

Lithium processing division update

Vulcan Energy Resources (Vulcan, the Company, ASX: VUL) herewith provides an update on the activities of its lithium processing division.

- Lithium Definitive Feasibility Study (DFS) progressing on track for mid-2022, led by Vulcan's in-house team and Hatch Ltd.
- Pilot plant and laboratory studies, which are informing the DFS, are successfully demonstrating multi-cycle sorption tests on Upper Rhine Valley geothermal brine using multiple commercially available aluminate-based sorbents from our partners including DuPont, providing optionality. Offsite lithium electrolysis test work is also ongoing.
- Strategy of the DFS team is to standardise the design of the DLE plants where possible, allowing for relatively modular engineering and build out in subsequent phases.
- New Vulcan laboratory to officially open in the town of Karlsruhe-Durlach in January, with full in-house analytical capability.
- Long lead items are on order and major skids are under construction for a new Demonstration Plant ("Demo Plant"), designed by the technical team of the Vulcan Group, which will demonstrate the full process from Direct Lithium Extraction (DLE) to lithium hydroxide production.
- The DLE section of the Demo Plant is targeted to commence operation on geothermal brine in Q2 2022, to an approximately 1:200 scale of the first commercial plant.
- The Demo Plant enables the Vulcan team to run the full process onsite and to provide training prior to first commercial plant operation, which is targeted for 2024.

Managing Director Dr. Francis Wedin commented: *"Our lithium processing division continues to make strides towards the completion of our DFS. Our new laboratory facility will afford us more space and analytical capability to further advance the DFS. Whilst the pilot plant operation continues to inform the DFS, a considerable focus of the team is engineering and construction of the Demo Plant, which we are targeting to enter into production by Q2 2022. This will be vital in building up the*

Highlights

Globally unique **Zero Carbon Lithium™** Project.

Combined lithium chemicals & renewable energy project in the Upper Rhine Valley of Germany.

EU's **largest** lithium resource.

Located at the heart of the EU Li-ion battery industry.

Fast-track development towards supplying the EU's battery & electric vehicle industry.

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operational expertise in the team prior to our target commercial production start date of the Zero Carbon Lithium™ Project in 2024.”

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About Vulcan

Vulcan is aiming to become the world's first lithium producer with net zero greenhouse gas emissions. Its Zero Carbon Lithium™ project will produce a battery-quality lithium hydroxide chemical product from its combined geothermal energy and lithium resource, which is Europe's largest lithium resource, in Germany. Vulcan's unique, Zero Carbon Lithium™ project will produce both renewable geothermal energy, and lithium hydroxide, from the same deep brine source. In doing so, Vulcan will address lithium's EU market requirements by reducing the high carbon and water footprint of production, and total reliance on imports. Vulcan aims to supply the lithium-ion battery and electric vehicle market in Europe, which is the fastest growing in the world. The Vulcan Zero Carbon Lithium™ project has a resource which can satisfy Europe's needs for the electric vehicle transition, from a source with net zero greenhouse gas emissions, for many years to come.



DFS, lithium piloting and laboratory studies update



Figure 1: Ongoing work by Vulcan's chemistry and chemical engineering teams

successfully demonstrate multi-cycle sorption tests on Upper Rhine Valley geothermal brine using multiple commercially available aluminate-based sorbents², providing commercial optionality for Vulcan. All sorbents have demonstrated >90% lithium recovery, in line with the assumptions used in the PFS, and consistent with commercial DLE development projects internationally.

Pre-treatment and post-treatment of the brine has also been demonstrated successfully, the former to enhance sorbent life and performance, and the latter to return the brine to materially the same state prior to re-injection. Whilst assuming pre and post treatment in its PFS and now DFS as a base case,



Figure 2: Ongoing work at Vulcan's in-house designed and operated Pilot Plant 1

Vulcan's Lithium Definitive Feasibility Study (DFS) for Phase 1 of its Zero Carbon Lithium™ Project is progressing on track for mid-2022, led by Vulcan's in-house team and by independent consultants Hatch Ltd¹, who also led Vulcan's Pre-Feasibility Study (PFS) published in 2021, and Scoping Study published in 2020. The strategy of the DFS team is to standardise the design of the DLE plants where possible, allowing for relatively modular engineering and build out in subsequent phases.

Pilot plant and laboratory studies, which are informing the DFS, are continuing to

informing the DFS, are continuing to successfully demonstrate multi-cycle sorption tests on Upper Rhine Valley geothermal brine using multiple commercially available aluminate-based sorbents², providing commercial optionality for Vulcan. All sorbents have demonstrated >90% lithium recovery, in line with the assumptions used in the PFS, and consistent with commercial DLE development projects internationally.

Vulcan's Research & Development team is also working on reducing the need for pre-treatment, which could provide an upside in terms of operating cost reduction. Vulcan will base its assumptions in the DFS on the performance of these sorbents, as it did in the PFS, and will be negotiating supply contracts with the sorbent manufacturers in the meantime. Importantly, the pilot plant is operating using "live" geothermal brine³, that is, real (not synthetic) brine coming directly from an operational geothermal plant.

¹ See ASX announcement 5 July 2021

² See Presentation released on ASX 4 May 2021

³ See ASX announcement 12 April 2021

This is important for representativity because geothermal brines change composition rapidly when taken offsite, and are cooled and/or de-pressurised. Offsite downstream lithium processing test work is also ongoing at external providers, which is also generating data to be used in the DFS. Vulcan's lithium division is led by Dr. Stephen Harrison, with Dr. Angela Digennaro leading the laboratory team and Dr. Thomas Aicher leading the pilot plant team. The team is expanding rapidly as it prepares to hire and train further personnel towards a targeted commercial operation. To assist with accommodating this expansion, a new Vulcan laboratory has been secured and has been undergoing refurbishments for the last six months. This new laboratory will officially open in the town of Karlsruhe-Durlach in January, with full in-house ICP and IC analytical capability.

Demo Plant

Vulcan's strategy for scaling up its process is to build a pre-commercial Demo Plant to train its technical and operations personnel, and therefore to develop a comprehensive understanding of the process and its operation prior to the construction of the first commercial plant, the start-up of which is targeted for 2024. The Demo Plant consists of two parts: the DLE plant and the lithium hydroxide production plant. The DLE plant will be located at an existing geothermal plant. It will extract, purify, and concentrate lithium chloride from the brine. The lithium hydroxide plant consists of an electrolysis plant producing lithium hydroxide solution which will be crystallised to produce battery-quality lithium hydroxide, and will be located in a chemical park. The plant will demonstrate the full process from DLE to lithium hydroxide production including recycle streams. For the Demo Plant, the long-lead time items have been ordered, and major skids are under construction. The plant was designed in-house by Vulcan's chemical engineering lithium team and by Vulcan's 100%-owned engineering company Gec-Co. The DLE section of the Demo Plant is targeted to commence operation in Q2 2022, and will represent an approximately 1:200 scale of the first commercial plant.

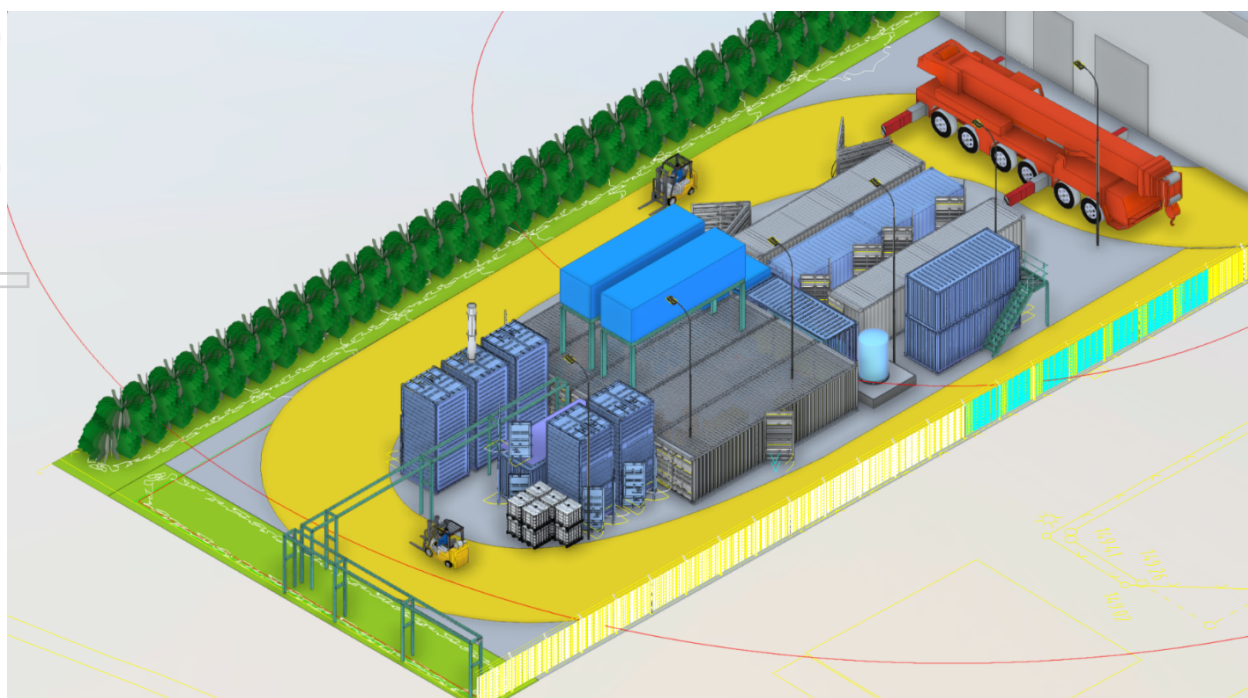


Figure 3: Rendering of Vulcan's Demo Plant, currently under construction

Appendix: background on lithium extraction techniques

For reference, an overview of Vulcan's understanding of the DLE technology options and evaluation of suitability thereof for the Vulcan Zero Carbon Lithium™ Project are provided, based on a modified version of the DLE Section of Vulcan's PFS which was originally authored by consultant Jade Cove Partners. A core principle driving the design of the Vulcan extraction flowsheet is to avoid the use of un-tested, higher risk DLE technology solutions. Through its in-house team and guided by external consultants, Vulcan has identified multiple commercially available sorbents using technology principles already proven at commercial scale in Argentina and China. Below is a summary of Vulcan's rationale for selection of a sorption-type DLE process.

Direct Lithium Extraction Overview

Direct lithium extraction (DLE) is a process that separates lithium ions or lithium chloride molecules from a complex brine matrix, leaving all other components in the brine (e.g. sodium, potassium, magnesium, calcium). As result, purified lithium-rich solution is produced and can be concentrated and converted into lithium chemical powders such as lithium carbonate and lithium hydroxide.

During evaporation processes applied on some salar-type brines, water evaporates from ponds gradually, which leads to sequential crystallization of different salts based on their solubility. Chemical reagents can be added to brine in order to precipitate certain impurities and to achieve higher recoveries. This results in producing large quantities of waste. After non-lithium salts are crystallized or chemically precipitated using reagents, a high purity, high concentration "end brine" is obtained and can be processed to lithium carbonate or lithium hydroxide.

The common thread between the two families of brine processing techniques is the production of a lithium concentrate for conversion to lithium chemical products.

The general principle of operation behind DLE is the non-chemical reversible bonding of lithium ions (Li^+) or lithium chloride (LiCl) molecules in raw brine to a selective site in extraction material (solid or liquid media containing the selective site). Ions of Li^+ have a high enthalpy of hydration compared to other monovalent ions and it is challenging to design a technology which will remove Li^+/LiCl from brine solutions selectively. Also, it is easier to use chemical reactions to separate monovalent Li^+ ions from divalent magnesium (Mg^{2+}) and calcium (Ca^{2+}) ions, than is the case for separation of Li^+ from Na^+/K^+ . This challenge is resolved using engineered materials, which are the basis for DLE.

One of the most important material streams that determines the performance of a DLE technology is the eluate from the DLE process. Li^+ or LiCl achieves a minimum energy state at a selective site in the DLE process, and when the brine is separated from the medium containing the DLE selective site, another high purity solution is contacted with the selective site to elute the lithium from the DLE medium to form a concentrate. This solution offers a lower energy state for the Li^+ or LiCl to dissolve in as well as complex water molecules. This solution is called the lithium concentrate. Different solutions,



such as pure water, LiCl solutions, and acids are used by different DLE technologies to form this lithium concentrate.

The three most important parameters when examining applicability of DLE technology to a certain process are selectivity, upgrading ratio, and recovery. None of the parameters is more important than the other, and there are always trade-offs between the three predicated by the lowest OPEX operating conditions for a particular process. Furthermore, there are other parameters such as pH, temperature, and reagent consumption which are also important to consider when developing a DLE-based process.

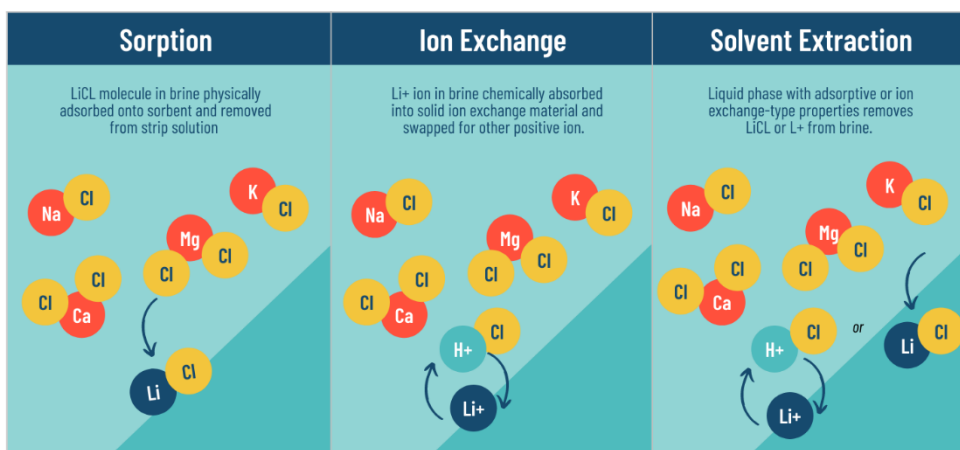
Recovery is the ratio of the quantity of lithium in the concentrate to the amount of lithium dissolved in the original brine. Lithium recoveries from well to lithium carbonate achieved using evaporation pond systems are typically between 10-50% (Garrett, 2004. Handbook of Lithium and Calcium Chloride). Based on the published information about the successful implementation of DLE technologies, commercial DLE developers generally claim to be able to achieve recovery of 90% or greater, thus allowing a significantly higher productivity of lithium chemicals from essentially the same feedstock. This has a notably positive impact on the economics of the project, because there are fixed costs of operating a lithium brine operation. Projects deploying DLE technology may generate more revenue due to higher productivity. Recovery is only one part of the project's economics, and the other major line items need to be considered to build the lowest OPEX flowsheet.

While the composition of the concentrate stream can provide a lot of information about the economics of a DLE process, the costs of operating the DLE process block are equally important for determination of overall economic feasibility of the project. To this end, one of the main costs of operating the DLE process is the consumption of the medium containing the selective site, either by breakage, dissolution or deactivation. DLE technologies with high media consumption should be avoided.

Moreover, different DLE technologies consume various reagents. The types and quantities of reagents influence OPEX and these should be understood and modelled as part of any investment decision.

Types of Direct Lithium Extraction Technologies

There are three main classes of DLE technologies: sorption, ion exchange, and solvent extraction. There are some other classes of technology, but none are developed enough for commercial deployment on natural brines.



The Three Classes of DLE Technologies (Source: Vulcan PFS, Jan 2021)

Sorption

Currently the only known operational DLE plants use sorption and are located in Qinghai province in China, and in Livent's Hombre Muerto facility on the border of the Salta and Catamarca provinces, Argentina. The latter plant has been operating for decades, producing a high fraction of battery-quality lithium product from its operations.

Commercial sorption DLE operations typically use a sorption process where lithium chloride is adsorbed on a solid aluminate material. Aluminate compounds feature a layered crystal structure. The void positions in the structure can fit positively charged lithium ions, whereas negatively charged chloride ions populate the space between the layers. As result, both lithium and chloride ions are selectively removed from the brine and adsorbed inside the aluminate. Both ions can be desorbed by washing the sorbent with water. This generates a concentrate solution which is then processed in a downstream plant to make battery chemicals. Conventional aluminates perform best at elevated temperature in the range between 60-100°C, which is due to improved kinetics of LiCl intercalation into the material. Commercial sorption-type DLE operations are likely to utilise heat from natural gas combustion to pre-heat the brine before their sorption process. This gives pre-heated, geothermal brines an operating cost advantage over salar-type brines.

The concentration of lithium eluted from the aluminate-filled column into the concentrate is typically in the range of 250-2,000 mg/L Li. The thermodynamics of the elution prevent lithium from eluting at much higher concentrations than this because then there would be too much competition for complexing water molecules in the concentrate. Sorbents typically do not dissolve in brine.

However, there are unavoidable processes that lead to consumption of sorbents over time. One of them is capacity loss due to irreversible structural changes, which leads to loss of lithium selective sites. Some void sites in the structure can be irreversibly occupied by elements other than lithium and become inactive and unavailable for lithium intercalation. Therefore, over time any sorption-based material will be consumed during the DLE process and it is important to understand the sorbent material consumption rate during test work with real “live” brine, not synthetic brine, as it has great implications for OPEX calculations.

Besides being deployed in Livent’s operation for over 20 years in Argentina, sorption-based DLE materials are also deployed in some of the new commercial projects in China. At least two different sorbents have been deployed in Qinghai, China to build commercial scale projects.

Ion Exchange

During an ion exchange process, a positively charged lithium ion is swapped for another positively charged ion contained inside an ion exchange medium. Although there are many positively charged ions that could theoretically be used during this process, the most common ion exchange media are acid-based and use hydrogen ions. The complete cycle for ion exchange involves a selective lithium absorption step from brine, washing with water, and elution using acid. The type of acid used to desorb the lithium is flexible and determines the anion of the lithium eluate. This specific ion exchange resin allows for swapping of the anion of the lithium compound.

The most conventional family of ion exchange media used for lithium extraction is represented by lithium metal oxides. These oxides are frequently mentioned in scientific literature as potential anode or cathode materials for lithium-ion batteries due to their layered structures and ability to reversibly intercalate and de-intercalate large amounts of lithium ions. Similar to the extraction process where sorbent-based DLE is deployed, these ion exchange media can be used in a column to extract lithium directly from brine. The metal oxide ion exchange media are not so different from cathode powders used in lithium-ion batteries. Similar to cathode materials, they are likely challenging to synthesize in order to achieve optimal performance results, since many factors can influence the chemistry of the material during synthesis. Many kinds of acid can be used to elute lithium from the ion exchange-based metal oxide media. The upgrading ratio of ion-exchange materials is often higher compared to that of aluminate-based sorbent materials, and this process obviates some energy consumption in the downstream flowsheet to prepare the concentrate for carbonation. Once the spent brine exits the column, it may need to be neutralized, and hence, ion exchange processes may consume a significant quantity of base.

Based on literature review, there is no evidence that the metal oxide ion exchange media require brine to be hot to have sufficient kinetics when contacted with the brine. Testing with the media has been



demonstrated at room temperature. This also means there is little evidence for their successful operation at higher temperatures.

Metal oxide ion exchange media usually do not dissolve in brine. However, the metal oxides ion exchange media dissolve in acids fairly easy, thus, the requisite use of acid to elute lithium leads to a dissolution and loss of the medium with every cycle. The rate at which the medium dissolves determines the consumption of the ion exchange media. There is one public patent focused on using protective coatings to mitigate this dissolution, which presumably could extend the lifetime of the media and minimize OPEX of media consumption.

The drawback of ion exchange-type DLE technologies is the requirement for a unit of acid and a unit of base for every single ion exchange cycle. Depending on the specifics of a project, this can increase the OPEX significantly, which cannot be reduced due to the principle of operation of the material. Worldwide, there is no commercial-scale operation that uses ion exchange for lithium extraction today.

Solvent Extraction

The selective site for both sorbents and ion exchange media belongs to solid materials, but it is also possible for the selective site to be in a liquid phase. In solvent extraction, a solvent that may contain an ionic liquid species that selectively binds on lithium ion or lithium chloride molecule. The ionic liquid molecule may have PO₄, F, B, Al, Fe, and N-based structures and the solvent suspending the ionic liquid (or selectively extracting LiCl from the brine) can be a variety of organic molecules. The functional groups in solvent extraction are often much more complex than those used in sorption and ion exchange. Most described in literature involve large organic molecules with polar functionalization.

The liquid solvent phase is contacted with the brine in a mixer or column like other standard solvent extraction processes. To accelerate lithium transport from the brine to the solvent, the surface area of brine/solvent contact is maximized by disturbing the flow of fluid through the column and breaking up the liquid. An acid or pure water can be used to extract the lithium from the solvent depending on the nature of the complexation by the molecules in the solvent, and in some processes, heat may also be required for absorption or desorption of the lithium into/from the solvent. The eluate of solvent extraction systems is typically in the same range as the eluate from sorption or ion exchange technologies, depending on if water or acid is used to elute the lithium.

A major issue with solvent extraction is the solubility of any component of the liquid phase in the brine. Most organic solvents have some solubility in water, and when an organic molecule contains a polar functional group, it only increases the probability that it will have solubility in brine. Dissolved solvents in the brine cannot be reinjected for environmental reasons, so post-treatment of the entire volume of brine may be required. Microbubbles of solvent can also become entrained in brine, and they are more



difficult to separate. Further, the complex functional groups of the solvent extraction molecules can also degrade over time. All of these issues drive the consumption of solvent, and therefore the OPEX.

Some solvent extraction systems cannot tolerate divalent ions in their feed because they poison the selective sites in the solvent/ionic liquid, and/or the selective sites are not selective against divalent ions. This necessitates the use of nanofiltration or chemical precipitation to scrub the entire volume of raw brine of divalent ions. These types of solvent extraction are limited to “cleaner” brines. The reduced application of solvent extraction to less pure brines reduces its value proposition against evaporation ponds. Further, low grade brines require the processing of larger volumes of brine, meaning more solvent is lost to entrainment and dissolution every cycle.

The liquid phase must have a density different from the brine to facilitate separation by settling. There may be a significant footprint required for the equipment that phase-separates the brine and solvent by settling, especially if the lithium concentration is low.

Furthermore, many solvents based on organic molecules have a high vapor pressure and are potentially flammable. Besides the environmental risk of solvent dissolution in the natural brine, there is a health and safety risk associated with explosivity for solvents which other DLE-types such as sorption and ion exchange do not have.

Less Developed DLE Technologies

Below is a list of other technologies for DLE which are less developed, have much less public information available, and which are currently not commercially relevant to Vulcan at this time.

- Metal Organic Frameworks (MOFs)
- Advanced Nanofiltration Techniques (e.g. with NaCl/KCl rejection)
- Electrodialysis with Bipolar Membrane

Vulcan’s selected lithium extraction method

Vulcan is developing a geothermal lithium brine project in the Upper Rhine Valley in Germany. This means that lithium feedstock will be a hot brine with lithium concentration in the range of 180 mg/L Li. These factors suggest that solvent extraction is unlikely to support an economic project because of the high risk that solvent will be lost in the brine, and because the material is potentially flammable when heated.

Vulcan’s main choices for DLE technology selection in its Scoping Study and PFS were between sorption and ion exchange. There is some commercial precedent for both classes of technology suggesting that the Vulcan brine could be amenable to economic processing using either class of technology. Given that sorption has received significantly more attention by technically experienced project developers globally, and that the sorption process does not consume large amounts of acid and base for every



adsorption/elution cycle, it is a strongly preferred DLE technology class for the Vulcan project. There are multiple sorbents available from commercial suppliers, giving Vulcan optionality in the market. Vulcan plans to employ one of the tested sorbents to extract lithium from Upper Rhine Valley brine.

Vulcan has conducted test work campaigns which included multiple vendors of sorption technologies, and demonstrated the potential for greater than 90% lithium recovery from brine to LiCl concentrate for multiple sorbents tested to date. To improve sorbent performance and life, Vulcan has assumed some pre-treatment in its PFS and DFS cost assumptions, and post-treatment to bring the brine back to a materially similar state suitable for re-injection. These pre-and post-treatments have also been successfully demonstrated in Vulcan's pilot and laboratory tests. Vulcan's R&D team will continue to work on solutions to minimise pre and post treatment, in order to reduce operating costs were possible.

Vulcan's pre-treated brine will be fed to a sorption DLE system which will produce a LiCl concentrate. This concentrate will be upgraded using reverse osmosis and evaporation, which also allows for most of the water in the LiCl concentrate to be recycled to the DLE system. This upgraded brine will be shipped to a centralized chemical plant where it will be purified further and converted into $\text{LiOH} \cdot \text{H}_2\text{O}$ electrochemically. The development of this electrochemical process will leverage the experience of the chlor-alkali industry which has been making NaOH from NaCl for decades. Based on guidance from chlor-alkali companies, Vulcan believes the technology risk in this operation is acceptable, and a better route in terms of carbon footprint than Vulcan's other downstream processing option, which is to produce a lithium carbonate and then use liming to produce lithium hydroxide, the so-called "traditional method". After a conventional double crystallization process, a battery-quality lithium hydroxide monohydrate is intended to be produced and sold.

Fast Facts

 Issued Capital: 123,834,613
 Market Cap (@\$10.65): \$1.32b

Table 1: Pros and cons for different DLE technologies for Vulcan's Zero Carbon Lithium™ Project (Source: Vulcan PFS, Jan 2021, Jade Cove)

DLE Method	Material	Main Advantages	Main Disadvantages	Technology Readiness Level
Main methods available for commercial operations	Sorption	LiCl:3Al(OH) ₃ n H ₂ O Many form factors <ul style="list-style-type: none"> •Water is used to recover the lithium chloride – no reagents required. •Global and multi-decade commercial precedent. •No acid requirement means media may degrade slower. •Highly selective for Li >90% extraction efficiency •Works well with heated brines. 	<ul style="list-style-type: none"> •Usually requires temperatures > 50oC, •Relatively low capacities 1 to 4 g/l •Difficult to prevent contamination with the brine. •Lower eluate LiCl concentration than IX, requires more reverse osmosis to recycle water. 	9 (commercial operation on solar-type brines)
	Ion Exchange	LiMnO _x LiFePO ₄ Li ₂ TiO ₃ <ul style="list-style-type: none"> •High capacity & therefore high concentration of Li in the strip solution. Contamination with impurities minimized. 	<ul style="list-style-type: none"> •Needs large amounts of base and acid to work, increases OPEX. •Some IX material are attacked during desorption. Degrade in acidic conditions. 	8 (demonstration plant phase)
	Solvent Extraction	Organic extraction in organic solvent	<ul style="list-style-type: none"> •High concentrations of lithium can be produced in the strip. Continuous. •Organic solvents are challenging environmentally. •Fire risk with high temperature brines. •Expensive relative to other technologies, potentially larger CAPEX for first fill. 	7 (pilot plant phase)
New methods under development	Membranes	MOFS, IX or LiCl:3Al(OH) ₃ in polymers	<ul style="list-style-type: none"> •No contact between brine and extractant, fewer impurities & continuous. •In their technological infancy, fouling, lack of stability in geothermal brines. Needs pretreatment. 	4 (research phase)
	Precipitants	AlCl ₃ , H ₃ PO ₄	<ul style="list-style-type: none"> •Selective •Requires filtration, separations can be difficult 	8 (demonstration plant phase)

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Competent Person Statement:

The information in this report that relates to Mineral Resources is extracted from the ASX announcement made by Vulcan on the 15 December 2020, which is available on www.v-er.eu. The information in this presentation that relates to the Pre-Feasibility Study for the Vulcan Lithium Project is extracted from the ASX announcement "Positive Pre-Feasibility Study", released on the 15th of January 2021 which is available on www.v-er.eu. The Company confirms that it is not aware of any new information or data that materially affects the information included in the original market announcements and that all material assumptions and technical parameters underpinning the estimates in the relevant market announcements continue to apply and have not materially changed. The Company confirms that the form and context in which the Competent Person's findings are presented have not been materially modified from the original market announcements.