Lithium Extraction from Geothermal Brine in the Salton Sea Region of Southern California

Using the Social Construction of Technology to Study the Effect of Environmental Concerns and Political Strife in Bolivia on their Domestic Production and Export of Lithium and Foreign Relationships in the Lithium Industry

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

Lithium is one of the most essential metals on the market in the 21st century. The USGS reported global lithium production and consumption grew by 21% and 41%, respectively, between 2021 and 2022 (USGS, 2023). The rising demand for personal electronics and batteries to replace internal combustion engines in electric vehicles are examples of where lithium is currently most needed. 80% of total lithium product is used in the battery industry for electric vehicles, electronic devices, and energy storage technologies (USGS, 2023). Growing support for sustainability is a key factor in the continued motivation to use lithium in rechargeable and versatile batteries.

Lithium is extracted from geothermal brines, evaporation ponds, or salt flats. The technical portion of this project highlights the unit operations necessary to acquire lithium from geothermal brine in the Salton Sea region of southern California. The Salton Sea region has a large reserve of geothermal brine that is currently under research for lithium extraction. Geothermal brine can be processed in a flash steam geothermal power plant to produce power while also being repurposed for lithium extraction.

While the Salton Sea region reaps the reward of its geothermal brine supply, other countries turn to mining pegmatite or evaporating brine in salt flats for lithium extraction (Kaunda, 2020). The lithium triangle, composed of Argentina, Bolivia, and Chile, holds 58% of global lithium reserves and utilizes evaporative extraction (Berg & Sady-Kennedy, 2021). Specifically, these reserves are in the Salar de Olaroz in Argentina, the Salar de Uyuni in Bolivia, and the Salar de Atacama in Chile (Kaunda, 2020). In July 2023, the president of Bolivia reported that they hold 23 million metric tons of lithium, confirming that Bolivia contains more lithium in the Salar de Uyuni than any other country on the planet (Ramos, 2023). Although

Bolivia contains more lithium than any other area in the world, they are far from ranking as one of the top lithium exporting countries. Their export and production values are miniscule in comparison to Argentina and Chile, who were responsible for 16.8% and 61% of global lithium carbonate exports in 2021, respectively. In contrast, Bolivia provided less than 1% of total global lithium carbonate exports in 2021 (OEC, 2021).

Countries that currently use evaporative ponds for lithium extraction face resulting environmental problems, such as possible groundwater loss from brine removal and chemical pollution from lithium extraction treatments. Leftover chemicals from the extraction process can pass through the plastic barriers in storage ponds, leading to the contamination of groundwater and soil species (Kaunda, 2020). Specifically, USGS reported that consuming 5 g of lithium is fatal to humans and lithium exposure overall negatively impacts metabolism, neuron communication, and development within invertebrates (Bradley et al., 2017). There are several issues associated with water pollution and land degradation due to all types of lithium extraction that arise in sociotechnical discussions, as they are often seen to affect impoverished and neglected communities.

While the environmental concerns mentioned previously are problematic for most countries that extract lithium, Bolivia has a unique set of political struggles related to their reserves. Bolivia has a complicated history with independence and capitalization of their resource supply. The 1952 Bolivian Revolution was the catalyst for Bolivia to promote independent ownership of their resources, specifically mineral and silver mines (Lunde Seefeldt, 2020). Since then, there have been several examples of uprising against leadership that tries to encourage lithium extraction with or without foreign help. For example, Bolivia had a brief relationship with Germany in 2018, granting them 85% of the lithium products from Uyuni.

However, the Potosi, the community who lives in the area where this project was to be carried out, protested lithium extraction in partnership with Germany and the Bolivian government shut down operations as a result (Lunde Seefeldt, 2020). The political instability exemplified in the government and community seems to capsize any opportunity for Bolivia to reap the benefits of their insurmountable lithium reserves. The sociotechnical section of this study focuses on how both environmental concern and political strife in several different social groups affects lithium exports in Bolivia. Environmentalists, indigenous communities, and nationalists who want either total independence or foreign partnerships are social groups with different opinions on the lithium industry in Bolivia.

The technical processes of lithium extraction are inevitably related to the residual environmental and social consequences. The political and social obstacles in the lithium industry must be discussed and solved to continue sustainable lithium production at a rate that effectively supplies societal demand. Bolivia is one such country where community and governmental issues are possibly quenching their lithium export success. The high supply of lithium in Bolivia doesn't seem to be enough to calm the rapid turnover of their authority and political rule. The relationship between lithium extraction and social groups in Bolivia is important to understand in order to ameliorate problematic situations in this area. The following sections discuss the technical and sociotechnical topics mentioned previously and conclude with their potential influence on the lithium industry.

Technical Topic: Process Design and Analysis of Lithium Extraction from Geothermal Brines

Motivation

Amid growing vehicle electrification efforts, the global market for lithium, a key component in lithium-ion batteries, is projected to rise dramatically. The World Economic Forum estimates that the global demand for lithium will reach more than 3 million metric tons by 2030, a prediction significantly higher than current production capacities (Ying Shan, 2023). With such a rapidly scaling market, the International Energy Agency predicts there will be a global lithium shortage in as few as 2 years (Shine, 2023). Furthermore, while the U.S. has among the highest demonstrated lithium reserves, much of these resources are untapped, with almost the entirety of the lithium in the U.S. being imported. Coupling rapid market growth with significant foreign dependance, the U.S. Department of Energy Geothermal Technologies Office has identified lithium as a “critical mineral” essential to the economic security of the U.S. (Department of Energy, n.d.).

Challenges

Traditional methods of lithium extraction, including underground or open pit mining, are highly energy, land, and freshwater intensive. Furthermore, global lithium reserves are commonly concentrated in South America and China where there are less stringent labor laws, leading to human rights violations (Earnshaw-Olser, 2023).

To decrease reliance on externally sourced and often harmful traditional extraction techniques, a new method of lithium sourcing, direct lithium extraction (DLE), is currently being researched by multiple groups, including the National Renewable Energy Laboratory (NREL). DLE is designed to retrofit to geothermal energy plants, selectively extracting lithium from underground brines before they are reinjected. By incorporating into existing processes, DLE requires less land disturbance than traditional lithium extraction methods (NREL, 2021). Furthermore, water requirements are reduced by relying on the closed loop circulation of underground water. By harnessing waste heat generated by the plant, the energy requirement for lithium extraction is also minimized. DLE has only been executed at small-scales, so the current challenge lies in scaling-up the process to achieve market viability.

Objectives

Our project involves the direct extraction of lithium from geothermal brines in the Salton Sea region of southern California. The final product, lithium hydroxide monohydrate ($LiOH \cdot H_2O$), is collected through a series of operations including lithium adsorption and regeneration, electrodialysis, and crystallization. The proposed process is designed to retrofit to a geothermal power plant. Figure 1 depicts the block flow diagram to accompany the process.

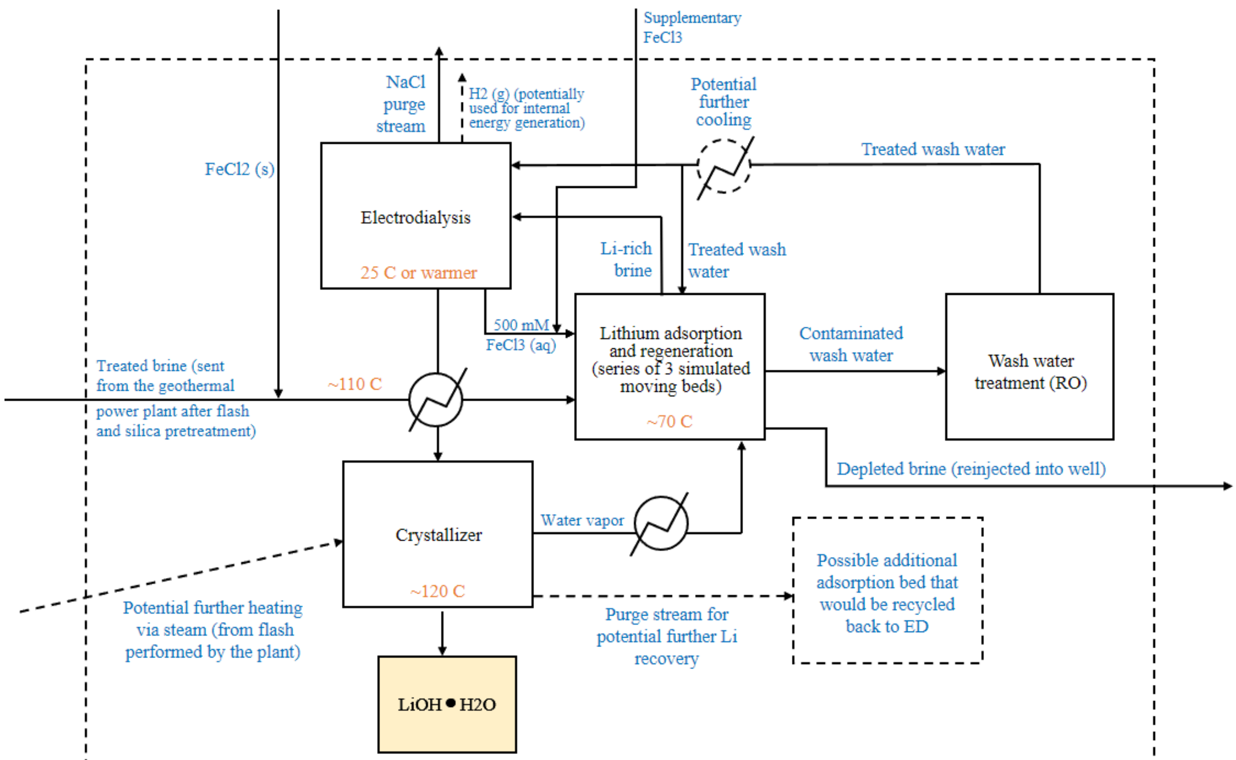

Figure 1. Generalized block flow diagram

Geothermal brine is pumped out of underground wells where it flashes and produces steam. The steam is sent to be used for power generation, which is outside the scope of this process. The plant must treat the remaining liquid brine prior to reinjection; as such, the brine entering will be considered silica-treated at its saturation temperature and atmospheric pressure. Iron (II) chloride powder is first added to the treated brine, supplementing the iron (II) ions already present, to facilitate the adsorption of lithium ions in the downstream adsorption beds. The brine is then transported to a heat exchanger for cooling before it enters the lithium adsorption and regeneration unit, which consists of a series of 3 simulated moving beds. In general, two beds are constantly adsorbing lithium ions onto an iron (III) phosphate bed, along with iron (II) ions, while the third is stripped of all adsorbed lithium.

After adsorption, depleted brine is reinjected into the well while the lithium-concentrated brine undergoes desorption. A stripping solution recycled from the electrodialysis (ED) unit removes lithium ions and regenerates the iron (III) phosphate sorbent. Supplementary iron (III) chloride is added to the stream leaving the ED unit to aid in the desorption process. Following desorption, the spent stripping solution (i.e., the lithium-enriched brine in Figure 1) is sent to the ED unit. In between the adsorption and regeneration processes, the beds are washed with condensed vapor from the crystallization unit. The contaminated wash water is then treated via reverse osmosis (RO). A portion of the treated water is recycled back into the adsorption unit, while the rest of the stream enters the ED unit. Because the ED temperature requirement is lower than that of adsorption, a potential idea is to cool the ED unit using a portion of our treated wash water stream. In the ED unit, lithium ions are drawn through a membrane by an electric current and separated from chloride ions. To maintain charge neutrality, water is split into hydroxide and hydrogen ions, generating lithium hydroxide. At the anode, iron (II) ions are oxidized to iron (III) ions, replenishing the stripping solution that is sent to the adsorber. Additionally, sodium chloride and hydrogen gas purge streams exit the ED. The hydrogen gas stream will potentially be directed to a fuel cell to generate power for this process while the sodium chloride becomes waste. The aqueous lithium hydroxide flowing out of the ED unit is sent through a heat exchanger, where heat from the original brine feed is used, in addition to external heating, to warm the fluid for crystallization. The aqueous lithium hydroxide is crystallized and dried to generate lithium hydroxide monohydrate. If calculations indicate that the purge stream exiting the crystallization unit still contains significant concentrations of lithium, it may be sent to a separate adsorption bed for further recovery. An alternative method, antisolvent crystallization, might be more energy efficient and economically viable than evaporative crystallization. A decision regarding the crystallization method will be made following forthcoming energetic and economic analysis.

Project Plan

Specific data will be obtained from University of Virginia Professors Geoffrey Geise, Gary Koenig, and Gaurav Giri. Additional information will be obtained from literature sources. Most of the process will be modeled using Aspen Plus V14. For other calculations that cannot be done in Aspen, we will use Excel and MATLAB. The team will divide the work amongst the different process blocks, with one member taking "lead" of each unit operation. That said, we aim to be actively collaborating with one another on all calculations, especially if a unit operation requires many calculations, such as the ED or adsorption unit.

Sociotechnical Topic: Using the Social Construction of Technology to Study the Effect of Environmental Concerns and Political Strife in Bolivia on their Domestic Production and Export of Lithium and Foreign Relationships in the Lithium Industry

Bolivia is more lithium dense than any other area on the globe, but community uprisings and leadership instability and turnover seem to outshine their "white gold" supply. This study asks, "How has pollution and political strife regarding the lithium industry affected lithium production, export success, and foreign relationships in 20-21st century Bolivia?" There are several social groups in Bolivia that have different attitudes towards lithium extraction, including environmentalists, indigenous communities, and nationalists who either support or oppose relationships with foreign partners in the lithium industry. Therefore, I plan to analyze this query with the Social Construction of Technology (SCOT) framework using a series of historical analysis and case study methodologies. It's important to evaluate the environmental, social, and political issues in Bolivia as a result of the lithium industry to minimize turmoil in this area.

The lithium extraction industry is familiar with the environmental consequences of their actions. According to one article titled *Bolivia's High Stakes Lithium Gamble*, lithium carbonate and residual potassium chloride production generates 4,000 tons of chemical waste everyday (Perreault, 2020). If handled improperly, these chemicals leach into the exposed groundwater reservoirs that are tapped into for lithium extraction as well as nearby soil. Another example of environmental destruction from lithium extraction is found in the Atacama Salt Flat (ASF) of Chile, an area adjacent to Bolivia but much more experienced in lithium extraction. One study by Liu et al. found that 4 national reserves located by the evaporative extraction mining plant in the ASF underwent higher rates of increasing daily temperature and minimized plant growth from 1997-2017 in comparison to the mainland (Liu et al., 2019). Although these analyses don't explicitly mention Bolivia, it provides context as to what could happen as a result of lithium extraction. These statistics encompass a few of the concerns of environmentalists who are apprehensive to the promotion of the lithium industry in Bolivia.

Besides the environmental dangers of lithium extraction, there are several political issues embedded in the lithium industry. FRUTCAS is a Bolivian grass-roots organization. They were formed by provinces in southwest Bolivia in the 1980s and continue to promote the power of the state to control all aspects of lithium production and exports in Bolivia (Sanchez-Lopez, 2019). These organizations aren't in favor of partnerships with foreign entities in the lithium industry, such as that of China supported by former President Morales. President Morales, who supported a political platform titled “Mining for industrialization”, was an example of a leader that fought for Bolivia’s relationships with other countries in the lithium industry to promote national lithium exports (Sanchez-Lopez, 2019). From 2006-2016, President Morales attempted to provide China with lithium exports for their products in hopes of an economic partnership. They successfully delivered $70,000 worth of lithium carbonate to China in 2016, but the partnership is assumed to have dissipated since Morales’s removal from office (Lunde Seefeldt, 2020). Clarity issues regarding who owns certain salt flats and other extraction sites in Bolivia also contribute to their unclear business relations. For example, the Bolivian state government classifies the Uyuni salt flat as a Fiscal Reserve but doesn’t sufficiently delegate instructions to the regional governments on who should carry out lithium operations (Sanchez-Lopez, 2019). The conflicting viewpoints between those who support and oppose transnational cooperation in Bolivia leads to political gridlock that likely slows lithium production and exports.

While Bolivia doesn’t currently export lithium at the same rate as the rest of the lithium triangle, they have attributed their GDP to other exports in prior years. After President Morales’s election, he prioritized industry and natural gas exports, consequently increasing the percentage of the GDP that was made up by petroleum and natural gas exports by 0.6% between 2004-2009 (Weisbrot et al., 2009). In 2009, the percentage of Bolivia’s GDP that was accounted for by hydrocarbon exports was 12.1%, the largest portion of the 4 sectors that were compared (agriculture, hydrocarbons, mineral extraction, and manufacturing) (Weisbrot et al., 2009). However, the World Bank reported that GDP growth in Bolivia decreased by 3% from 2021-2022, reflecting a decrease in natural gas exports (World Bank, 2023). In the same report, the World Bank noted that 15.6% of Bolivians lived below the poverty level in 2022. The recent decrease in natural gas exports as well as increase in poverty offer the opportunity for lithium to replace natural gas as a more sustainable and profitable export. It may have the potential to mitigate issues of economic despair and poverty in Bolivia as a result. This study will investigate connections between Bolivia's exports, poverty levels, and politics to understand how the previously identified social groups came to develop platforms regarding lithium extraction and exportation.

Most of the data to answer this question will be gathered from secondary sources including academic literature, reports, and internet accessible databases. This topic focuses on the change in the lithium industry in Bolivia over time as a result of environmental pleas and political turmoil. Therefore, I plan to employ historical analysis and case study comparisons to analyze the gathered data. The Social Construction of Technology framework can be used to compare the various priorities and experiences of each social group relating to lithium extraction, production, and exportation in Bolivia. By using a collection of facts and opinions from varying sources, I hope to understand the interactions between the technical processes behind lithium extraction and environmental and social issues promoted by the lithium industry.

Conclusion

The lithium industry is experiencing pressure to increase their extraction levels to compensate for the rising production of electronics and electric vehicles. The Salton Sea region is rising to this challenge by extracting lithium from local geothermal brine, providing the process for the technical focus of this paper. There are other methods of lithium extraction to contribute to the demand, such as evaporative extraction and salt flat mining. Bolivia has more lithium in the Salar de Uyuni than any other area on the globe. However, clashing social groups in Bolivia along with their temperamental government have made it challenging to export lithium. The sociotechnical portion of this project asks, "How has pollution and political strife regarding the lithium industry affected lithium production, export success, and foreign relationships in 20-21st century Bolivia?” to propose possibilities for their future with lithium. A thorough understanding of the technical process behind lithium extraction provides sufficient background to understand consequential environmental and social concerns. Lastly, this research hopes to discover how the lithium industry could economically benefit from increased production in the Salton Sea region and more exports from Bolivia.

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