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Diamond Modeling in World Lithium Brine Utilization Assessment

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The global transition away from hydrocarbons toward energy alternatives increases demand for many scarce metals. Among these is lithium, a key component of lithium-ion batteries for electric and hybrid vehicles.

Global lithium resources are estimated to be 39 million metric tons (MT) and lithium is mined from three types of deposits: brines, pegmatites and sedimentary rocks. Continental brines and pegmatites (or hard-rock ore) are the main sources for commercial lithium production. Lithium (Li) brine deposits account for about three-fourths of the world's lithium production (USGS, 2011). Brine deposits represent about 66 percent of global lithium resources and are found mainly in the salt flats of Chile, Argentina, China and Tibet.

There are three types of brine deposit — continental, geothermal and oil field — with the most common being continental saline desert basins (also known as salt lakes, salt flats or salars). They are located near tertiary or recent volcanoes and are made up of sand, minerals with brine and saline water with high concentrations of dissolved salts. A playa is a brine deposit whose surface is composed mostly of silts and clays; they have less salt than a salar.

There are four driving forces useful in assessing the world lithium brine processing market, which can be analyzed under a diamond modeling system or framework. These four factors of technology, resources, demand and capital acquisition have made extraction from brine sources more economical than commercial production from hard-rock ore, which could be a meaningful tool for next quantitative resources potential assessment with degree measures of possibility.

First of all, emerging technology may become the biggest lithium game changer. New lithium extraction

technologies are emerging, and, if successful, may further lower the cost of production at brine deposits, widening their economic advantage over hard-rock deposits. Recently, two companies — California startup Simbol Materials and South Korean steelmaker POSCO— have unveiled new lithium extraction methods that dramatically cut the cost and time it takes to produce lithium carbonate from brine deposits. China's lithium consortium mainly located in Qinghai also developed key technology for high Mg/Li ratio brine extraction and recovery process with pro-ecology low pollution.

Secondly, lithium brine endowments (brine deposits) including the amount, quality, complexity of contents in different districts vary greatly. So the continental brine resources are very important factors influencing the pattern of world lithium brine processing market. For instance, the majority of lithium carbonate is now produced from continental brines within Argentina, Chile and Bolivia, Latin America's lithium triangle. Of these countries, Chile in particular dominates global continental brine production: two of the world's leading lithium

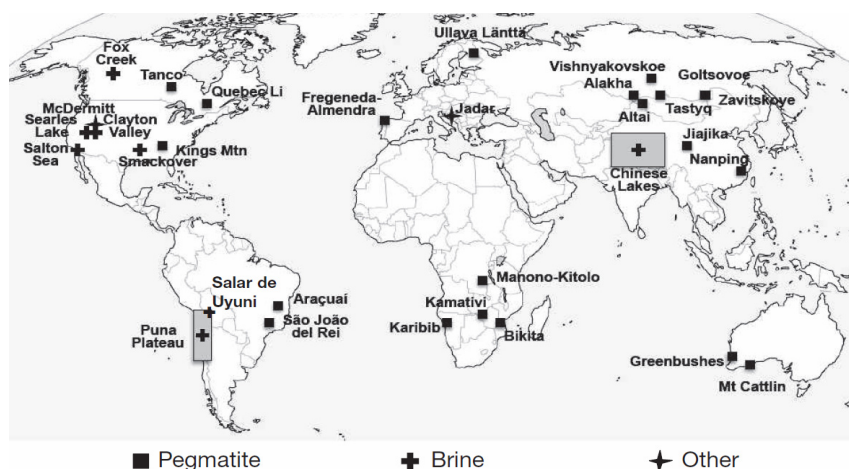


Fig. 1. Global distribution of lithium resources in pegmatite, brine, and other (hectorite or jadarite) deposit types (Kesler et al., 2012). The gray boxes correspond to maps shown in Kesler et al.(2012).

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Table 1 Diamond modeling for lithium brine assessment

Driving force	Element contents	Main cases	Credit Range
technology	Know-hows	Argentina, Bolivia, Chile	
	Key Knowledges	POSCO, QISL, CAS	
	Cost Savings	Mitsubishi Corp. Qinghai Salt Lake Industry etc	
resources	Location	Latin America	
	Infrastructure content	Tibet plateau	
	ratios	High- or Low- Li%	
demand	brine types	High- or Low- Mg/Li	
	Battery Energy	cell phones	
		laptop computers	
Capital		vehicles	
	M&A	Galaxy Resources Ltd.-	
		Lithium One Inc.	
Total			

Note: Credit Range column is left blank for estimate values and their possibility.

producers, Sociedad Quimica y Minera (SQM) and Rockwood Holdings (ROC), operate on the country's Salar de Atacama, which produces more than half of the world's lithium. In Chinese Tibetan saline lakes, there are also several huge lithium deposits reserves such as West Taijinar Salt Lake in Qaidam Basin, Chabyer Caka of western Tibet plateau and so on.

Thirdly, as for now rapidly increasing consumption demands for lithium metal from many traditional and emerging applied fields like military are pushing ahead world lithium production and technological innovation to lower cost and consuming time and complexity. Lithium is an energy-critical element (American Physical Society, 2011) that is used in lightweight rechargeable lithium-ion batteries to power a wide array of portable electronic devices such as cell phones, laptop computers, power tools, and vehicles (Goonan, 2012). The growing use of lithium in rechargeable batteries for electric and hybrid vehicles is expected to dominate the market in the 21st century (Gruber et al., 2011; Goonan, 2012). However, five or six years ago the world financial crisis indeed caused the demand and price for lithium metal to fall down dramatically. So the market demand is a very important motivation for lithium production and researching.

Last but not the least, capital acquisition or market financing activity could reflect the estimates and expectations from the market influencing

the confidence of investors and operators. They adjust and arrange their plan timetable and investing schedule according to their situation judging and market prediction. Lithium exploration and production filed are among the most attractive and dynamic capital acquisition targets. For example, in 2012, Galaxy Resources Ltd. acquired Lithium One Inc. in a friendly deal for approximately \$112 million. Galaxy owns the Mount Cattlin10 hardrock lithium mine in Australia and a lithium carbonate processing plant in China. The company, which has indicated a production capacity of 17,000 tonnes a year, has off-take agreements with Mitsubishi Corp. in addition to Chinese battery manufacturers. Lithium One owns the James Bay hardrock project in Quebec, in which Galaxy already held a 20 percent stake, along with the Sal de Vida brine project in Argentina. It is of interest for investors to note that Galaxy and Lithium's Sal de Vida project is located in the neighboring province of Catamarca, while Orocobre Ltd. has operational exposure in the Salta region.

The diamond assessment model for lithium brine production is a practical analyzing and prediction method both in the world market (Fig. 2A) and in a regional area (Fig. 2B), which is significantly meaningful for future resources potential quantitative assessment.

Key words: diamond modeling, lithium brine, resources assessment

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Fig. 2. World main lithium brine deposits from Dwight Bradley et al. USGS (2013). Note: (A) World map of lithium brine deposits (red dots). (B) Detail in South America.