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ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

Pilot Scale Recovery of Lithium from Geothermal Brines

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DISCLAIMER

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission, and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation, and bring ideas from the lab to the marketplace. The EPIC Program is funded by California utility customers under the auspices of the California Public Utilities Commission. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas and Electric Company, and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the Energy Research and Development Division at ERDD@energy.ca.gov.

ABSTRACT

Expansion of geothermal energy production in California will greatly benefit from the creation of a value stream generated from the recovery of useful metals, such as lithium, from geothermal fluids.

The efficient direct extraction of lithium from geothermal brines promises to make geothermal power generation economically favorable and secure lithium production in the United States to support a carbon-free economy.

The purpose of this project was the pilot scale demonstration of lithium extraction from geothermal brines. The direct lithium extraction process was validated on the pilot scale skid with synthetic brine resulting in direct production of lithium carbonate. Extraction of lithium from geothermal brine provides several advantages. At a high temperature, lithium-rich fluid is pumped to the surface, heat is removed from the brine and used to drive a turbine to produce electricity, and lithium is extracted from the brine before the spent brine is reinjected underground. The estimated cost of direct lithium extraction is on par with that of hard rock-based lithium production processes. The direct lithium extraction process permits the rapid processing of brines and extraction of lithium with high recovery efficiency taking hours instead of months and is environmentally friendly compared to conventional production processes.

Further research is needed to increase the sorbent lifetime as sorbent replacement represents a significant part of the operating cost. To ensure suitability of materials of construction and components, the skid should be operated in field at a geothermal site for an extended duration.

Keywords: Lithium, geothermal brine, direct lithium extraction, DLE, lithium carbonate, carbon dioxide, sorbent, regeneration, and Salton Sea

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Executive Summary

Background

Geothermal energy is an important component of the state's energy mix and benefits both the state and investor-owned utility (IOU) ratepayers. Geothermal energy is renewable, essentially carbon-free, and provides reliable baseload power and frequency response features that stabilize the grid. Despite these benefits, the high capital costs and risks of building geothermal power plants have limited the number of new installations.

The creation of an additional value stream generated from the recovery of useful metals, such as lithium, from geothermal fluids will lead to an expansion of geothermal energy production. Lithium production in the Salton Sea geothermal resource area has the potential to become an important source of lithium for the United States. Lithium is found in low but significant concentrations in these geothermal waters (i.e., a few hundred mg/L). Because of the very large volume of brine processed in a geothermal power plant (>6000 gallons per minute), even low-lithium brines represent a valuable resource. The Salton Sea geothermal resource area is believed to have the highest concentration of lithium contained in geothermal brines in the world and is well-positioned to become a competitive source of supply. The expansion of geothermal power production to 1110 MW from existing and announced geothermal plants over the next several years in the Salton Sea geothermal resource area would enable producing up to 320,000 metric tons of lithium carbonate equivalent per year or more than 45 percent of the 2022 worldwide production. The efficient direct extraction of lithium from geothermal brines promises to make geothermal power generation in the Salton Sea geothermal resource area economically favorable and will secure lithium production in the United States in support of a carbon-free economy.

Extraction of lithium from geothermal brine provides several advantages. At a high temperature, lithium-rich fluid is pumped to the surface, heat is removed from the brine and used to drive a turbine to produce electricity, and lithium is extracted from the brine before the spent brine is reinjected underground. The Direct Lithium Extraction process permits the rapid processing of brines and extraction of lithium with high recovery efficiency taking hours instead of the months that conventional evaporation ponds take. It is also environmentally friendly compared to the environmentally destructive conventional production processes of hard rock mining or evaporation ponds.

Project Purpose and Approach

The purpose of this project is the pilot scale demonstration of lithium extraction from geothermal brines using a technology the research team previously demonstrated at laboratory scale.

The process is based on two steps. The first step consists of the selective extraction of lithium from the brine by utilizing a new composite sorbent composed of inorganic lithium-ion sieves and lithium-ion-imprinted polymers that target lithium ions. The second step consists of removing the lithium from the sorbent using desorption driven by carbon dioxide in water. The resulting lithium bicarbonate solution is further treated to remove any divalent metal ions, and concentrate the solution. The concentrated lithium bicarbonate solution is then heated to precipitate high purity lithium carbonate, which is a form of lithium that is desirable for battery manufacturers. This process is a novel solution that eliminates the need to isolate lithium chloride as an intermediate product, thus simplifying process steps and reducing the cost of the Direct Lithium Extraction process.

The project's purpose was to assemble skid-based equipment and subsystems capable of processing up to 10L of brine per minute and demonstrate the selective extraction of lithium as lithium bicarbonate, along with its conversion to lithium carbonate. With the goal of building a portable mobile system, the equipment and subsystems were designed to fit inside a shipping container that can be eventually moved to any site where geothermal brines are available. The pilot system was tested in the recipient's facility using synthetic geothermal brine. An additional goal was to demonstrate that the lithium carbonate production process is cost-effective and compares favorably to the cost of other conventional processes, such as brine evaporation or mining.

A bench scale test system was also employed to test the lifetime operation of the sorbent using actual geothermal brine. The geothermal brine was obtained from a geothermal operator in the Salton Sea area. Before testing, the brine was treated to adjust its pH and to separate silica and heavy metals. Lithium absorption tests were performed at room temperature, 50ºC and 70ºC, successfully demonstrating selective separation of lithium.

The project's technical performance goals include:

- Demonstrate pilot scale operation (up to 10L brine/minute)
- Projected lithium carbonate cost less than $5,000/metric ton
- Projected payback period of less than 5 years
- Achieve technology readiness level of 6

Key Results

The team successfully developed and demonstrated scale-up processes for the preparation of lithium manganese oxide and the sorbent beads containing lithium manganese oxide and a lithium-imprinted polymer. Sorbent bead production was scaled up from 20g per batch in the lab scale project to 1.5kg per batch in the pilot scale project. A total of 54 kg of sorbent beads were prepared, a critical achievement to support the skid-based demonstration system.

Lithium extraction from actual geothermal brine was demonstrated at the bench scale test system to test the lifetime operation of the sorbent. Lithium absorption tests performed at room temperature, 50ºC and 70ºC, successfully demonstrated five hundred cycles of consecutive lithium absorption/desorption steps.

The entire process was validated in the pilot skid using synthetic geothermal brine at a brine equivalent flow rate of >6 liters/minute, resulting in the production of high purity (>99 percent) lithium carbonate. The sorbent for the pilot skid was produced in multiple batches which resulted in some bead size variation. This caused higher than expected back pressure while passing the brine through the sorbent columns. Scaling back the flow rate enabled the system to run at an acceptable back pressure and get useful process data. This also helped in managing the quantity of synthetic brine needed for each test run. As the process development moves forward, sorbent will be produced at a toll manufacturer in larger batches with better quality control. A backpressure problem is not anticipated in the next version. By the end of the project, the lithium extraction process reached a technology readiness level of 6.

The end-to-end process development contributed to updating previous preliminary techno-economic analysis. Based on the current data and process assumptions, the operating expenses are estimated at $6,200 per metric ton of lithium carbonate equivalent and the capital expenses are estimated at $225M for a 25,000 metric tons per year lithium carbonate equivalent plant. This cost is on par with that of hard rock-based lithium production processes. Importantly, it carries distinctive environmental advantages since it does not require a large land footprint, does not generate significant hazardous waste and the spent brine is reinjected underground. The payback period is dependent on the selling price of lithium which has been very volatile. Based on a conservative selling price of $15/kg of lithium carbonate, the payback period is one year.

Knowledge Transfer and Next Steps

During this project, the research team engaged in several activities to share project information with other interested stakeholders and the public.

The pilot skid operation and summary of technical and economic data report was shared with one of the major geothermal operators in the Salton Sea Area.

A member of the research team participated in the Session on Securing California’s Battery Supply Chain of the 2022 EPIC Symposium where the Direct Lithium Extraction process being developed under this project was discussed along with the importance of securing lithium production in the Salton Sea geothermal resource area to support a zero-carbon economy, provide national security and support long-term California competitiveness.

Efforts to commercialize this Direct Lithium Extraction technology will continue through the engagement with geothermal power producers and other entities with lithium resources. Beyond this project, the next goal is to move the portable skid-mounted system to sites where lithium brines are available for an online process demonstration.

Further research is needed to increase the sorbent lifetime as sorbent replacement represents a significant part of the operating cost. To ensure suitability of materials of construction and components, the skid should be operated in field at a geothermal site for an extended duration.

CHAPTER 1: Introduction

Background

Expansion of geothermal energy production in California will greatly benefit from the creation of a value stream generated from the recovery of useful metals like lithium from geothermal fluids. The efficient direct extraction of lithium from geothermal brines promises to make geothermal power generation economically favorable and secure lithium production in the United States in support of a carbon-free economy.

Geothermal energy is an important component of the state's energy mix and benefits the state as well as investor-owned utility (IOU) ratepayers. Geothermal energy is renewable, essentially carbon-free and provides reliable baseload power and frequency response features that stabilize the grid.

Geothermal energy production in California will support the state objective to have at least 60 percent of all state electricity procured from renewable energy sources by 2030 and 100 percent of all electricity procured from renewable and zero-carbon energy sources by December 31, 2045.

An additional target of the State is to reduce greenhouse gas (GHG) emissions to 40 percent below 1990 levels by 2030 and achieve carbon neutrality by 2045. To meet these targets, the State is also introducing new mandates on the sales of new zero-emission vehicles and trucks, including a mandate on all new passenger vehicles sold in the State to be zero-emission by 2035. The electrification of the transportation sector will lead to an increased demand for lithium rechargeable batteries and the critical minerals needed for manufacturing these batteries, especially lithium.

Ensuring lithium production in the United States is therefore critical to support a zero-carbon economy and provide national security. Currently lithium production in the United States is very small, and almost all the global lithium supply is mined in Argentina, Chile, China, and Australia.

Lithium production by Direct Lithium Extraction (DLE) in the Salton Sea Known Geothermal Resource Area (Salton Sea KGRA) is expected to be a more sustainable and environmentally friendly approach to lithium recovery and could become an important source of lithium for the United States. Compared to traditional hard rock mining or evaporation pond processes, DLE does not require a large land footprint or large volumes of water, does not generate significant waste (the spent brine is just reinjected underground), and high purity lithium products can be produced in a timely fashion.

Lithium is found in low but commercially significant concentrations in the geothermal waters of the Salton Sea KGRA (i.e., a few hundred mg/L). Because of the very large volume of brine processed in a geothermal power plant (>6000 gal per min), even low-lithium brines represent a valuable resource. Furthermore, the Salton Sea KGRA is believed to have the highest concentration of lithium contained in geothermal brines in the world and is well-positioned to become a competitive source of supply. The expansion of geothermal power production to 1,110MW from existing and announced geothermal plants in the Salton Sea geothermal resource area over the next several years would make possible production of up to 320,000 metric tons of lithium carbonate equivalent (LCE) per year (McKibben M.A., 2022) or more than 45 percent of the 2022 worldwide production (U.S. Geological Survey, 2023).

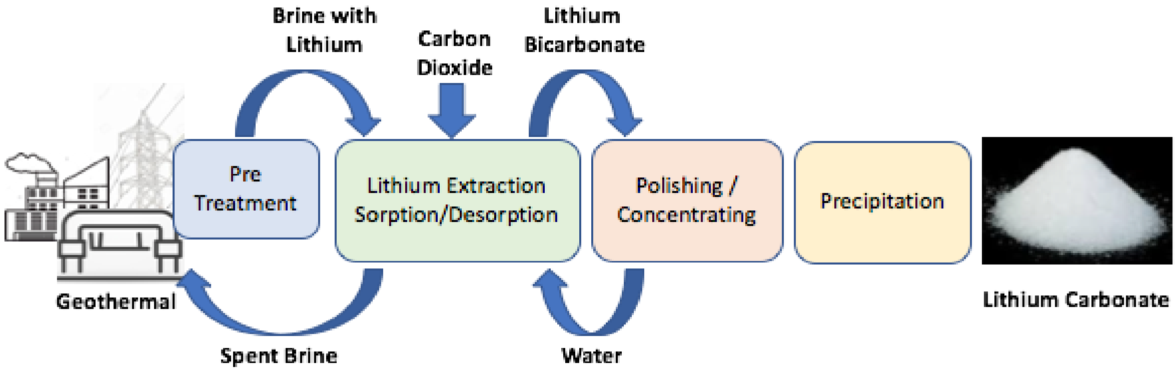
Super-heated natural geothermal fluids present in the Salton Sea KGRA can reach temperatures exceeding 250°C. Under these conditions, while in contact with underground rock formations, they may dissolve a variety of natural mineral underground deposits, including the metals sodium, potassium, calcium, potassium, silicon, iron, manganese, zinc, lead, and lithium (Neupane G. et al., 2017). The concentration of dissolved sodium, potassium and calcium are usually tens of thousands of mg/L of brine, while lithium is usually present in the brine at a relatively low concentration (100-400mg-Li/L of brine). Other dissolved species, such silica, iron, and other heavy metals may also interfere with the processing of the brine. Because of this, the lithium extraction process is required to be selective and efficient. Furthermore, the metal extraction process should not alter the chemical characteristics of the geothermal fluid since it is necessary to reinject it to sustain the geothermal reservoir.

Project Purpose

A laboratory scale solid-phase extraction process was previously demonstrated for the recovery of lithium from geothermal brines based on: (1) a new high-capacity selective composite sorbent that uses inorganic lithium-ion sieves and lithium-ion-imprinted polymers; and (2) a new sorbent regeneration process using eco-friendly carbon dioxide to directly form high-purity lithium carbonate (Li_2CO_3).

This process is based on the selective extraction of lithium from the brine by absorption onto a custom sorbent, followed by lithium desorption driven by carbon dioxide in water. The resulting lithium bicarbonate solution is further treated to remove any divalent metal ions that may be still present in solution, and concentrated. The concentrated lithium bicarbonate solution is then heated to precipitate high purity lithium carbonate. The process is schematically shown in Figure 1.

Figure 1: Schematic Process of Lithium Extraction from Geothermal Brine



Source: Materials Research

The purpose of this project was to demonstrate, at the pilot scale, the process for the recovery of lithium from geothermal brines based on proprietary solid sorbent and CO_2-based regeneration process at temperatures consistent with geothermal operations.

The project technical performance goals include:

- demonstrate pilot scale operation (up to 10L brine/min)
- projected lithium carbonate cost less than $5,000/metric ton
- Projected payback period of less than 5 years
- Achieve technology readiness level of 6

CHAPTER 2:
Project Approach

Process Description

The purpose of this project was the pilot scale demonstration of a low-cost patented process for the extraction of lithium from geothermal brines under laboratory conditions. With previous support from the California Energy Commission, the Department of Energy, and private entities, a new high-capacity sorbent for the selective capture of lithium from brines, and a new sorbent regeneration process based on eco-friendly carbon dioxide that leads to the direct production of high-purity lithium carbonate (Li_2CO_3) was demonstrated at laboratory and bench scale.

Extraction of lithium from geothermal brine provides several advantages. At a high temperature, lithium-rich fluid is pumped to the surface, heat is removed from the brine and used to drive a turbine to produce electricity, and lithium is extracted from the brine before the spent brine is reinjected underground. The DLE process permits the rapid processing of brines and extraction of lithium with high recovery efficiency taking hours instead of months and is environmentally friendly.

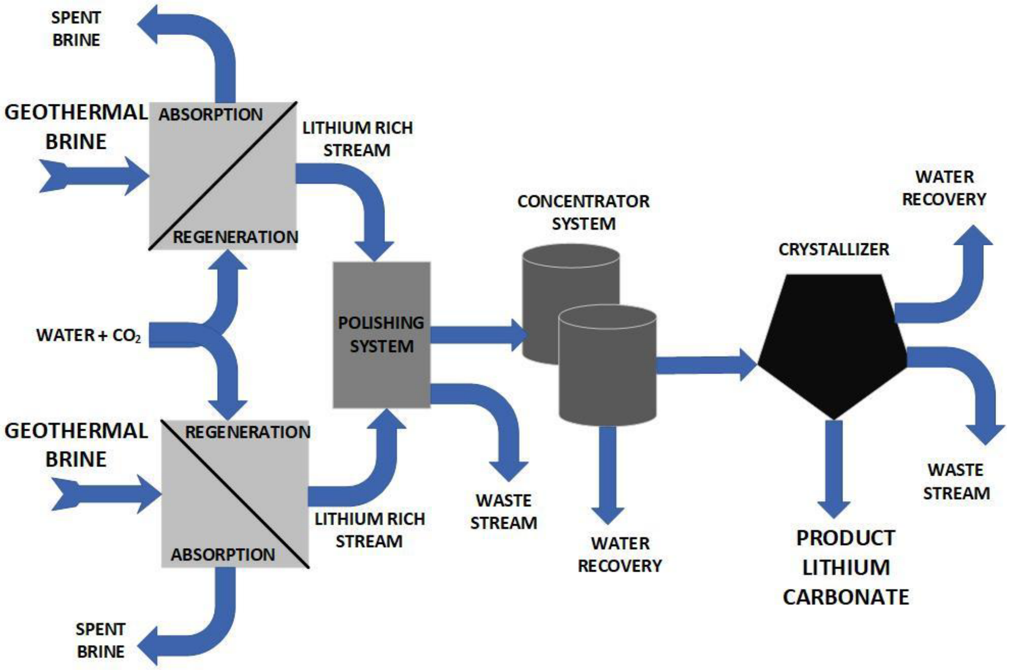
The sorbent beads are comprised of an inorganic lithium-ion sieve, such as hydrous manganese oxide (HMO), and a lithium imprinted polymer. Inorganic ion sieves, such as HMO, have well-known high lithium uptake capacity (Feng Q. et al., 1992), while the Li-imprinted polymer binds lithium ions and enhances its concentration at the HMO-polymer interface, improving the Li uptake kinetics. Furthermore, the sorbent beads were designed to be porous for better contact with the brine liquid phase and enhanced kinetics of absorption.

The brine was initially passed through a fixed sorbent bed that preferentially absorbed lithium ions. After the wash step, carbon dioxide and water were used to release lithium ions and regenerate the sorbent. The resulting lithium bicarbonate aqueous solution was lithium enriched and contained minor amounts of monovalent and divalent metal ions. The regenerated solution was polished to capture the divalent metal ions using an ion exchange resin. The resulting lithium bicarbonate aqueous solution was concentrated, and high purity lithium carbonate was produced by crystallization.

The basic process consisted of four unit-operations: Absorption, Polishing, Concentration and Crystallization. Additional operations included pre-processing brine, water recycling, product washing and drying, return of lithium-depleted brine and waste management. The process flow is summarized in the block flow diagram shown in Figure 2.

Geothermal brine pre-treatment was not part of the project scope.

Figure 2: Process Block Flow Diagram



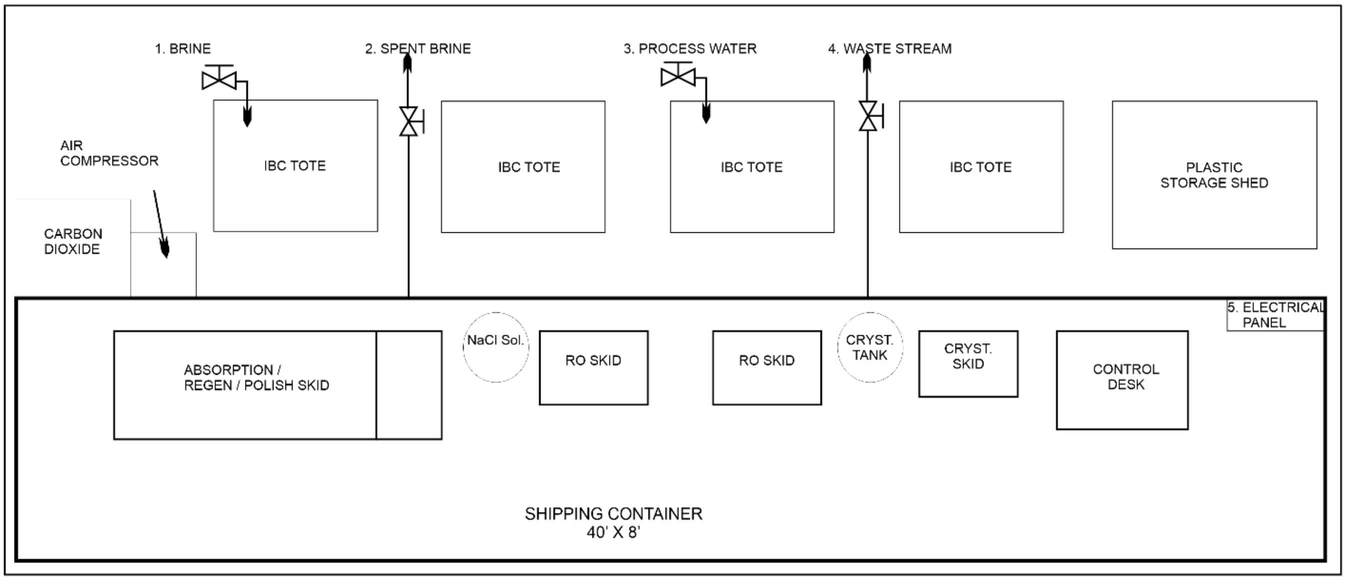
Source: Materials Research

Pilot Skid Design and Fabrication

The skid was designed to fit inside a 40′ shipping container. A 3′ walkway in the front for personnel movement and a 1′ utility corridor in the rear to accommodate plumbing and electrical interconnects were incorporated in the design. Plastic totes were used for storing brine, process water and as intermediate tanks.

Figure 3 shows the general arrangement of sub systems, tanks, major equipment, and utility interconnects. Strut based frames are designed to attach various vessels, pipelines, instrumentation, and valves. Strut based frames provide flexibility in design and equipment changes as may be required during shakedown, operation and maintenance of the system.

Figure 3: General Skid Layout



Source: Materials Research

All equipment sizing was based on a nominal brine flow rate of 10 liters per minute (LPM). Each unit operation was designed to allow cyclic or batch operation, allowing flexibility in system operation where the duty cycle of each unit operation can be adjusted based on conditions at the site to accommodate wide variation of lithium concentration in the source brine.

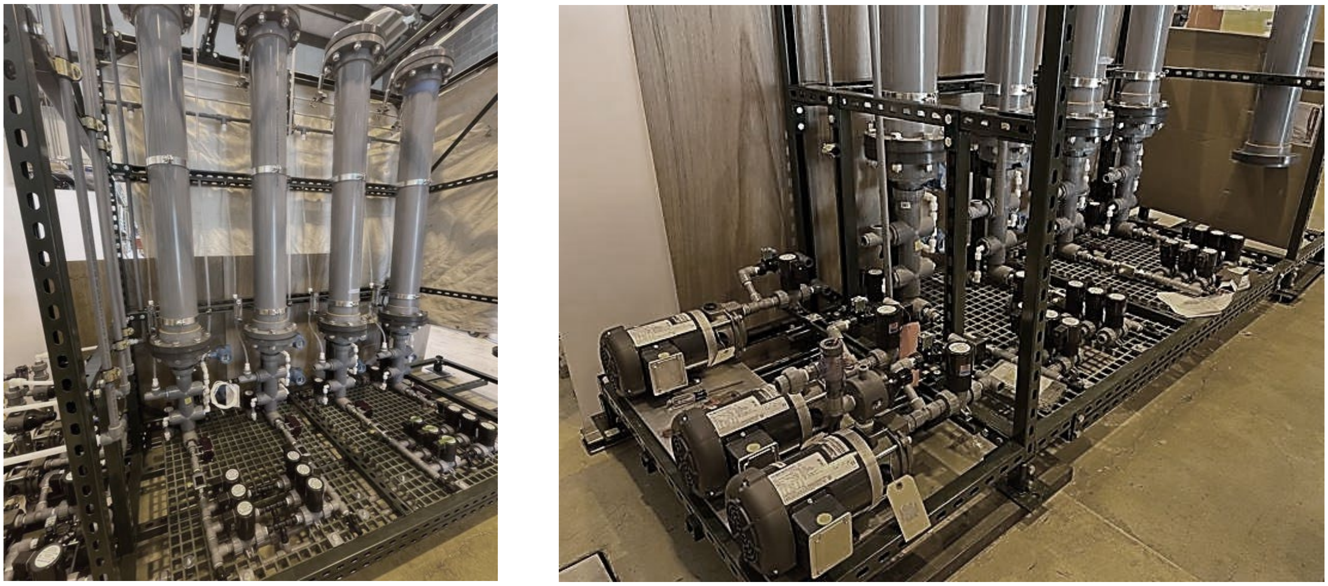
The operating units were separated by storage tanks to add flexibility of operation for the whole system. An automation, control and data acquisition system were designed and installed to operate the system.

Absorption/Regeneration Skid

The absorption unit comprised of two trains of two parallel packed bed columns. The two trains were designed to operate in parallel absorption and regeneration steps. All four columns can also be configured to run in parallel as a single train. The material of construction of the packed bed columns, interconnects, valves etc. was compatible with brines to prevent corrosion. Pumps with stainless steel 316 impellers were used to pump brine and water through the packed bed columns. Figure 4 shows the packed bed columns with associated valves and pumps under construction. Figures 5 and 6 show completed skid and associated components.

The absorption unit consisted of instrumentation to monitor parameters like pH, total dissolved solids (TDS), temperature, pressure, differential pressure, and flowrate. The data was collected and stored using a computer.

Figure 4: Absorption/Regeneration Skid (under Fabrication)



Source: Materials Research

Figure 5: Completed Valve and Instrumentation for the Absorption/Regeneration Skid

Source: Materials Research

Figure 6: Front View of the Absorption/Regeneration Skid

Source: Materials Research

The absorption/regeneration skid was designed to operate at 70 – 90 psig pressure with brine or reverse osmosis (RO) water as the liquid stream and air or CO_2 as the gas stream. During the absorption step, brine was passed at a feedrate of 1-5LPM in each column. The spent brine was collected during the absorption step in the spent brine tank and was reused by replenishing salt concentrations as needed for subsequent runs (i.e., reconstituted brine) for in-house testing with synthetic brine.

After the absorption cycle, the sorbent was rinsed with wash water that was separately collected for reuse/recovery. RO water @ 1-5LPM with air was used during the water wash step. The wash step was followed by the regeneration step with RO water with CO_2.

Polishing System

The polishing system consisted of two columns packed with commercially available ion exchange resin used for water softening. It was operated downstream of the absorption/ regeneration skid. Figure 7 shows the polishing unit under fabrication and after completion.

The Figure also shows associated valves, instrumentation, and an online hardness monitoring unit.

The main purpose of the polishing system was to remove any divalent ions like calcium and magnesium and exchange them for sodium. The ion exchange resin was regenerated using high concentration sodium chloride solution followed by washing with water.

Figure 7: Polishing Unit

Source: Materials Research

Water Recovery and Concentration System

The wash water produced during the wash step following the absorption step was collected in a raw water/wash water storage tank. The water recovery skid was operated periodically to reclaim clean water. Figure 8 shows water recovery and concentrator subsystems.

The purpose of the concentration system was to increase the concentration of the lithium bicarbonate solution before it was fed to the crystallization system, and to recover water.

The water recovery and concentrator subsystems included pressure, flow, and TDS measurements. Density of the concentrated solution was also recorded in the concentrator subsystem.

Figure 8: Water Recovery Subsystem and Concentrator Subsystems

Source: Materials Research

Crystallization Unit

The crystallizer was designed to operate in a batch mode. It utilized a combination of external heating and steam injection to convert the concentrated bicarbonate solution to carbonate and precipitate lithium carbonate. The 30L crystallizer tank capacity was designed to accommodate solutions resulting from 2-3 hours of operation of the concentrator. Each cycle of the crystallizer was designed to produce approximately 175g of lithium carbonate product.

Figure 9: Crystallizer

Source: Materials Research

Process Control Strategy

The process control and data acquisition system was designed to allow maximum flexibility and control by system operators. Each unit operation has an independent control system with either automatic or semiautomatic start, run and stop sequences. The unit operation was integrated using intermediate surge tanks with a capacity of about 1 hour of operation. This control strategy allowed the system to be operated under a wide range of flow conditions based on brine availability and quality (e.g., lithium concentration).

A data acquisition system recorded and plotted data trends real-time from the process instrumentation. This enabled the operator to follow the process progress and take necessary actions for process control. A few closed loop controls were incorporated in the system. This helped operate the system without operator intervention. A mimic diagram showed the status of the valves while process data was displayed along various process lines. Some of the instruments were equipped with local data display.

The system was designed to operate unattended and continuously. Figure 10 shows the computer-based process control and data acquisition system.

Figure 10: Control and Data Acquisition System

Source: Materials Research

Sorbent Preparation

To support the pilot scale lithium extraction from brines, scale up of the sorbent synthesis was demonstrated and more than 50Kg of sorbent beads were produced.

In the previous lab scale process development, a 1L reactor was used to produce about 20g sorbent beads per batch by suspension polymerization. A scaled up and standardized suspension polymerization process in a 10L jacketed glass reactor (Figure 11) was first demonstrated under this project. The 10L reactor was equipped with a Teflon coated stainless steel stirrer with one impeller, a stirrer motor with controller, an external heating/cooling jacket connected to a circulating temperature-controlled water/glycol bath and bottom drain valve to collect the sorbent beads at completion of the polymerization reaction.

Figure 11: 10-L Jacketed Glass Reactor Used for the Preparation of Sorbent Beads

Source: Materials Research

The optimal process conditions for the sorbent synthesis in the 10L reactor was then applied to the preparation of larger batches in a 60L reactor. The 60L reactor system with associated accessories is shown in Figure 12. The glass jacketed reactor is externally heated using a water glycol mixture. The reactor is equipped with a stirrer and an air motor, temperature measurement and controlled gas purge and blanket.

Figure 12: 60-L Jacketed Glass Reactor Used for the Preparation of Sorbent Beads

Source: Materials Research

Brine Procurement

A 65gal sample of geothermal brine was received from a geothermal operator in the Salton Sea geothermal geographical area. Since the amount of geothermal brine received was not sufficient to operate the pilot system, synthetic brine was used instead. The synthetic brine contained only alkaline and alkaline earth metal chlorides in concentrations close to what is found in geothermal brines. Extraction of lithium from the geothermal brine was tested in the 1in diameter column automated system.

Project Advisors

A Technical Advisory Committee (TAC) was constituted at the start of the project to review progress and provide technical and market guidance to the project team.

The TAC included Jason Czapla, Principal Research Engineer at CSIRO (Australia) and previously Principal Engineer at Controlled Thermal Resources (El Centro, California); Pamela Dugan, Business Development Manager at Carus Corporation (Peru, Illinois); Eli Gal, President of EIG Inc. (Sunnyvale, CA) and Robert Miller, President of ExSorbtion Inc. (Miami, Florida).

With their combined experience on geothermal resources and power generation, industrial scale production, desalination and environmental technologies, and mining industry, the TAC provided insights on the state of geothermal power production in California and guidance on handling high temperature geothermal brines including its effect on equipment, and on scaling up sorbent production. The global and domestic lithium market and opportunities for this technology were also discussed.

Key Project Milestones

The purpose of this project is the pilot scale demonstration of the lithium extraction process by developing an automated skid-mounted system that can process geothermal brines at a flow rate of up to 10LPM. A key project goal is to demonstrate the selective extraction of lithium directly as lithium bicarbonate, and its conversion to lithium carbonate. By using proprietary sorbent regeneration based on CO_2, this process eliminates the need to isolate lithium chloride as intermediate, thus simplifying process steps and minimizing cost.

The pilot scale test is a critical demonstration step before this technology can be applied to a commercial scale. With this work the goal was to demonstrate production of lithium carbonate at a cost of about $5,000/metric ton of LCE.

CHAPTER 3:
Results

This project demonstrated on a pilot scale, a new high-capacity sorbent for the selective capture of lithium from brines, and a new sorbent regeneration process based on eco-friendly carbon dioxide that leads to the ultimate production of high-purity lithium carbonate (Li_2CO_3).

Sorbent Scaleup Synthesis

Sorbent scaleup was performed in two steps. First, production of 200g batches in the 10L reactor was demonstrated, followed by production of 1.5Kg batches in a 60L reactor. A total of 54Kg of sorbent was prepared under this program.

Production of Lithium Manganese Oxide

Lithium manganese oxide (LMO) was prepared by lithiation of manganese oxide. For this preparation, both commercial manganese dioxide as well as manganese dioxide prepared in-house from the chemical oxidation of manganese sulfate were used. Lithiation of manganese dioxide was performed by solid state reaction of manganese oxide with a lithium salt.

The resulting LMO was characterized by its X-ray diffraction pattern, surface area and elemental analysis to determine the Li/Mn ratio. The LMO powder was converted to the corresponding HMO and the lithium uptake test was performed to determine its lithium uptake capacity.

A batch production process for producing LMO was developed and a total of over 30 Kg of LMO was prepared.

Commercial as well as in-house produced lithium manganese oxide was then used as starting material for the preparation of sorbent beads containing both lithium manganese oxide and a lithium functionalized polymer.

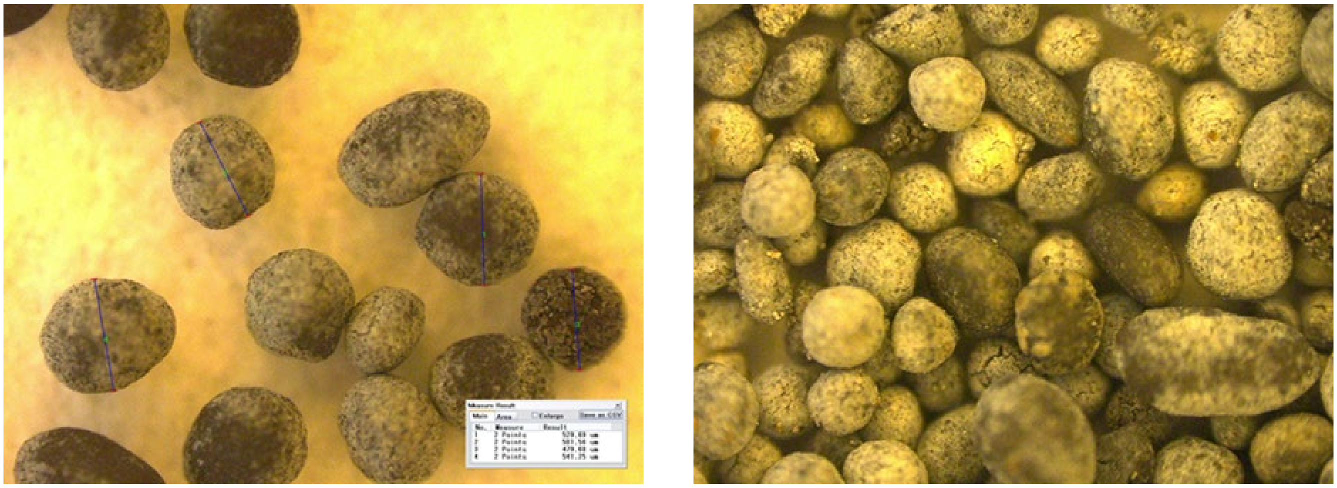
Production of Sorbent Beads

The sorbent beads were prepared by suspension polymerization. The process was first scaled up and standardized in a 10L jacketed glass reactor. Multiple batches of about 200g of sorbent per batch were prepared in the 10L glass reactor to evaluate process parameters including:

- Nature and amount of additives to form an LMO dispersion
- Stirrer speed
- Polymerization temperature and time
- Relative proportion of LMO and monomers.

These preliminary set of experiments led to selection of operating conditions to prepare ~1mm beads with high yields and high loading of LMO (Figure 13).

Figure 13: Optical Microscope Photographs of Sorbent Beads



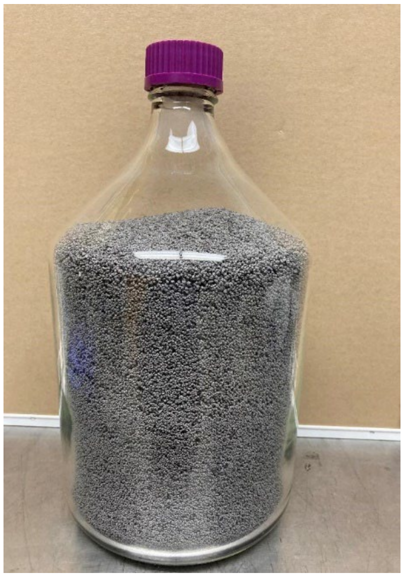
Source: Materials Research

Sorbent Production in the 60L Reactor

The optimal process conditions identified for the sorbent synthesis in the 10L reactor were then applied to the preparation of larger batches of the sorbent in the 60L reactor.

Each production run of the 60L reactor yielded about 1.5Kg of sorbent beads (Figure 14).

Figure 14: Sorbent Beads



Source: Materials Research

Multiple batches were prepared and a total of 54Kg of the sorbent was produced (Figure 15).

Figure 15: Sorbent Beads Produced from Multiple Synthesis Runs in the 60L Reactor

Source: Materials Research

After running multiple sorbent productions in the 60L reactor, the sorbent production process was considered robust and ready to be transferred to a toll manufacturer for production and commercial scale demonstration.

Sorbent Bench Scale Testing

The lithium uptake of the activated sorbent beads was confirmed both in columns with 1cm diameter (lab scale test system, Figure 16), as well as larger columns with 1in diameter (bench scale test system, Figure 17).

Figure 16: Lab Scale Sorbent Testing System

Figure 17: Bench Scale Sorbent Testing Systems

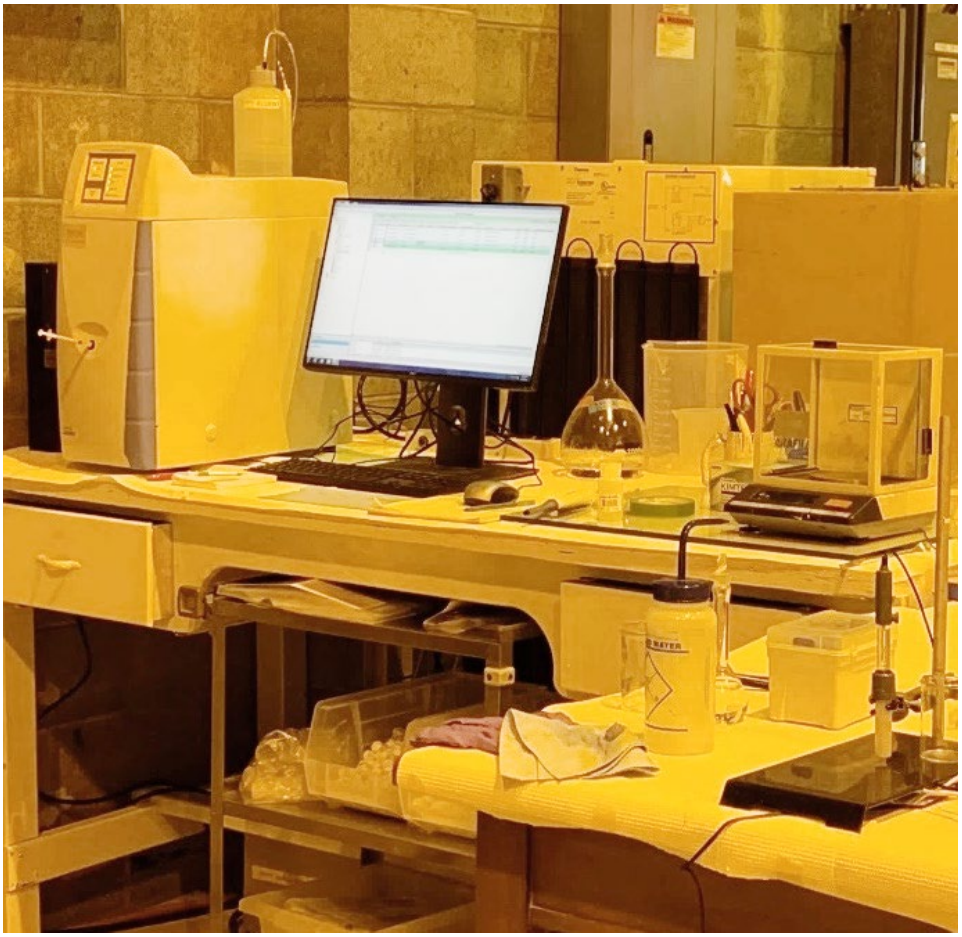
Source: Materials Research

Lab Scale Sorbent Tests

The lab scale system was set up to test each batch of sorbent during scale up and production steps. The 1cm diameter reactors were loaded with 4-10g of sorbent. A few absorption / regeneration cycles were run to determine lithium capacity of the sorbent. These tests were used to validate the sorbent scale-up process.

Liquid samples were collected during each step of absorption, wash, and regeneration and analyzed for lithium capacity as well as rejection of other interfering ions. The liquid samples were analyzed in-house using an ion exchange chromatograph, shown in Figure 18.

Figure 18: Ion Exchange Chromatographs for Cation Analysis

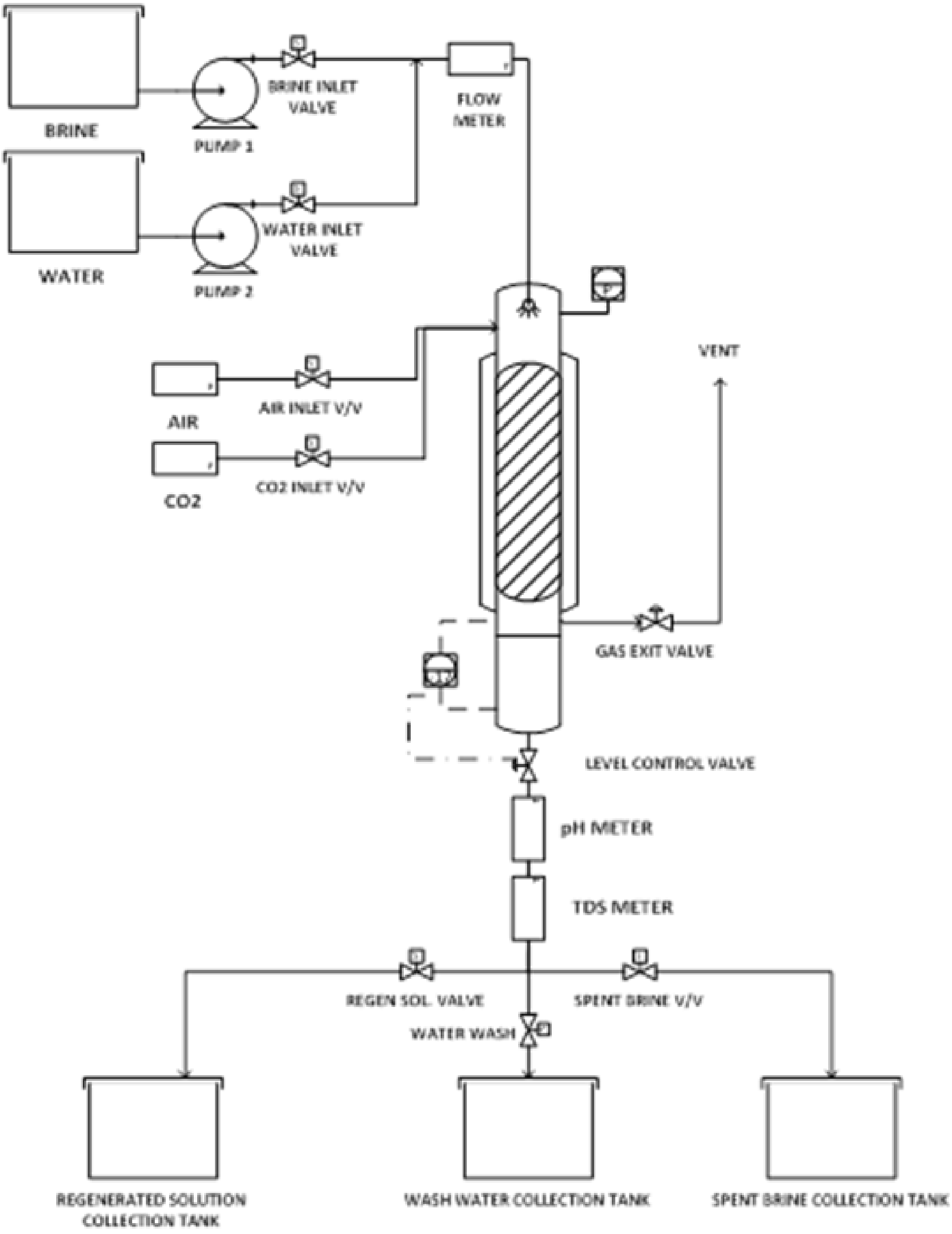


Source: Materials Research

Bench Scale Sorbent Tests

Sorbent batches were also tested using bench scale systems comprised of a 1in diameter reactor that can hold 20-40g of sorbent (Figure 17). A set of pumps, valves, and instrumentation are installed in the bench scale system to automate the operation and data collection. Figure 19 shows a schematic diagram of a bench scale test system.

Figure 19: Schematic Diagram of a Bench Scale Test System



Source: Materials Research

Sorbent replacement constitutes a major cost component of the operating cost of a DLE based lithium production plant. A robust sorbent with a long useful life is therefore very important for reducing the overall operating cost of production.

It has been observed that the lithium uptake capacity of LMO-based sorbents degrades over time. There are many reasons reported in the literature for sorbent degradation, including dissolution of manganese from LMO based sorbent under harsh regeneration conditions (D.-F. Liu, et al., 2019). By utilizing carbon dioxide to regenerate the sorbent instead of hydrochloric acid, extended sorbent lifetime was demonstrated at bench scale testing. Continued sorbent lifetime improvement is warranted to reduce the operating cost of lithium production from brines using the direct lithium extraction process. Frequent sorbent replacement not only takes plants out of operation, but also creates waste in the form of spent sorbent. Long sorbent lifetime is key to reducing waste, cost of sorbent replacement and thus the operating cost.

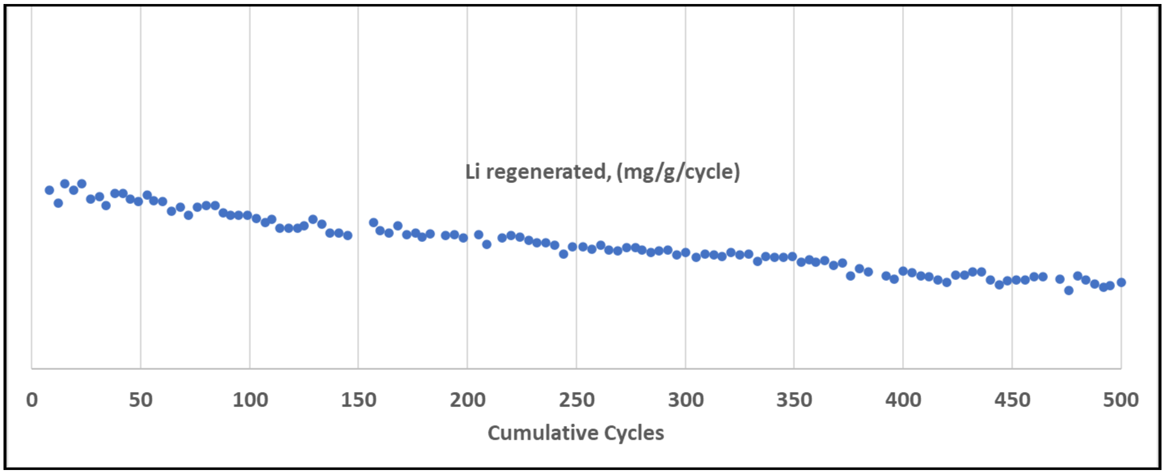
The automated test skid runs alternatively absorption and regeneration steps by passing brine during absorption step and CO_2 with water during the regeneration step. A wash step is included after the absorption step to remove any remaining spent brine from the sorbent.

Spent brine, wash water and regenerated solution are collected and analyzed for weight and lithium concentration to track mass balance for absorption and regeneration.

In addition to continuously cycling the sorbent through absorption/wash/regeneration steps, the bench scale automated skid also collects data including pH, temperature, conductivity, pressure, and differential pressure. This data provides information regarding completion of the step, health of the sorbent and helps with monitoring the process conditions.

Figure 20 shows the lithium sorbent capacity measured at each regeneration step. As shown, the sorbent was successfully cycled five hundred times.

Figure 20: Lifetime Test Results from Bench Scale Test Setup



Source: Materials Research

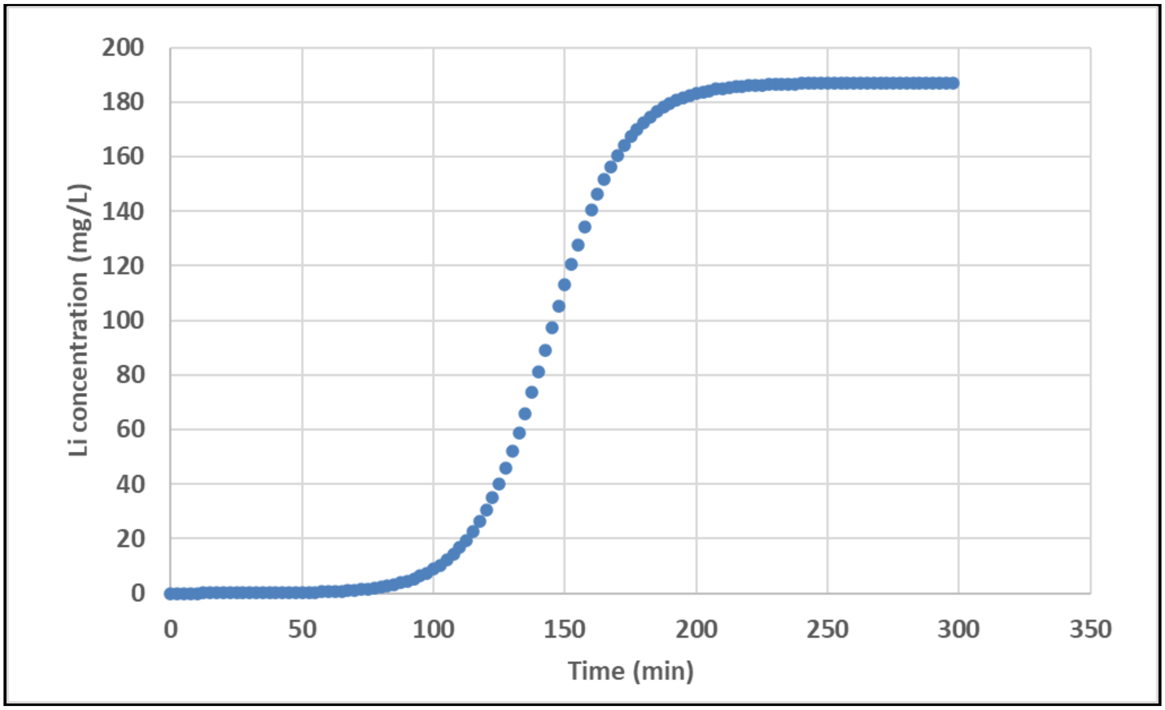
The bench scale setup was also used to determine the effect of brine residence time on the sorbent lithium absorption. A 5ft tall column was set up to replace the standard jacketed 1ft tall column (Figure 21).

Figure 21: Bench Scale Test System Equipped with 5ft Tall Column

Source: Materials Research

The 5ft tall column was loaded with 200g sorbent and subjected to automated absorption and regeneration cycles. A synthetic brine was used for this test. A lithium breakthrough curve was generated by plotting the lithium concentration on various samples collected as a function of time (Figure 22). The Bohart-Adams model was used to determine dynamic lithium absorption parameters from its breakthrough curve. The Bohart-Adams model is widely used to model breakthrough curves in fixed bed laboratory columns and derive parameters, such as time and bed depth, which are needed to design the separation process (Patel, H., 2019).

Figure 22: Lithium Breakthrough Curve Obtained for the 5 ft Tall Packed Bed



Source: Materials Research

Data from 5 ft tall column operation were used to set up the initial absorption/regeneration step timing for the pilot scale skid.

Lithium Extraction Tests from Geothermal Brine

High-temperature geothermal fluids found in the Salton Sea are rich in a variety of minerals and metals, including sodium, potassium, calcium, potassium, silica, iron, manganese, zinc, lead, and lithium. Table 1 shows the Salton Sea geothermal brine chemical composition with average values calculated from values reported in the literature representing post-flash geothermal brines.

Table 1: Salton Sea Geothermal Brine Composition

Analyte	Mean Concentration (mg/L)	Standard deviation (SD)	% Relative Standard Deviation (% RSD)	Number of measurements included (N)
Cl	142,015	18,853	13	13
Na	49,249	5,578	11	13
Ca	25,684	3,050	12	13
K	14,467	3,370	23	13
Fe	1,347	653	48	13
Mn	1,201	393	33	13
Zn	463	169	36	12

Analyte	Mean Concentration (mg/L)	Standard deviation (SD)	% Relative Standard Deviation (% RSD)	Number of measurements included (N)
Sr	434	67	15	12
B	298	69	23	11
Ba	205	57	28	11
Li	202	39	20	13

From: W.T. Stringfellow and P.F. Dobson, Proceedings, 46th Workshop on Geothermal Reservoir Engineering, Stanford University, Feb 15-17, 2021.

One of the Salton Sea area geothermal operators provided about 65gal of geothermal brine for lab scale testing (Figure 23). Before shipment, the brine was acidified to a pH of ~2.5 to avoid any precipitation.

Figure 23: As Received, Geothermal Brine

Source: Materials Research

Before use, the geothermal brine was pre-treated by purging air in the hot brine (Figures 24 and 25) and by adding a saturated solution of NaOH to raise the pH.

Figure 24: Small Scale Brine Treatment

Figure 25: Large Scale Brine Treatment

Source: Materials Research

A vacuum filtration system was set up to separate solids from treated brines as shown in Figure 26. The solids precipitated upon addition of aqueous NaOH were filtered and the brine, referred to as pre-treated brine, was collected (Figure 27). Solids were disposed of as hazardous waste. An analysis of the filtrate showed the presence of various heavy metals, including iron.

Figure 26: Brine Filtration

Figure 27: Solids Collected from Filtration

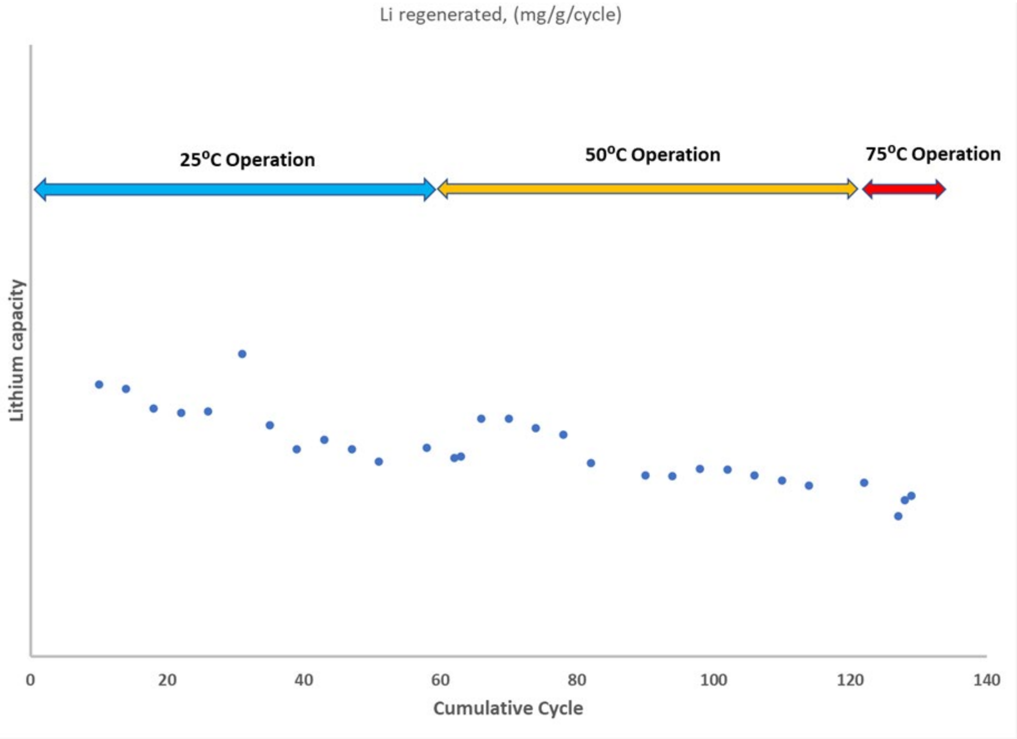
Source: Materials Research

Lithium recovery from the treated geothermal brine was tested using the bench scale automated test skid. A tube-in-tube heat exchanger was added to the system to preheat the brine to a desired temperature. The sorbent vessel was jacketed carrying heated fluid to minimize heat loss during the absorption step.

Initially 60 absorption/regeneration cycles were carried out at room temperature, showing reasonably stable operation. Additional 60 absorption/regeneration cycles were carried out using brine at 50ºC during the absorption step. Subsequently, the temperature of the brine was raised to 75ºC (Figure 28). The sorbent did not perform well at 75ºC. The testing was abandoned after 10 additional cycles at 75ºC.

An analysis of the data showed a rise in differential pressure across the sorbent bed during 75ºC operation. A possible cause of increased differential pressure is swelling of the sorbent when subjected to high temperature. To minimize sorbent swelling, the polarity of the polymer binder may be reduced and its degree of cross-linking increased.

Figure 28: Lithium Capacity as a Function of Cycle Number from Absorption/Desorption Tests Using Pre-treated Geothermal Brine



Source: Materials Research

Pilot Skid Commissioning and Operation

The pilot skid was commissioned to check its absorption/desorption, polishing, concentration and crystallization subsystems for completeness, safety, and suitability for intended operation.

To support skid operation, 300 gal (~1100 liters) of synthetic brine was prepared.

Based on bench scale skid with 1in diameter, 5ft tall column operation, a scaling factor of 36 was adopted for the skid operation with 6in diameter x 5ft tall columns. A total of 7.5kg of activated sorbent was added to column #2 of the skid.

The calculated cycle time for skid operation was set as follows:

- Absorption – 180min
- Wash – 100min
- Regen – 360min.

To ensure safety of operation, it was decided to operate the skid in manual mode and have an operator in attendance at all times.

During the absorption step, brine and air were used with brine fed at 1LPM to 1.5LPM along with air flow to ensure transport of brine through the bottom filter. RO water at 1LPM with air was used during water wash step. The regeneration step was performed using CO_2 and RO water.

Pilot Skid Test Data

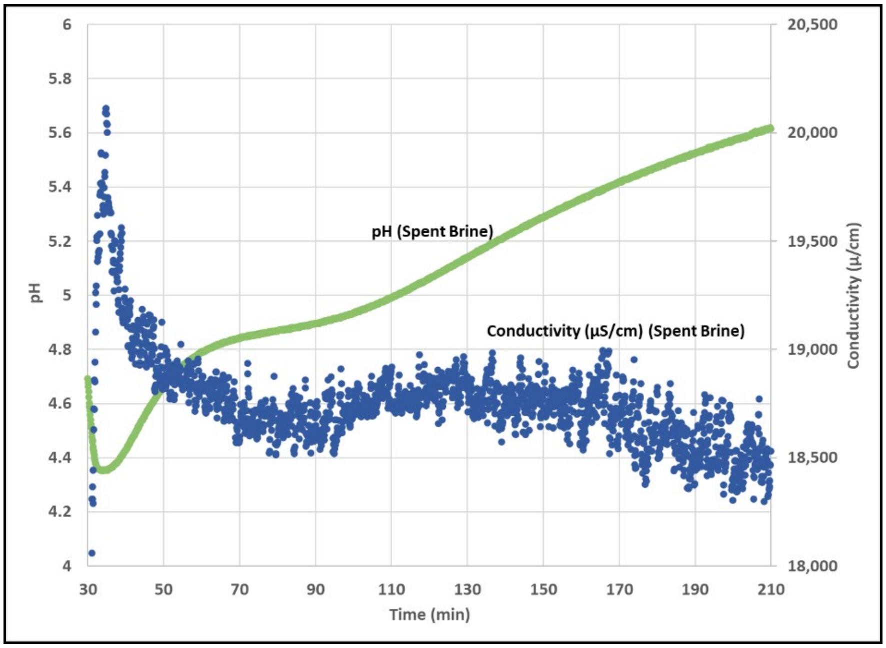
The entire process was validated in the pilot skid at a brine equivalent flow rate of > 6LPM, resulting in the production of high purity (>99 percent) lithium carbonate. Since the sorbent for the pilot skid was produced in multiple batches, there was some bead size variation which caused higher than expected back pressure while passing the brine through the sorbent columns. Scaling back the flow rate from the designed 10LPM enabled the system to run at an acceptable back pressure and get useful process data. This also helped in managing the quantity of synthetic brine needed for each test run. Each absorption run was 4-6 hours long, requiring storing and handling of a significant amount of brine and spent brine. As the process development moves forward, sorbent will be produced at a toll manufacturer in larger batches with better quality control. A backpressure problem is not anticipated in the next version.

Liquid samples were collected during each of the absorption, wash and regeneration steps, and tested to determine the instantaneous values of Li and other ion concentrations. At the end of absorption, wash and regeneration step, the entire collected samples were analyzed for their lithium content to calculate the total lithium absorbed and desorbed at each step.

Absorption Step

In addition to liquid samples analysis, the pilot skid was equipped with several sensors to monitor the process conditions. From bench scale testing, it was determined that pH of spent brine is a good indicator for lithium capture by the sorbent during the absorption step. Figure 29 shows the typical conductivity and pH of the spent brine during an absorption cycle run at a brine flow rate of 1LPM.

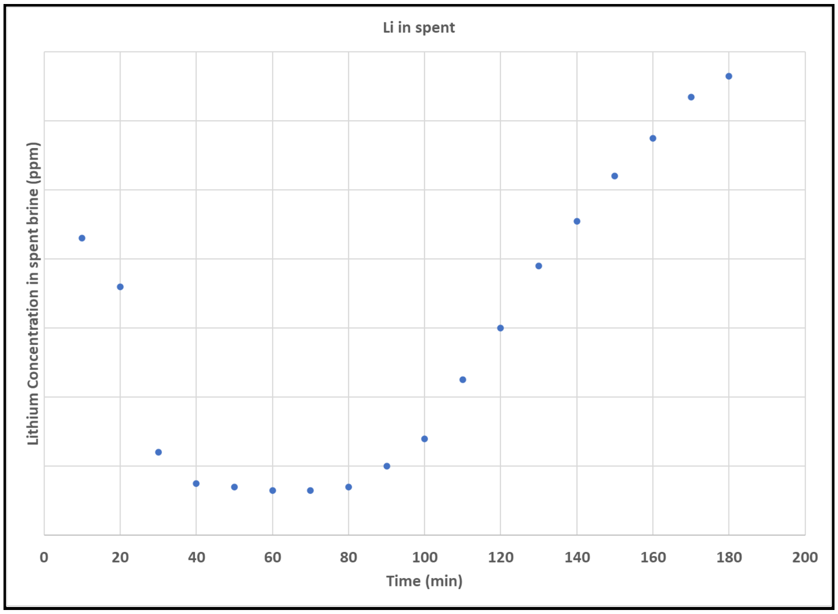
Figure 29: Conductivity and pH of the Spent Brine During an Absorption Cycle



Source: Materials Research

Figure 30 shows a Li breakthrough curve during an absorption cycle. This provides information on Li uptake by the sorbent as well as separation factors between Li and various other interfering ions.

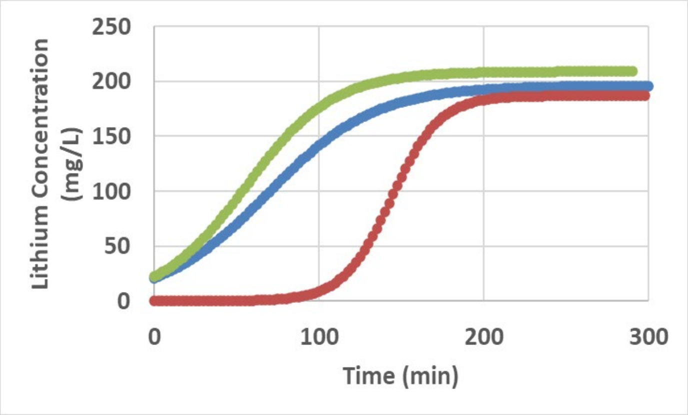
Figure 30: Lithium Breakthrough Curve During an Absorption Cycle



Source: Materials Research

Figure 31 shows breakthrough curves measured at various brine flow rates. The data were fit using a Bohart-Adams model to determine sorbent capacity and kinetic parameters. These results were used to size the columns for desired lithium capture efficiency, model the process and run the techno-economic analysis to calculate operating expenses and capital expenses to build and operate a commercial scale plan for lithium extraction.

Figure 31: Lithium Breakthrough Curves at Various Brine Flow Rates

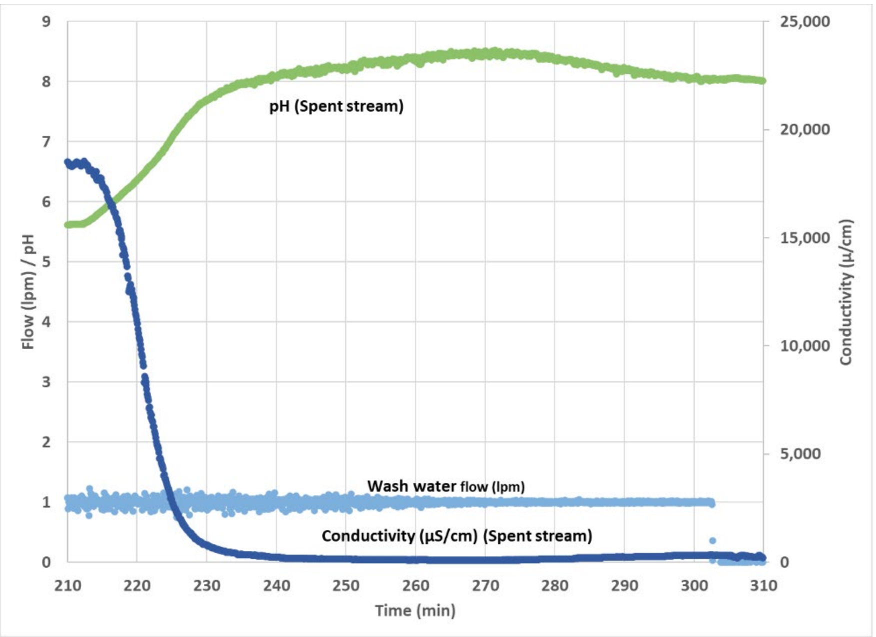


Source: Materials Research

Water wash

RO water was passed through the sorbent to wash and remove any remaining brine before sorbent regeneration. This step ensures that the concentration of interfering ions is minimized in the regenerated solution. In addition to sensor data, liquid samples were taken and analyzed to optimize the wash step flow rate and duration. Figure 32 shows typical sensor data during wash step.

Figure 32: Conductivity and pH of the Stream During a Wash Cycle



Source: Materials Research

Regeneration

In the sorbent regeneration cycle, the lithium captured by sorbent during the absorption step was released by pH swing with displacement of Li^+ in the sorbent by H^+ from an acidic aqueous solution. Conventionally LMO-based sorbents are regenerated by strong acids such as $HCl_{(aq)}$ or $H_2SO_{4(aq)}$ to recover lithium as lithium chloride or sulfate. These salts are subsequently converted to lithium hydroxide or lithium carbonate.

A major innovation in this process is to use carbon dioxide, dissolved in water, to form carbonic acid that releases lithium ion from the sorbent, forming lithium bicarbonate. Upon heating, lithium bicarbonate is converted to lithium carbonate and readily precipitated from the aqueous solution.

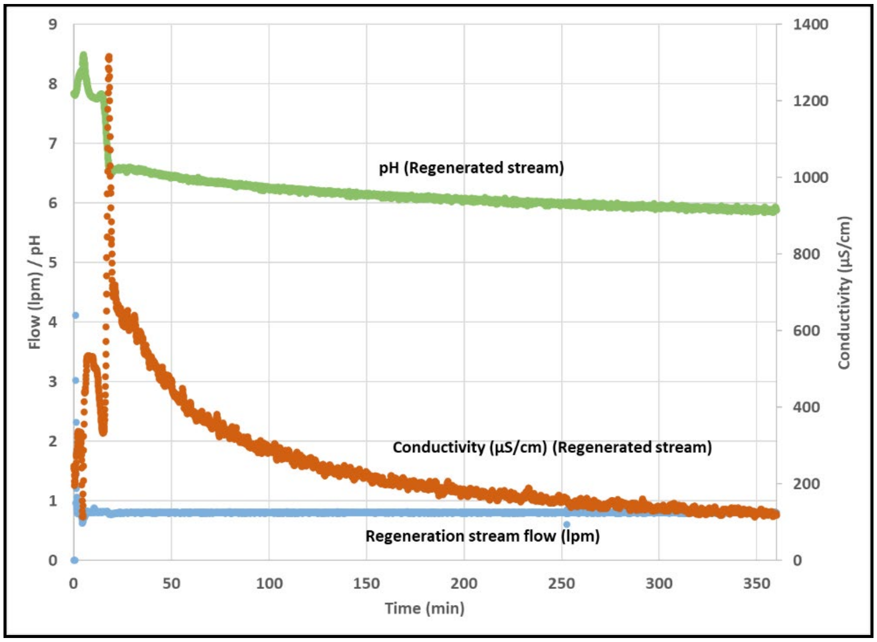
The advantage of using carbon dioxide is twofold. First it directly produces lithium carbonate which is a saleable product and saves a conversion step. More importantly, it was found during experimentation that the use of CO_2 minimizes manganese dissolution from the LMO and thus prolongs the lifetime of sorbent.

Sorbent lifetime is a major contributor to the operating expenses, thus long sorbent life leads to fewer replacements and lower operating expenses for this lithium extraction technology.

Furthermore, the use of carbon dioxide to produce lithium carbonate is environmentally friendly since it eliminates the generation of undesirable acidic process streams and hazardous wastes.

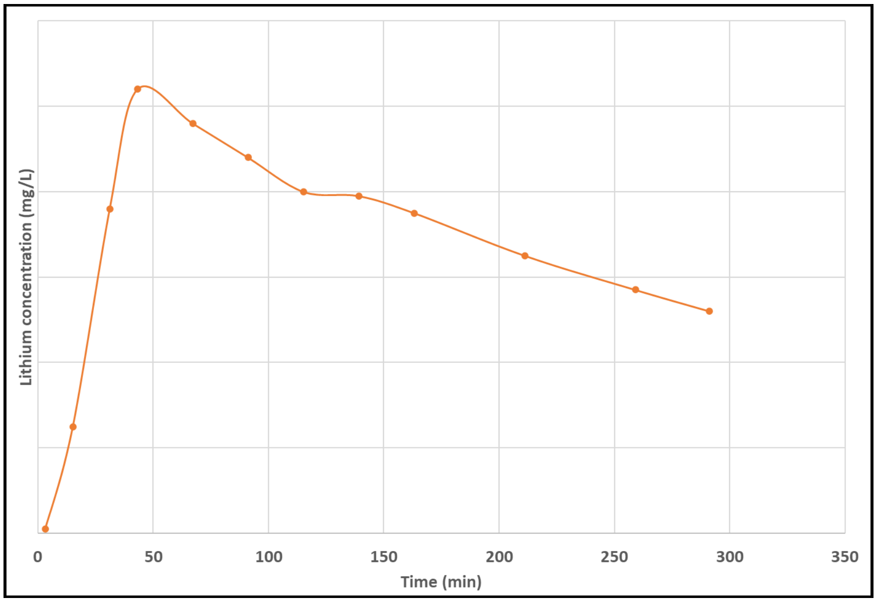
As shown in Figures 33 and 34, conductivity data follow the same trend as the lithium concentration measured in samples collected at various times during the regeneration cycle.

Figure 33: Conductivity and pH During a Regeneration Cycle



Source: Materials Research

Figure 34: Lithium Concentration Measured during a Regeneration Cycle

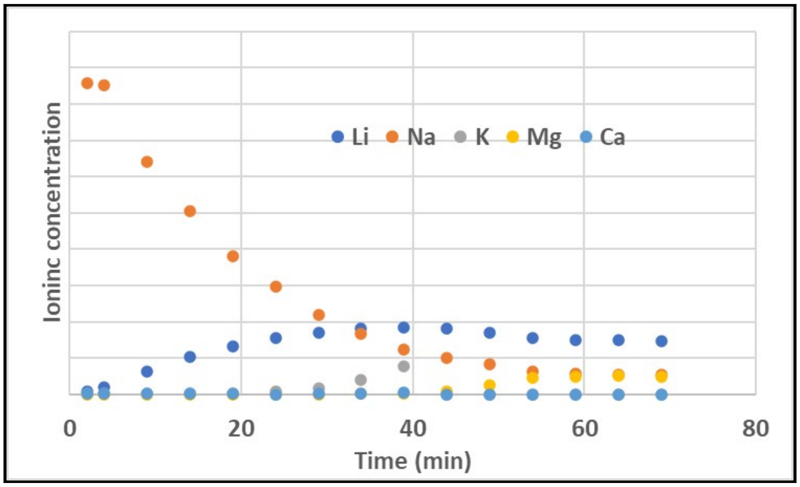


Source: Materials Research

Polishing Step

During the polishing step, a commercial ion exchange resin in the Na+ form is used to capture divalent ions such as calcium and magnesium, while releasing Na+ ions (Figure 35).

Figure 35: Breakthrough Curves of Various Metal Ion Species Present in Solution during a Polishing Cycle



Source: Materials Research

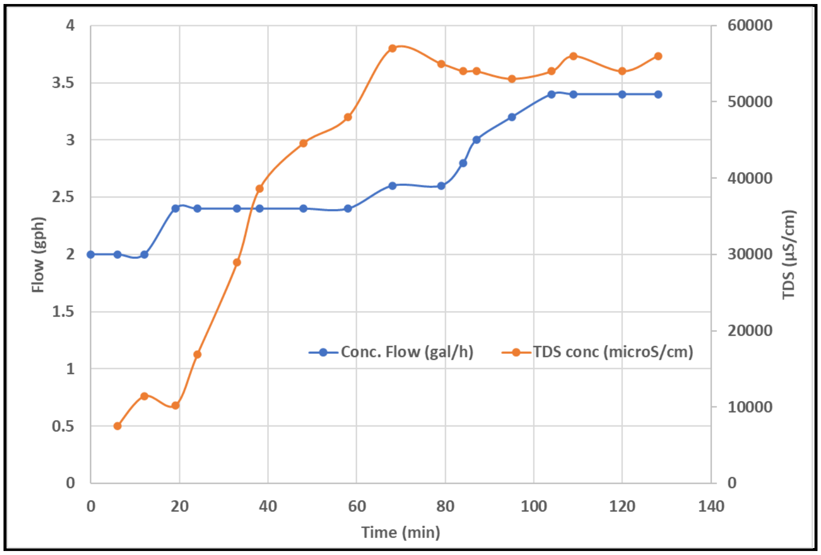
A small magnesium ion breakthrough was observed during polishing. This can be eliminated by modifying the absorption/regeneration cycle of the polishing column.

Concentration System

A membrane-based process was used to concentrate the polished/regenerated lithium bicarbonate stream while recovering water. Liquid samples were collected periodically and analyzed. Due to the large holdup time in the membrane modules, a significant time was required to build up a stable lithium concentration before crystallization. A typical 40 times concentration of the polished solution resulted in a significant water recovery. This is an important step that minimizes water usage in this DLE technology.

During the concentration step, flow rate and total dissolved solids in the form of conductivity of the concentrated solution were typically measured (Figure 36).

Figure 36: Flow Rate and Conductivity of the Lithium Bicarbonate Solution during a Concentration Step

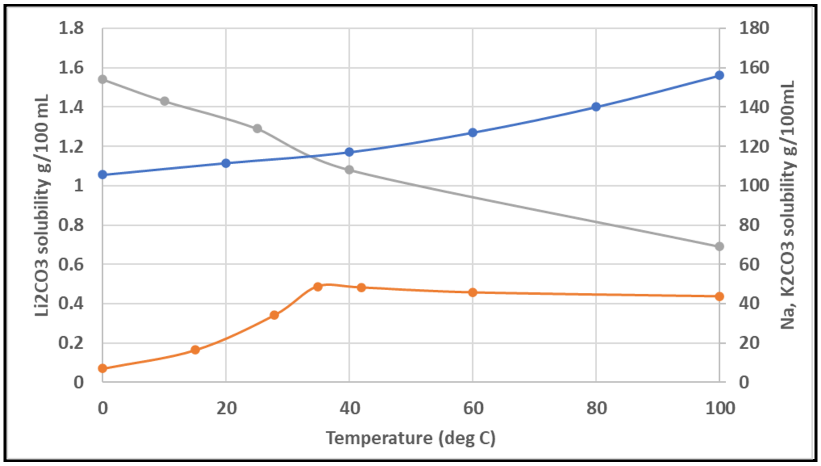


Source: Materials Research

Crystallization

The concentrated lithium bicarbonate solution containing some sodium and potassium bicarbonates was collected in a stainless steel 316 vessel and heated to 90ºC using external heaters. The crystallization step takes advantage of the fact that the solubility of lithium carbonate decreases with temperature while that of sodium and potassium carbonate increase with temperature (Figure 37).

Figure 37: Solubilities of Lithium Carbonate (Grey Line), Sodium Carbonate (Orange Line) and Potassium Carbonate (Blue Line) as a Function of Temperature



Source: https://en.wikipedia.org/wiki/Solubility_table

As the concentrated solution is heated, carbon dioxide is released from bicarbonates, converting them to carbonates. As temperature was further increased, lithium carbonate preferentially precipitates. The resulting solids are discharged from the bottom of the vessel, filtered and dried (Figures 38 and 39).

Figure 38: Lithium Carbonate Filtrate

Figure 39: Lithium Carbonate Samples

Source: Materials Research

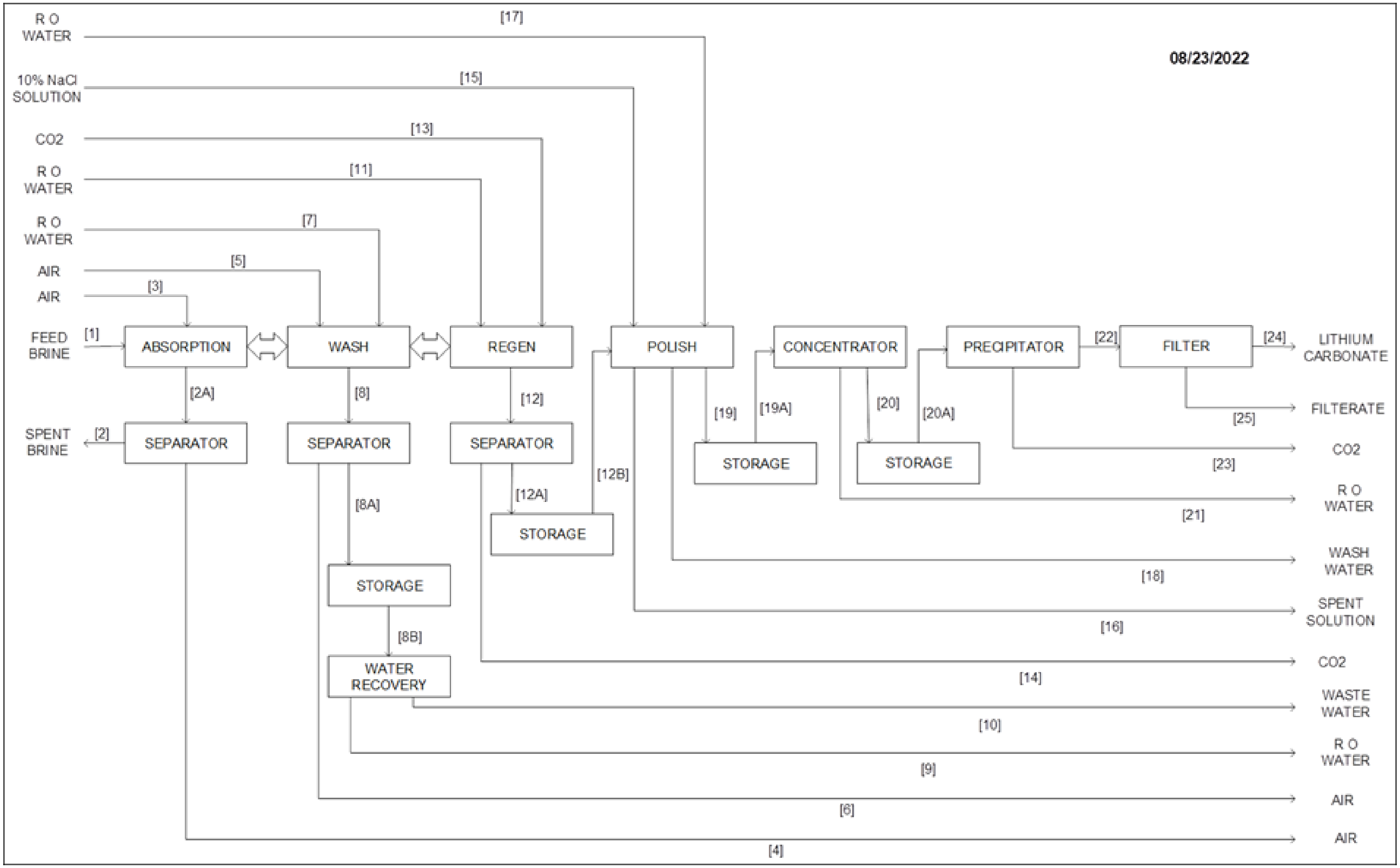
Process Economics

Previous bench scale process development effort of this DLE technology focused on sorbent development, lithium capture by the sorbent and its regeneration using CO_2. Based on the bench scale process data, an initial techno-economic analysis was performed to determine the financial viability of the proposed DLE technology. The preliminary TEA (base year 2018) showed an OPEX of $4,000/metric ton of LCE and a CAPEX of $75 million for a 20,000 tonnes per annum (TPA) plant (Ventura, S. et al., 2020).

Process modelling

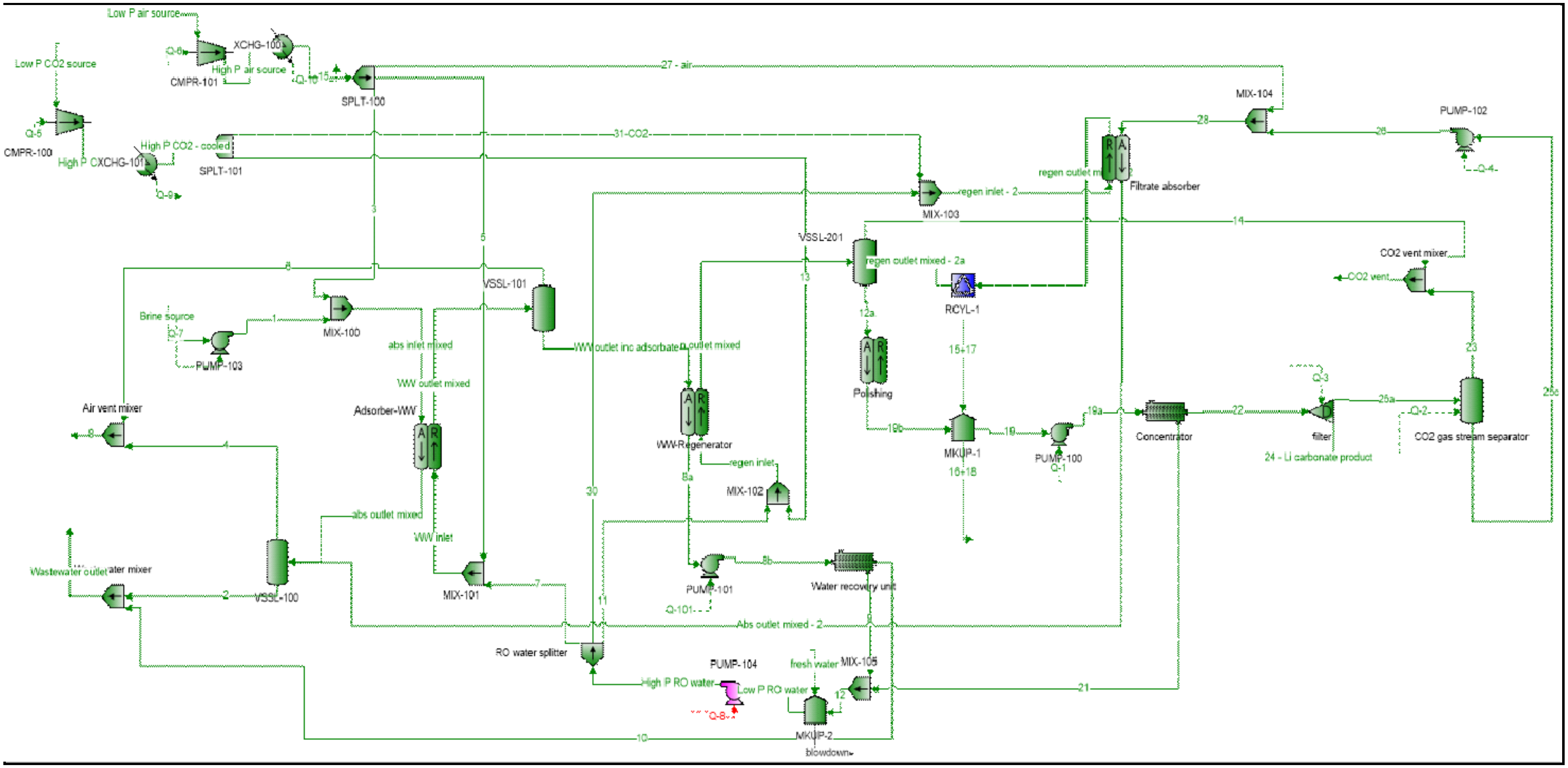
Data from the various steps of the pilot process were collected and used in process modelling. PromaxTM software was used in setting up the flow streams and sizing equipment. Figure 41 shows the major process streams, while Figure 42 shows the flowsheet developed for the integrated continuous process.

Figure 41: Major Process Streams



Source: Materials Research

Figure 42: Flowsheet of the Integrated Continuous Process



Source: Materials Research

The end-to-end process development helped develop more accurate equipment sizing and cost estimate for the process. Based on current data and process assumptions, the OPEX is estimated at $6,200/metric ton of LCE while the CAPEX is estimated at $225M for a 25,000 TPA LCE plant.

Pilot plant scale design and operation of all sub-systems of the process helped improve the process understanding and highlighted the limitations of certain steps. At the same time market forces have significantly changed the cost of fabrication and construction.

CAPEX

There is a significant increase in CAPEX estimate for the process from the preliminary TEA estimates from 2018 to the present estimate. This increase can partly be attributed to the cost of raw materials required and is a general industry trend, not specific to the DLE process development. For example, the cost of iron ore has increased about 300 percent in the last two years while the steel production was significantly impacted by the COVID pandemic and resulting shutdowns and economic slowdowns. Consequently, alloy steels, especially stainless steel 316 has seen a many fold price increase. Similarly, major equipment costs have risen appreciably and availability of the same was hampered by shipping and logistical delays at every level.

In addition to market forces, the understanding of the process has improved, resulting in more accurate equipment sizing based on test data. The preliminary TEA included cost of downstream process subsystems based on guidance from literature. During pilot scale testing, a water recovery system, polishing system, concentration system and a crystallization system were operated, and data was collected that informed the inclusion of subsystem sizing and costs in the present estimates.

OPEX

The operating pilot plant data highlighted some practical limitations of the downstream processes. The DLE process includes a novel CO_2 use for regeneration instead of traditional strong acid. This reduces the cost of acid handling and waste stream generation. However, during pilot plant operation, it was observed that a significant amount of CO_2 is required exceeding the preliminary estimates. Moreover, only part of the excess CO_2 can be easily collected and recycled. The process also requires the additional separation of dissolved CO_2 from the regenerated stream before further processing.

Commercially available water softening resin was used for polishing the regenerated stream and removing divalent ions. The non-traditional use of these resins in this DLE process highlighted the need to modify the system to make it suited for this process' needs. The relative amount of various ionic species in the solution to be treated also required particular attention to the absorption and regeneration steps used for the ion exchange resin.

Preliminary lab scale experiments had previously informed the decision to include a crystallization system to directly produce lithium carbonate. A large-scale system design and operation highlighted some of the limitations of the crystallization process and a secondary processing stream was added to the overall process to improve product recovery.

The above-mentioned factors affected the OPEX and CAPEX estimates, and at the same time they also improved the confidence level in the overall techno economic analysis. This is typical for any chemical process development, where every larger scale operation step leads to discovery of process gaps, improves process understanding and helps build a realistic process cost model.

While the process cost estimate has significantly increased over the preliminary data, it cannot be ignored that the price of lithium carbonate has risen at a much higher rate to meet the increasing demands of the lithium battery manufacturers. All projections show that lithium demand will continue to grow over the coming decades, while the price of lithium may lower somewhat from the current peaks, it is expected to stay high. The price of LCE is more than $51,000/metric ton as of early March 2023 (https://tradingeconomics.com/commodity/lithium).

Knowledge Transfer and Next Steps

During this project, the team engaged in several activities to share project information with other interested stakeholders and the public.

One of the major geothermal plant operators in the Salton Sea geothermal geographical area provided the geothermal brine. This enabled test of the sorbent with actual brine and demonstrated its stability and performance. As a part of collaboration, information on the pilot skid operation and summary of technical and economic data was shared with this entity.

The project team was represented at the Session on Securing California’s Battery Supply Chain of the 2022 EPIC Symposium (October 2022). This session focused on how direct lithium extraction from geothermal brines in the Salton Sea geothermal resource has the potential to establish a stable, secure, low-cost source of in-state lithium for manufacturing lithium-ion batteries and critical battery components, and support California goals on new zero-emission vehicles and trucks with a reduction of GHG emissions to 40 percent below 1990 levels by 2030 and achieve carbon neutrality by 2045.

Efforts to commercialize this DLE technology continue through the engagement with geothermal power producers and other entities that possess lithium resources. Beyond this project, the next goal is to move the portable skid-mounted system to sites where lithium containing brines are available for an online process demonstration.

CHAPTER 4: Conclusion

This project demonstrated the pilot scale extraction of lithium from brines with production of lithium carbonate using a new DLE process. The project also demonstrated the process feasibility of extracting lithium from geothermal brines.

This DLE process is based on: (1) a high-capacity selective solid sorbent for the extraction of lithium; and (2) a carbon negative sorbent regeneration process for the direct formation of high-purity lithium carbonate (Li_2CO_3). Compared to traditional methods of Li recovery from brines, this process provides reduced processing time and improved lithium extraction efficiencies.

The basic process consists of four unit-operations: Absorption, Polishing, Concentration and Crystallization. Additional operations include pre-processing brine, water recycling, product washing and drying, return of lithium-depleted brine and waste management. To support the skid demonstration, the sorbent production was scaled up resulting in >50kg of sorbent production.

During testing, brine was initially passed through a fixed sorbent packed bed that preferentially absorbs lithium ions. A synthetic brine was used since the team could not procure the large quantities of geothermal brine needed for the pilot skid tests. After passing water through the sorbent bed to wash out any leftover brine, carbon dioxide and water was used to release lithium ions and regenerate the sorbent. The resulting lithium bicarbonate aqueous solution was lithium enriched and contained only minor amounts of other monovalent and divalent metal ions. In the polishing step divalent metal ions still present in the solution were removed using a commercial ion exchange resin. The resulting lithium bicarbonate aqueous solution was concentrated, and high purity lithium carbonate was precipitated by crystallization.

The entire process was validated in the pilot skid with the production of high purity lithium carbonate. By the end of the project, the lithium extraction process reached a technology readiness level of 6. Based on current data on the end-to-end operation of the pilot scale skid and other process assumptions, the OPEX is estimated at $6,200/metric ton of LCE while the CAPEX is estimated at $225M for a 25,000 TPA LCE plant. The OPEX LCE estimate of the DLE process is at par with hard rock-based lithium production processes, and very importantly, has a distinctive environmental advantage since it does not require a large land footprint, does not generate significant waste and the spent brine is just reinjected underground. The payback period is dependent on the selling price of lithium which has been very volatile. Based on a conservative selling price of $15/kg of lithium carbonate, the payback period is one year.

The skid-based equipment and subsystems can be installed inside a shipping container. For any future work, the shipping container can be transported to the source of brine and the pilot scale system can be tested at site with natural brines.

DLE technology will enable lithium production in the Salton Sea KGRA where lithium is found in low but significant concentrations in geothermal fluids. Because of the very large volume of fluid processed in a geothermal power plant (>6000 gal per min), even brines with low lithium concentration represent a valuable resource.

The Salton Sea KGRA is well-positioned to become a competitive and significant national source of lithium. Currently lithium production in the United States is very small, and almost all the global lithium supply is mined in Argentina, Chile, China, and Australia.

Ensuring lithium production in the United States is critical to support a zero-carbon economy that relies on the manufacturing of lithium rechargeable batteries for transportation and energy storage.

Additionally, the efficient direct extraction of lithium from geothermal brines promises to make geothermal power generation economically favorable by creating a value stream generated by the production of lithium and other useful metals from geothermal fluids.

Existing and new geothermal facilities will co-benefit from the production of lithium-based minerals from brines by adding another source of revenue. This will favor the expansion of geothermal power production in the Salton Sea geothermal geographical area. Experts estimate that the Salton Sea geothermal geographical area is capable of supporting the development of additional geothermal power plants with a capacity of 2330 to 2950 MW over the current installed capacity of 414 MW generated by ten power plants (Paz S. et al., 2022). Renewable baseload geothermal power will provide grid stability, reliability and resiliency in California, the western energy grid and the United States.

The State of California issued the world’s first plan to achieve net zero carbon pollution (CA.gov). As part of this plan, the State plans to cut air pollution by 70 percent, reduce GHG emissions by 85 percent and reduce fossil fuel consumption by 94 percent by the year 2045.

Geothermal energy is an important component of the state’s energy mix and benefits the state as well as IOU ratepayers. Expansion of geothermal energy production is highly beneficial to the environment since it is renewable, essentially carbon-free and provides reliable baseload power and frequency response features that stabilize the grid.

Recovery of lithium from geothermal brines will additionally help California minimize GHG emission and improve air quality by supplying battery-grade lithium-based products to support manufacturing of electric vehicles and battery storage systems.

This project therefore supports the state’s goals by making ‘always ON’ renewable geothermal power more affordable, make US self-reliant in lithium production, a material critical for the domestic production of electric vehicles, while significantly reducing the environmental impact of lithium production.

Further research is needed to increase the sorbent lifetime as sorbent replacement represents a significant part of the operating cost. To ensure suitability of materials of construction and components, the skid should be operated in field at a geothermal site for an extended duration.

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Project Deliverables

The following interim reports, questionnaire and fact sheet were produced during the duration of this project.

- Skid Design Report
- Skid Fabrication Report
- Skid Commissioning Report
- Brine Report
- Test Report
- Final Benefits Questionnaire
- Final Project Fact Sheet
- Technology/Knowledge Transfer Report.

These reports are available upon request by submitting an email to pubs@energy.ca.gov