ALBERTA INNOVATES

CLEAN RESOURCES FINAL REPORT PACKAGE

Project proponents are required to submit a Final Report Package, consisting of a Final Public Report and a Final Financial Report. These reports are to be provided under separate cover at the conclusion of projects for review and approval by Alberta Innovates (AI) Clean Resources Division. Proponents will use the two templates that follow to report key results and outcomes achieved during the project and financial details. The information requested in the templates should be considered the minimum necessary to meet AI reporting requirements; proponents are highly encouraged to include other information that may provide additional value, including more detailed appendices. Proponents must work with the AI Project Advisor during preparation of the Final Report Package to ensure submissions are of the highest possible quality and thus reduce the time and effort necessary to address issues that may emerge through the review and approval process.

Final Public Report

The Final Public Report shall outline what the project achieved and provide conclusions and recommendations for further research inquiry or technology development, together with an overview of the performance of the project in terms of process, output, outcomes and impact measures. The report must delineate all project knowledge and/or technology developed and must be in sufficient detail to permit readers to use or adapt the results for research and analysis purposes and to understand how conclusions were arrived at. It is incumbent upon the proponent to ensure that the Final Public Report **is free of any confidential information or intellectual property requiring protection**. The Final Public Report will be released by Alberta Innovates after the confidentiality period has expired as described in the Investment Agreement.

Final Financial Report

The Final Financial Report shall provide complete and accurate accounting of all project expenditures and contributions over the life of the project pertaining to Alberta Innovates, the proponent, and any project partners. The Final Financial Report will not be publicly released.

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CLEAN RESOURCES FINAL PUBLIC REPORT TEMPLATE

1. PROJECT INFORMATION:

Project Title:	Ion-Exchange Extraction of Lithium from Petro-Brines in Alberta
Alberta Innovates Project Number:	2488
Submission Date:	June 30, 2022
Total Project Cost:	$270,500
Alberta Innovates Funding:	$100,000
AI Project Advisor:	David Van Den Assem

2. APPLICANT INFORMATION:

Applicant (Organization):	E3 Lithium
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3. PROJECT PARTNERS

Project partners included University of Alberta (U of A), GreenCentre Canada (GCC), and Kingston Process Metallurgy (KPM).

A. EXECUTIVE SUMMARY

This project involved the development of a lithium extraction technology that utilized ion-sieve sorbents designed to be highly selective towards lithium ions. The sorbent also concentrated the lithium ions from dilute brine streams into a concentrate stream – the concentrated lithium stream can be converted to create products for use in lithium batteries. Lithium batteries are in significant demand for energy storage applications in the operations of electric utilities as well as electric vehicles.

E3 first refined and optimized the ion exchange sorbent chemistry and formulation, and then developed, tested, and manufactured a commercially applicable ion exchange material using the optimized chemistry. Using the optimized chemistry, sorbent was manufactured and tested at lab-scale in a continuous flow system to test and optimize process operating parameters for implementation into a future pilot plant.

The testing allowed E3 to continue to evaluate the efficiency of the ion exchange material and demonstrate the scalability of the process. Test work was completed to modify and optimize the chemistry to repeatedly achieve lithium recoveries greater than 80%, volume concentration factors >20 times and impurity elimination >99%. Achieving these performance goals further improved downstream efficiencies and utility requirements for the polishing and purification steps.

B. INTRODUCTION

Sector Introduction

The technology developed by E3, in collaboration with the U of A, is a lithium extraction technology that utilizes ion-sieve sorbents designed to be highly selective towards lithium ions in Alberta brines that also concentrate the lithium ions into a product stream. This concentrated stream can be processed in standard industrial flowsheets to produce battery-grade lithium products used for lithium-ion batteries.

Technology Gap

There is currently no commercial technology existing today that can simultaneously concentrate and purify dilute lithium brine sources, while operating at scale. The technology being tested in this project has the potential to fill this gap and operate at high flow rates, processing thousands of cubic meters of water per day, and producing significant quantities of battery-grade lithium. The project is designed to optimize the technology so it may operate economically at scale.

C. PROJECT DESCRIPTION

Technology Description and Objectives

The goal of this project is to further refine and optimize the sorbent chemistry, followed by the development, testing, and manufacturing of ion exchange materials using the optimized chemistry. The project has been divided into four key Milestones that represent the critical advancements to be achieved throughout the progression of the project. These Milestones include:

1) Replicate the U of A results to ensure consistency of sorbent generation;
2) Modify and test new variations in sorbent chemistry;
3) Test commercially viable sorbent materials; and
4) Complete testing in a continuous flow column.

Performance Metrics

Project success was measured using the following criteria:

- Lithium recovery: >80%
- Brine concentration: >20 times volume reduction
- Impurity reduction: >95%
- Sorbent losses: <1%

D. METHODOLOGY

Work was completed at GreenCentre Canada (GCC) and Kingston Process Metallurgy (KPM). Initial sorbent synthesis methods were provided by the U of A, which were subsequently replicated by GreenCentre Canada. Opportunities for further chemistry improvements and methods to produce larger batch sizes were identified and tested. Multi-cycle tests were also completed to validate sorbent performance over time. Tests were ultimately completed in a flow column designed jointly by GCC and KPM.

E. PROJECT RESULTS

Milestones and results are summarized below.

MILESTONE 1: Reproducibility of U of A Results

1. *Reproducibility*: The U of A sorbent was successfully reproduced by GCC and provided a baseline for future sorbent development.

MILESTONE 2: New Sorbent Synthesis and Testing

1. *Optimized procedure*: An optimized sorbent synthesis procedure was identified, addressing challenges related to larger batch synthesis. Milestone 2 achieved better results at an increased sorbent production scale and increased testing volumes, meeting the sorbent performance project goals.
2. *Multi-cycle testing*: Multi-cycle tests were completed while maintaining consistent sorbent performance during each cycle. The work completed at GCC achieved consistent lithium extraction, lithium concentration, lithium recovery and impurity removal. Consistent sorbent performance over multiple cycles will directly impact commercial project economics.
3. *Lithium extraction tests*: Initial testing of sorbents made with alternate synthesis methods using E3's brine was completed, resulting in a high performing sorbent that was synthesized through a more efficient and less costly technique. Results from this testing demonstrated that performance metrics can be achieved using this simplified synthesis approach.

MILESTONE 3: SORBENT-SUBSTRATE PRODUCTION AND EXTRACTION TESTING

1. *Sorbent substrate*: GCC performed a literature study and analysis of various high-potential substrate materials with the goal of infusing them with E3's sorbent material to perform extraction testing. Based on the findings of the literature study, five substrate candidates were identified.
2. *Substrate Synthesis and Extraction Testing*: Syntheses and characterization of substrates were conducted to determine how the materials reacted in extraction and elution conditions. Extraction testing was completed in batch beaker tests using each material to compare the performance and applicability to E3's project.
3. *Candidate selection*: Two forms were identified for further testing and development.

MILESTONE 4: FLOW COLUMN TESTING

1. *Construction*: KPM and GCC designed and constructed a continuous flow system to perform extraction/desorption testing.
2. *Commissioning*: After assembly of the flow system, KPM commissioned the system and performed leak testing. Preliminary tests were completed using E3's brine to evaluate system performance, flow rates and troubleshoot the system setup before running extraction/desorption tests. The system performed to E3's expectations, allowing brine to flow continuously through the system with no negative effects to brine chemistry or flowrate limitations.
3. *Extraction and Desorption Tests*: Four extraction/desorption tests were completed using the continuous flow system to evaluate sorbent and system performance. Lithium recoveries were

comparable to batch test work previously completed using E3's brine and sorbent material. Tests completed provided E3 with data to optimize the test program.

4. *System Optimization*: Based on the results and observations from extraction and desorption testing, E3 and KPM designed a more optimized system to improve process control and reduce human error during experiments. KPM procured materials and equipment to implement changes to the system setup.

F. KEY LEARNINGS

Lessons learned during this project are outlined below.

1. *Sorbent Selectivity*: Sorbent performance showed high selectivity for lithium throughout the project and was not impacted by differences in batch size or synthesis method. In each test, impurity removal in excess of target thresholds was achieved.
2. *Lithium Recovery:* Through batch and continuous flow testing, E3's sorbent achieved high lithium extraction efficiency and high lithium recoveries meeting and exceeding target thresholds.
3. *Lithium Recovery Repeatability*: Continuous sorbent performance over several repeated tests was linked to sorbent structure. Characterization methods were identified to identify optimum sorbent structures.
4. *Synthesis Simplification*: Alternative synthesis methods were evaluated to optimize production time and material costs. Methods that met or exceeded U of A sorbent performance results were identified.
5. *Choice of substrates*: Several potential substrate candidates were identified as potentially compatible with E3's sorbent. Particle size, structure and porosity of substrate materials were evaluated.
6. *Substrate Extraction Performance*: Substrates maintained their structure and shape, providing data regarding their use in industrial process equipment.
7. *Flow Column Selection*: a column system was used to perform extraction and desorption using sorbent material to evaluate sorbent stability, lithium recovery and sorbent loss. This continuous process eliminated mechanical losses experienced in batch testing.

G. OUTCOMES AND IMPACTS

Project Outcomes and Impacts

There is currently no commercially available technology that can economically concentrate and purify dilute lithium brine sources. The technology tested in this project identified sorbent candidates that can

be used for commercial applications, filling this gap. Test results met project targets, supporting E3's decision to continue developing the technology.

Clean Energy Metrics

The following clean energy metrics were identified for the project:

- *Technology Readiness Level (TRL) advancement:* sorbent development and testing advanced the TRL from TRL 3 to TRL 4.
- *Field pilots/demonstrations*: following this project, the next stage will continue to refine sorbent production methods and test conditions. This data will be used to build a larger field pilot that mimics commercial operating conditions. The pilot will generate data required for commercial plant design.
- *Future capital investment*: Alberta hosts large lithium-bearing brine resources. By leveraging the technology developed by this test program, many commercial plants could be constructed. Each plant is expected to result in hundreds of millions of dollars of capital investment.
- *Projected new jobs created from future deployment*: During the pilot plant stage, seven new E3 technology positions are expected, as well as six new operator positions. Initial commercial deployment is forecasted to result in 500 new full-time equivalent positions, including positions in academia, construction, trades, operations, and maintenance. Additional commercial plants will generate more employment.

Program Specific Metrics

Program specific metrics include:

- *Number of renewable energy technologies deployed*: E3's technology will allow E3 to extract lithium from Alberta brines and produce high quality lithium products used for lithium-ion battery production. E3's technology is key to unlocking this production method. Subsequently, lithium-ion batteries can be deployed in many renewable energy technologies.
- *Renewable electricity on grid*: Lithium-ion batteries can be deployed in grid storage applications. Grid storage can be leveraged to maximize intermittent electrical production from renewable wind and solar resources.
- *Clean technology companies with headquarters in Alberta*: E3 is currently headquartered in Alberta, near our world-scale lithium mineral leases. As an owner of Alberta-based resources, E3 expects to maintain our headquarters in the province, as we continue to refine the technology and build multiple future commercial lithium extraction plants in the province.

Project Outputs

The following objectives and outputs were achieved for the project:

- *Sorbent formulation and synthesis method*: An optimized synthesis method was developed that lowered material costs and improved performance.
- *Sorbent substrate development*: substrates were identified and tested to produce larger agglomerates with better solid-liquid separation characteristics.
- *Lab-scale flowsheet development*: Lithium extraction tests were completed in equipment that could be scaled up to commercial process equipment.
- *Multi-cycle testing*: sequential tests were completed, using the same sorbent, to show that consistent lithium recovery could be achieved over multiple cycles.
- *Economic model development*: lab performance data were used to refine a commercial plant financial model. Improvements in sorbent properties were shown to improve capex and opex for the commercial plant.

H. BENEFITS

Economic

Successful testing of E3's ion exchange technology advances E3's commercialization plans. This represents a substantial opportunity for economic diversification for the province. The production of lithium from E3's proprietary extraction technology will initiate an entirely new clean technology industry in Alberta. This new industry utilizes Alberta's oil and gas infrastructure and technological know-how to help Alberta retain a leadership position in the energy industry while transitioning to a low-carbon future. Lithium production represents a tangible and sustainable economic opportunity with significant employment potential without having to re-skill the Alberta workforce.

Environmental

E3 is leveraging the opportunity to lower costs and decrease our environmental footprint by using existing oilfield infrastructure for sampling, delineation and extraction testing. This has allowed us to define one of the largest lithium resources in the world with no new land disturbance as a result of not requiring typical exploration drilling. As the project evolves, the company plans to commercialize lithium production by, in part, leveraging existing oil & gas pipelines, wells, roads, power lines and surface sites into "closed-loop" lithium infrastructure. In doing so, we aim to produce lithium at a fraction of the land disturbance of traditional lithium mines and salars while providing our customers with sustainably produced, battery-grade lithium products.

E3's process flow sheet results in a 97% reduction in land use on a per-tonne basis when compared with Atacama-sourced lithium, assuming 20,000 tonnes LCE/year and sustained production. One potential by-product of E3's operation is large volumes of spent brine for use in fracking operations, which would reduce fresh water use in the fracking industry. Low-grade heat from the brine may also be used to displace natural gas used for heating buildings and greenhouses.

Social

Advancing commercial lithium production from Leduc formation brines requires sophisticated technical, operational and engineering expertise. This expertise is abundant in Calgary and in Alberta, which has a highly skilled, technically diverse workforce that is at risk of lower employment levels as Alberta transitions to renewable energy forms. E3's design and commercialization activities will provide alternate employment opportunities for this workforce. Every member of E3's current team draws upon experience from the oil and gas industry, and as the Company grows, our growth will be staffed largely by Alberta residents skilled in oil and gas development. Direct employment generated from E3's headquarters and operating facilities is estimated to grow to 400 - 600 full time jobs by 2026. Additional indirect employment opportunities are conservatively estimated at 700 full time jobs, with induced employment of approximately 1100 - 3500 full time jobs.

The commercial project will also require initial capital deployment including wells, associated surface infrastructure and the construction of the lithium process facility. Much of this equipment is expected to be manufactured in Alberta; in the vicinity of Red Deer. The project is expected to grow to a full operation capacity in our first development phase of 20,000 t per year, with an expected annual gross revenue of over $700,000,000. A project of this scale will generate direct annual royalty and tax benefits to provincial and federal governments as well as significant indirect tax, employment and investment benefits to the City of Calgary and the Province of Alberta.

Building Innovation Capacity

Building on a significant source of lithium in Alberta, E3 also believes in the development of a vertically integrated industry for battery manufacturing. This larger, long-term goal reflects the opportunity to be part of a new and growing industry. E3 believes the province is in a unique position to support not just the production of the commodity, but also grow the downstream manufacturing of an end use products. The leverage of having lithium production in Alberta, unlocked by E3's technology funded under this project, will be critical to this growing industry.

I. RECOMMENDATIONS AND NEXT STEPS

Long Term Commercialization Plan

E3 plans to de-risk the commercial plant design by completing a series of tests at progressively larger scales. Initially, E3 will build a lab prototype to further test and optimize the sorbent and operating conditions. Using this data, a field pilot will be designed and built. Field pilot data will provide the design criteria to ultimately complete a commercial plant design.

Two Year Plan

E3 will continue to refine sorbent production methods to reduce cost and complexity while improving sorbent capacity and longevity. Using these improved sorbents, additional lab-scale flow column tests will be completed to optimize process parameters and test conditions. Using this lab data, a field pilot will be designed.

Partnerships

E3 will continue to develop our proprietary technology, working with qualified lab partners. In June 2019, E3 was selected as recipient of GreenCentre's RISE program to continue technology advancement in preparation for the pilot plant (https://www.greencentrecanada.com/go/RISE/). Under this program, GreenCentre directly assists innovators and entrepreneurs developing sustainable chemical and advanced materials technologies. E3, as a successful applicant to this competitive program, will receive a project with access to GreenCentre's full suite of services at no cost or equity dilution.

J. KNOWLEDGE DISSEMINATION

During the project, E3 engaged with several partners, including the University of Alberta, GreenCentre Canada, and Kingston Process Metallurgy. E3's staff, as well as our partners' staff, developed knowledge related to lithium extraction and the variables impacting process equipment design.

As E3 proceeds with more testing and a larger client team, this knowledge will disseminate to the new members of E3's team and our selected test lab partners. As we proceed to pilot plant and commercial plant designs, the knowledge will disseminate to hundreds of E3's engineering, fabrication, and construction contractors.

Ultimately, this technology may be extended to brines outside of Alberta to the rest of the globe.

K. CONCLUSIONS

This project involved the development of a lithium extraction technology that utilized ion-sieve sorbents designed to be highly selective towards lithium ions. The sorbent also concentrated the lithium ions from dilute brine streams into a product stream – the concentrated lithium stream can be converted to create products for use in lithium batteries. Lithium batteries are in significant demand for energy storage applications in the operations of electric utilities as well as electric vehicles.

The project successfully:

- Replicated U of A results sorbent generation results,
- Modified and tested new variations in sorbent chemistry,
- Tested commercially viable sorbent materials; and
- Completed testing in a continuous flow column.

The project met or exceeded the following success criteria:

- Lithium recovery: >80%
- Brine concentration: >20 times volume reduction
- Impurity reduction: >95%
- Sorbent losses: <1%

Successful results provide the basis for E3 to continue to develop the technology, ultimately targeting a commercial plant in south central Alberta.