Design of a Processing Plant for the Extraction of Lithium and Other Minerals from Geothermal Brines in the Salton Sea, California
(Technical Prospectus)

How does Cultural Background affect Risk Perceptions of Nuclear Power and Fossil Fuels?
(STS Prospectus)

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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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1. INTRODUCTION

With technological advancements in electric vehicles and batteries, global demand for high-energy density materials, such as lithium, has increased significantly. It is estimated that rising demand will push production of lithium from 447 thousand tons of lithium carbonate equivalent in 2018 to over 2 million tons by 2050 (Stringfellow & Dobson, n.d.). However, there is currently a significant gap between the projected supply and demand for lithium in the future. Therefore, new large-scale sources of lithium will be needed in order to meet the rapidly increasing global demand for lithium.

Geothermal brines are highly concentrated, salty solutions located underground that have been superheated by the Earth's core. These brines are located in various places around the world and offer themselves as a low emissions source of energy. Geothermal brines have become an area of interest as they contain a significant amount of lithium. The lithium in these brines is at a low concentration; only a couple hundred milligrams per liter. However, a geothermal powerplant will take in thousands of gallons of hot brine every minute. Therefore, even at low concentrations, a single well could potentially produce thousands of tons of lithium a year if it can be separated and purified. An extraction plant could utilize the existing infrastructure of the geothermal powerplant in order to lower the cost of production. For our technical project, my team proposes a design for a lithium extraction plant that can be retrofitted to a geothermal brine powerplant in the Salton Sea, California. We aim to create a design that offers both an economical and environmentally conscious method of increasing the production of battery grade lithium.

Increasing the availability of lithium will surely help improve the viability of renewables. However, the truth is that no silver bullet solution does or will ever exist, and thus a variety of approaches will be needed. Wind and solar energy have grown in popularity, but currently lack the grid-scale energy storage technologies capable of providing a constant power base load. On the other hand, nuclear energy is capable of providing base load power while producing almost no emissions. Since its debut in the 1950's, nuclear energy has grown significantly worldwide, currently providing around 17% of the world's energy (*Nuclear Power Today*, n.d.). Despite proving to be an effective large-scale source of low-emissions energy, an apparent strong risk bias exists against nuclear power. These risk perceptions are primarily concerned with accident potential and the management of nuclear wastes.

While there are certainly valid and important criticisms of nuclear power, there is strong evidence supporting 1) the safe implementation of nuclear energy at all stages of its life-cycle and 2) the consequences of continuing to utilize fossil fuels to support our energy needs. However, the anti-nuclear risk bias creates political and economic barriers that prevent the effective large-scale implementation of nuclear energy, leading to a larger dependence on fossil fuels. My STS project will examine a comparative study of risk perceptions of nuclear energy and fossil fuels through the framework of cultural theory, as outlined by Rippl et al (2002). Here, I will advocate for policy that effectively implements nuclear energy while properly reflect the actual risks associated with nuclear power.

2. TECHNICAL PROSPECTUS

Currently, the United States relies on lithium imported from Chile and Argentina, where an energy intensive and environmentally damaging process known as evaporative extraction is utilized (Warren, 2021). Geothermal brines from the Salton Sea in California contain a significant amount of lithium along with trace quantities of other valuable elements, such as rubidium and cesium. Directly adsorbing lithium from Salton Sea brines offers an attractive, environmentally conscious alternative to meet increasing lithium demands. With eleven geothermal wells drawing from the Salton Sea in California, lithium extraction holds the potential to produce $5 billion annually (Jones & McKibben, 2022).

For this project, we propose a plant design to extract lithium and other valuable metals from an existing 6000 gal/min well located in the Salton Sea (Ventura, 2020). At 6000 gal/min of brine feed, a single geothermal brine well has the potential to produce 2500 mt/yr of lithium. The proposed plant can be separated into three distinct sections: pre-treatment, lithium extraction, and alternative products capture. Pretreatment of the feed involves the removal of silicates from brine by introducing calcium hydroxide to precipitate iron silicates, which are then physically filtered from the solution (Koenig, personal communication, 2022). Once silicates are removed, the stream is passed through a boiler, where the hot brine is used to produce high pressure vapor for geothermal power plants (See Figure 2.1).

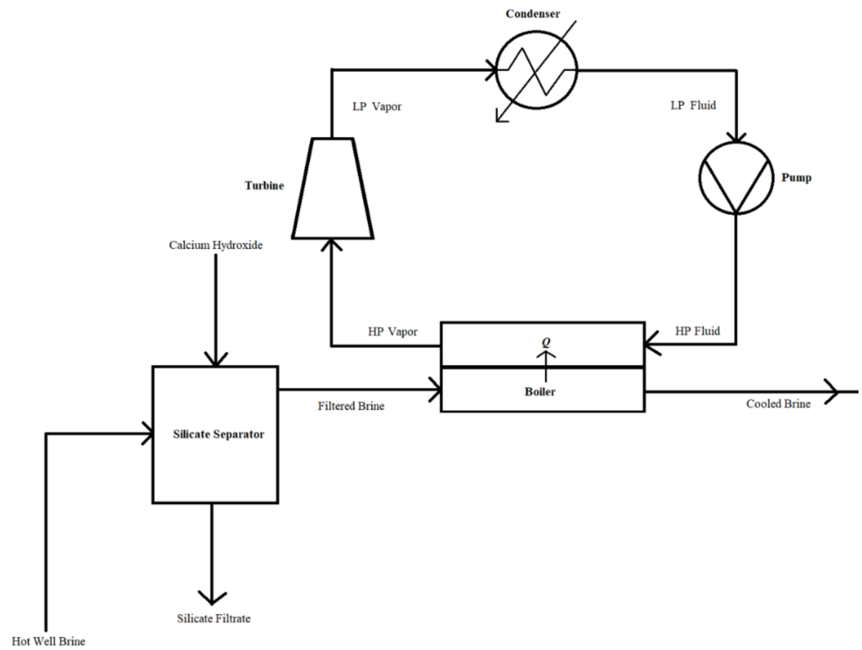

Figure 2.1: *Process Flow Diagram of Brine Pretreatment Process*

After passing through the power plant, cooled brine is processed using a series of packed bed reactors containing iron (III) phosphate, which selectively adsorbs lithium through a reduction-oxidation (redox) reaction (Geise, personal communication, 2022). The spent brine is then sent away for further product extraction. After reaching sorption capacity, iron (III) chloride is then fed to the reactor, which reacts with the lithium iron (II) phosphate to regenerate iron (III) phosphate and lithium chloride. The packed bed reactors are operated such that half are in adsorption mode and half are in regeneration mode to ensure the process is continuous.

Lithium rich brine is then sent to an electrolysis unit, which selectively isolates lithium ions from chloride and iron ions via a redox reaction. Chloride ions from brine (Cl^-) are oxidized at the anode to form chlorine gas (Cl_2), while water is reduced at the cathode to form hydroxide ions (OH^-). Lithium ions pass from the anode to the cathode to form lithium hydroxide monohydrate ($LiOH \cdot H_2O$), which is sent to a crystallization unit for further purification. Oxygen

(O_2) and hydrogen (H_2) gas are produced as side products as well as iron (III) chloride, which can be reused in the reactor. The full lithium extraction process is outlined in Figure 2.2.

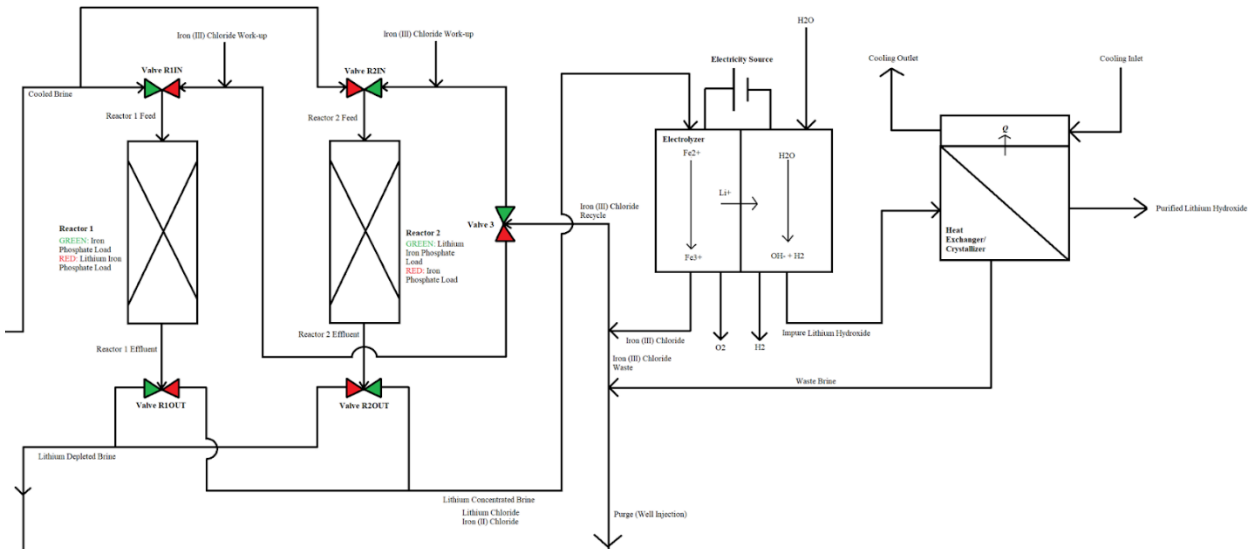

Figure 2.2: *Process Flow Diagram of Lithium Extraction Process*

Additional product capture involves the extraction of alkali metals from spent brines. While only present in small concentrations, rubidium (32 ppm) and cesium (6 ppm) have high market values (Warren, 2021). Rubidium and cesium can be selectively separated from other minerals via an ion exchange process using zeolite-based sorbents (Neupane & Wendt, n.d.). A similar operation structure to the lithium extraction process could be implemented to extract rubidium and cesium products.

For proprietary adsorption and electrolysis unit operations, experimental design data will be sourced from professors Gaurav Giri, Gary Koenig, and Geoff Geise. Additional information regarding other components of the process, such as other alkali metals capture, will be acquired through peer reviewed journals. Data will be consolidated into a thermodynamic model using Aspen Plus design software with the Electrolyte-Nonrandom Two-Liquid equations activity model (ELECNRTL) which has shown to be successful in simulating high temperature and pressure brines in previous literature (Ye et al., 2019). Over the course of two semesters in CHE 4474 and CHE 4476, this project will be completed as a team of five members. Work will be divided equally where each member will focus on a specific unit operation's design and economic analysis; a project management tool, such as a Gantt chart, will be used to assess group progress.

3. STS PROSPECTUS

3.0 NUCLEAR POWER & CULTURAL THEORY

Fossil fuels are generally advantageous as an energy source because 1) they are plentiful and thus inexpensive to procure and 2) they are capable of providing a consistent base load of electricity to an energy grid. Renewables such as wind and solar have seen significant cost reductions in the past few decades (He et al., 2020); however, the energy they generate is intermittent. This variability creates an issue as it leads to periods where either too much or not enough energy is produced. Ideally, excess energy is stored at times of excess generation and offloaded at times of poor generation in order to keep a consistent base load. However, very few energy storage technologies are commercially viable on a grid-level scale. In order to effectively transition away from fossil energy, energy production needs to be capable of providing base load power in addition to producing low emissions. Here, nuclear energy presents itself as a promising solution. Similarly to natural gas or coal fired power plants, nuclear power plants work by producing a high-pressure working vapor that drives a turbine to generate electricity; the main difference being that the heat comes from nuclear fission rather than combustion (Anadón et al., 2012). Since combustion is not utilized to produce heat, no carbon dioxide is released during power generation, making nuclear a low emissions source of energy. Additionally, the consistency and controllability of the fission reaction makes nuclear capable of providing base load power (Davis, 2012).

For several decades, nuclear power has proven to be a reliable and safe source of low-emissions energy; however, many countries are hesitant to pursue nuclear power as a primary energy source due to political and social stigma that surrounds it (Koerner, 2014). Nuclear is generally perceived as a high safety risk, whether due to the fear of accident (Drottz-Sjöberg &

Sjoberg, 1990), the release of nuclear waste, or the proliferation of nuclear weapons (Goldston, 2011). Despite a few high-profile incidents, such as the power plant meltdowns at Three-Mile Island (1979), Chernobyl (1986) and Fukushima (2011), nuclear energy has historically been one of the safest sources of energy available. It is estimated that fossil energy, including coal, natural gas, and oil, have an associated mortality rate per unit of electricity generated that is over 2500x higher than that of nuclear energy (Sovacool et al., 2016). Reasonably, this is due to the plethora of safety regulations that are in place to ensure the safe utilization of nuclear fuel. Additionally, many modern nuclear power plants are designed to withstand the worst of worst-case scenarios.

Currently, the main barrier to nuclear energy is not safety, but cost. In the U.S., the average nuclear powerplant takes 5-6 years or more to construct (Moreira et al., 2013). This is not due to any complexities in the construction process, rather the intense regulatory barriers that slow down the process significantly. This creates an enormous cost of entry barrier that, to many potential investors, makes nuclear too risky to place their dollars on. The investment risk is further perpetuated by the variability of policy; its hard to convince someone to invest in a decade-long construction of a nuclear power plant if the regulations in a couple years could change in a way that makes it even more expensive (Nam et al., 2021). While heavy regulation has contributed to the high level of safety associated with nuclear, some might say that is has been unfairly targeted compared to the immense safety and environmental issues that come with fossil energy. In essence, the perceived risk of nuclear energy is not reflective of the actual risk.

This research aims to focus in on the discrepancy in risk perceptions of nuclear energy versus fossil fuels. Through this research, I will apply the framework of cultural theory of risk as outlined by Rippl (2002). Cultural theory argues that trends in risk perceptions are caused by relative associations with the four “cultural biases” (Rippl, 2002):

- **Individualism** – the values, goals, and rights of the individual should have precedence over the state or a social group
- **Egalitarianism -** all people are fundamentally equal and should be accorded exactly equal rights.
- **Fatalism -** people have no power to influence the outcome of the future with their own actions.
- **Hierarchy** – people should be organized in society based on corporate groups

Each of these cultural biases are based on how one associates themselves within a hierarchical and social group structure (See Figure 3.1). For example, both individualist and egalitarians value less social hierarchy. However, egalitarians value group structure (such as governments), while individualists do not. As an analogy, individualists would likely belong to libertarian political groups, while egalitarians would likely belong to socialists' political groups. Alignment with the cultural biases is measured based on one's "myths of nature", or systems of beliefs that are shaped and internalized by persons. Several studies have been done on nuclear energy in the context of cultural theory, some of which have shown that there is generally no tradeoff between the perceived risk of nuclear energy and the perceived risk of climate change (Bian et al., 2021; McNeeley & Lazrus, 2014) in groups that value less social order (i.e., individualists and egalitarians). . With this research, I aim to expand upon previous research and explore the cultural origin of these risk perceptions and explain why the perceived risk of nuclear energy is much higher than fossil energy despite the greater risk fossil energy presents to the world.

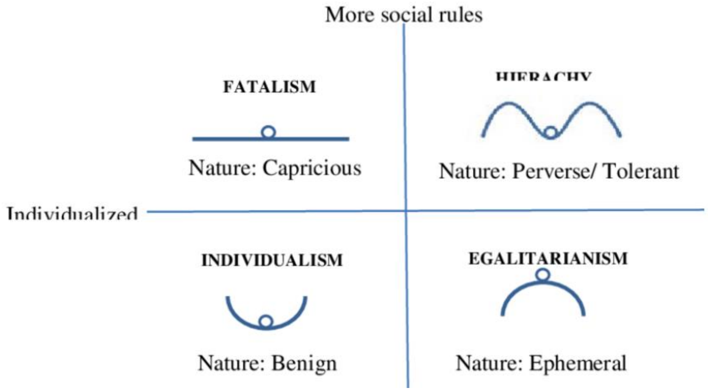

Figure 3.0.1: *Grid-Group Chart for the Four Cultural Biases outlined by Cultural Theory of Risk (Mahmoudi & Knierim, 2015)*

3.1 RESEARCH QUESTION & METHODS

This paper will consider the question: How does cultural background influence risk perceptions of nuclear power and fossil fuels? This question will be analyzed through the framework of cultural theory of risk. Through my research, I will utilize the methods of discourse analysis and reading and synthesizing literature. To facilitate a discourse analysis, I will look at news stories in the United States that pertain to nuclear and fossil energy. Trends in media stories about nuclear and fossil energy will tend to reflect what risks these targeted groups tend to perceive about Through my literature review, I will investigate trends in cultural beliefs for certain groups in the United States. Rippl (2002) outlines a framework for effectively analyzing groups for how they align with the four cultural biases. Combining the results of the discourse analysis and review of cultural background, I will apply the framework of cultural theory of risk to showcase how specific beliefs about nuclear energy risks and fossil energy risks are correlated with the four cultural biases (Cambardella et al., 2020). Furthermore, I will conduct a policy analysis on key energy policy in the past 50 years that has influenced the directions of both nuclear and fossil energy. Here, I will focus specifically on U.S. energy policy, which can be obtained from policy archives. This will help illuminate the impact that cultural biases have had on the implementation of nuclear energy.

3.2 CONCLUSION

My research will both improve the available supply of lithium for lithium-ion batteries and explore the larger social ramifications of energy production. I will investigate the discrepancy in the risk perceptions of nuclear energy versus fossil fuels despite evidence showing that nuclear much safer. Utilizing the framework of cultural theory of risk, I will argue how key cultural beliefs influence the unfair risk perceptions of nuclear energy and thus implementation of anti-nuclear policy. The goal of this research is to communicate with policy makers to develop and implement effective energy policy that safely implements nuclear energy while reducing costly roadblocks.

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