallization of post magmatic fluids. They occur in close proximity to large magmatic intrusions and vary greatly in size. In the U.S. lithium containing pegmatites are numerous in the nearly 16 mile long tin-spodumene belt in North Carolina. The principal lithium minerals in pegmatites are spodumene, petalite and lepidolite. All these have been used in the manufacture of lithium chemicals and also have direct applications in certain glasses and glass ceramics if the iron content is sufficiently low. In the absence of a sufficient market many pegmatites have not been fully explored due to the expense involved. The situation is now changing and recently, with the potential increase in demand, exploration activity has increased. Talison Minerals in Australia, for example, has recently tripled its reserves to 1.0 million tons of lithium. Many pegmatites contain tin and tantalum as well.

Continental Brines

Lithium is leached from certain volcanic rocks and when the surface or groundwater flows into

closed basins where solar evaporation rates exceeds rainfall, lithium and other elements become more concentrated. At one end of the scale is the Great Salt Lake in Utah but net evaporation is low and lithium values cannot reach a commercially viable level although sodium chloride, potash and magnesium are recoverable. At the Clayton Valley in Nevada, another closed basin, lithium has been recovered for decades. The major brine deposits, though, are at moderate elevation in the Salar de Atacama in Chile and high elevations in Bolivia and Argentina and in Western China and Tibet. Most contain economic contents of potassium and boron.

Oilfield & Geothermal Brines

Oilfield brines in the Smackover Formation particularly in Arkansas and in the Paradox Basin in Utah contain possible viable brines. The Salton Sea KGRA contains an estimated 2.0 million tons of lithium and is currently being evaluated as a source possibly using wells currently used for power generation.

Hectorite

Hectorite is a magnesium lithium smectite, a clay similar to bentonite and occurs in numerous areas in the western U.S. The largest known deposit straddles the Nevada-Oregon border and contains approximately 2.0 tons of lithium in a series of seven shallow lenses.

Jadarite

Recently discovered in Serbia by Rio Tinto Zinc Corporation during a boron exploration program, a deposit containing 850,000 tons of lithium was discovered. Once explored the total reserve could be at least double this.

Reserves and Resources

At the 2009 Santiago lithium conference, global lithium reserves and resources were estimated at nearly 30 million tons with 7.6 million tons in pegmatites, 17.6 million in continental brines, 1.75 million in geothermal and oilfield brines, 2.0 million in hectorites and 0.8 million in jadarite. In one presentation mention was made of another estimate from authors at the University of Chile and the Colorado School of Mines of some 35 million tons. Estimates from three major producers represented ranged from 28 million (FMC and Chemetall) to 35.7 million from SQM. The National Research Council (NRC) reports a fairly wide definition of reserves and resources.

This definition follows the logic of Donella Meadows in a 1972 statement which follows:

Reserve is a concept related to the amount of material that has been discovered or inferred to exist and that can be used given reasonable assumptions about technology and price. The US Geological Survey (USGS) publishes more narrowly constrained estimates. In the NRC report the authors made adjustments to the gross tonnages of the pegmatites included in the estimate

to allow for mining and processing losses. In the case of anticipated open pit operations the tonnages were reduced by 25% and by 50% in the case of anticipated underground projects. The brine reserve tonnages were not reduced as recoveries vary greatly as the data is generally proprietary. (This precedent is retained in this paper.)

Current Production

Lithium mineral concentrates are used predominantly in glass, glass ceramics and ceramics (approximately 90% of demand) where they act as a powerful flux, provide silica and alumina to the mix and provide thermal shock resistance. Most of the rest of the market is metallurgical. The largest producer is Talison Minerals in Western Australia which has a capacity of 250,000 tons per year of spodumene concentrates with a range of lithia grades. Other producers are Bikita Minerals in Zimbabwe with the mineral petalite and Tanco in Canada with spodumene.

All the lithium pegmatite minerals have at one time been used as feedstock for the production of lithium chemicals and a high percentage of Chinese production with approximately one-third from domestic sources and two thirds from spodumene imported from Australia. Eighty five percent of the demand for ores and concentrates is in Europe and Asia. Until recently, in reporting production data, the non-chemical concentrates and lithium chemicals, from whatever source, were treated separately but some reporters combine the two to report on total lithium demand. This accounts for some confusion as simply reporting tons of concentrate produced or sold does not allow the calculation of the tonnages of contained lithium as the percentage of lithium in concentrates varies.

This is not a problem with lithium chemicals where the many products with varying lithium contents are reported in terms of lithium carbonate equivalents (LCE's) as lithium carbonate is the predominant lithium product. One pound of lithium metal (Li) is equivalent to 5.32 pounds of lithium carbonate. The 2008 market for lithium chemicals approximated to 95,000 tons of LCE's with the principal products being metal and metal derivatives, carbonate, hydroxide and bromide. At the Santiago conference, the company FMC's breakdown of lithium markets served was: air treatment 8%, construction 2%, aluminum production 6%, glass & ceramics 20%, batteries 29%, grease & lubricants 13%, polymers and pharmaceuticals 5% and others 17%. Of the battery demand some is in the form of metal for primary batteries and the remainder as carbonate and some hydroxide as the feedstock for the lithium based materials used in rechargeable lithium-ion batteries. Currently, the demand is mainly for small versions as used in computers, cell phones etc. but a major demand is anticipated for vehicular batteries. Lithium-ion battery production is currently concentrated in Japan (39%), China (36%) and South Korea (20%). In short, despite the availability of lithium as a material for the production of lithium-ion batteries, battery production remains outside the U.S. There is considerable disagreement regarding Chinese capacity and production. Much of current production is spodumene-based despite the existence of large brine reserves some of which have complex

chemistries. Various observers estimate potential capacities by 2011 at between 60,000 and 85,000 tons. The geographical distribution of metal and chemical sales is Asia at 53%, the Americas at 21%, and Europe at 26%.

Future Demand

In the battery sector demand in conventional applications is estimated to be growing at 7% but major demand growth is expected with the large scale electrification of vehicles. Quantifying this is extremely difficult involving estimating the annual production of new vehicles over time, estimating the percentage of these vehicles that will be battery powered and how many of these will have lithium-ion batteries. Then there is the question of which of the many lithium chemistries will be adopted and whether the electric vehicles will be hybrids, plug-in hybrids or purely electric each with varying requirements based on battery size. The International Monetary Fund (IMF) estimates that the number of the cars in the world currently approximates to 700 million and this figure will rise to 3 billion by 2050. In five or six years the IMF believes China will overtake the U.S. in car sales and in forty years it will have as many as the whole world currently has. Other random items are that Hitachi, alone, is developing the capacity to produce sufficient batteries for 700,000 cars a year. JP Morgan estimates that electric vehicles will total 9.6 million by 2018 and Toyota estimates that plug-ins will be produced at the rate of 20,000-30,000 year by 2012. At the Santiago lithium conference estimates of lithium demand to satisfy vehicle requirements were presented by the three major lithium producers and, in addition, the Tru Group presented a study they had undertaken on behalf of Mitsubishi Corp.

All the producers used the same lithium demand figure of 0.6 kilos of carbonate per kWh with a range, by vehicle type, of 1.2 kilos in a mild hybrid with a 2 kWh battery (new generation lead batteries are a competitor), through 7.2 kilos in a 12 kWh battery in a plug-in hybrid electric vehicle (PHEV) to 15 kilos in a 25 kWh battery in an electric vehicle (EV). They each looked at a range of scenarios covering estimated market penetrations and vehicle types and the demand estimates to meet these ranged from 5,000 to 70,000 tons of lithium carbonate a year by 2020. FMC went a little further and estimated total carbonate equivalent demand in 2020 for both conventional and vehicle demand split between a vehicle demand of 70,000 tons and conventional demand of 223,000 tons – a total of 293,000 tons of LCE's. SQM also estimated that in 2030 between 15% and 25% of new vehicles would be battery powered with between 75% and 90% of these being Li-ion batteries with a carbonate demand of between 65,000 and 145,000 tons.

Meeting Demand

How is the increase from the current 95,000 tons of lithium carbonate equivalents (LCE's) going to be met? The world's largest reserve is in the Salar de Uyuni in Bolivia with reserves (a recently revised estimate) of 8.9 million tons with a considerable upside potential. Comibol's

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Written by Keith Evans

Thursday, 27 August 2009 00:00

initial target is between 20,000 and 30,000 tpa with the co-production of 400,000 tpa potash. The Salar de Uyuni receives an inordinate amount of publicity. However, suggestions that the future of the electric vehicle is dependent upon its development are clearly in error based on the large volumes of reserves in other countries.

The company Chemetall announced that subject to demand the company would double its production at the Salar de Atacama to approximately 40,000 tons per year (tpa) by 2020. SQM operates to the north of Chemetall but pumps brine from the same aquifer with reserves of approximately 7.0 million tons of Li (approximately 36.0 million tons carbonate). This operation is driven by the production of 860,000 tpa of potash. The amount of lithium in the brine pumped to the solar evaporation ponds greatly exceeds current lithium processing plant capacity and the company states that 280,000 tpa of carbonate is currently returned to the brine aquifer. Lithium production can be readily increased with plant expansions and minor increases in the solar ponds area. SQM is planning to increase potash production to 1.3 million tpa and this will add considerably to the already large quantities of surplus-lithium.

FMC states that its current reserves in Argentina are adequate for 70 years implying that reserves are sufficient to support expansion. In China, as stated earlier, there is no single opinion regarding whether expansion plans will be implemented, but the stated target is to produce 85,000 tpa from brine alone. Reserves are variously quoted as being between 2.6 and 4.8 million tons of Li. Reserves and resources at current operations excluding China approximate to 7.75 million tons of Li or 41 million tons of lithium carbonate. There are numerous projects in various stages of evaluation.

In Argentina the evaluation of the Salar de Rincon is reputedly close to completion and the initial target from a 1.4 million ton reserve is 17,000 tpa. Both the above salares are relatively low grade (although Uyuni contains an area containing 400,000 tons Li with higher lithium concentrations) but the brines have a high magnesium content and other technical issues which could increase costs. Exploration activity is at a high level at nearly a dozen Andean salares including at the Salar de Olaroz in Argentina. A number of companies are active in Nevada in geological environments similar to the one containing Chemetall's Silver Peak (Clayton Valley) operations.

Regarding pegmatites, Kelibar Resources a subsidiary of Nordic Mining, is planning a 6,000 tpa project in Finland. Canadian Lithium Corp. is completing a study to reactivate a former operation in Quebec with an optimal production case of 20,000 tpa, and in Western Australia Galaxy Resources is planning to develop the Mt. Marion pegmatite, ship the concentrate to China and produce carbonate at the rate of 20,000 tpa to take advantage of lower sulfuric acid and soda ash prices there. Talison, owners of the very large Greenbushes pegmatite operation and who have invested considerable sums in expanding its reserves, is considering chemical production.

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Of the unconventional sources the Siberian jadarite deposit has current reserves sufficient to produce at 60,000 tpa from one of three known horizons and the initial target at Western Lithium's hectorite deposit is 25,000 tpa. With the probable exception of the pegmatite based projects with announced production targets, the reserves at the other pipeline projects total listed above are sufficient to support production levels at rates much higher than the initial tonnages listed with, between them, approximately 14.0 million tons of lithium or 74 million tons of lithium carbonate.

Production Costs

It is generally considered that lithium production costs are lowest at the Salar de Atacama in Chile which is unique in its high lithium concentrations, outstanding solar evaporation conditions and proximity to the coast. Other brine deposits are not so fortunate in terms of lithium grade, more complex chemistries, less attractive climate conditions or location. Any or all of these factors will increase costs at other project sites.

At this time it is not known what costs will be incurred in recovering lithium from jadarite, hectorite and geothermal brines. Studies are ongoing. Production costs from pegmatites using well known technologies will vary. In 2008 SQM estimated Chinese production costs from spodumene at about \$2.00/lb and a rough estimate for costs at possibly reactivated operations in North Carolina could be being between \$2.50 and \$3.00/lb. However, the company conference Chemetall has pointed out that the cost of lithium in a lithium-ion battery is approximately 1% of the total battery cost so in this application, expected to be the leading application in the future, the price of lithium is not a significant factor.

Additionally, of course, lithium is not consumed in the process of storing energy and, in time large volumes are expected to be recycled. To put the 30.0 million tons of reserve and resource estimate into context, each million tons of recovered lithium (5.62 million tons of carbonate) is sufficient for 560 million vehicles requiring a 10 kWh battery.

In short, the large-scale manufacture and development of electric vehicles using lithium-ion batteries should not be hindered due to lithium availability but has more to do with cost-issues related to the manufacture of the batteries themselves and to their reserve-charge potential demanded by drivers themselves.

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