ELSEVIER

Science of The Total Environment

Volume 639, 15 October 2018, Pages 1188-1204

Review

Lithium recovery from brines: A vital raw material for green energies with a potential environmental impact in its mining and processing

Victoria Flexer [a], Celso Fernando Baspineiro [a], Claudia Inés Galli [b c]

https://doi.org/10.1016/j.scitotenv.2018.05.223

Abstract

The electrification of our world is driving a strong increase in demand for lithium. Energy storage is paramount in electric and hybrid vehicles, in green but intermittent energy sources, and in smart grids in general. Lithium is a vital raw material for the build-up of both currently available lithium-ion batteries, and prospective next generation batteries such as lithium-air or lithium-sulphur. The continued availability of lithium can only rely on a strong increase of mining and ore processing. It would be an inconsistency if the increased production of lithium for a more sustainable society would be associated with non-sustainable mining practices. Currently 2/3 of the world production of lithium is extracted from brines, a practice that evaporates on average half a million litres of brine per ton of lithium carbonate. Furthermore, the extraction is chemical intensive, extremely slow, and delivers large volumes of waste. This technology is heavily dependent on the geological structure of the deposits, brine chemical composition and both climate and weather conditions. Therefore, it is difficult to adapt from one successful exploitation to new deposits. A few years of simulations and piloting are needed before large scale production is achieved. Consequently, this technology is struggling with the current surge in demand. At time of writing, only 5 industrial scale facilities are in operation worldwide, highlighting the shortcomings in this technology.

Both mining companies and academics are intensively searching for new technologies for lithium recovery from brines. However, focus on the chemistry of brine processing has left unattended the analysis of the sustainability of the overall process. Here we review both the current available technology and new proposed methodologies. We make a special focus on an overall sustainability analysis, with particular emphasis to the geological characteristics of deposits and water usage in relation to mining processes.

Graphical abstract

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Introduction

Lithium has been historically used in the production of ceramic and glass materials, greases, aluminium and others. In the last decade its demand has boosted because of its use in the lithium battery industry. According to the EU, lithium exceeds the threshold for economic importance and it is very close to the threshold of the supply risk (Report on Critical raw materials for the EU. Report of the Ad hoc Working Group on defining critical raw materials, 2014). A continuous and sharp increase in the demand for lithium is expected in coming years, since different types of lithium batteries are the most promising candidates to power electric or hybrid vehicles (Opitz et al., 2017; Evans, 2010). These batteries include both existing technologies, such as lithium-ion, as well as emerging battery technologies such as lithium-air or lithium-sulphur (Winter and Brodd, 2004; Bruce et al., 2012; Van Noorden, 2014; Arias et al., 2018).

While the general public largely associates lithium batteries to portable electronics and electric and hybrid vehicles, high capacity lithium batteries are also strong candidates for a possible solution for the storage of energy for the electrical power grid, i.e. smart grids. Large capacity batteries are needed for the accumulation of green energy, i.e. solar, wind and waves, which are all by nature intermittent energy sources (Brouwer et al., 2016; Pellow et al., 2015; Sternberg and Bardow, 2015; Bazán et al., 2018). In a world that is struggling to move forward towards a larger percentage of green energy, large capacity batteries or energy banks are a must. Indeed, if in a not so distant future we would like our energy matrix to rely to a large extent in renewable energies, energy banks will be needed to inject continuous power to the grid while these intermittent energy sources are either off or not working at their peak (night-time, no wind, no waves) (Brouwer et al., 2016; Pellow et al., 2015; Sternberg and Bardow, 2015). Finally, regardless of the energy source, large capacity batteries are also an alternative for energy accumulation in periods of low demand, allowing for this excess of energy to be re-injected into the grid at peaks of high demand (e.g. unusual cold or hot weather conditions, peak industry times, etc.) (Rahimi-Eichi et al., 2013).

Lithium is currently relatively inexpensive (about 15,000US$ for a ton of battery grade Li_2CO_3), but its price is likely to increase with demand (The Economist, 2016). Lithium is produced from lithium rich brines (dissolved lithium chloride) and hard rock ore (lithium minerals, spodumene, petalite and lepidolite). From lithium rich brines or salt lakes (called salars) comes by far the largest share of the worldwide lithium carbonate production and all worldwide lithium chloride production. Extraction from these salt lakes is the easiest and most cost-effective method (Kesler et al., 2012).

The viability of large scale production of many different types of lithium batteries with well varied characteristics and capacities is largely dependent on the availability of raw materials to build these batteries (Prior et al., 2013). Moreover, the diverse group of industries requiring large amounts of lithium salts, that up-to-date add up to roughly 65% of the worldwide lithium demand (Roskill's Information Services Ltd., 2016; Swain, 2017; British Geological Service, 2016), are also expected to keep growing, albeit at a slower pace, due to an increase in world population. In this context, the sustainability of lithium salts as a raw material can only rely on a strong increase of mining and ore processing.

An industrial mineral strongly associated to renewable and green energies, it would certainly be an inconsistency that the increased production of lithium salts would be associated with non-sustainable practices and contamination. Indeed, concern about mining practices is growing and many questions are being raised in particular amongst the populations living within or close to the Lithium Triangle in South America. Therefore, it is of paramount importance to continue research in an attempt to answer the open questions regarding lithium mining and ore processing, while sustainable solutions should be sought to replace processes of known environmental impact. In this analysis article we aim to discuss the current situation regarding lithium mining and processing, including recently proposed new methodologies with a special focus on lithium from continental brines. We will discuss which are the open questions regarding mining operations, and we will present our interdisciplinary analysis of why we believe some of the proposed new methodologies might not be as sustainable as they present themselves to be, and might actually imply a harsher environmental impact than the currently used technology.

Section snippets

Lithium extraction

Lithium is relatively abundant on Earth, being the 25th more abundant element (Taylor and McLennan, 1985). Lithium is found in more than 150 minerals, in clays, in many continental brines, geothermal waters, and in sea water. Lithium concentration in sea water is very low, averaging 0.17 ppm (Vikström et al., 2013; Talens Peiró et al., 2013). Geothermal waters across the world show varying concentrations from 1 to 100 ppm (Kesler et al., 2012; Kunasz, 2006). While lithium deposits in all the…

Geologic setting of the Puna Plateau and salar characteristics

In order to assess the sustainability of both the current and potential future technologies for lithium salts production, the whole process involving mining, brine processing and waste production/disposal needs to be understood, and the impact of those processes in the specific geographical environment where brines are found needs to be assessed. Because the largest share of lithium resources in brines is located in the Lithium Triangle, in the Andean Highlands of South America, also known as …

Economic shortcomings of the evaporitic technology

Why should research be carried out to find out new brine processing methodologies? There are numerous strong reasons, both from an economic, and from a sustainability perspective.

We will first analyse some economic implications of the current methodology. Above all, the evaporitic process is an extremely slow process. After pumping from the underground reservoirs, brine is poured into huge shallow evaporation ponds and let to evaporate. A period of up to 24 months takes place before the…

Sustainability issues of the evaporitic technology

Beyond the economical driving force to look for new extraction technologies, there are 2 big questions regarding the overall sustainability of the whole process: water usage and waste generation/disposal. In close relation to these issues, rises the question of flora and fauna conservation.

It is of outmost importance to make a difference between the two different types of water that lithium mining from brines makes intensive use of. The first type of water corresponds to brine: high ionic…

New technologies

In view of the current evaporitic technology, different alternatives have been proposed by both academic and industrial researchers. Many researchers have focused on improving lithium extraction procedures from concentrated brines, *i.e.* brines with a Li^+ concentration which is at least three times higher than the natural concentrations found in brine (An et al., 2012; Song et al., 2017; Alurralde & Mehta, n.d.). These are alternatives to Li_2CO_3 precipitation by addition of soda ash, the most…

Water: from waste to resource

As we have just described, the evaporitic process consumes a large excess of water in one of the driest areas of the world (annual precipitations below 300 mm) (Castino et al., 2017). The exact amount of water evaporated per ton of extracted Li_2CO_3 and precise Li^+ recovery values will be dependent on the native brine composition (not only the absolute Li^+ content, but the ratio of Li^+ to other ions), and the details of the specific process used in the fine recovery plant. Because these are…

Conclusions

Lithium is currently extracted from concentrated brines in desertic environments by a relatively inexpensive but extremely slow and relatively inefficient methodology consisting in brine evaporation in open air ponds where the different salts precipitate sequentially, with lithium carbonate being recovered from a concentrated brine in a fine treatment plant at the end of the evaporation process. This technology is only applicable to brines of certain compositions. Even for those brines where…

Acknowledgments

VF and CIG are CONICET Research Fellows. CFB acknowledges a CONICET doctoral fellowship. Funding from Agencia Nacional de Promoción Científica y Tecnológica, through PICT V-2014 3654 and FITR-INDUSTRIA 9/2013 are gratefully acknowledged.…

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