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California Energy Commission
CONSULTANT REPORT

Well-to-Wheels: Lithium Design Final Report

Prepared for: California Energy Commission

Prepared by:

EnergySource
MINERALS

Gavin Newsom, Governor
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PREFACE

The California Energy Commission's Geothermal Grant and Loan Program is funded by the Geothermal Resources Development Account and provides funding to local jurisdictions and private entities for a variety of geothermal projects.

EnergySource Minerals Well to Wheels: Lithium Design is the final report for the Geothermal Grant and Loan Program Agreement Number GEO-16-006, conducted by EnergySource Minerals, LLC. The information from this project contributes to the overall goals of the Geothermal Grant and Loan Program to:

- Promote the use and development of California's vast geothermal energy resources.
- Reduce any adverse impacts caused by geothermal development.
- Help local jurisdictions offset the costs of providing public services necessitated by geothermal development.

For more information about the Geothermal Grant and Loan Program, please visit the Energy Commission's website on the Geothermal Grant and Loan Program Web page (https://www.energy.ca.gov/programs-and-topics/programs/geothermal-grant-and-loan-program) or contact the Energy Commission's Renewable Energy Division toll-free in California at 844-454-2906 and outside California at 916-653-0237.

ABSTRACT

By extracting lithium from geothermal brine, California has an opportunity to become a global-scale producer of sustainably sourced lithium while providing an important cornerstone in achieving California's clean energy goals. Globally, much of the supply chain is localizing as automakers and suppliers, including battery cell manufacturers, are regionalizing the production of vehicles and components in target markets. Coupling lithium facilities with geothermal power in one of the state's most economically disadvantaged communities has a range of public benefits, including the creation of quality full-time jobs.

EnergySource Minerals, LLC (ES Minerals) pursued a grant project with the California Energy Commission to reduce the uncertainty around the installed costs of the first commercial lithium hydroxide monohydrate plant using geothermal brines. ES Minerals performed significant process and design work to supply an engineering package to a contractor to produce an accurate construction cost estimate. ES Minerals completed (1) design criteria, (2) detailed engineering and design, (3) pilot facility confirmation, (4) product certification, and (5) construction costing.

ES Minerals observed customary factored estimates used early in construction cost assessments were reasonably accurate, but site-specific civil works costs, such as foundations, were notably improved with the engineering and construction cost estimate work. In addition, the engineering work and pilot confirmation provided improved operating costs estimates as well as efficiency improvements.

The recovery of minerals from geothermal brines is commercially viable today. Salton Sea Geothermal Field brines present unique challenges and opportunities. With the right lithium separation technology, California's renewable baseload generation could increase while providing a key mineral necessary for the electrification of transportation, as well as high-paying, full-time, clean energy jobs in one of California's most economically disadvantaged counties.

Keywords: California Energy Commission, EnergySource Minerals, geothermal, mineral extraction, lithium

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Introduction

California has an opportunity to become a global-scale producer of sustainably sourced lithium and reach an important cornerstone in achieving its clean energy goals. Lithium is a key component in batteries, which are needed for electric vehicles, energy storage, and numerous consumer products, and is recognized as a critical mineral by the federal government. Globally, the supply chain is transforming as automakers and suppliers, including battery cell manufacturers, are focusing the production of vehicles and components in target markets. Based on an internal analysis, the demand for lithium is expected grow 3 to 4-fold by 2025 with demand exceeding supply in 2026. California has a unique position to complement its ambitious electric vehicle goals with renewably powered, California-based lithium sourcing.

The geothermal industry has struggled over the years to be cost-competitive with other renewable energy generation technologies. Coupling the production of lithium, a high-value and critical mineral and perhaps other minerals, is a way to help the geothermal industry reduce the levelized cost of electricity and become more competitive. Geothermal is an important source of renewable energy as it provides baseload electricity that will be increasingly needed to transition away from reliance on nonrenewable fuels and to the electrification of transportation. Introducing lithium plants with geothermal power in one of the state's most economically disadvantaged communities has a range of public benefits, including creating quality full-time jobs.

The work conducted as part of this grant addressed the lack of integrated engineering design for a first-of-its-kind lithium production plant using geothermal brines. EnergySource Minerals, LLC (ES Minerals) is using commercially available processes and equipment from the water treatment, metal processing, and chemical processing industries to produce lithium and mineral coproducts.

The project objectives included reducing the risk and cost associated with a first commercial lithium plant using geothermal brines and secure viable financing without the need for loan guarantees, other taxpayer supported financings, or burdensome levels of contingency or a combination thereof. ES Minerals performed significant process and design work to supply an engineering package to a contractor to produce an accurate construction cost estimate. The construction cost estimate improved the accuracy of the capital budget to acquire financing in the commercial construction lender market.

Technical Tasks

ES Minerals' scope of work generated an integrated engineering design and capital cost estimate for the first lithium production plant using geothermal brines. ES Minerals executed the tasks identified below to more accurately estimate installed project costs.

- Process specification and interface criteria (design criteria)
- Detailed engineering and design

- Operation of pilot facility
- Product certification
- Construction costing and scheduling

Table 1.1 describes the criteria for the design and operation of the lithium hydroxide plant, produced commercially in the form of a monohydrate, with the formula LiOH·H20.

Table 1.1: Facility Design Basis

Design and Operational Parameters	Values
Lithium Hydroxide Monohydrate Production (tonnes/yr.)	20,000
Availability Factor	98%
Capacity Factor	95%
Lithium Recovery	90%
Lithium Hydroxide Content, wt. %	56.5%

Source: ES Minerals

These criteria set the targets for the design and engineering work that followed. The production amount refers to the target production amount of Lithium Hydroxide Monohydrate (LHM) in tonnes per year. The availability factor refers to the percentage of time the facility is available to operate, and the capacity factor refers to percentage of time the facility is operating. Lithium recovery is the percent of lithium recovered by the process. The lithium hydroxide (compound without the H_2O) content represents the percentage by weight needed to meet battery grade material. The team incorporated numerous principles and inputs, including site conditions, redundancy requirements, codes and standards, piping and mechanical requirements, as well as operability into the facility design.

This engineering was done through three major units of operation including 1) impurity removal (IR), 2) counter-current adsorption desorption (CCAD), and 3) evaporation, crystallization, and packaging. Major engineering tasks for each of the three major unit operations were completed during the detailed engineering and design of the commercial LHM production plant. These tasks included:

1) Process engineering design.
2) Mechanical engineering design.
3) Piping engineering.
4) Structural standards.
5) Electrical and instrumentation.

A few design elements were modified or optimized during engineering design, so the project team conducted a pilot run to provide empirical confirmation of these values used as engineering inputs for the process flowsheet, mass and energy balances, and operational targets for the commercial project. The lithium product was then subjected to extensive analytical test work focused on three primary criteria: (1) lithium carbonate or lithium hydroxide content, (2) impurity levels, and (3) crystal size and distribution. The team used numerous specifications to establish the threshold for battery grade material confirmation. The test results confirmed that the process approach employed by ES Minerals successfully produces battery grade material.

Lastly, the project team established the basis of the construction estimate from produced documents by the engineering work performed on each of the major unit operations of the project, including IR, CCAD, and evaporation and crystallization. These documents established the sizing, quantity, routing, and service requirements for all equipment within the process boundaries. The construction cost estimate included the civil works, foundations, process equipment installation, piping, electrical, instrumentation, process and operation buildings, balance of plant works, geothermal facility tie-ins, painting, insulation, construction management/indirect costs, and construction consumables.

Successes and Challenges

ES Minerals and vendor teams spent significant time improving the mass and energy balance. The benefits to the project were significant as numerous recycle streams were identified that allow for reducing reagents, which lower the consumption of reagents throughout the process. This time requirement was not adequately forecasted at the beginning of this effort. However, with three-unit operations being worked on by separate groups for much of the design phase, it took time to rebalance the design flows across the team. On a couple of occasions, this rebalancing resulted in the reworking of some equipment.

ES Minerals conducted an independent life-cycle analysis of lithium hydroxide from geothermal brines outside the scope of work of this grant. The results indicate that LHM produced by ES Minerals' process will lead in every environmental metric, including carbon footprint, water consumption, and land use compared to all other current lithium extraction practices. The accuracy of this independent life-cycle analysis was enhanced greatly by the engineering data generated from this work.

The process approach employed by ES Minerals was validated in the pilot test as it confirmed successful production of battery grade LHM material. This successful production definitively demonstrates geothermal brines can leverage commercially available and widely used technology in the hydrometallurgical and crystallization industries to produce battery grade lithium products. The pilot operation was successful in providing empirical data to corroborate the commercial design basis.

Unfortunately, the team's efficiency toward the end of the project period was hampered by the ongoing COVID-19 pandemic. Beginning in early March 2020, the emerging pandemic caused companies to reevaluate working in an office environment. Since the ES Minerals team was working from the Featherstone Geothermal Plant, the directive and guidance by power regulating authorities were to remove all nonoperating/nonessential personnel as soon as possible, resulting in relocation of team members. By the middle of March 2020, all engineering groups working on ES Minerals' commercial LHM plant had most employees working from home. Progress during these first two weeks was understandably slow as companies and employees adapted to unanticipated, new working conditions.

Conclusion

The project work conducted as part of this grant addresses the previous lack of integrated engineering design for a first-of-its-kind lithium production plant using geothermal brines. Even though ES Minerals is using commercially available processes and equipment and completed significant early engineering and pilot work before this effort, the team still encountered engineering challenges integrating the three primary unit operations. These challenges mainly occurred during the engineering work on the mass and energy balance for the fully integrated flow sheet. The project team identified numerous opportunities for water recycling and reagent reductions, resulting in several iterations of work by multiple firms in several locations. A single engineering program lead would have been more efficient but was not practical for this effort.

The recovery of minerals from geothermal brines is commercially viable today. ES Minerals pursued this project to reduce the uncertainty around the installed costs of the first commercial LHM plant using geothermal brines. The completed project objectives reduce the uncertainty of the cost estimate and justifies a lower contingency level. ES Minerals estimates the total equipment and construction costs for the first full-scale LHM plant from geothermal brines to be $419 million (2019$). With the anticipated demand for LHM in the coming years, the timing of this LHM plant has the potential to provide a critical role in fulfilling global demand. While LHM can be produced domestically, California does not have a cathode manufacturing infrastructure. As a result, the LHM must be transported overseas, processed and then returned for the vehicle assembly process. Ideally, California or other states, will attract cathode manufacturers stateside enabling the entire process to be done in the United States. The benefits to this are 1) cost savings in terms of not needing to ship outside of the country 2) geopolitical risks of tariffs or disruptions are eliminated 3) reduced environmental emissions associated with streamlined transport and supply chain logistics and 4) potential job creation in the United States.

Receiving the CEC grant was very beneficial to the overall project effort. There is the obvious financial benefit of the monetary funds, but also the increased visibility of the company's progress contributing to achieving California's clean energy goals and demonstrating the CEC's ongoing support of renewable energy technologies, energy storage, and electrification of transportation. ES Minerals believes CEC involvement raises awareness of all its grant recipients and provides a measure of credibility for each company, and ES Minerals is no exception. The CEC grant enabled ES Minerals to allocate significantly more resources to the engineering effort earlier in the cycle, minimizing risk of investment in accelerating the project and accelerating advancement to commercial execution.

Benefits to California

While the benefits to California as part of this engineering effort are relatively modest and reflect mostly the labor and personnel time to execute the work, the real benefits to California would be realized if a fully operational LHM facility is built and helps speed up California achieving its clean energy goals. This relatively small, public investment to produce engineering plans will help reduce contingency costs significantly making the full-scale project more likely to succeed. This project laid a solid foundation for a full-scale commercial LHM plant and serves as an investment in the game-changing opportunity for California to become one of the largest and most sustainable producers of lithium on a global scale.

ES Minerals estimates that a commercial facility would produce 20,000 tonnes per year as LHM. In an economically disadvantaged part of the state, this scale of commercial facility would generate more than $400 million (2019$) in direct capital investment and would create roughly 300 local construction jobs.

In addition, it would create about 70 local full-time jobs to operate the plant continuously. ES Minerals estimates another 100–150 jobs will be created in transportation, contractor services, outside maintenance, and local procurement. These estimates are based upon specific unit operations of the plant, material movements required to deliver reagents and supplies, transport of finished products, and equipment maintenance schedules.

The economic effect to California includes payroll and benefits, royalties, property tax payments, and local procurement of goods and services that are estimated to be more than $150 million per year. Of this amount, the local community would realize nearly $24 million per year in local tax payments.

The above-mentioned benefits are monetary and direct, however, the availability and certainty of battery material supply increase the value of a fully operational LHM plant because these are vital factors as electrification of transportation efforts increase in California and across the globe. The process used by ES Minerals has been verified to produce LHM with the smallest carbon, land, and water impacts of any existing process approach. As California promotes its clean energy goals with the decarbonization of transportation, building resiliency and decarbonizing the supply chain for electric vehicles is the expected complement and supporting partner to this effort.

Lastly, California has experienced great success installing renewable energy capacity in general, but geothermal resources have not enjoyed similar success. This situation exists because of factors beyond the scope of this document, but the cost of new geothermal power projects is often hindered by the high mineral content of the production resource. Mineral recovery provides a meaningful second revenue stream and possible royalty payments to new and existing operations. By improving the economic resiliency of current geothermal facilities and enhancing the development prospects for new geothermal development, this project can be a critical first step to billions of dollars in direct capital investment, approximately $100 million per year in local economic activity, and the creation of quality full-time jobs in an economically depressed region of California. Geothermal power can be a cost-effective contributor to the greening of California’s electric grid while providing the most sustainably derived material inputs for battery-electric vehicles that will help clean California’s air and reduce greenhouse gas emissions.

CHAPTER 1:
Introduction

Goal, Objective, and Need

This project addresses the lack of integrated engineering design for a first-of-its-kind lithium production plant using geothermal brines. ES Minerals proposed to use commercially available processes and equipment from the water treatment, metal processing, and chemical processing industries to produce lithium and mineral coproducts. To achieve this, ES Minerals delivered a robust engineering package and accurate capital budget to help acquire financing in the commercial construction lender market.

The project reduces the risk and cost associated with a geothermal brine-based commercial lithium facility and helps secure commercially viable financing without the need for loan guarantees, other taxpayer supported financings, or burdensome levels of contingency.

ES Minerals believes traditional financing will become available because the approach uses commercially available technology and the significant engineering work is complete. Because no reference project exists for lenders to compare and validate against, significant upfront engineering and design work was needed to accurately illustrate the process and budget the capital expenditures. These efforts will help secure project financing. Ultimately, ES Minerals anticipates engineering and associated overhead cost will be approximately $15 million to support construction of a commercial facility. This level of engineering is normally done after construction financing, but because this is the first project to market, a significant portion must occur earlier, and this creates a large burden on the early stage project development.

Figure 1.1: Project Management Life Cycle

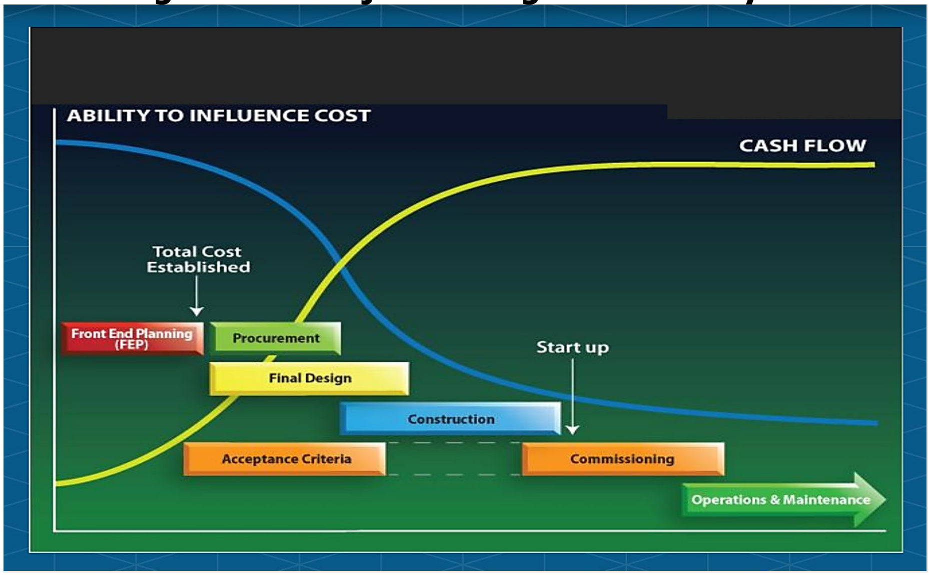


Photo Credit: EPCM Global

Figure 1.1 above illustrates how front-end planning can be used to establish total project cost. Importantly, front-end planning, including tasks such as early engineering and design, provide a greater ability to influence project cost. Because the process is well-known, large industrial projects using a well-established design, for example, natural gas power generation, do limited upfront engineering and carry contingency levels of around 10 to 15 percent, depending on the location. For a new integrated process, even one using commercial technology, a contingency of 20 to 25 percent would be required without significant design and construction costing efforts.

The additional 10 to 15 percent contingency could be as much as $50 million or more in additional monies required for financing, putting an undue burden on the project and placing it at a competitive disadvantage in the marketplace. By overcoming this barrier for the first commercial project, the widespread commercial deployment of additional facilities is made easier and will progress more quickly because the market can leverage the experience and installed cost information gained. Therefore, this relatively small, public investment to produce engineering plans will help reduce contingency costs significantly making the full-scale project more likely to succeed.

Previous Mineral Recovery Efforts

The Salton Sea Geothermal Field (SSGF) is one of the largest geothermal resources in the western hemisphere and one of the largest fluid-dominated hydrothermal reservoirs in the world. However, mineral recovery at the SSGF has been challenged by various technical and commercial hurdles. These hurdles present a very specific challenge for new mineral recovery projects to overcome. ES Minerals recognized this challenge and embraced and learned from the historical lessons at the Salton Sea.

The “discovery well” for geothermal resources in the SSGF was drilled by the Kent Imperial Corporation in 1957, hoping to discover oil or gas. The first commercial effort to pursue mineral recovery was Imperial Thermal Products, an affiliate of Morton Salt, which pursued potash and salt production in the early 1960s. This project ceased development because the potash market collapsed.

Other operators recognized the potential of minerals extraction and commenced development of a zinc recovery facility in 1993, when pilot testing commenced. Commercial-scale plants for zinc recovery were constructed in 2000, achieving commercial operations in 2001. However, the commercial plant faced technical problems and ultimately shut down.

In 2008, EnergySource (the geothermal power company) engaged a firm to develop a minerals extraction facility at the Featherstone Geothermal Plant. It constructed and operated a demonstration facility at the Featherstone Geothermal Plant starting in 2012. EnergySource assisted and advised on lessons learned from experience and a deep knowledge of handling highly corrosive and scaling Salton Sea brines. There were technical problems experienced with the proposed commercial approach that could not be overcome. The firm ceased operations in 2015.

A clear take-away was the need for converting geothermal brines into a profile that was more consistent with state of the industry brines, in particular, continental brines of South America that were free of silica and metals. ES Minerals did extensive work in support of this project in 2016, focused on the recovery of lithium and minerals using techniques and technologies that are commercially available and financeable if sufficient engineering is conducted. In late 2016 and early 2017, without the support of the CEC, ES Minerals built a small pilot unit in collaboration with commercial process and equipment vendors. This pilot facility focused on the integration of these commercially available technologies. The project team gathered extensive operational data and used it to guide this project's process specifications and preliminary engineering work.

Scope of Work

The primary objective of this grant project was to increase the cost certainty of a fully operational lithium hydroxide monohydrate (LHM) plant. Early and significant engineering of the project was necessary to support a robust equipment and construction cost effort. This engineering was done through three major work efforts including 1) process specifications, 2) engineering and design, and 3) construction costing for three unit operations of the LHM commercial production plant. The three major unit operations are: 1) impurities removal (IR), 2) counter-current adsorption (CCAD), and 3) evaporation, crystallization, and packaging.

The scope of work for the process specifications task was to generate process specifications and design considerations for each primary unit operation in the lithium production process and coproduct processes, including materials of construction, necessary interconnections with the host geothermal power facility, instrumentation and controls, civil works, and structural requirements.

The scope of work for the engineering and design effort was to develop detailed engineering plans for each unit operation in the lithium production process and coproduct processes. Detailed engineering was based on the engineering criteria, design criteria, and other information contained in the plant conceptual design basis document and prudent engineering practices.

The project team completed major engineering tasks of the three major unit operations during the engineering and design of the commercial LHM production plant. These tasks included:

1) Process engineering design, including mass and energy balance, process flow diagrams (PFD), and piping and instrument diagrams (P&ID).
2) Mechanical engineering design, including a site plan, equipment specifications, and equipment list.
3) Piping engineering
4) Structural engineering
5) Electrical and instrumentation engineering design

With this early engineering work package, the construction cost could be estimated. This scope of work effort included the commercial process vendors' equipment, foundations, structures, and balance of plant and includes development of a construction schedule, mechanical completion tests, and commissioning.

CHAPTER 2:
Process Specifications and Interface Criteria

Design Basis of Major Unit Operations: Impurity Removal, Lithium Recovery, and Crystallization

The project process for producing battery grade lithium products from geothermal brines uses commercially proven processes and technologies in a resource-specific arrangement. The process begins with IR unit operations that remove iron and silica, and then manganese and zinc, in a two-stage precipitation sequence. The IR part of the proposed flowsheet involves standard hydrometallurgical process steps for removing these elements. These are demonstrable turn-key processes that have low technical risk but are essential to "normalizing" geothermal brines for subsequent unit operations.

The project then uses continuous countercurrent adsorption desorption (CCAD) to provide an initial 10x concentration of lithium chloride *while* reducing sodium, calcium, and potassium species by nearly 99 percent. The project employs ES Minerals' proprietary resin-based lithium selective adsorbent.

The subsequent purification and crystallization steps include softening, high-pressure reverse osmosis, evaporation of the lithium chloride solution, and subsequent production of battery grade LHM crystalline product.

This section describes the major unit operations of the production process that will recover lithium from the brine. The process employs industry-standard, commercially available equipment that will be assembled in a unique arrangement. The recovery process consists of the following major operations as shown in Figure 2.1.

Figure 2.1: Simplified Process Flow Diagram

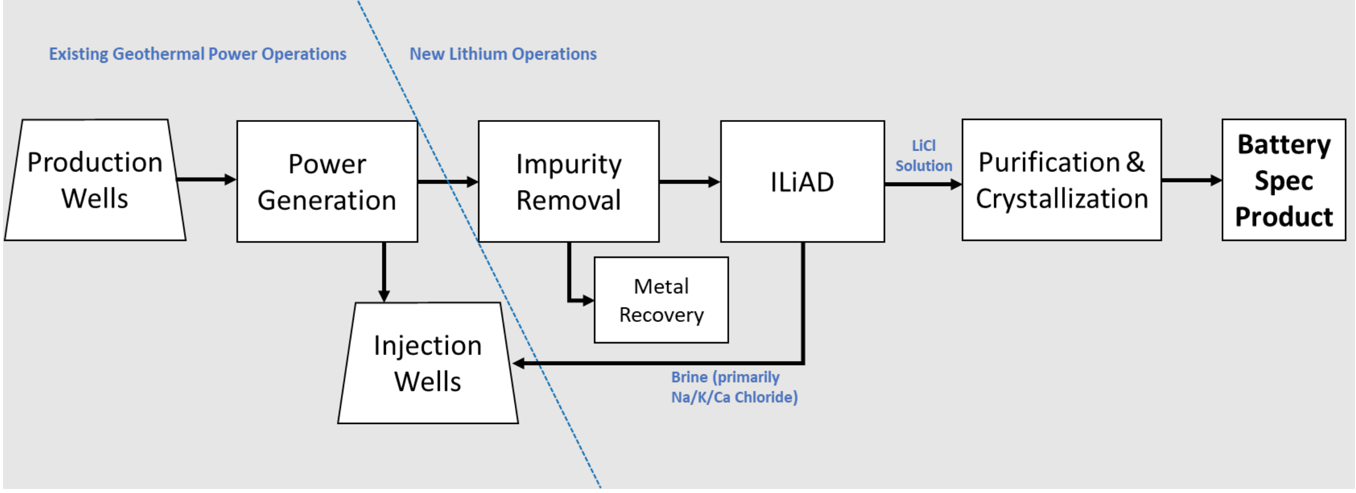


Photo Credit: ES Minerals

As depicted in Figure 2.1, the initial processing begins at the existing power generation plant and includes:

- Brine production from wells (at existing Featherstone Geothermal Plant).
- Heat rejection via power generation (at existing Featherstone Geothermal Plant).
- Clarifier based initial impurity (iron/silicon) removal (at existing Featherstone Geothermal Plant).

At which point the lithium recovery and production can be implemented and consist of the following major unit operations:

- Clarifier based secondary impurity removal (metals/silicon)
- CCAD based impurity reduction and lithium concentration
- Brine polishing and concentration
- Lithium product precipitation (multistage)
- Product packaging

Table 2.1 describes the criteria for the design and operation of the LHM plant.

Table 2.1: Facility Design Basis

Design and Operational Parameters	Values
Lithium Hydroxide Monohydrate Production (tonnes/yr.)	20,000
Availability Factor	98%
Capacity Factor	95%
Lithium Recovery	90%
Lithium Hydroxide Content, wt. percent	56.5%

Source: ES Minerals

Operating Standards

The project will be completed with all new equipment and materials, and in working order capable of full commercial operation at the design net output of 20,000 metric tons per year of battery grade LHM, at the design flow of 4.4 million pounds per hour of geothermal brine coming from the designated outlet of the Featherstone Geothermal Plant unit.

The facility will be consistent with the standards of the mining industry in design, equipment selection, and construction, and will be designed to meet all applicable regulatory requirements. In addition, the facility will be capable of idling for 48 hours with no brine inlet flow and capable of sustaining instantaneous load variations of 5 percent of rated output. Where redundant or backup equipment is installed in the plant, such backup equipment will be capable of automatic startup.

Site Conditions

The project is at a site elevation of -223 feet below sea level. The average summer day temperature is 106°F with extremes of high 121°F and low 21°F. The design basis high temperature is 120°F and low temperature of 30°F.

Seismic general ground motion parameters are based on the risk-targeted maximum considered earthquake (MCER). The U.S. Geological Survey "U.S. Seismic Design Maps Web Application" (USGS, 2018) was used to obtain the site coefficients and adjusted maximum considered earthquake spectral response acceleration parameters. The site soils have been classified as Site Class E (soft clay soil profile).

Redundancy

The unit systems will be designed for maximum reliability such that any pump, filter, or other rotating equipment (except for the clarifiers) will not cause a reduction in throughput. Facility process mechanical systems, including liquid pumping, transformers, and filtering streams, will consist of two 100 percent capacity units or three 50 percent capacity units. Exceptions to these systems include the clarifier train. Redundant equipment and systems will be isolatable to allow maintenance while the plant is on-line.

Codes and Standards

All equipment and materials supplied and structures designed must comply with all local, state, and federal codes in effect at the time of purchase, wherever these codes are more stringent than those listed below. Modifications for local government rules, regulations, and codes, or for ES Minerals' unique design requirements will be made only if such modifications exceed the requirements of the codes and standards. ES Minerals' unique design requirements, exceeding the code requirements for the service will be specified and take precedence unless waived in writing.

Piping and Mechanical Requirements

The construction for pipe, pumps, valves, and instrumentation needs to be compatible with the system fluid. Brine handling, steam production piping, and all other piping of the fully operational LHM facility will be designed, fabricated, installed, and tested in accordance with ASME B31.1. All piping will be in accordance with the material selection flow diagram, index flow sheets, facility pipe specifications, and pipe and valve selection guidelines.

Pumps will be capable of operating continuously over the full operating range without overheating, cavitating, excessive noise or vibration, surging or instability when operating alone or in parallel with other pumps.

The desert site, where the project will be located, is subject to severe winds and blowing dust. Many of the motors are at outdoor locations remote from the main facilities. Motors will be severe duty Totally Enclosed Fan Cooled (TEFC) or Totally Enclosed Non-Ventilated (TENV) types for 460 volts (V) and below motors and WPII type for all 4000V motors with materials of construction suitable for the dusty geothermal environment. Motors used for mixing and transferring of chemicals shall be of the type guaranteed for use in the application. All motors will be with service factor of 1.15. No encroachment on the service factor will be permitted.

Motor-operated valves will be designed to open and close the valve under scaled conditions.

In general, line and vessel protection will be accomplished using rupture disks in brine and two-phase services and pressure safety valves for steam service. For applications protecting against thermal expansion and low flows, safety relief valves may be used.

Civil/Structural

The California Building Code based on the 2006 International Building Code is used for all structures as well as the ASCE 7-05 Minimum Design Loads for Buildings and Other Structures, and Cal/OSHA. LandMark Geo-engineers and Geologists prepared the geotechnical reports.

Variation From Plan

Early development work focused on producing battery grade lithium carbonate. Over the last couple of years, it became apparent that battery manufacturers were moving away from lithium carbonate and toward LHM. The transition from one form of lithium to the other did not require any changes to the front end of the process. Additional crystallization steps and specialized material handling equipment on the back end were added to the project scope. This change resulted in increased cost for engineering to be covered by additional ES Minerals funds. It also increases the capital cost and operating costs of the commercial-scale project but will be worth the redesign in order to better meet market demand.

CHAPTER 3: Engineering and Design

Engineering Effort on Major Unit Operations: Impurity Removal, Lithium Recovery, and Crystallization

Building on the design basis work, ES Minerals developed a thorough engineering package for the unit operations of the LHM commercial production plant, including 1) impurities removal (IR), 2) CCAD, and 3) evaporation, crystallization, and packaging.

The process design is based on previous ES Minerals pilot work that established lithium recovery rates as well as the initial mass and energy balance and reagent usage. The engineering effort then created a mass and material balance for the full-scale facility. This balance set the basis of design and sizing for the remaining process engineering. Engineering was also completed for mechanical, piping, electrical, and instrumentation of those unit operations.

Process Flow Diagram Development

Process engineering and design started with the mass balance proven from ES Minerals' previous pilot plant campaigns. Using the proven process flows, full-scale commercial unit process flow diagrams (PFD) were designed. These documents went through several iterations to optimize water usage and product LHM streams. The optimization and finalization of the PFDs and mass balance took roughly four months. These processes took much longer than expected but highlights the value of this early engineering due to the optimization of the process return streams across the unit operations and existing Featherstone Geothermal Plant tie-ins. The final mass balance also set the reagent usage for the IR process unit, which is the largest consumer of reagents in the flow sheet. The complete integrated PFDs allowed for the completion of the process design criteria and for the sizing of all process equipment and vessels.

Piping and Instrumentation Diagrams Development

Once PFDs and facility-wide mass balances were complete, the optimized process design for all three unit operations were used to finalize the piping and instrument diagrams (P&IDs). The P&IDs were developed with an emphasis on known service requirements from geothermal brine and the knowledge of operating the Featherstone Geothermal Plant. The issue review and finalization of the P&IDs considered piping and valve arrangements, as well as valve types that have been proven through years of operation to perform in the corrosive and abrasive geothermal process environment. The project team designed and reviewed the unit operations for plant operation redundancy as all pumps and valving arrangements have a spare on standby to allow continuous operation in the event of maintenance or equipment failure. The team designed the instrumentation setup for the process units for operation safety, automation, and on-line adjustability. The P&IDs also considered the commissioning and start-up sequencing of the individual unit operations to ensure that the plant front end is working without fouling equipment further down line. A hazard and operability analysis (HAZOP) was prepared and will be performed to further analyse the start-up and operation of the three unit operations.

From the complete P&IDs, the team generated a mechanical equipment list and valve list.

Mechanical Engineering

Mechanical engineering work started with the issuing of the plant general arrangement (GA) plot plan. This plan was reviewed and optimized for equipment access and solids handling truck routing. An overall equipment list was generated. The project team generated equipment specifications for this equipment along with data sheets to be sent to equipment suppliers for budgetary pricing from approved vendors. A portion of the GA showing the clarifiers from the top view is shown below in Figure 3.1.

Figure 3.1: Portion of GA

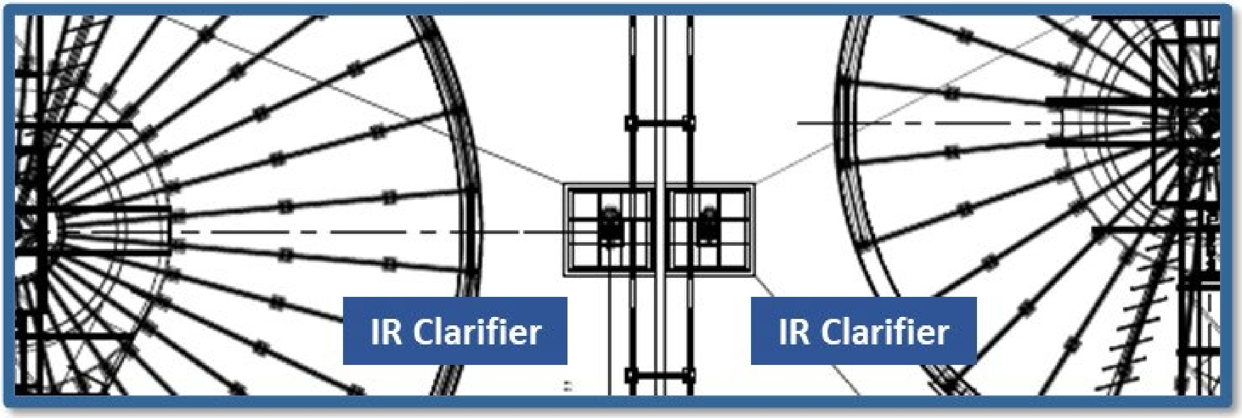


Photo Credit: ES Minerals

Structural Engineering

Engineering started with establishing specifications for structural steel and miscellaneous steel of equipment needing steel support such as tanks, clarifiers, vessels, equipment, pipe racks, and their appurtenances. These specifications included bonding of structural steel as well as the grouting of columns. The mechanical engineering of sizing the equipment also allowed the column and vessel point loading to enable the foundations designs for equipment. This information was required to determine where deep foundation support is needed for the construction effort in Task 4.

The P&IDs and mechanical and structural engineering efforts culminated in a 3D model for some unit operations to confirm arrangements, clearances, and operability. An example of the 3D plant model of the IR process is shown below in Figure 3.2.

Figure 3.2: Excerpt From 3D Model of Plant Design, IR

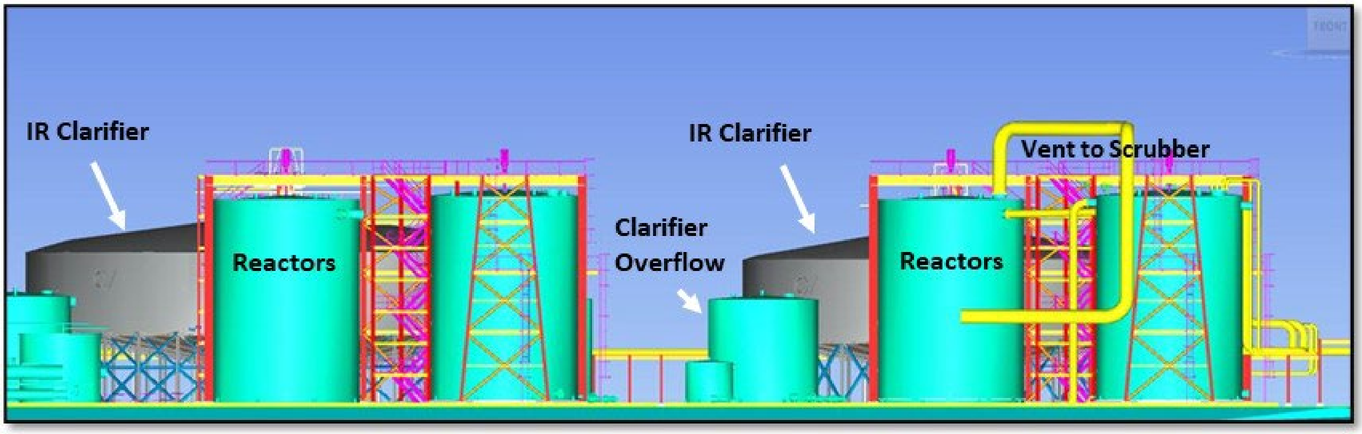


Photo Credit: ES Minerals

Electrical Engineering

The electrical engineering began with establishing an electrical design criteria for the project, which covered the design philosophy for the electrical distribution equipment, electrical rooms, motors, grounding, electrical routing by type, wire/cable, and control systems. The project team generated an electrical load list for all equipment specified to enable the sizing of the power distribution equipment, as well as the premanufactured buildings that house the power distribution centers (PDCs) and motor control centers. Equipment required to stay on-line in the event of a power outage to prevent fouling, and plugging was placed on a critical load circuit that will have an emergency diesel generator. The equipment GA and pipe rack locations, as well as wire and raceway types from this engineering work, enabled the creation of a material take-off for the required electrical cable, conduit, and raceway for the project estimated in Task 4. Final plant electrical integration of the three process units, as well as DCS integration, will be engineered when ES Minerals has negotiated and entered into an engineer, procure, and construction (EPC) contract after project financing has been achieved.

Materials of Construction

Materials of construction (MOCs) are dictated by produced engineering documents. Piping line classifications are defined by process fluid service and temperature from the PFDs and P&IDs. The individual line classifications are listed in the general piping specifications of the three unit operations. These specifications cover the piping material and strength per classification, allowable fittings and flanges, and valve type. The valves are listed with materials to be used for the body and valve components per service type. For equipment and vessels, MOCs are listed on the equipment specifications and data sheet of mechanical supplied equipment. Electrical equipment that includes cables, electrical enclosure types, raceway types, seals and fittings, control systems, grounding, alarms, and metering are listed on the electrical design criteria. Electrical duty requirements are dictated by installed location. MOCs have been chosen from experience of equipment used in geothermal brine service from operation of the Featherstone Geothermal Plant, as well as ES Minerals' pilot operations. Materials used are for optimized service life for the installed location, as well as the minimization of routine maintenance.

Utility Service (Water and Power Supply)

The commercial LHM plant will receive raw water from a storage pond on the east side of the Featherstone Geothermal Plant. A backup delivery water supply from Imperial Irrigation District's (IID) "N" lateral will be installed as a part of the new plant construction. This supply will add redundancy and ensure water supply to the Featherstone Geothermal Plant, as well as the new LHM facility. The predicted water usage for the lithium plant is about 2,000 acre-feet per year.

ES Minerals' LHM plant will require about 6 megawatts (MW) of power to supply unit operations. This power will be purchased from the IID because all the generation from the Featherstone Geothermal Plant is already under contract. IID will install a new power distribution line from the Featherstone Geothermal Plant substation to a new metering panel. An emergency diesel generator will be on hand for use in keeping vital plant systems operating during power outages.

The commercial LHM plant will also require steam to facilitate evaporation and drying. The steam required is low-pressure steam that can be integrated and supplied by the geothermal operations of the Featherstone Geothermal Plant, another benefit of accessing the brine from a geothermal facility.

Successes and Challenges

Engineering and design of the commercial LHM facility did not uncover any roadblocks that would prevent a commercial production plant to be built. The level of detail of this engineering effort prior to financing is more complete than what was available before financing the Featherstone Geothermal Plant and will lead to an accurate construction cost estimate.

As noted, ES Minerals and vendor teams spent significant time optimizing the mass and energy balance. This time requirement was not adequately forecasted at the beginning of this effort. The benefits to the project are significant as numerous recycle streams were identified that will lower overall reagent consumption. However, with three separate groups working on the three major unit operations for much of the design phase, it took more time to rebalance the design flows across the teams. On a couple of occasions, this rebalancing resulted in a rework of some equipment.

Outside this grant scope of work, ES Minerals conducted a life-cycle analysis (LCA) of LHM from geothermal brines. The results indicated that LHM produced by ES Minerals will lead in every environmental metric, including carbon footprint, water consumption, and land use compared to all other current lithium extraction practices. The accuracy of this LCA was enhanced greatly by the engineering data generated from this work.

Progress during these first few weeks of the COVID-19 outbreak slowed down productivity as companies and employees adapted to new remote working conditions. Consequently, the schedule was delayed by a few weeks.

Variation From Plan

Engineering and design kicked off with the target product from the commercial operating plant to be 99.5 percent pure battery grade lithium carbonate. During the latter half of 2019, ES Minerals was faced with the market reality that LHM is the product in ever-growing demand by automotive original equipment manufacturers (OEMs) as they transition to higher nickel content batteries. At that time, ES Minerals decided to change the final product to LHM instead of lithium carbonate. The change to battery grade LHM did not change the IR or CCAD process units. However, this change resulted in lengthening the duration of the engineering schedule but will ultimately allow a better response to market demand.

CHAPTER 4:
Operation of Pilot

Pilot Process

As part of the scope of work, ES Minerals contemplated a short pilot campaign be conducted to confirm any updated process inputs that might be updated based the early engineering effort. ES Minerals onsite pilot included the IR and CCAD unit operations. These unit operations are best piloted onsite to preserve the temperature and constituent profile of geothermal brines. If geothermal brines are tested offsite, the fluid cools, causing the chemistry profile to change, rendering offsite testing invalid even if reheated.

Confirmation of Process Parameters

The project team modified or optimized a few design elements so the pilot run was conducted to provide empirical confirmation. These values were used as engineering inputs for the process flowsheet, mass and energy balances, and operational targets for the commercial project. This pilot campaign achieved:

1. Sizing of equipment and materials of construction for the commercial plant.
2. Verifying material inputs and quantities.
3. Determining key operational parameters.
4. Further refining capital and operating costs.

Figure 4.1: ES Minerals Pilot Unit (Outside)

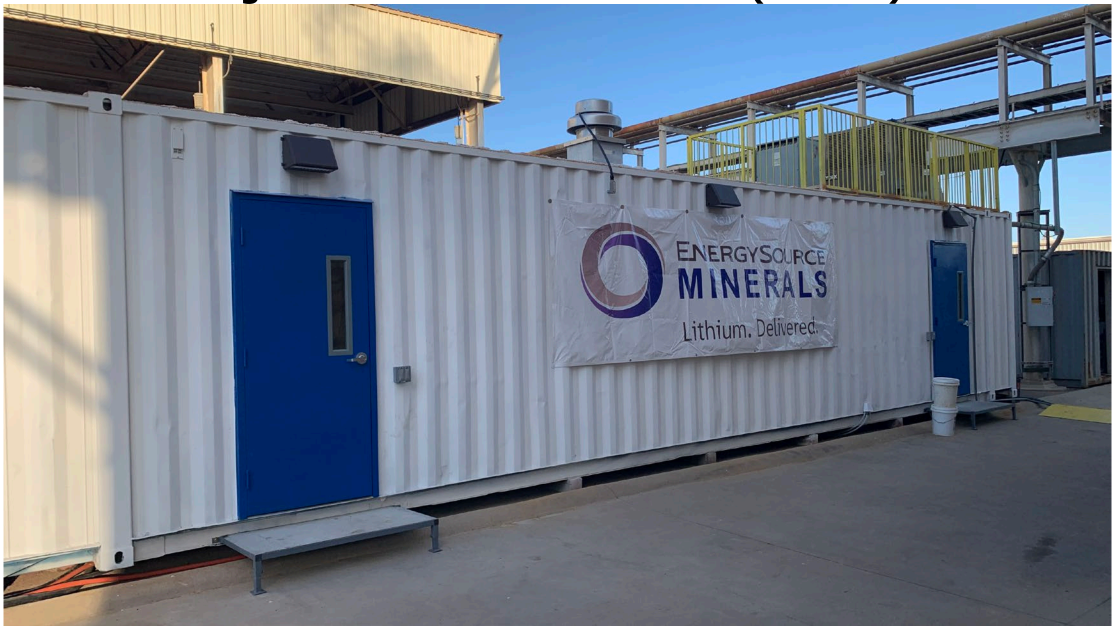


Photo Credit: ES Minerals

IR Piloting Conclusions

1. Operation of Train one was improved by controlling reagent feed based on grams of reagent per kilogram of feed brine, rather than pH control scheme.
2. The pilot operation helped establish a more accurate residence time in the process reactors for optimal reagent consumption.
3. IR process effluent met specifications for downstream operations.

CCAD Piloting Conclusions

1. Established set of operating conditions for CCAD that will produce a superior eluant for crystallization.
2. CCAD process was readily controllable and tunable.
3. Between 85 to 95 percent of the available lithium was recovered.
4. CCAD products of 2,500 to 3,200 parts per million (ppm) lithium and having less than 500 ppm calcium is achievable.

Value of Empirical Data

The pilot data are valuable as they provide empirical data for process operations and calibrate the stoichiometric models in use for mass and energy balances. These data provide ES Minerals with better capital and operating budget estimates for commercial-scale installation and are critical in preparing for California’s first lithium production plant using geothermal brines.

CHAPTER 5:
Product Certification

Analytical Testing

ES Minerals' goal for the product certification was to produce additional lithium product for testing if the proposed process was materially modified during engineering design. The engineering and design initially envisioned the target product from the commercial operating facility to be 99.5 percent pure battery grade lithium carbonate. This target product was later changed to LHM.

As noted, the onsite pilot unit was run to produce lithium chloride. This intermediate solution was then softened, concentrated, and crystallized in LHM. The analytical test work conducted focused on three primary criteria: (1) lithium hydroxide content, (2) impurity levels, and (3) crystal size and distribution. The project team used numerous specifications to establish the threshold for battery grade material confirmation.

Lithium Hydroxide Monohydrate Results

The test results described herein confirm the alternate process approach employed by ES Minerals succeeded in producing battery grade LHM material. The samples were produced using ES Minerals' pilot facility and vendor equipment. Figures 5.1 and 5.2 are photo micrographs of the battery grade LHM crystals generated from crystallization.

Figure 5.1: Photo Micrographs of Battery Grade $LiOH-H_2O$ Crystals

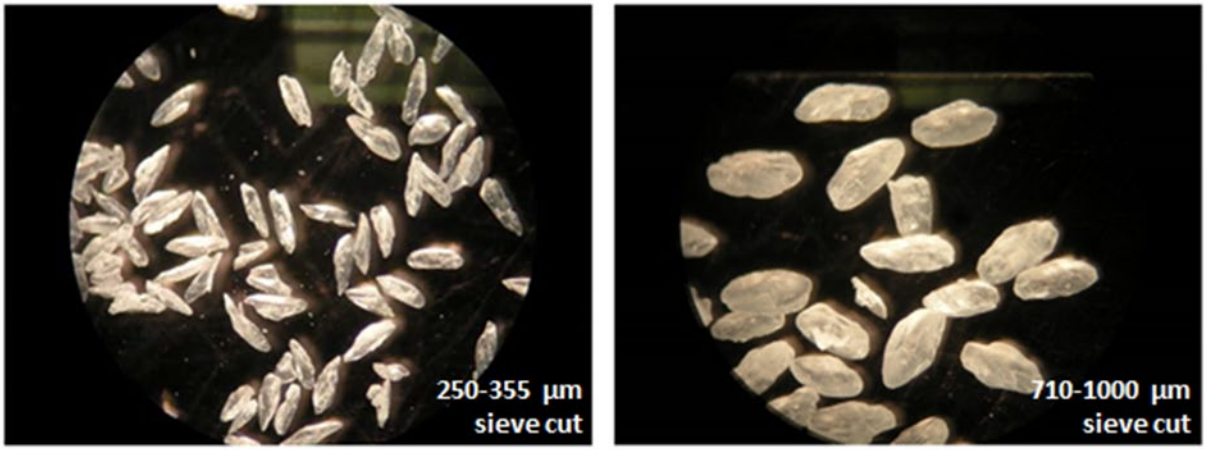


Photo Credit: ES Minerals

Figure 5.2: Polarized Micrographs of Battery Grade LiOH-H_2O Crystals

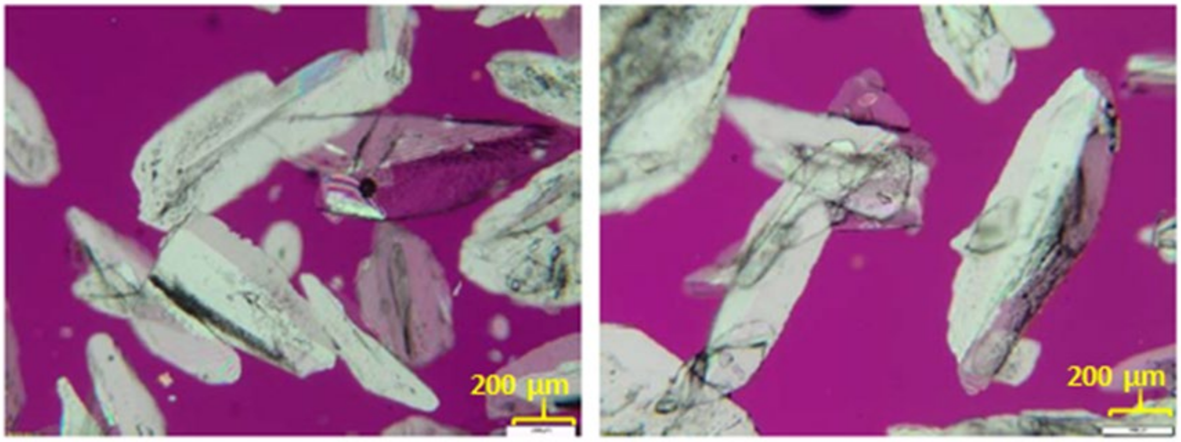


Photo Credit: ES Minerals

Moreover, the project team analyzed the LHM samples for lithium content and a wide spectrum of impurities. Table 5.1 summarizes the product composition.

Table 5.1: Lithium Hydroxide Product Sample Analysis

Element	Specification	Units	Results	Analysis
Lithium Hydroxide	56.5	wt.%	56.5	ICP*
Carbon Dioxide	3000	mg/kg, max	656	TIC
Chlorine	15	mg/kg, max	<10	Titration
Sodium	20	mg/kg, max	<10	AA
Potassium	10	mg/kg, max	<10	AA
Calcium	10	mg/kg, max	<1	ICP
Magnesium	10	mg/kg, max	<10	AA
Iron	20	mg/kg, max	<1	ICP
Manganese	5	mg/kg, max	<1	ICP
Copper	5	mg/kg, max	<1	ICP
Nickel	10	mg/kg, max	<1	ICP
Zinc	10	mg/kg, max	<1	ICP

Element	Specification	Units	Results	Analysis
Sulfate	50	mg/kg, max	<50	ICP
Boron	0	mg/kg, max	<1	ICP
Silicon	30	mg/kg, max	9	ICP
Aluminum	10	mg/kg, max	<1	ICP
Chromium	5	mg/kg, max	<1	ICP
Heavy Metals as Lead	10	mg/kg, max	<1	ICP

*ICP reported as OH

Source: ES Minerals

The results in Table 5.1 above confirm ES Minerals process approach can produce battery grade LHM. This approach definitively demonstrates that geothermal brines can leverage commercially available and widely used technology in the hydrometallurgical and crystallization industries to produce battery grade lithium products.

Variation From Plan

As noted above, during the latter half of 2019, ES Minerals was faced with the market reality that LHM is the product in ever-growing demand by automotive OEMs as they transition to higher nickel content batteries. At that time and with the permission of the CEC, ES Minerals decided to change the final product to LHM.

CHAPTER 6: Construction Costing

Need for Costing Effort

As a fundamental basis of the project approach, ES Minerals proposes to use commercially available processes and equipment from the water treatment, metal processing, and chemical processing industries to produce lithium and mineral coproducts from geothermal brine. This stated project requirement is advantageous in commercial financing as it provides evidence to lenders that the technical risks are lowered through demonstrated success in similar applications.

However, there are unique attributes to any project, and the first-of-its-kind lithium facility from geothermal brines is no exception. The core of this effort is taking the robust engineering package and process confirmation and coupling it with an accurate capital budget to acquire financing in the commercial construction lender market. This entails producing a detailed construction cost estimate based on detailed design and engineering information and eliminating most of the factored estimates used in early stage project development.

This cost estimation included the building foundations, installation of commercial process equipment, structural steel, mechanical piping, electrical, instrumentation, and balance of plant elements. It also included development of a construction schedule that included completion tests and commissioning. The accurate construction costing effort was essential to satisfying the lender's and lender's engineer's due diligence to secure commercial financing. The accurate capital budget was critical to the pro-forma model that serves as the basis for financing.

ES Minerals selected Performance Mechanical Contractors (PMC) of Holtville (Imperial County) to complete the cost estimating task. PMC was the general contractor for the Featherstone Geothermal Plant. PMC is particularly qualified to estimate construction work in Imperial County and the unique working conditions present in the extreme heat environment.

Method

The basis of the construction estimate was established from the engineering work performed on the IR, CCAD, and evaporation, crystallization, and packaging unit operations. The engineering documents, such as PFD and P&ID, established the sizing, quantity, routing, and service requirements for all equipment within the process boundaries. The construction cost estimate commenced when the engineering efforts of the three major process islands had produced ample deliverables for PMC to perform the estimate uninterrupted. PMC's estimate included the civil works, foundations, process equipment installation, piping, electrical, instrumentation, process and operation buildings, balance of plant works, Featherstone Geothermal Plant tie-ins, painting, insulation, construction management/indirect costs, and construction consumables. The engineering effort included the costing of the major commercial process vessels and equipment.

The site general arrangement (GA) drawings established the boundaries of where site civil works will be required. The site civil work, which includes site demolition and clearing, site grading, fencing, and area paving, incorporates the new lithium production facility into the existing grade around the Featherstone Geothermal Plant. The estimate covers the items that need to be cleared, demolished, or relocated that are in the footprint of the lithium production plant before site grading. The grading plan was designed to minimize the use of off-site borrow fill material. The GA also established area paving quantities from shown major roads through the lithium production facility as well as parking lots. The remainder of the areas to be paved outside process areas were estimated from guidelines established during construction of the Featherstone Geothermal Plant.

The process vessels and equipment were sized from the process flow diagrams as well as the process design criteria. From this sizing, vessels were classified as either shop-fabricated or field-erected by shipping dimensions. Vessels too large to be shipped on highway legal or permit loads were estimated to be field-erected vessels to be assembled in place. The vessel design and loadings along with the geotechnical report established foundation sizing as well as where deep foundations (piling) were necessary to include on the estimate. An equipment list was generated by engineering to show all sized equipment. As with the vessels, the estimate of the equipment foundations was taken from major equipment sizing, the GA drawings, and the geotechnical report for the site.

The project team derived the estimate for the piping supply and installation from the piping specifications created in the engineering effort, which established MOCs for the piping design per line classification based off process fluid and temperatures. The sizing of the piping was designed and shown on the P&IDs. Engineered pipe routings were designed and modeled for all line diameters greater than 3 inches for piping quantities to be estimated. Pipe racks were designed to convey piping on establish routing. Lines specified smaller than 3 inches in diameter were routed for the estimate. The constructor’s estimate of piping insulation was established from engineered process requirements, as well as personnel protection based off best practices in the Salton Sea Geothermal Field. The P&IDs were also for the basis for the engineering developed valve, instrument, and specialty equipment lists that, along with the engineering produced specifications, allowed the constructor to establish quantities to supply and install manual valves, control valves, and instrumentation for the estimate.

Tonnages of structural steel estimated to be supplied and installed were based on vessel support design, equipment support design, equipment support structures, and pipe rack design. Accessory steel on vessels was estimated based on past designs from previous PMC projects. Foundations for the pipe rack steel were also estimated.

A combination of the mechanical equipment list, general arrangement drawings, P&IDs, and the electrical one-line drawings were used to estimate electrical cable sizes, communications cable quantities, underground electrical, cable footages, required electrical equipment, and terminations quantities. Pre-engineered/manufactured PDCs were specified by the engineering team. Grounding and area lighting were estimated by PMC.

A pre-engineered metal building was proposed and quoted for the new operations facility and lab that will serve the lithium production facility. This building will house the control room and management facilities of the new unit. A large pre-engineered metal building was also proposed for the lithium packaging plant.

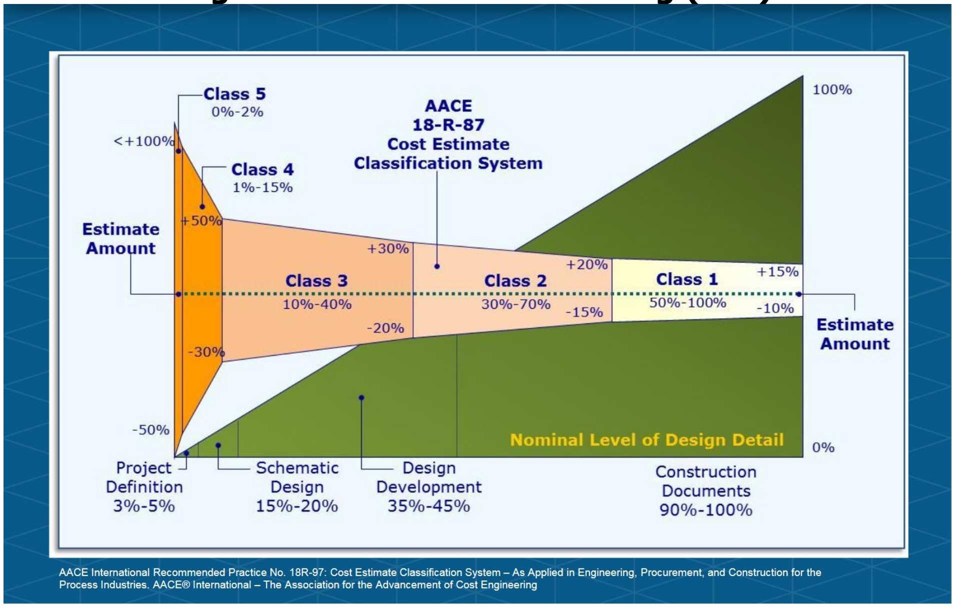
PMC estimated all work associated with tie-ins to the existing Featherstone Geothermal Plant. This work included the extension and modification of the existing fire water system, process water connection to the existing freshwater pond, utility water connection, LP steam connection, and sewer connection. This work also included the new lithium production plant process tie-ins.

The constructor included all costs to execute and complete facility construction, which included all indirect costs, insurance, legal, consumables, temporary construction power, construction equipment, and home office support.

Construction Costs

The total equipment and construction costs were estimated to be $419 million (2019$). These costs included the equipment, foundations, installation, mechanical piping, structural, electrical, and instrumentation. The previous process equipment and installed cost estimates were reasonably accurate with some minor increases noted. Site civil works, construction management, and some balance of plant elements were previously underestimated. Importantly, the risk of project scope additions is significantly reduced.

Figure 6.1: Front-End Planning (FEP)



AACE International Recommended Practice No. 18R-97: Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries. AACE® International – The Association for the Advancement of Cost Engineering

Photo Credit: EPCM Global

Variation From Plan

Estimates prior to the engineering effort were based on vessels and equipment required to upscale the pilot operations with materials of construction based on the Featherstone Geothermal Plant. The installed cost came from a factored estimate of the equipment costs. The engineering produced process flow diagrams, process design criteria, P&IDs, and project specifications sized and quantified all major equipment and vessels while specifying the materials of construction. This effort refined the preliminary estimate to one based on person-hours for construction of the entire plant, as well as vessel and equipment estimates from vendor-supplied quotations based on engineered designs.

The refinement of information through the design, along with the construction estimate, resulted in a potential cost increase from the early budgetary estimate of nearly $24 million. This cost increase was due in part from change of the product from lithium carbonate to LHM, as well as the upsizing of certain vessels and equipment, particularly in the impurities removal process island. There is potential to bring costs down as value engineering of the project is performed prior to the finalization of the detailed engineering.

CHAPTER 7: Public Outreach

ES Minerals has participated in several public forums, hosted geothermal site tours, and is a member of the CEC Lithium Recovery Initiative, as well as the Geothermal Resources Council (GRC), now known as Geothermal Rising. In these venues, the project team has shared results of this project, the related effect on advancing the extraction of lithium and other mineral coproducts from geothermal brines, and the effect of the project on geothermal energy production.

Conferences and Public Events

ES Minerals participated in three conferences in 2019 and early 2020 — the GRC Annual Meeting and Expo held September 15-18, 2019, in Palm Springs (Riverside County); the VERGE 2019 (VERGE 19) Conference and Expo held October 22-24, 2019, in Oakland (Alameda County); and California's Lithium Recovery Initiative – Symposium hosted by the CEC and the Governor's Office of Business and Economic Development (GO-Biz) on February 12, 2020, at Stanford University, Palo Alto (Santa Clara County).

The GRC Annual Meeting & Expo brings together geothermal companies, academics, financiers, policy leaders, students, and other individuals working in the geothermal industry. This venue is typically well represented by California geothermal power producers, and for 2019 was coincidentally held close to the Salton Sea. On September 16, 2019, ES Minerals participated in the panel discussion "Accelerating Geothermal Lithium Extraction Technology." The panel reviewed the world lithium supply including geothermal brines, economics of recovery, environmental issues, associated with current lithium resources, and how to accelerate the extraction technology.

The VERGE 19 Conference and Expo is a platform for accelerating the clean economy and brings together leaders from large companies, utilities, government, nongovernmental organizations, solution providers, and startups to explore the emerging technologies and scalable solutions within energy, transportation, material reuse, and carbon. On October 23, 2019, an ES Minerals representative participated in the panel discussion "Lithium Valley? California's Untapped Lithium and Battery Resource." The panel discussed how the large deposit of untapped lithium brines in the Salton Sea near California's southern border could be used to make lithium-ion batteries that power cell phones, laptops, and increasingly electric cars.

The CEC and the GGO-Biz jointly facilitated presentations and panel discussions on lithium recovery from geothermal brine at California's Lithium Recovery Initiative – Symposium on February 12, 2020, where an ES Minerals representative participated in the panel discussion on lithium supply.

Subsequent public events and industry forums were cancelled because of the COVID-19 pandemic.

CHAPTER 8: Conclusion

Key Project Lessons

The work conducted as part of this grant award addresses the previous lack of integrated engineering design for a first-of-its-kind lithium production facility using geothermal brines. As part of the engineering and confirmatory pilot run, ES Minerals was able to accurately estimate reagent use, instrumentation and data requirements, and the associated staffing levels required to maintain process controls.

Even though ES Minerals used commercially available processes and equipment and completed significant early engineering and pilot work before this grant effort, the project team still encountered engineering challenges integrating the three primary unit operations. These challenges occurred mainly during the engineering work on the mass and energy balance for the fully integrated flow sheet. Numerous opportunities for water and reagent recycling were identified, resulting in several iterations of work by multiple firms in multiple locations. An engineering program lead would have been more efficient but was not practical for this effort.

Moreover, project developers/owners need to evaluate the level of engineering that should be conducted in the project development phase to ensure the delivery of the greatest risk reduction or cost certainty or both. This will vary considerably based on the technology readiness level of a given process, equipment component or both. ES Minerals' experience found the optimal level to minimize risks associated with construction cost estimates around 30 to 40 percent engineering completion. For any project using new technologies, an even greater amount of piloting and engineering should be done to achieve financeable capital and operating cost projections.

ES Minerals work resulted in a more accurate equipment and construction cost estimate of nearly $419 million (2019$). The cost detail provided from this project prove and support a robust estimate based on actual equipment design and buildout costs. Site civil works, construction management, and some balance of plant elements were previously underestimated. Importantly, the risk of project scope additions is significantly reduced.

Benefits to California

While the benefits to California as part of this engineering effort are relatively modest and reflect mostly the labor and personnel time to execute the work, the real benefits to California would be realized if a fully operational LHM facility is built and would play an important role in California achieving its clean energy goals. This relatively small, public investment to produce engineering plans will help reduce contingency costs significantly making the full-scale project more likely to succeed. This project laid a solid foundation for a full-scale commercial LHM plant and serves as an investment in the game-changing opportunity for California to become one of the largest and most sustainable producers of lithium on a global scale.

ES Minerals estimates that a commercial facility would produce 20,000 tonnes per year as LHM. In an economically disadvantaged part of the state, this scale of commercial facility would generate more than $400 million (2019$) in direct capital investment and would create roughly 300 construction jobs.

In addition, it would create about 70 new, full-time jobs to operate the plant continuously. ES Minerals estimates another 100–150 new jobs will be created in transportation, contractor services, outside maintenance, and local procurement. These estimates are based upon specific unit operations of the plant, material movements required to deliver reagents and supplies, transport of finished products, and equipment maintenance schedules.

The economic effect to California includes payroll and benefits, royalties, property tax payments, and local procurement of goods and services and are estimated to be more than $150 million per year. Of this amount, the local community would see nearly $24 million per year local tax payments.

The above-mentioned benefits are monetary and direct, but there are additional benefits that would accrue to California if a fully operational LHM plant is built. The availability and certainty of battery material supply are important factors as electrification of transportation efforts increase in California and across the globe. The process used by ES Minerals has been verified to produce LHM with the smallest carbon, land, and water impacts of any existing process approach. As California advances its clean energy goals with the decarbonization of transportation, it is important to build resiliency and decarbonize the supply chain for electric vehicles as well.

Lastly, California has had great success with the development and cost reductions of solar and wind in general, but the cost reductions for new geothermal resources has not enjoyed similar success. This lack of deployment is in part due to factors beyond the scope of this document, but the cost of new geothermal power projects is often hindered by the high mineral content of the production resource. Minerals recovery provides a meaningful second revenue stream or royalty payment or both to new and existing operations. By improving the economic resiliency of current geothermal facilities and enhancing the development prospects for new geothermal development, this project can be a critical first step to billions of dollars in direct capital investment, $100 million per year in local economic activity, and hundreds of new, high-paying jobs in an economically depressed region of California. Geothermal power can be a cost-effective contributor to the greening of California’s electric grid while providing the material inputs for battery-electric vehicles that will help clean California’s air and reduce greenhouse gas emissions.

Conclusions

California has an opportunity to become a global-scale producer of the most sustainably sourced lithium and be an important cornerstone in California in achieving its clean energy goals. Lithium is a key component in batteries, which are needed for electric vehicles, energy storage and numerous consumer products, and is recognized as a critical mineral by the Federal government. Globally, the supply chain is localizing as automakers and suppliers, including battery cell manufacturers, are focusing the production of vehicles and components in target markets. California has a unique position to complement its green vehicle manufacturing with green lithium sourcing.

Geothermal has struggled over the years to be cost-competitive on energy-only pricing. Coupling the production of lithium and perhaps other minerals is a way to assist the geothermal industry in reducing the levelized cost of electricity. Geothermal is an important source of renewable energy as it provides baseload electricity that will be increasingly needed with the continued expansion of intermittent renewables and the electrification of transportation. Introducing lithium plants with geothermal power in one of the state's most economically disadvantaged communities has a range of benefits, including creating quality full-time jobs.

The recovery of minerals from geothermal brines is commercially viable today. ES Minerals' grant project was pursued to reduce the uncertainty around the installed costs of the first commercial LHM plant using geothermal brines. The objectives of the grant project were met enabling a more accurate estimate of the capital cost of the project, which allows a commensurate reduction in the level of contingency, and the burden that would otherwise be placed on the project.

Receiving the CEC grant was beneficial to overall project effort. There is the obvious financial benefit of the monetary funds, but also the increased visibility due to the CEC's ongoing support of renewable energies, energy storage, and electrification of transportation. ES Minerals believes that CEC involvement raises awareness of all its grant recipients and provides a measure of credibility for each company, and ES Minerals is no exception.

ES Minerals could have completed the project without the funding, but it would have required notably more time to reach the same phase of work, so the grant funding was very welcome and delivered value beyond the face amount. ES Minerals took a very deliberate approach to minimize risks associated with the development phase of the LHM project, wanting to avoid mistakes of the past and using capital to meet milestones. The CEC grant enabled the allocation of significantly more resources to the engineering effort earlier in the cycle and thereby minimizing risks of the project and accelerating to commercial execution.

While LHM can be produced domestically, California does not have a cathode manufacturing infrastructure. As a result, the LHM must be transported overseas, processed and then returned for the vehicle assembly process. Ideally, California or other states, will attract cathode manufacturers stateside enabling the entire process to be done in the United States. The benefits to this are 1) cost savings in terms of not needing to ship outside of the country 2) geopolitical risks of tariffs or disruptions are eliminated 3) reduced environmental emissions associated with streamlined transport and supply chain logistics and 4) potential job creation in the United States.

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GLOSSARY

Abbreviation, Acronym, or Term	Definition
AA	Atomic Absorption spectroscopy is an analytical technique that measures the concentrations of elements in a sample.
CCAD	Counter-Current Adsorption Desorption is EnergySource Minerals' proprietary method for impurity reduction and lithium concentration.
CEC	State Energy Resources Conservation and Development Commission or, the California Energy Commission.
EPC	Engineering, Procurement, and Construction is a prominent form of contracting agreement in the construction industry. The engineering and construction contractor will carry out the detailed engineering design of the project, procure all the equipment and materials necessary, and then construct to deliver a functioning facility or asset to their clients.
GA	General Arrangement drawings for piping systems and equipment are developed by piping designers. These drawings indicate the locations of main equipment in the plant. The main piping items, valves, and fittings are also indicated in the General Arrangement or GA drawings.
HAZOP	Hazard and Operability Analysis is a review of the safety implications of design and operation proposals. HAZOPs are widely used in any industry where safety is a particular concern.
ICP	Inductively Coupled Plasma is an analytical method used to detect and measure elements to analyze chemical samples.
IR	Impurities Removal is part of EnergySource Minerals' process in which unit operations remove iron and silica, and then manganese and zinc, in a two-stage precipitation sequence.
Kg	Kilogram is a basic unit of mass in the metric system. A kilogram is very nearly equal (it was originally intended to be exactly equal) to the mass of 1,000 cubic cm of water. The pound is defined as equal to 0.45359237 kg, exactly.
L	Liter is a unit for measuring the volume of a liquid or a gas, equal to 1,000 cubic centimeters.

Abbreviation, Acronym, or Term	Definition
LCA	Life-Cycle Analysis is a technique to assess environmental impacts associated with all the stages of a product's life, which is from raw material extraction through materials processing, manufacture, distribution, and use.
LHM	Lithium Hydroxide Monohydrate (LHM), or $LiOH.H_2O$ is a water soluble chemical compound. It is a key component of lithium ion batteries.
MCER	Risk-Targeted Maximum Considered Earthquake (MCER) ground motions for designing new buildings and other structures. The MCER ground motions were developed by the Building Seismic Safety Council and the U.S. Geological Survey for the 2009 NEHRP Recommended Seismic Provisions for New Buildings and Other Structures.
mg	Milligram is a unit of mass equal to 0.001 grams.
mL	Milliliter is a unit of volume that is equal to 0.001 liters.
MOC	Materials of Construction are a selection of construction materials based on plant processes and the environmental conditions to which the plant will be subjected. The process information can be obtained from Process Flow Diagrams (PFD) and Heat and Material Balance spread sheets provided by the Process Engineering Discipline.
PFD	Process Flow Diagrams illustrate the arrangement of the equipment and accessories required to carry out the specific process.
P&IDs	Piping and Instrumentation Diagrams are a graphic representation of a process system that includes the piping, vessels, control valves, instrumentation, and other process components and equipment in the system. The P&ID is the primary schematic drawing used for laying out a process control system’s installation.
ppm	Parts per million is a unit for measuring the amount of a substance that is mixed with a liquid or another substance.
TEFC	Totally Enclosed Fan-Cooled electric motor, this enclosure type has an external fan which blows air across the motor frame's external cooling fins. The air inside the motor recirculates and is cooled by heat transfer through the frame. The TEFC

Abbreviation, Acronym, or Term	Definition
	designation is assigned by the National Electrical Manufacturers Association (NEMA) which designates certain motor enclosure types, and the degree of protection against environmental intrusion that each affords.
TENV	Totally Enclosed Non-Ventilated electrical motor, similar to TEFC, but the motor is designed with a low enough temperature rise so that an external fan is not required for cooling, or duty is limited so the motor does not overheat. The TENV designation is assigned by the National Electrical Manufacturers Association (NEMA) which designates certain motor enclosure types, and the degree of protection against environmental intrusion that each affords.
TIC	Total ion chromatogram is a plot created by summing the intensity contributions of all ions from a series of mass scans. the tic provides a way of viewing an entire data set in a single pane. it consists of the summed intensities of all ions in a scan plotted against time in a chromatographic pane.
Titration	Process of chemical analysis in which the quantity of some constituent of a sample is determined by adding to the measured sample an exactly known quantity of another substance with which the desired constituent reacts in a definite, known proportion.
WPII	Weather Protected Type II motor has baffles on the inlet of the motor force air to change direction by 90 degrees 3 times. The WPII designation is assigned by the National Electrical Manufacturers Association (NEMA) which designates certain motor enclosure types, and the degree of protection against environmental intrusion that each affords.