Design of a Lithium Extraction Plant

The Case of the Potosi Protests

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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

The current global energy sector is overwhelmingly dominated by fossil fuels. With high energy density, fossil fuels boast a long history of implementation resulting in these sources being well understood, relatively optimized and largely integrated into modern society despite being a large contributor of greenhouse gas emissions. Recently, a significant push for decarbonization has grown as concerns over climate change rise. For the scaleup of largely intermittent renewable energy sources such as wind and solar, along with electrification of the transportation industry, requirements for efficient energy storage are increasing as well. The leading technology to meet these demands are lithium ion batteries. However, one complicating factor of this technology is material acquisition. Direct lithium extraction from geothermal brine is one possibility in overcoming acquisition challenges. Development of a lithium extraction plant integrated into an existing geothermal power plant is proposed.

Both technical and social factors contribute to the necessity of such a plant, and thus it is vital to understand the controversial traditional method of underground or open pit mining in developing countries. Drawing on Actor Network Theory, I will investigate the Potosi protests in Columbia where direct extraction technology failed to be implemented. Considering both human and nonhuman actors provides a more comprehensive approach to understand how political inequality and a history of poverty led to public dispute towards adapting a new extraction technology. Because the challenge of lithium acquisition is socio-technical in nature, it is vital to consider both the technology for extraction as well as the social implications in an area that employs lithium extraction. In what follows, I elaborate two related research proposals: a technical project detailing a lithium extraction plant in the Salton Sea region and the examination of the public's opposition to a lithium technology deal. Understanding issues related to lithium mining in developing countries and the failure of such plants in Potosi informs the purpose and importance of the suggested geothermal brine processing plant. The plant will be designed to obtain lithium more sustainably while simultaneously considering the social impacts.

Technical Project Proposal

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 (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.

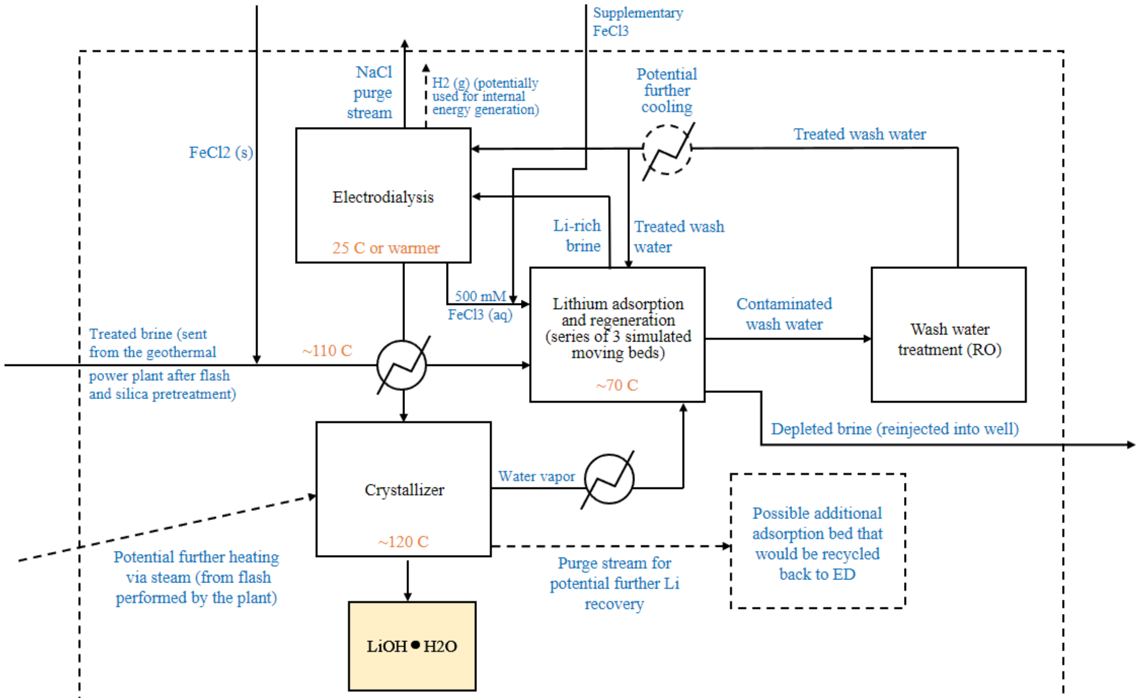

Figure 1. Generalized Block Flow Diagram

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.

STS Project Proposal

Lithium ion batteries are revolutionizing the electricity industry by demonstrating more efficient energy use and storage coupled with reduced environmental impact. Lithium is sometimes referred to as "white gold" due to its current economic value and challenging extraction. In 2022, 130,000 metric tons of lithium were mined worldwide, and this number is expected to continue growing rapidly. Although abundant in the earth's crust, lithium is finely distributed and difficult to extract. About 200 billion tons of lithium are estimated to be in oceans, 98 million tons as deposits in rocks and salt lakes, and about 26 million tons economically mineable in the coming decades. While 47% of global lithium demand was met by mining solid rocks in Australia's open-pit mines in 2022, the world's largest lithium deposits are found in underground salt lakes of Bolivia, Argentina, and Chile (Rueter, 2023).

Typical lithium extraction involves pumping brines into ponds and processing the lithium salts that crystallize after evaporation. While this method works well in Chile and Argentina, lithium found in Bolivia has high levels of impurities. Additionally, the country has several rainy seasons making traditional methods less effective. After observing poor yields, the government invoked aid from foreign governments for direct lithium extraction technologies. In 2018, the Bolivian government headed by president Evo Morales signed a deal with German company ACISA. The Potosi civic committee began protests at the time of the ACISA deal which coincided with the reelection of Morales amid allegations of electoral fraud. Initially, protests caused Morales to cancel the deal, but as protests continued, he was later forced to resign. By some accounts, the protests were due to the fraudulent election in which Morales was reelected in defiance of the constitutional term limit. However, focusing only on the political atmosphere at the time of the protests fails to acknowledge the longstanding history of poverty in Potosi after exploitation of its resources. Attributing the failure of the deal to political conflicts neglects the underlying explanation for the public's defense and allows for the repetition of a detrimental cycle (Reed, 2023).

In the case of the Potosi protests, I argue the public's learned distrust led to failure in technological advancements of lithium extraction methods. My analysis draws on the science, technology, and society (STS) concept of actor-network theory (ANT) in which all actors must be accounted for and recruited towards a common goal for a network to function well (Callon, 1987). ANT studies the activity of network builders who recruit human and non-human actors to construct heterogeneous networks to solve a problem or accomplish a goal (Callon, 1987). Specifically, I will discuss how the government network builder was unsuccessful in the formation of a direct lithium extraction plant due to a failure to recruit the vital actor of the community. To undertake this analysis, I will utilize evidence from interviews with citizens and news articles detailing the protests to provide information about the rogue actor that caused the network to fail.

Despite the government's desire for outside aid in development of direct lithium extraction processes, the people of Bolivia in which the plants would be built have historically opposed deals with foreign nations (Köppel, 2023). When considering the implementation of massive technology that affects the natural ecosystem, the promise of jobs, money, and development for the region may be outweighed by concerns of water stability and harmony with nature (Reed, 2023). Although a foreign government was successfully recruited, the deal between the Colombian government and ACISA was criticized for violating Bolivia's interests and the public was a rogue actor unaccounted for in the deal (Köppel, 2023). Another contributing factor to this opposition was the distrust of the citizens of Potosi towards both their own government as well as foreign governments (Köppel, 2023). Following exploitation of a nearby silver mine producing riches for colonizers and poverty for the Potosi public, the people must be assured of the sustainability and benefits of a new lithium extraction plant to be recruited to support such a technological undertaking.

Conclusion

The deliverable for the technical problem discussed in this paper will be a full design of a lithium extraction processing plant integrated into an existing geothermal power plant in the Salton Sea region. With detailed modeling and calculations, the plant will be accurately designed to achieve economically viable lithium extraction. The STS research paper will strive to understand the lack of direct lithium extraction technology in Columbia as a result of the Potosi protests and public sentiment. This will be accomplished by applying Actor-Network theory to characterize the importance of both human and nonhuman actors, and insights on fundamental actors to recruit will be considered in the design of the lithium extraction plant. The combined results of this technical and STS report will serve to address the issue regarding sustainable lithium acquisition for batteries, highlighting key considerations of material procurement and proposing the adoption of direct lithium extraction from geothermal brine.

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