Design of a Processing Plant for Direct Lithium Extraction from Geothermal Brines from the Salton Sea Region
(Technical Paper)

Motivations and Implications of Electric Vehicle-Spurred Cobalt Mining in the Democratic Republic of Congo
(STS Paper)

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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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Prospectus

Introduction

The current global energy sector is overwhelmingly dominated by fossil fuels. Boasting immense energy density and with a long history of implementation, these legacy power sources are well understood, highly optimized, and thoroughly integrated into our modern society. They are also, however, major sources of emissions - particularly greenhouse gasses such as CO_2. As concerns over the global climate emergency rise, there has been a significant push for decarbonization, that is, the adoption of cleaner, more renewable energy sources. In the transportation sector, which accounts for an impressive 36% of energy consumption in the US, several strategies have been proposed to reduce reliance on carbon-based fuels, and in turn, transportation-related emissions (*U.S. Energy Facts*, 2023). Perhaps leading the pack, however, is vehicle electrification. By using lithium ion batteries to fuel vehicles, it is possible to achieve not only significantly reduced emissions, but also improved energy efficiency. Though these advancements are hugely beneficial, there are a number of complicating factors associated with large-scale implementation of EVs. One such factor is material acquisition.

The following sections will focus on 2 distinct but related subtopics. Firstly, focusing on the technical, we introduce a process design and analysis plan for lithium extraction from geothermal brines in the Salton Sea region of California. Secondly, a sociotechnical analysis on the impacts of EV-spurred cobalt mining is presented.

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.

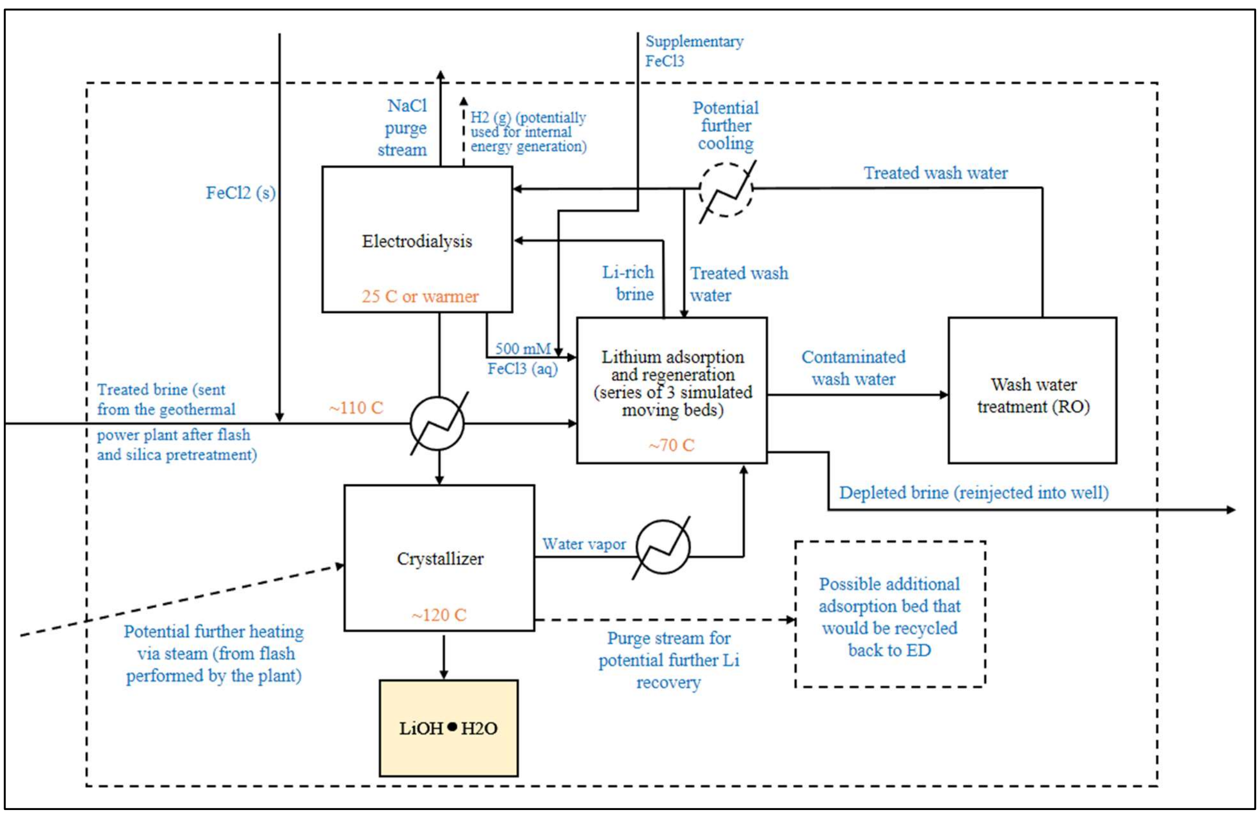

Figure 1. Generalized block flow diagram

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.

<u>STS Topic: Evaluating the Social Impacts of Cobalt Mining in the Democratic Republic of Congo</u>

Objective

The rise of electric vehicles is sometimes referred to as a revolution, conjuring images of battlefields and radical change. Though the development of vehicle electrification is admittedly (and fortunately) not a literal fight, it is in many ways quite an uphill battle. Though technical and infrastructural factors are certainly obstacles, it is equally important to consider the social aspects both affect*ing* and affect*ed* by EV development. The objective of this analysis is to understand the complex and interwoven relationship between the social and technical aspects of the developing EV market. Implementing Co-production of Science and Technology as a guiding framework, this paper will investigate the social factors that underscore the rise of electric vehicles, as well the social impact of this market growth, specifically in the context of cobalt mining in the Democratic Republic of Congo (DRC).

Background and motivation

Lithium batteries can be traced back to the 1970s, when chemist Lewis Urry developed the "lithium metal battery" consisting of a metallic lithium anode and manganese dioxide cathode (*Lewis Urry | Lemelson*, n.d.). Following safety and efficiency concerns associated with dendrite formation on the lithium anode, lithium metal batteries were soon replaced by lithium *ion* batteries. In 1980, scientist John B. Goodenough proposed the use of cobalt oxide as a cathode material, a significant breakthrough which allowed for higher energy density and improved performance (Goodenough, n.d.). As the 90s rolled in, so did wider scale commercialization of lithium ion batteries, notably in laptop computers and camcorders. As portable electronic technologies developed, LIB usage expanded still further as their higher energy density, lighter weight, and longer lifecycle edged out more traditional competitors. The true boom in the LIB market, however, would come in the mid 2000s as LIBs found their niche in the emerging electric (EV) and hybrid electric vehicle (HEV) markets. Intuitively, this rapidly growing EV and HEV market translated to significant market growth for materials involved in LIB fabrication. For several of these materials, demand quickly overpowered supply and material acquisition efforts were forced to scale rapidly. Generally considered the least plentiful and most expensive raw material used in LIBs, cobalt rose to particularly high demand. Demand which the DRC, home to a staggering 48% of global cobalt reserves, took advantage of and soon began to dominate (*Global Cobalt Reserves by Country 2022*, 2023). While this boom promised significant economic growth for the DRC, the intensity of the market paired with volatile governance, economic desperation, and lack of alternative livelihoods, led to unlicensed and risky “artisanal mining”. These unregulated practices have brought concerns over working conditions, child labor, and environmental impacts - problems that must be understood and addressed as the EV market only continues to grow.

Co-production of Science and Social Order (CPoSSO)

The Co-production of Science and Social Order theory emerged in the late 20th century largely in response to critiques over traditional views of science as an objective and neutral entity. Contrasting these ideas, CPoSSO emphasizes the inherent, inextricable, and interdependent relationship between social, cultural, and political factors and scientific development. CPoSSO posits that scientific knowledge and practices have a significant impact on shaping social norms, policies, and institutions, and in turn, existing norms, policies, and institutions affect the direction and manner in which technology develops (Jasanoff, 2004). Proponents of CPoSSO laude the emphasis on considering diverse perspectives and interests in the production of technology, as well as the understanding of science as a dynamic being, subject to evolving social contexts. Conversely, critics argue that this theory may undermine the credibility of empirical evidence and ability of science to provide objective insights. Despite these critiques, if used carefully, CPoSSO can be a valuable tool in understanding complex sociotechnical phenomena, such as those discussed in this presentation.

Analytical Plan

The analysis presented in this paper will be broken into 2 main sections. Firstly, I will explore the factors which spurred the development of electric vehicles. Focusing on political, cultural, and economic motivators, I will seek to understand how these social factors have impacted the EV market and subsequently, raw material markets. Next, I will conduct a more geographically focused analysis, zeroing in on the cobalt mining practices in the Democratic Republic of Congo. This portion will focus on the environmental and human rights issues that arose as a result of DRC mining practices. Though this section will focus primarily on the impact of EV technology on social phenomena, it will also include an investigation of how existing social structures (e.g., policy, leadership, etc) enabled technology to have such a profound social impact.

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