DIRECT LITHIUM EXTRACTION FROM GEOTHERMAL BRINES IN THE SALTON SEA REGION OF CALIFORNIA

ANALYSIS OF FOREIGN EXPLOITATION OF BOLIVIA AS A RESULT OF LITHIUM EXTRACTION OPERATIONS

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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

In the late 1970s, lithium-ion batteries (LIBs) emerged as a groundbreaking energy storage solution. Boasting high energy density, fast rechargeability, robust power output, and extended lifespans, LIBs catered to the growing amount of energy storage needs. As climate change concerns and decarbonization efforts intensified, LIBs found a new niche in electric vehicle (EV) markets. With EVs positioned as a pivotal tool in curbing emissions within the transportation sector, lithium-ion battery demand surged, solidifying its role in the future of energy storage.

The United States relies heavily on foreign lithium imports to meet its lithium demands, which is not only costly, but also a humanitarian concern. Lithium extraction operations have historically resulted in the destabilization of the supplier country. The specific case to be examined is Bolivia; home to the Salar de Uyani salt flat, Bolivia has the capacity to supply over 50% of the world's lithium demand (Ahmad, 2020). However, since Bolivia lacked the proper infrastructure to extract and sell lithium on its own, the country invited foreign operators in the late 2010s. This led to the exploitation of Bolivia's resources and people by countries like Germany- jobs were not being offered to Bolivian citizens, local land and water was polluted and damaged, and the country was not given the previously promised profit share, destabilizing their government and economy (Bos and Forget, 2021).

Current extraction methods are time-consuming and energy, land, and water intensive. Additionally, reliance on foreign lithium imports enables exploitation of the supplier's resources and people. Thus, meeting the global lithium demand is not just a technical issue, but a social one as well, and both must be addressed simultaneously.

In the following sections, I propose the direct lithium extraction (DLE) from the Salton Sea region in California to produce lithium hydroxide monohydrate. DLE involves pumping geothermal brine to a processing unit that removes the lithium and reinjects the spent brine back into the source. Using DLE over traditional extraction techniques greatly reduces operation time and water consumption while increasing product purity. DLE is also designed to be retrofitted to geothermal power plants, decreasing land requirements and increasing domestic production (Nicolaci et al., 2023).

Concurrently, I will apply the STS framework of technological politics to analyze the exploitation of Bolivia by foreign operators. Specifically, I will assess how the foreign extraction of Bolivia's lithium supply marginalized Bolivia's citizens and government, resulting in the destabilization of the country's government and economy. The insights drawn from the STS project will be applied to argue for domestic production of lithium by highlighting the negative effects current operations have on supplier countries. The insights will also be used to ensure the design of the proposed process is not unintentionally harming nearby communities, thus creating a sustainable and morally-just lithium extraction operation.

Technical Project Proposal

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 •

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.

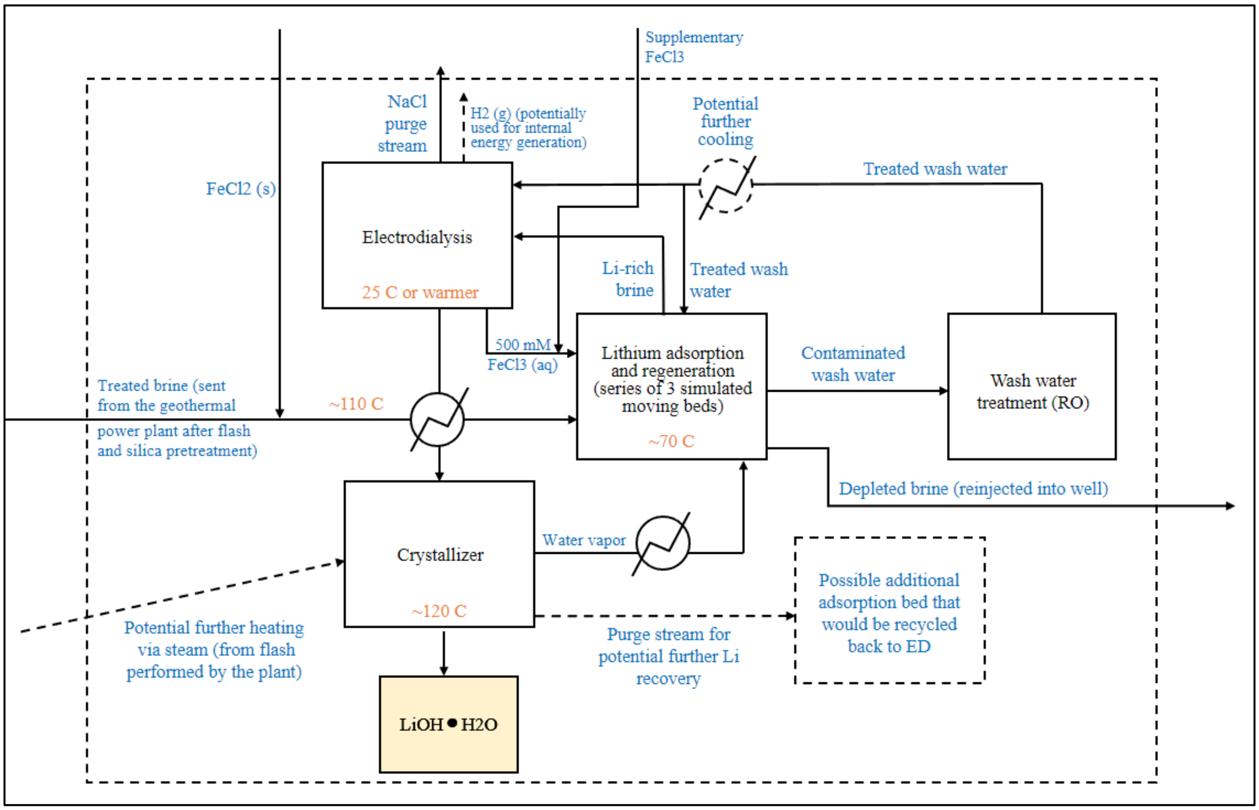

Figure 1. Generalized block flow diagram

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 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.

STS Project Proposal

The Lithium Triangle, comprised of Chile, Argentina, and Bolivia, is home to more than 75% of the world's lithium supply beneath its salt flats (Figure 2). Notably, Salar de Uyani, located in Bolivia, is the world's largest salt flat- Uyani spans over 4,000 square miles and contains 50% of the world's lithium supply. In 2008, Bolivia's President, Evo Morales, launched his campaign for "transferring natural resources back to the Bolivian people," beginning the development of extraction processes from the Uyani salt flat to manufacture lithium compounds and battery cells (Obaya, 2021).

The country lacked the infrastructure and monetary resources to invest in proper equipment- the country imported the most basic manufactured goods, making the project ambitious to achieve without foreign partners (Abelvik-Lawson, 2019). Although President Morales initially excluded foreign partners from lithium extraction operations, the restrictions were relaxed in 2017 to improve production and profit, causing dissent amongst Bolivia's citizens (Hunziker, 2018).

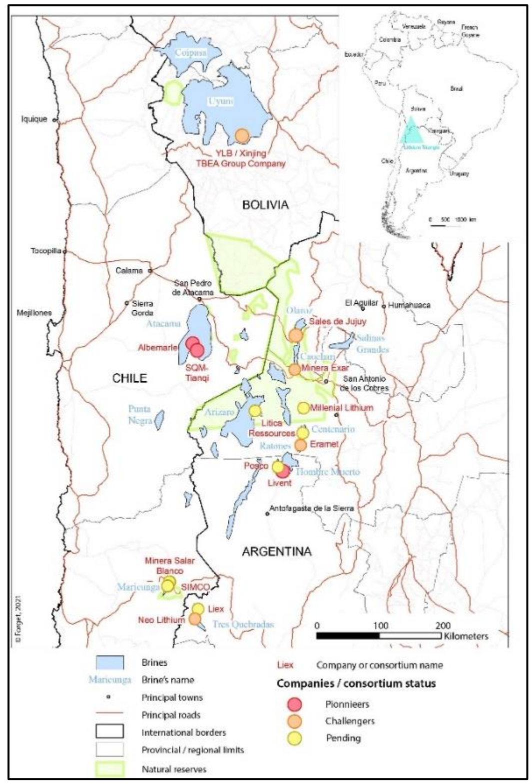

Figure 2. Map of the Lithium Triangle (Bos and Forget, 2021)

In 2018, a public consultation regarding the construction of a lithium carbonate plant was hosted by the State-owned company Yacimientos del Litio Boliviano (YLB). Concerns were publicly expressed by 152 attendees, yet the official report produced by YLB only included endorsements towards development, evidently hosting the consultation for the sake of formality (Carlos Solon, 2022). That same year, the government formed a joint venture with ACI Systems Alemania, a German company, to construct three lithium hydroxide factories in Bolivia for the German battery market. From the German perspective, they were given direct control over the extraction and production stages of the process due to the lack of pre-existing structure of the industry as well as public dissent towards the Bolivian government. Seldom jobs were offered to Bolivian citizens and ACI Systems kept most of the revenue. As a result, the venture was rescinded by the Bolivian government in

November 2019. A similar story was repeated with China in the following years, further destabilizing the country's government and economy (Bos and Forget, 2021).

Presently, the highlighted issues with lithium extraction operations in Bolivia are solely environmental ones- most, if not all the articles, report how current operations are damaging Bolivian water and land (Campbell, 2022). While current operations are indeed destroying Bolivia's environment, this justification fails to report the civil unrest and shaky economy that also resulted. Thus, the push for domestic production is halted under the notion that operations are "only bad for the environment", facilitating the exploitation of Bolivia's resources and people.

I argue that the lithium extraction operations in Bolivia severely marginalized Bolivia's people, and eventually, the country itself. Specifically, I seek to understand how the push for domestic lithium production in Bolivia influenced the government to begin operations it inherently was not ready for, resulting in civil unrest, economic instability, and foreign exploitation. To frame my analysis, I will use the Science, Technology, and Society (STS) framework of Technological Politics. Technological Politics aims to understand how technology affects relations of power and privilege amongst groups of people; specifically, how technology can marginalize some groups while benefiting others, which is exemplified in this case (Winner, 1980). Additionally, I will apply the concept of resource nationalism, which is a country's desire to maintain full control of extracting, producing, and selling its natural resources, to further assess the Bolivian government's push to begin domestic lithium production (Pryke, 2017). Applying these concepts, I will analyze the relationship between the Bolivian government and its citizens and foreign operators as shaped by domestic lithium production. I will utilize reports from Bolivian citizens affected by lithium extraction developments, as well as analyses of foreign exploitation by news outlets, research articles, and Bolivian government reports, to aid my analysis.

Conclusion

The final deliverable for the technical project will be a scaled-up process for DLE fitted to pre-existing geothermal power plants. The design will include detailed calculations, modeling, and simulations to support the proposal. The STS project will analyze the power dynamics between the Bolivian government and its citizens, as well as the dynamic between the government and foreign powers, as shaped by lithium extraction operations. The STS framework of Technological Politics will be used to guide the research. The analysis will be used to justify the need for domestic lithium extraction operations, including DLE, to end the exploitation of South America's Lithium Triangle. The insights will also be applied to understand how lithium extraction operations can be designed to minimize impact to the supplier's resources and people, paving the way for more sustainable lithium production to meet global demand.

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