Vulcan Energy Resources

Direct Lithium Extraction (DLE) Technical Update

Friday, 12 November 2021

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Dr Stephen Harrison, Chief Technical Officer, Vulcan Energy Resources

VULCAN ENERGY
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Agenda

Welcome and introduction

- Dr. Francis Wedin, MD
- Dr. Stephen Harrison, CTO

How does DLE work?

- Types of direct lithium extraction
- Why Vulcan is advancing a sorption process

Development history of DLE and sorption

How sorption applies to geothermal brines

How Vulcan is applying sorption to its Zero Carbon Lithium™ Project

Dr. Stephen Harrison, Chief Technology Officer, Vulcan Energy Resources

PhD Chemical Engineering
MSc Electrochemical Science

- Dr. Harrison has a diverse multi-industry background in electrochemistry and lithium extraction, with thorough knowledge of all steps of industry process/product commercialisation in the lithium industry dating back to 1998.
- Dr. Harrison was CTO of Simbol Materials for seven years (2008-2015), where he led the company's scientific and engineering teams through rapid process development, taking less than one year to develop a process to extract lithium from geothermal brine, which is today recognised as the potentially lowest cost production method to lithium hydroxide from brines.
- As CEO of Rakehill Technology LLC, Dr. Harrison has since consulted to the lithium industry on various lithium extraction technologies including sorption.
- Dr. Harrison holds a PhD Chemical Engineering from the University of Newcastle-upon-Tyne and Master of Science (MSc) Electrochemical Science, from the University of Southampton.

Dr Stephen Harrison

> *The Zero Carbon Lithium™ Project is an opportunity to leverage decades of knowledge in Direct Lithium Extraction techniques to unlock sustainable sources of lithium*
> *Dr Stephen Harrison*

How does DLE work?
Types of DLE
Why has Vulcan chosen sorption?

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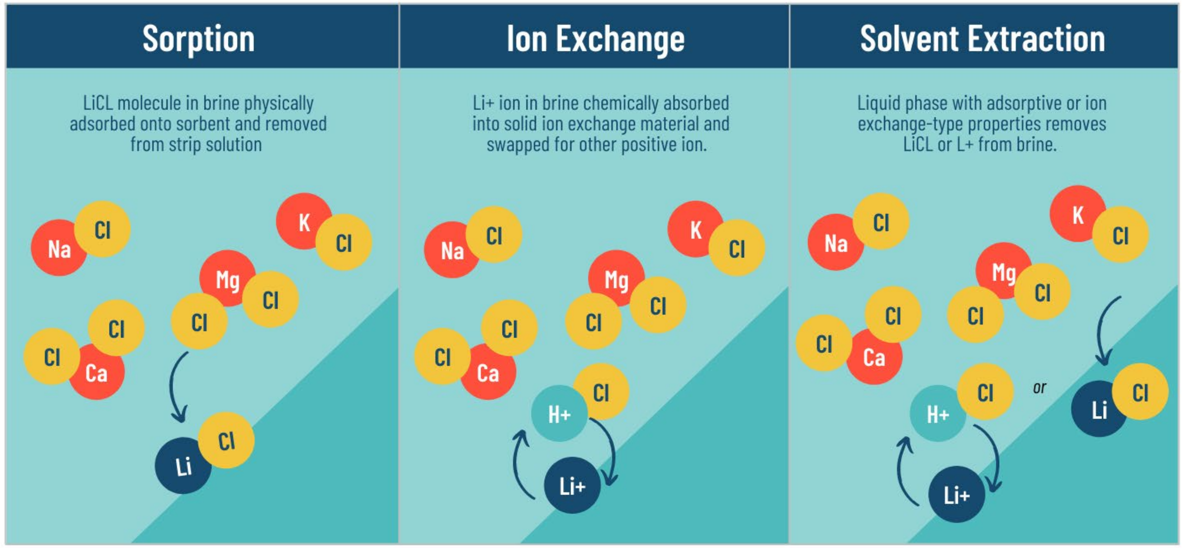
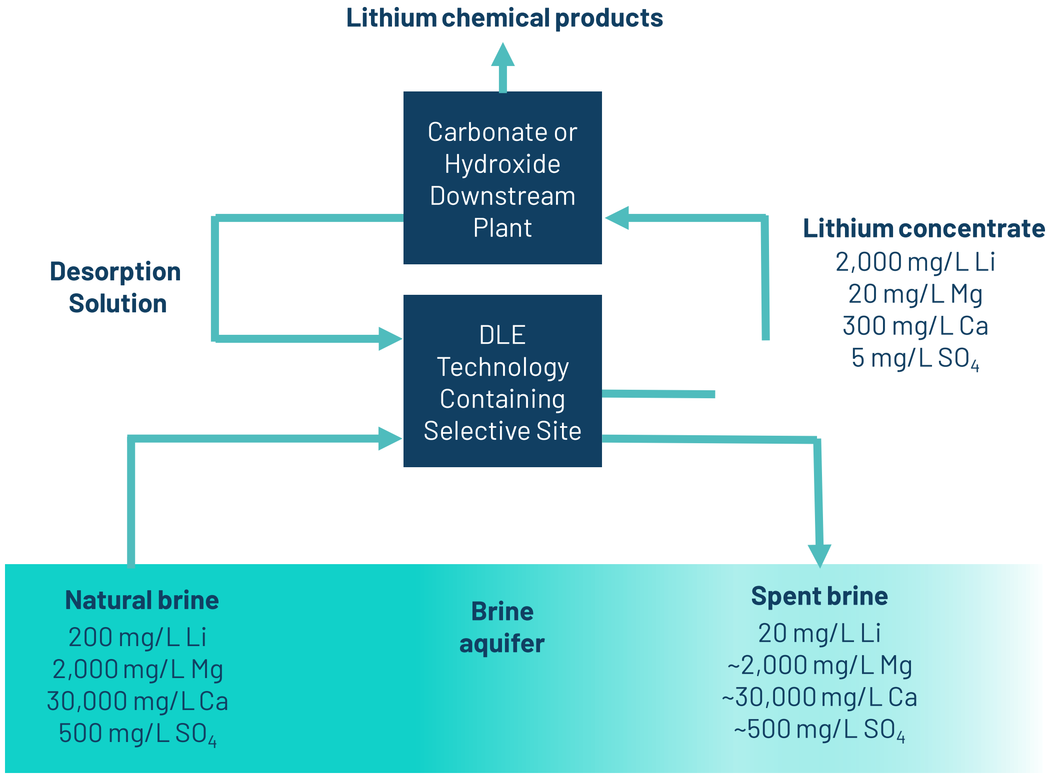
Direct lithium extraction is a proven technology

- Direct lithium extraction (DLE) using sorption has a fifty-year development and implementation history
- Sorption-type DLE practiced commercially in South America for 26 years by Livent (previously FMC). More recently sorption-type has been deployed in China [1,2]
- Three main families of DLE[3]



Schematic of a generalised DLE process[4]



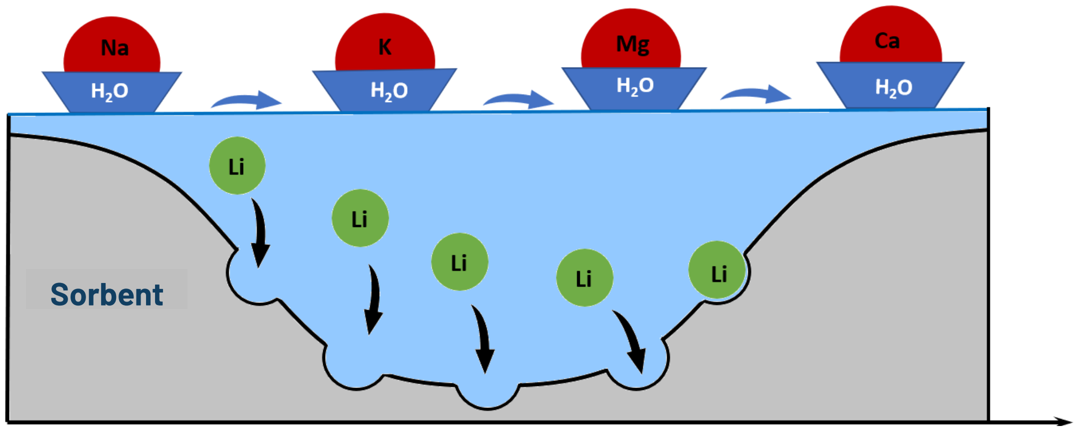
Vulcan has chosen a sorption approach due to its successful commercial deployment globally, and because sorption approaches have been shown to optimally produce lithium chemicals from hot brines.

DLE perceived advantages/disadvantages and Vulcan's choice of method[5]

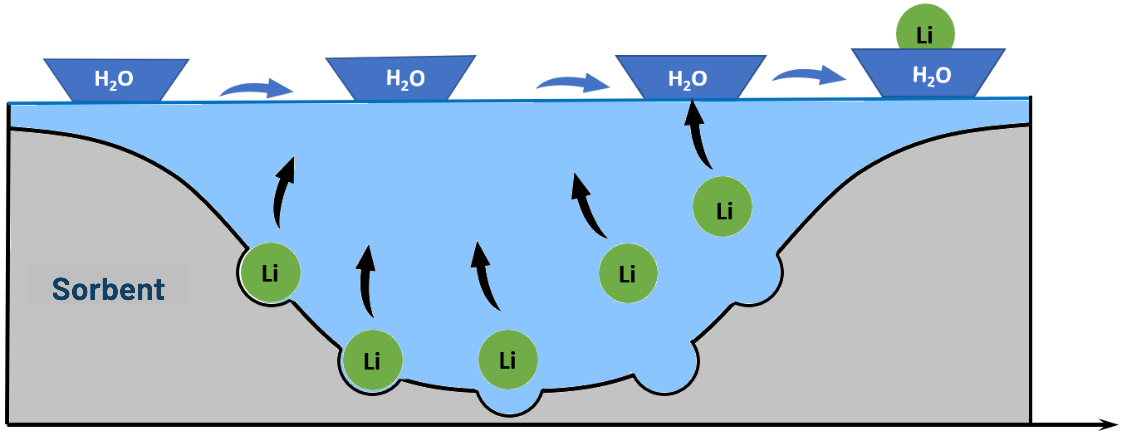
	DLE method	Material	Main advantages	Main disadvantages	Technology readiness level
Main methods available for commercial operations	Sorption	$LiCL:3Al(OH)_3n$ H_2O Many form factors	• Water is used to recover the lithium chloride – no reagents required • Global and multi-decade commercial precedent • No acid requirement means media may degrade slower • Highly selective for Li >90% extraction efficiency • Works well with heated brines	• Usually requires temperatures > 50°C • 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 salar-type brines)
	Ion Exchange	$LiMnO_x$ $LiFePO_4$ Li_2TiO_3	• High capacity and therefore high concentration of Li in the strip solution. Contamination with impurities minimised	• Needs large amounts of base and acid to work, increases OPEX • Some IX material are attacked during desorption. Degrade in acidic conditions	8
	Solvent Extraction	Organic extraction in organic solvent	• 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
New methods under development	Membranes	MOFS, IX or $LiCL:3Al(OH)_3$ in polymers	• No contact between brine and extractant, fewer impurities and continuous	• In their technological infancy, fouling, lack of stability in geothermal brines. Needs pretreatment	4
	Precipitants	AlCl3, H3PO4	• Selective	• Requires filtration, separations can be difficult	4

Sorption process[6]

Step 1



Step 2



- Geothermal brine has a high salinity – it contains ions of various sizes and electric charges.
- Water molecules surrounding the ions make up a hydration shell.
- Small lithium ions require a double hydration shell to stabilise their electric charge in the solution.
- In brines with high salinity this is not possible due to the competition for water molecules with the other ions.
- Thus, lithium chloride 'sinks' to the surface of the sorbent material.
- During loading, lithium chloride is sorbed on the sorbent while all the other ions stay in the brine.

- When the loaded sorbent is washed with water, an excess of free water molecules becomes available to the lithium ions.
- Formation of a double hydration shell is an energetically favored process, which drives the desorption of the lithium chloride from the surface of a sorbent material.
- This process is called elution and the collected wash water is called the eluate.
- Eluate has a high concentration of lithium chloride and low concentration of impurities, enabling conversion to lithium hydroxide.

Development history of DLE and sorption

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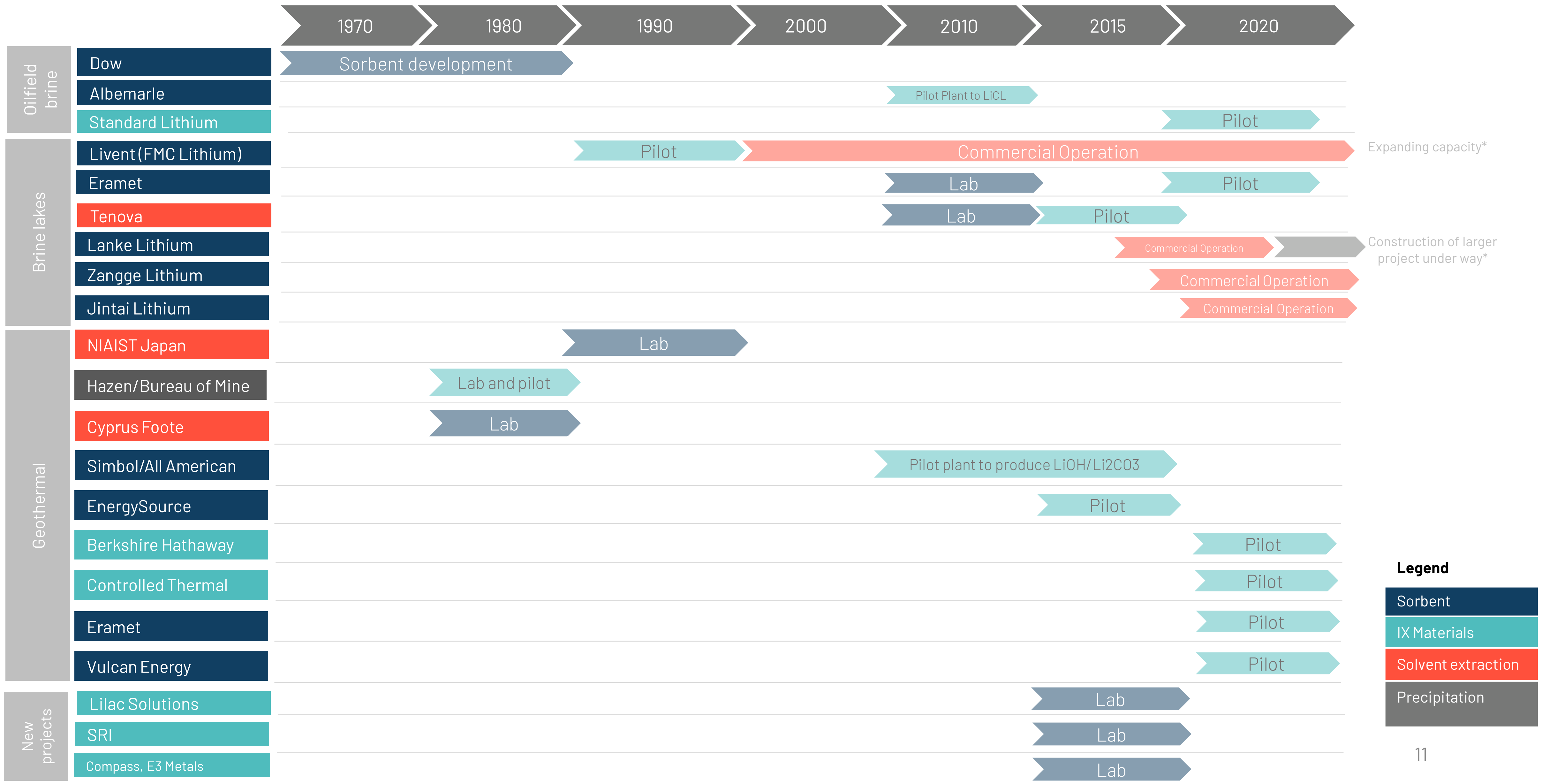
History of direct lithium extraction[7,8,9]



Timeline of commercial development

- Dow (now Dupont) developed lithium sorbent for its brine plants in the Smackover region where DOW operated calcium chloride and bromine production in late 1970's through the 1990's
- An aluminum hydroxide-based lithium sorbent in an ion exchange resin
- Technology updated by Baumann & Burba, numerous patents filed[10]

- Livent announced plans to increase capacity to 27,000 tpa in 2019[11]
- Following a pause in 2020 due to COVID-19, Livent now plan to increase capacity to 60,000 tpa

1970s 1980s 1990s 2000 2010 2020

- Sorption-type DLE commercially adopted by FMC Lithium Division for its Li extraction at the Salar Hombre Muertos in 1995

中国五矿集团公司 CHINA MINMETALS CORPORATION

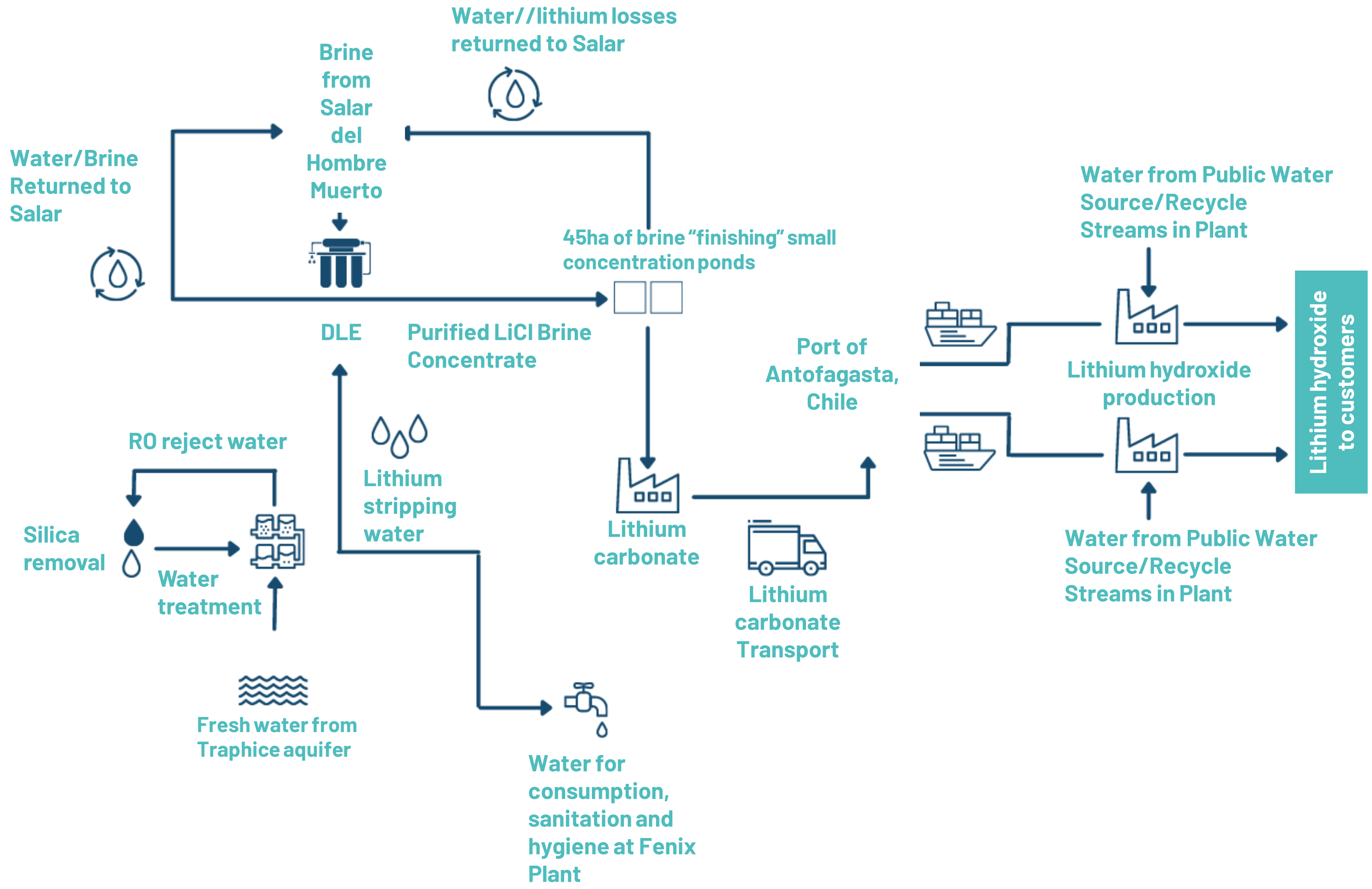
青海盐湖钾肥股份有限公司 Qinghai Salt Lake Potash Co.,LTD

SUNRESIN Driving the innovation

藏格锂业 lithium

- All of the DLE projects built since lithium demand started to increase rapidly in the 2010s have been brownfield projects, built to extract lithium from waste brines of evaporative brine facilities in Qinghai, China[12]

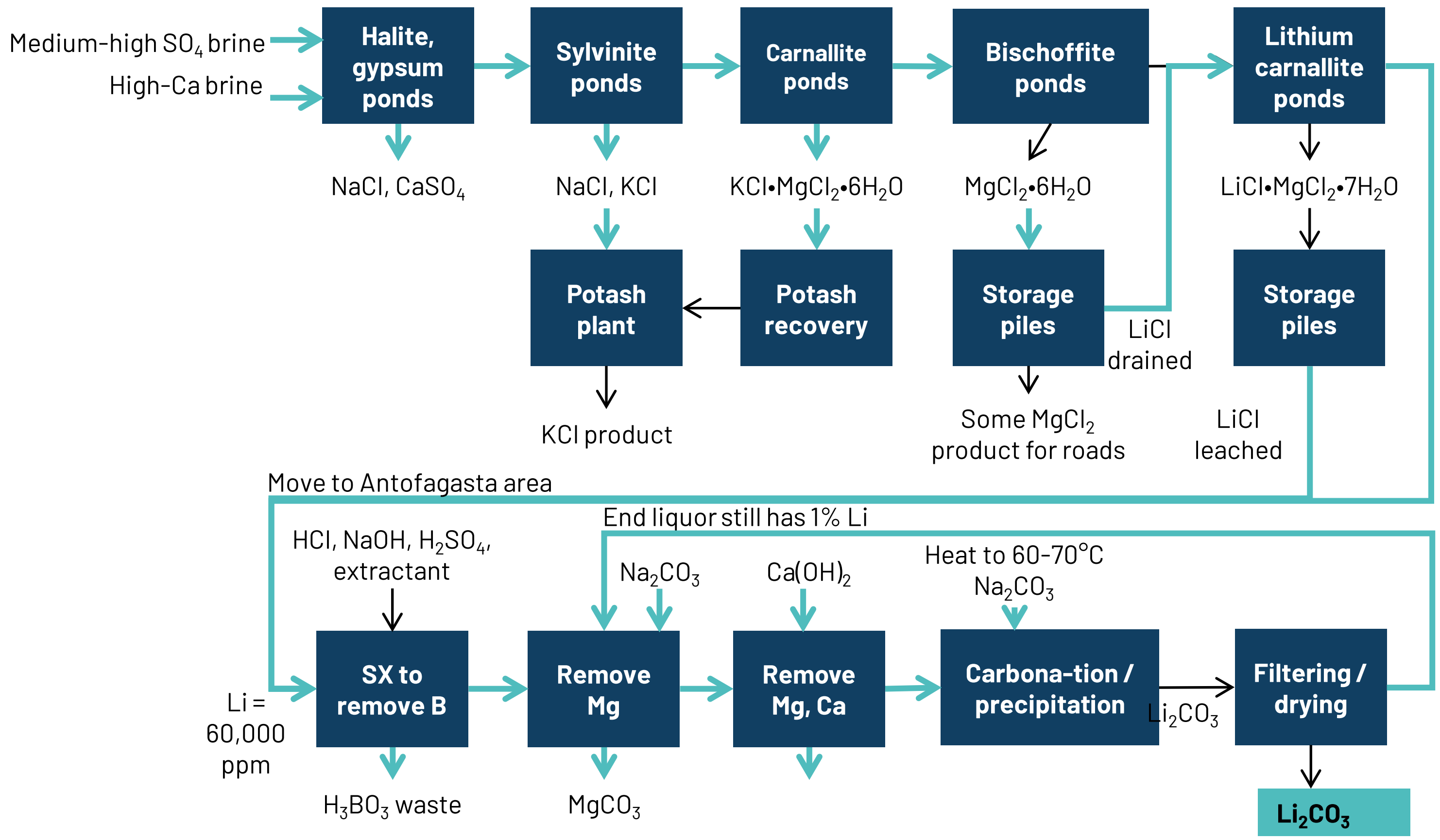
- More rapid production process due to the use of lithium sorbent which separates the lithium chloride from the main constituents of the brine: sodium, potassium and calcium.
- Requires heating the brine to prepare the brine for lithium extraction with the sorbent
- Some solar evaporation to concentrate the lithium chloride.
- Purification of lithium to remove borate and sulfate prior to reaction with soda ash to precipitate lithium carbonate.
- Lithium hydroxide produced in the USA and China via reaction of lithium carbonate with lime.



Evaporative lithium production from brine: other producers

- Operators in Chile and Argentina, transform the brine to product offsite
- Evaporation ponds take 18 months to precipitate out other salts and produce a lithium chloride stream which is then converted to lithium carbonate and then from carbonate to lithium hydroxide
- Low lithium recovery, extent depends on Mg/Li ratio
- Significant water consumption through evaporation of brine

Generalised evaporation type flow sheet[14]



Starting brine[1] (ppm)									
Na	71,700	Ca	310	Li	2,500[2]	Cl	160,400	Br	50
K	18,500	Mg	9,600	B	400	SO_4	14,600		

How sorption applies to geothermal brines

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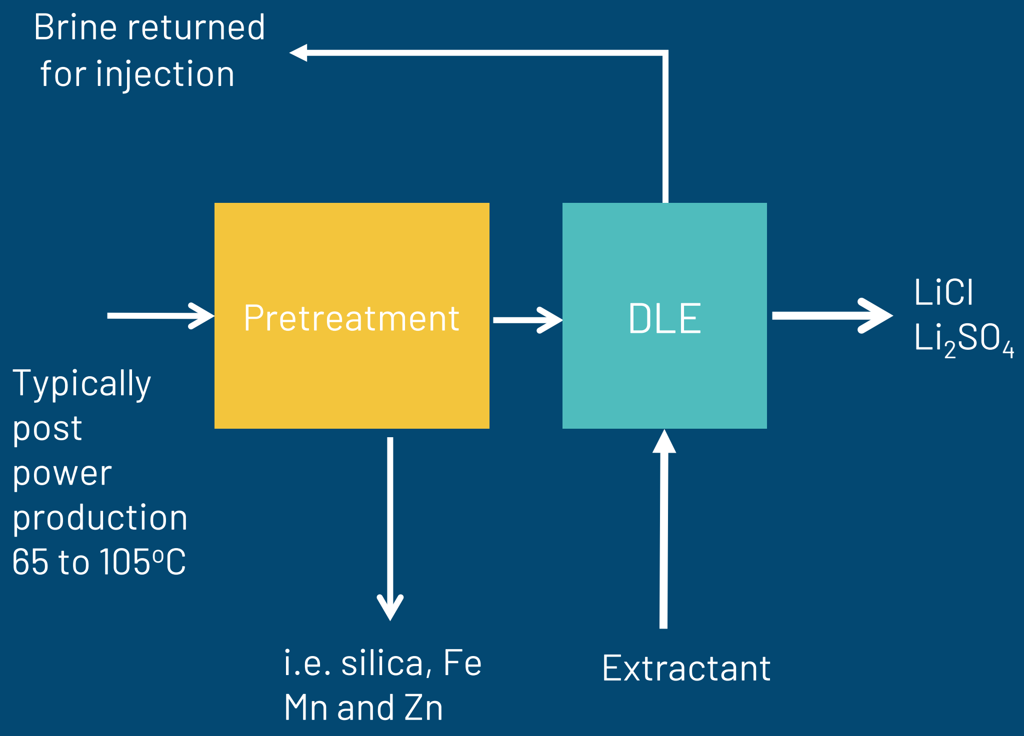
Unique advantage of pairing geothermal brines with DLE

- Geothermal brine is different from salar-type brines.
- Usually lower lithium grade on the downside, but on the upside it's already hot and it's not at 4,000m elevation above sea level as some salars are.
- Some geothermal brines are also closer to infrastructure and power than salars, another key advantage.
- Geothermal brines are expected to operate profitably with lower lithium grades than salar-type, non-heated counterparts, because of the advantage of built-in renewable energy for improved DLE and lack of need for fossil fuel consumption.



Simbol – a successful technical demonstration of lithium extraction from geothermal brine

- Operated several pilot plant units using its own sorbents.
- Thousands of hours of operation, 2010 through 2014 at several locations in Salton Sea, California:
  - BHE Elmore
  - EnergySource Featherstone Plant
- Complete process piloted:
  - Technical success
  - Produced battery grade lithium carbonate from geothermal brine
- According to press sources, Simbol's board rejected a takeover from Tesla in 2014, then ran out of funding in 20151[15].
- Global EV penetration was insignificant in January 2015, therefore the lithium market was small and investment was limited. Lithium carbonate price was only approx. $5-6,000/t[16].

What is different now?

- Global EV penetration is significant and rapidly increasing, with every large automaker having an electrification strategy[17] and 20 countries with electrification targets or ICE bans for cars[18]
- Spot lithium carbonate is now approximately $27,000/t[19]. Sustainability is now much more important for customers which include large automakers.
- Multiple parties now developing lithium extraction from geothermal brines in Salton Sea[20], including the successor to Simbol: All American Lithium and its JV partner Oxy (Terralithium[21]), as well as Energy Source Minerals, Berkshire Hathaway Renewables.

TECH

Tesla offered $325 million for Salton Sea startup

Sammy Roth The Desert Sun

Published 1:32 p.m. PT June 8, 2016 | Updated 3:41 p.m. PT June 8, 2016

View Comments

The letter from Elon Musk left no doubt about his intentions: He wanted Simbol Materials, and he was willing to pay handsomely for it.

Simbol claimed it had developed extraordinary technology for extracting lithium — a key ingredient in the batteries that power Tesla's electric cars — from the mineral-rich brine by the southern shore of the Salton Sea, southeast of Southern California's Coachella Valley. Tesla's rock-star co-founder and chief executive was on the hunt for lithium, and Simbol planned to produce huge quantities of the valuable metal.

Source: The Desert Sun, 8 June 2016, Tesla offered $325 million for Salton Sea startup

How Vulcan is applying sorption to its Zero Carbon Lithium™ Project

Progress update and next steps

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Vulcan lithium division current status[22]

- Pilot plant 1 focused on:
  - Brine pre-treatment
  - Lithium extraction
  - Post treatment to return brine to same state
- Multiple sorbents from commercial providers have been successfully tested, including from DuPont and others, providing optionality
- Lab and pilot studies generating data for DFS
- Scale-up of piloting continuing during 2021
- Rapidly growing team on pilot and lab sites in Germany
- New laboratory to be opened in January 2022
- Complemented by a 1:200 Scale Demo Plant
  - Targeting operation start of DLE part in Q2 2022
- DFS by Hatch Ltd targeting completion mid-2022[23]

First battery quality lithium hydroxide produced from pilot operations[24]

- The sample exceeds traditional battery grade lithium hydroxide monohydrate (LHM) product including best on the market battery grade specifications required from offtake customers, at >56.5% $LiOH.H_2O$ and very low impurities.
- The lithium chloride extracted by the sorbent in the pilot plant was recovered with water and sent offsite, where it was purified and concentrated by a third-party provider to prepare the lithium chloride for electrolysis to produce lithium hydroxide solution.
- The solution was then crystalized to produce battery grade LHM.

Images of lithium hydroxide monohydrate from Zero Carbon Lithium™ project

> We will continue to methodically progress, de-risk and execute on our plan to build a fully integrated renewable energy and battery-quality lithium chemicals project in Europe to service the battery and electric vehicle industry.

Process flow sheet[25]

1

- Hot brine extracted from the ground and generates steam that powers turbines and produces renewable electricity

2

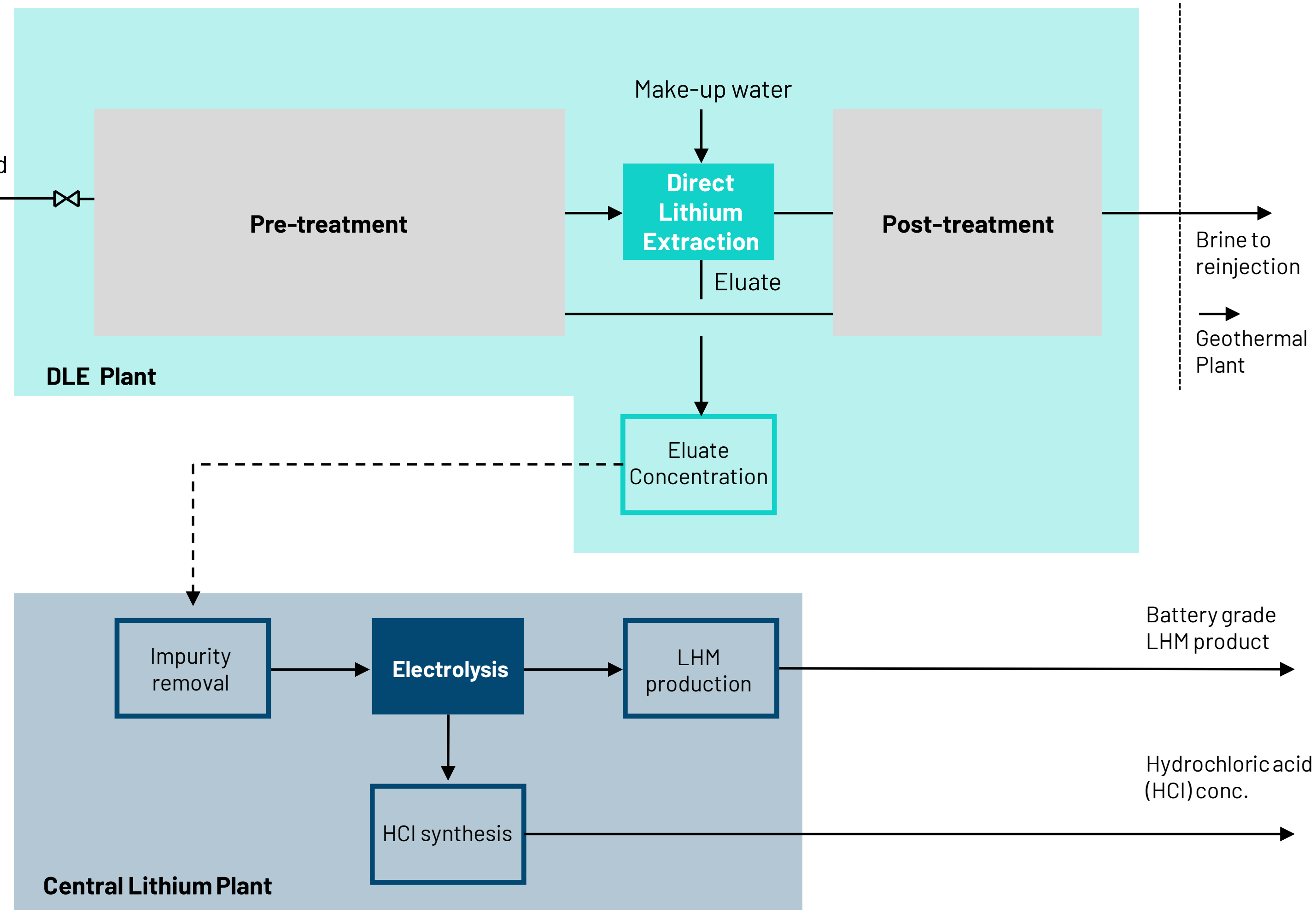
- Brine flow is diverted, and lithium is extracted from the solution with a Direct Lithium Extraction (DLE) process.

3

- Lithium chloride sent to lithium refining plant which will be converted LiCl to battery quality LiOH
- Water is recycled, no toxic wastes, no gases are emitted, heat and power from renewable resources, no fossil fuels are burnt

ZERO CARBON FOOTPRINT

Vulcan has IP protection around flowsheet

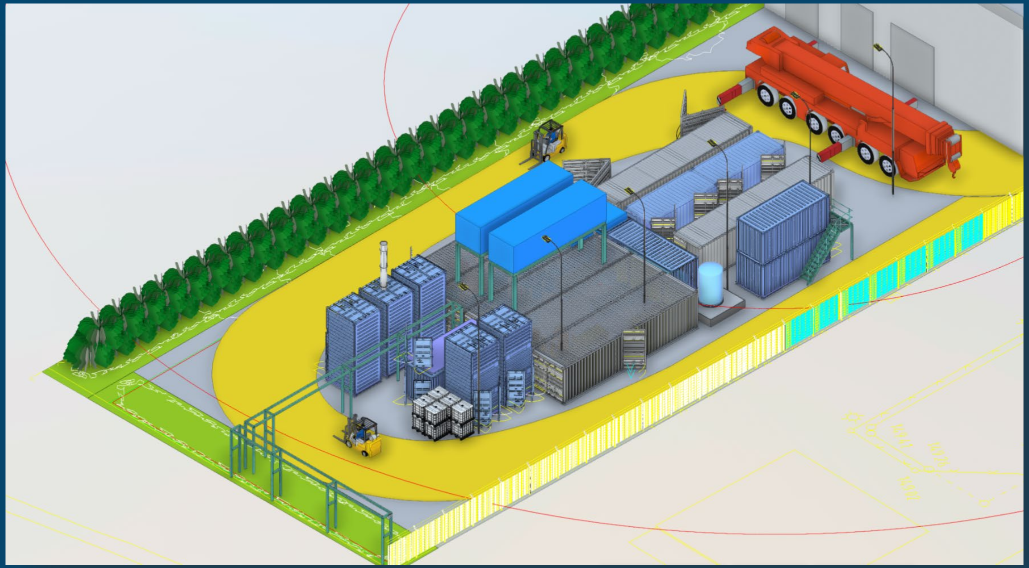


A note on our choice of lithium electrolysis

- We can use DLE because we have the heat and infrastructure which make it commercially attractive.
- Because we use DLE, we are able to produce a very pure lithium chloride concentrate.
- Because of this purity, we can use electrolysis, which requires high purity lithium chloride solution to work, to produce a direct to lithium hydroxide product.
- There are a lot of similarities between lithium electrolysis and chlor-alkali technology, which has been in use for over a century. Germany is the largest chlor-alkali producer in Europe.
- We don't have to use electrolysis. We can use the "traditional" industry route of lithium chloride to lithium carbonate, then using lime to create a lithium hydroxide, with a similar cost profile but high reagent usage and low-quality by-product production.
- However, we believe electrolysis, using green power, is a more sustainable approach for us and more suitable given our strict "net zero" mandate.

Demonstration plant[26]

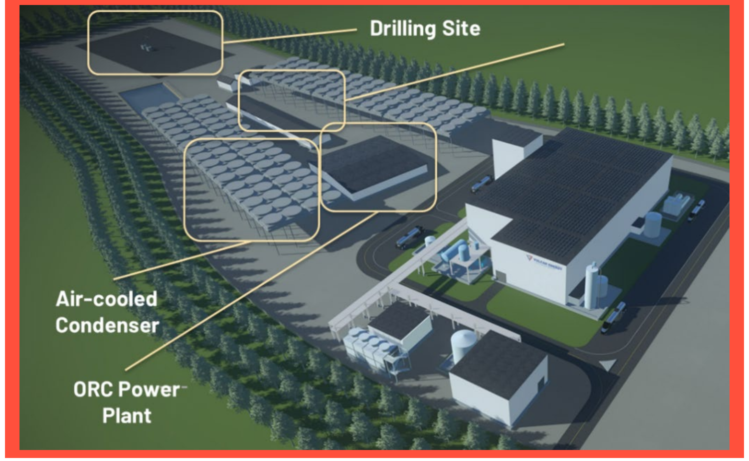
- Demo Plant to include all process steps in two locations
  - Fully integrated with all process steps including electrolysis
    - DLE at site with “live” geothermal brine
    - Conversion to LHM in a chemical park (same as commercial plant design)
  - All recycles to be included
- Enables the Vulcan team to run the full process onsite and provide training prior to commercial operation
- Major skids ordered and under construction
- The DLE section of the Demo Plant is targeted to commence operation on in Q2 2022, and will represent an approximately 1:200 scale of the first commercial plant.



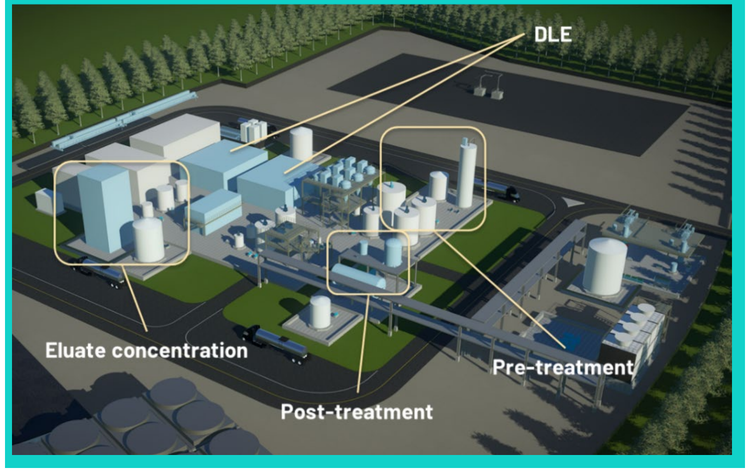
Rendering of Vulcan’s Demo Plant, major skids ordered and currently under construction.

First commercial operation: targeting 2024[27]

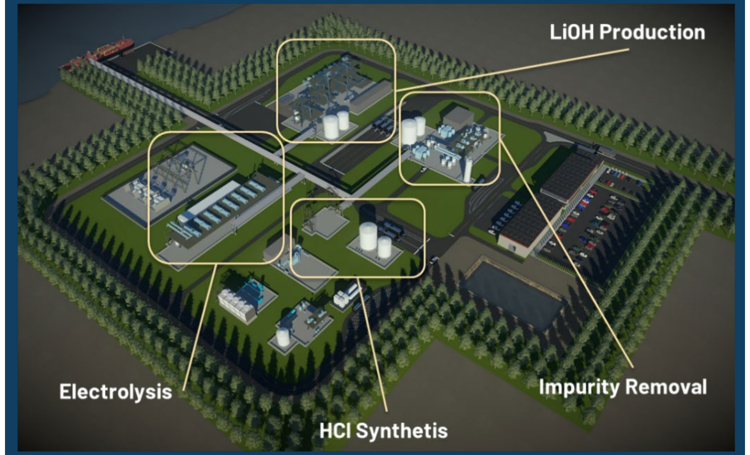
Binary Cycle Geothermal Plant



Lithium Sorption Plant



Central Lithium Plant



"The Vulcan team is committed to advancing renewable energy development and decarbonisation for the benefit of all stakeholders, and is on track with the development of our Zero Carbon Lithium™ Project, targeting phase one production in 2024."
Dr Francis Wedin, MD

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Reference list

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