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A DIRECT LITHIUM EXTRACTION METHOD FOR LI-RICH BRINES

DLE SOLVENT EXCHANGE FOR THE FUTURE

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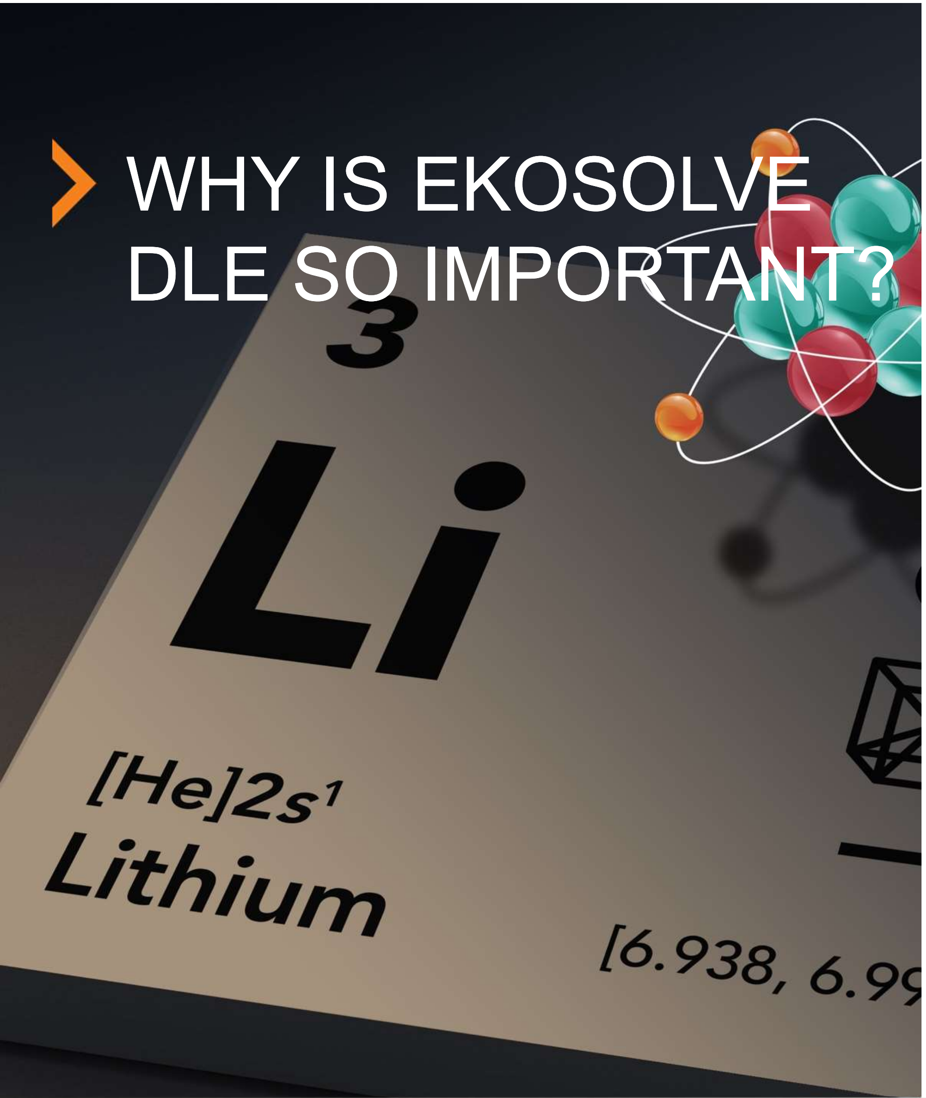
EkoSolve Ltd
An Australian unlisted Public Company • ACN 657 738 120

WHY IS EKOSOLVE DLE SO IMPORTANT?



The Lithium market in 2022

Lithium is a critical commodity for the production of electric vehicles.

The market is not in equilibrium as mining production cannot supply the demand, evidenced by the growth in lithium prices.

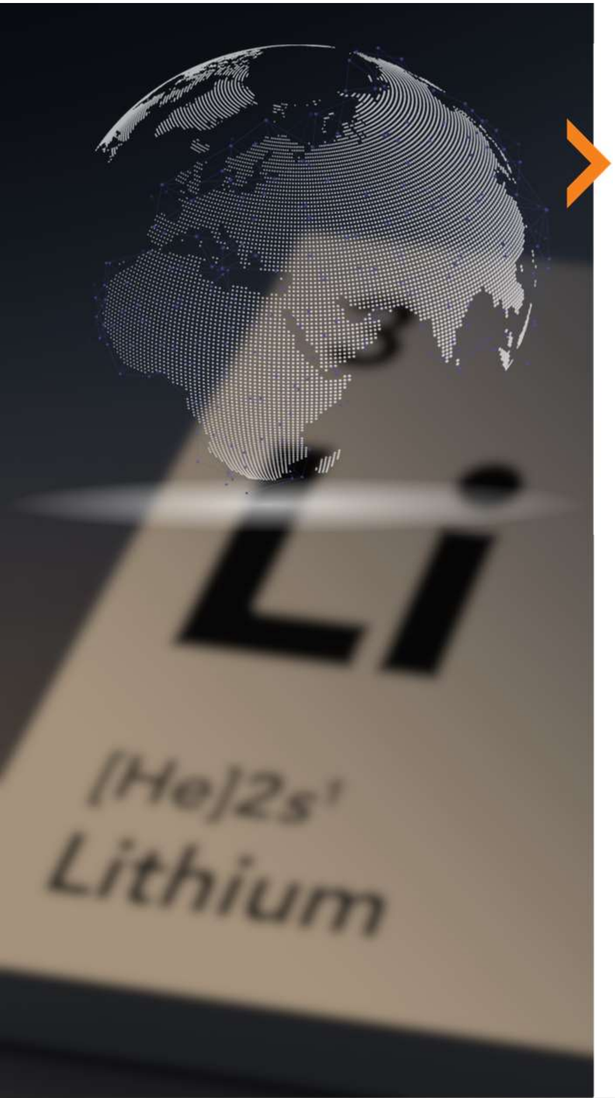
The are 53 lithium production projects in the post-preliminary economic assessment stage.

Of them, 11 are set to start production by 2024 and 42 are projected for 2030.

Argentina leads with 14 projects, all of which are Li-rich brines in the Lithium Triangle.

These 53 projects have estimated capital costs ranging from $64 to $1,970 million, involving a total investment of $27 billion.

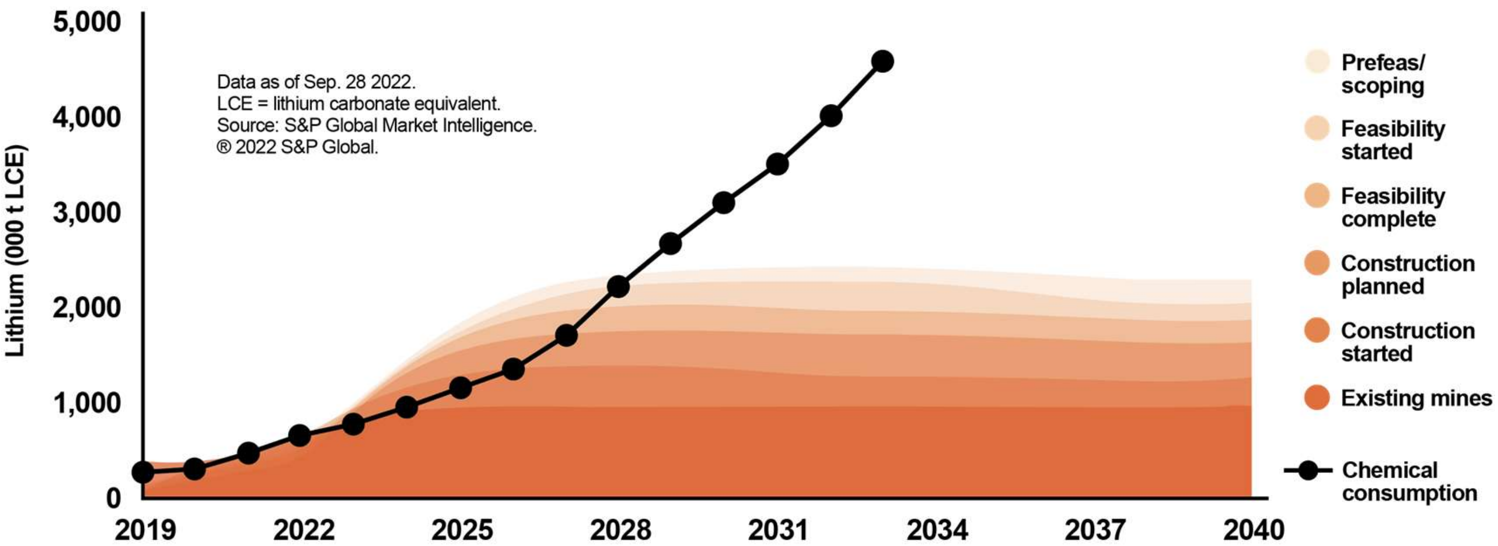
They are projected to increase supply with an additional 42 million tonnes of lithium carbonate.



S&P Global Market Intelligence forecasts that even assuming the aggressive development of all these 53 projects, there will still be a demand gap of 605,000 tonnes of LC by 2030.

To fill this gap and restore market equilibrium will require an additional investment of $38 billion.

PROJECT PIPELINE INSUFFICIENT TO MATCH LITHIUM DEMAND GROWTH



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The supply shortage is partly caused by the commercial methods used to extract the metal: **Solar evaporation and Selective ion-exchange resin.**

SOLAR EVAPORATION FOLLOWED BY ‘LIMING’ AND LI2CO3 PRECIPITATION

Used by:

- *Albermale in Silver Peak, USA,*
- *Albermale and SQM in Atacama, Chile, and*
- *Orocobre in Olaroz, Argentina.*

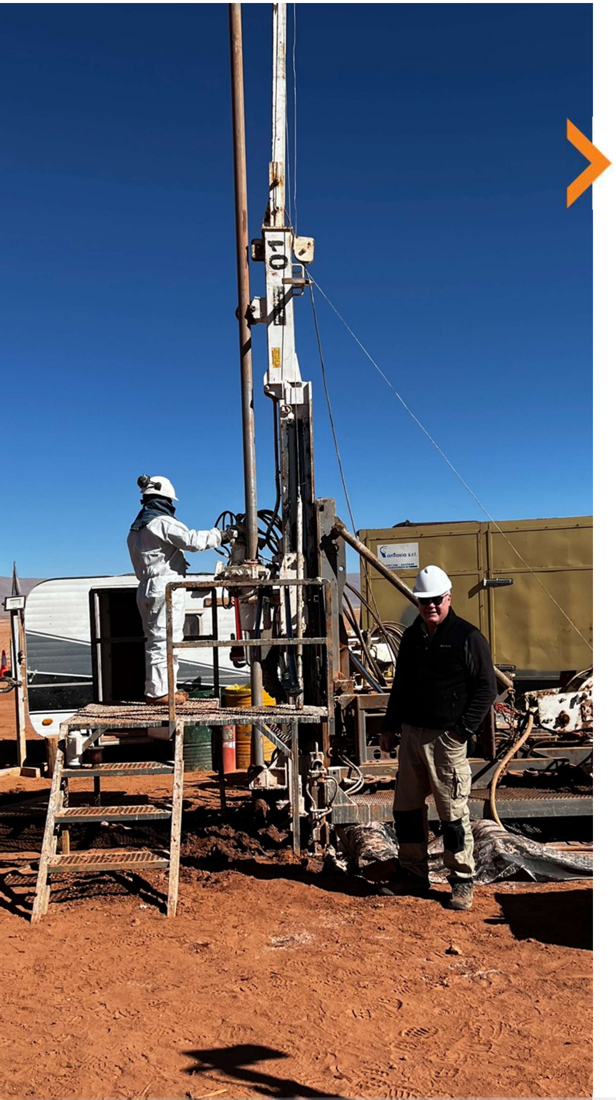
SOLAR EVAPORATION PRE-CONCENTRATION FOLLOWED BY LI SELECTIVE ION-EXCHANGE RESIN EXTRACTION

Used by:

- *Livent in Hombre Muerto, Argentina.*

More than half of Li production worldwide is made using these two methods.

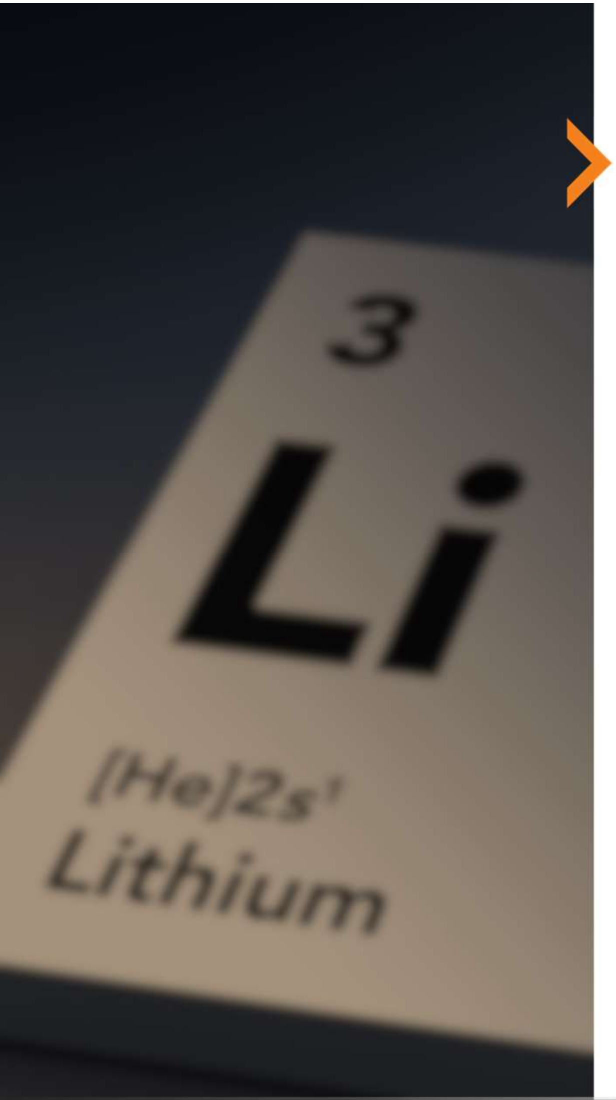
Several other recovery systems have been proposed, although they have not been demonstrated commercially.



These commercial processes pose several problems

- Their construction is capital-intensive,
- There is a long lead time from commissioning until the first production, determined by the time needed to solar evaporate the brines,
- These processes negate the possibility of exploiting some brines:
  - the “liming” process precipitates Mg (and Ca) cations that co-precipitate with the Li_2CO_3. Brines with a Li to Mg ratio exceeding 1 to 10 are not economical and challenging because of the weight of the magnesium waste produced,
  - because of this, some Salares are not exploited, including Li-rich Salares in China, Argentina, and Uyuni in Bolivia,
- This explains the high capital intensity needed to develop a new mine.
- S&P Global Market Intelligence estimates that new projects will have an average capital intensity of $17,400 per tonne of Li_2CO_3 produced annually,
- These extraction methods have been criticised from an environmental point of view as unsustainable.

ABOUT THE EKOSOLVE DLE SOLVENT EXTRACTION PROCESS



In 2016, EkoSolve began investigating its **Solvent Extraction** process as an alternative to the conventional Li recovery methods.

What is *Solvent Extraction?*

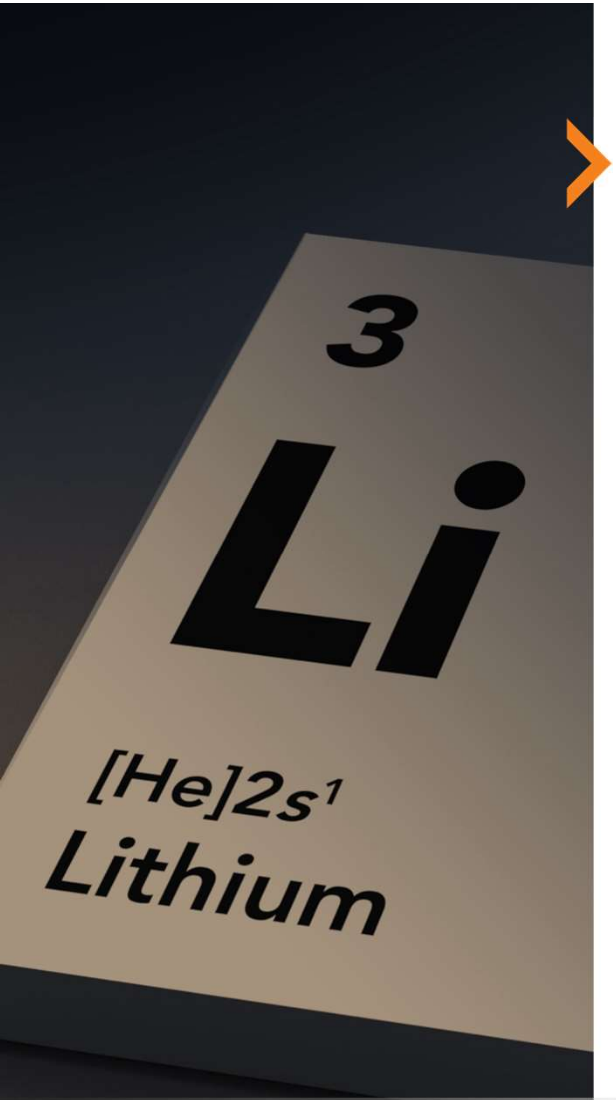
Solvent Extraction, SX, also known as *liquid-liquid extraction*, is a method to separate compounds or metal complexes based on their relative solubilities in two different immiscible liquids, usually water (polar) and an organic solvent (non-polar).

The solvent that is enriched in the organic phase is the extract. The aqueous feed solution that is depleted in Li is the raffinate.

Its most significant advantage is the ability to selectively separate-out cations with very similar chemical behaviour and to obtain high-purity single metal streams from where the metal value can be 'stripped' from the 'loaded' organic phase, making it possible to precipitate the metal.

In this case, there is a net transfer of one or more species from one liquid into another liquid phase from the Li-rich brines to an organic solvent.

The transfer is driven by chemical potential, i.e. once the transfer is complete, the overall system of chemical components that make up the solutes and the solvents are in a more stable thermodynamical state; that is to say, the system has a lower free energy.



Lithium extraction

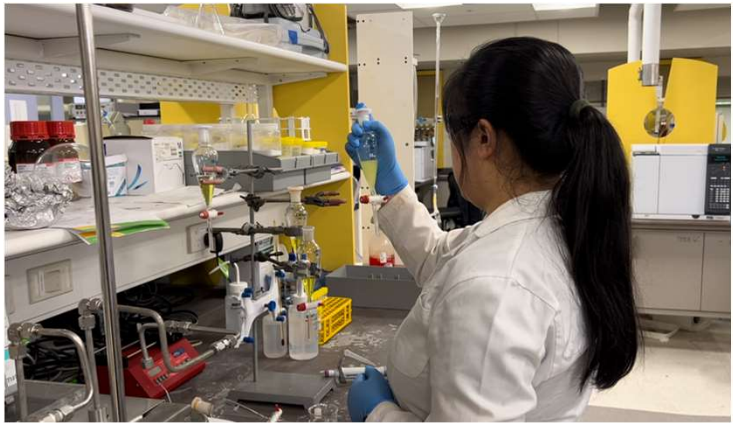
Lithium extraction has been studied extensively since the 1930s.

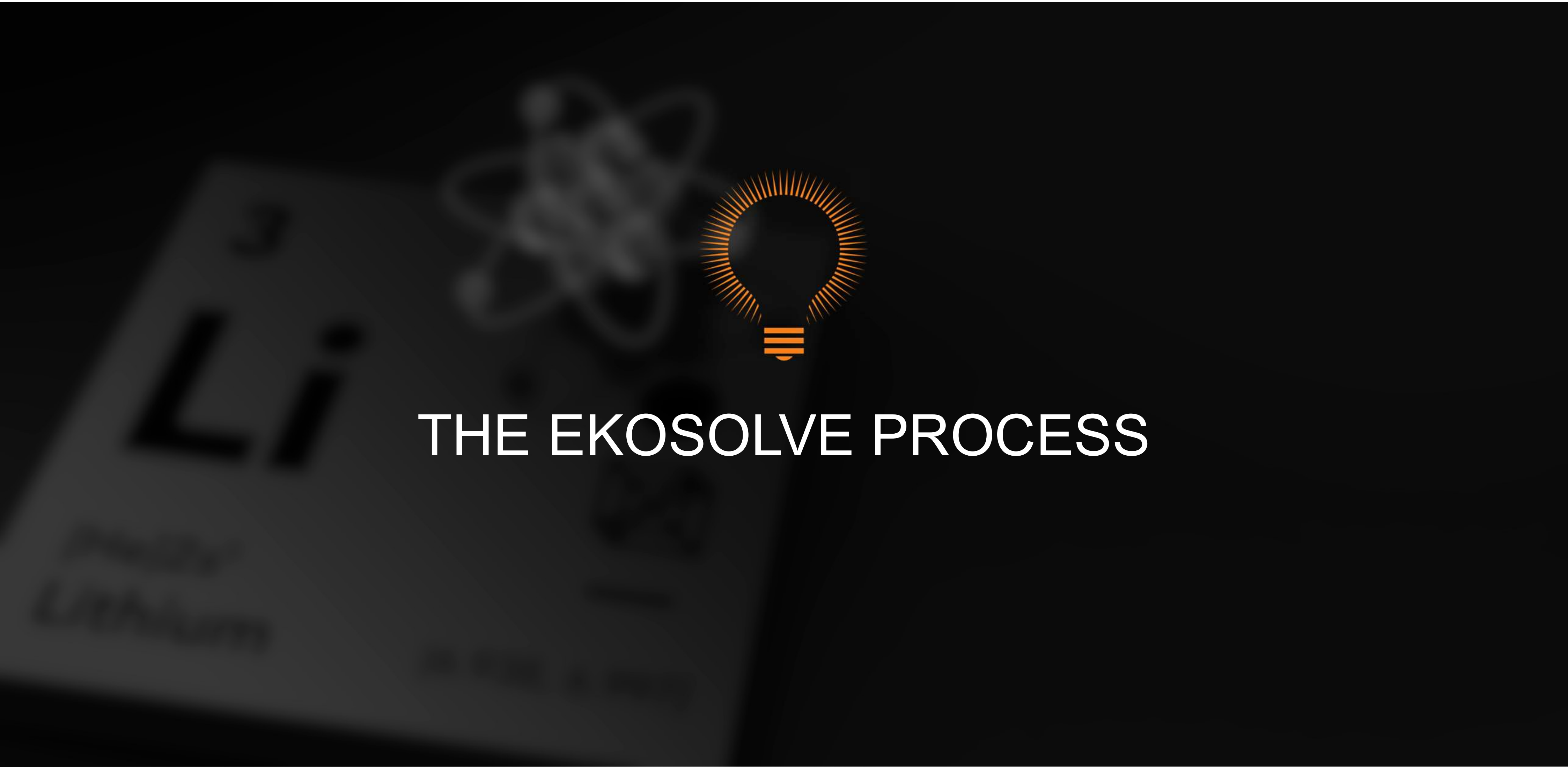
SX is a well-known, commonly used and well-tested commercial method for the recovery of metals.

SX is the preferred method to separate and purify metals such as Co, Cu, Nd, Ni, Pt and Pd, U, Po, Zr and Hf, Zn and Cd, and for the separation and purification of Rare Earth Elements.

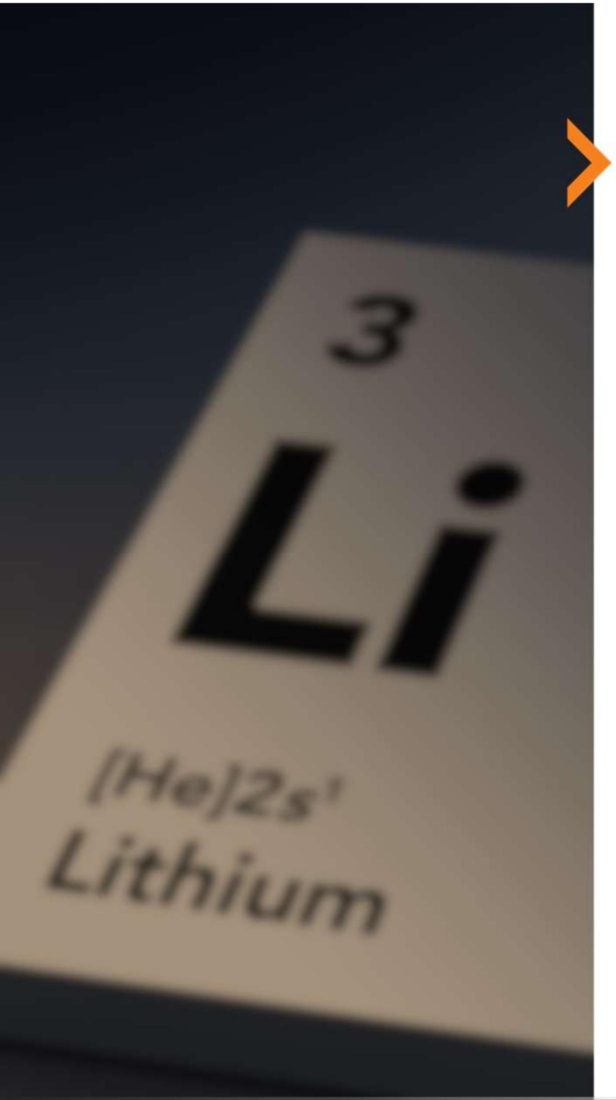
In 2016, EKOSOLVE LTD undertook an exhaustive review of solvent extraction, leading to an exchange of information with Tsinghua University.

In 2017, the Department of Chemical Engineering at the University of Melbourne was engaged to carry-out extensive bench-scale and Pilot Plant tests aimed at ascertaining the feasibility of using SX to directly extract Li from Li-rich brines obtained from Argentinian Salares, leading to the development of EKOSOLVE.



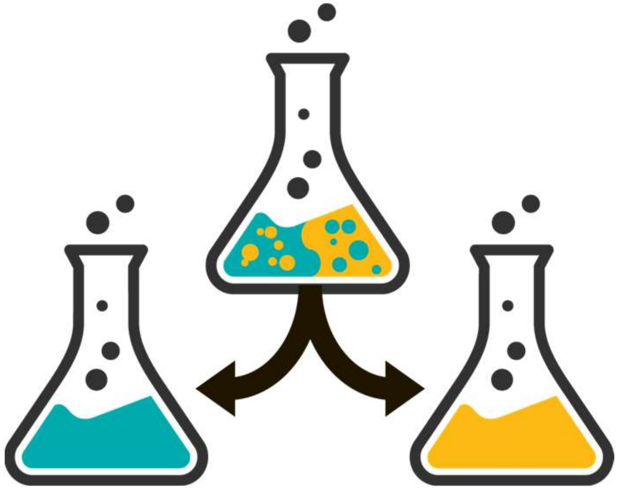


THE EKOSOLVE PROCESS



EKOSOLVE consists of several stages

- **Preconditioning** of the Li-rich brines using a proprietary co-extractant, here symbolised as "**Cx**", and hydrochloric acid;
- **Extraction** of the Li from the conditioned natural brines into an organic phase made of **TBP** as the extractant, dissolved in **MIBK** aided by Cx.



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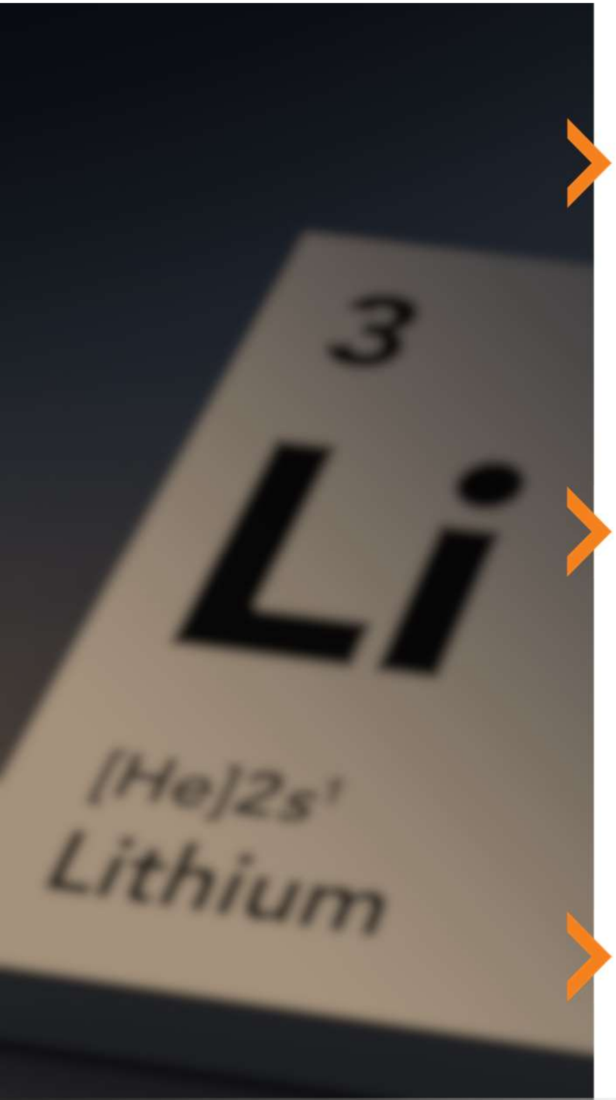


Washing to strip the Mg^{2+} from the loaded organic with a minimum loss of Li^{+} using LiCl and NaCl as the washing agents obtained from the stripping solution:

$$Li^{+}_{(aq)} + \tfrac{1}{2}Mg(CxCl)_{2}\cdot 2nTBP_{(org)} \Rightarrow LiCxCl\cdot nTBP_{(org)} + \tfrac{1}{2}\, Mg^{2+}_{(aq)}$$

Stripping of the organic phase with the help of hydrochloric acid:

$$LiCxCl\cdot nTBP_{(org)} + HCl_{(aq)} \Rightarrow HCxCl\cdot nTBP_{(org)} + LiCl_{(aq)}$$

Higher HCl concentrations result in higher Li^{+} stripping efficiencies and lower Cx losses.

Regeneration of the organic phase and the extractants.

THE EKOSOLVE CHEMICAL PROCESS IS:

$$Cx_{(aq)} + Cl^{-}_{(aq)} \rightleftharpoons CxCl^{-}_{(aq)}$$

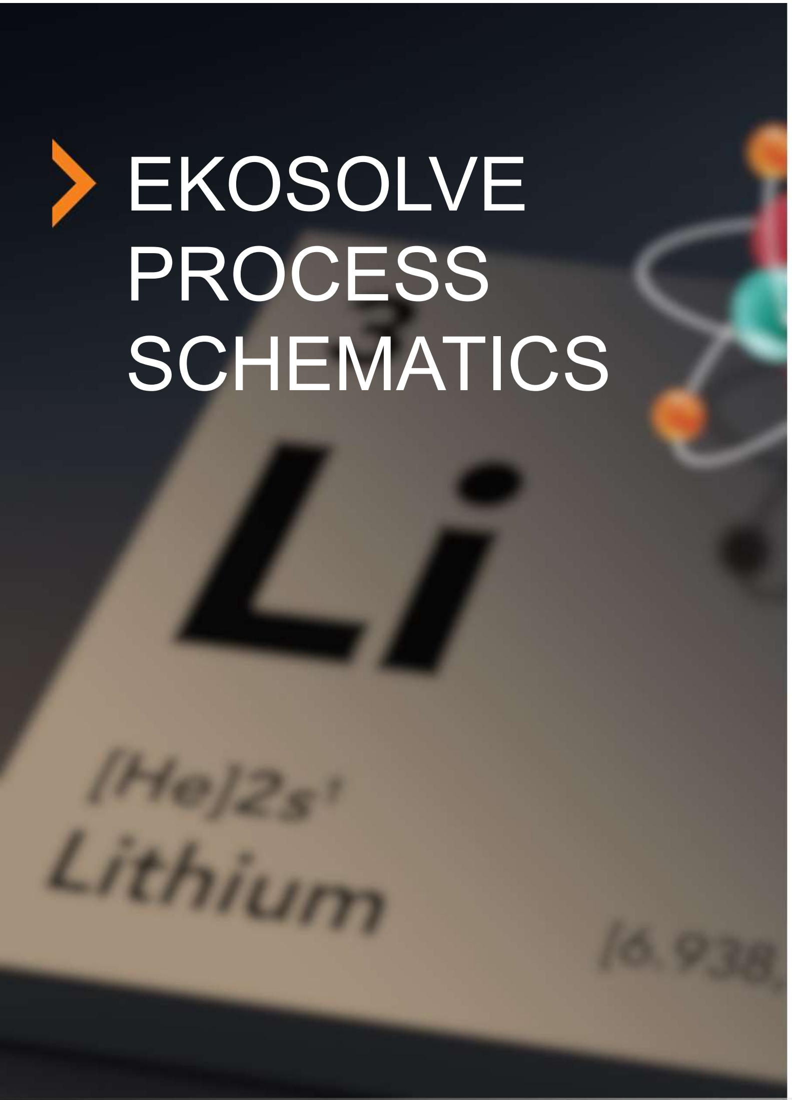
$$H^{+}CxCl^{-}_{(aq)} + nTBP_{(org)} \rightleftharpoons HCxCl^{-}{\bullet}nTBP_{(org)}$$

$$Li^{+}_{(aq)} + HCxCl^{-}{\bullet}nTBP_{(org)} \rightleftharpoons LiCxCl^{-}{\bullet}nTBP_{(org)} + H^{+}_{(aq)}$$

In this stage, some Mg^{2+} is also extracted:

$$\tfrac{1}{2}\,Mg^{2+}_{(aq)} + NaCxCl{\bullet}nTBP_{(org)} \rightleftharpoons \tfrac{1}{2}Mg(CxCl)_{2}{\bullet}2nTBP_{(org)} + Na^{+}_{(aq)}$$

EKOSOLVE PROCESS SCHEMATICS



INPUT BRINE

EXTRACTION
loaded organic
with Li ions

WASHING
Washed organic

STRIPPING
stripping agent
Stripped organic

LITHIUM CHLORIDE PRODUCTION

LITHIUM CARBONATE PRODUCTION

REGENERATED ORGANIC
Acid washing solution
Regenerating agent

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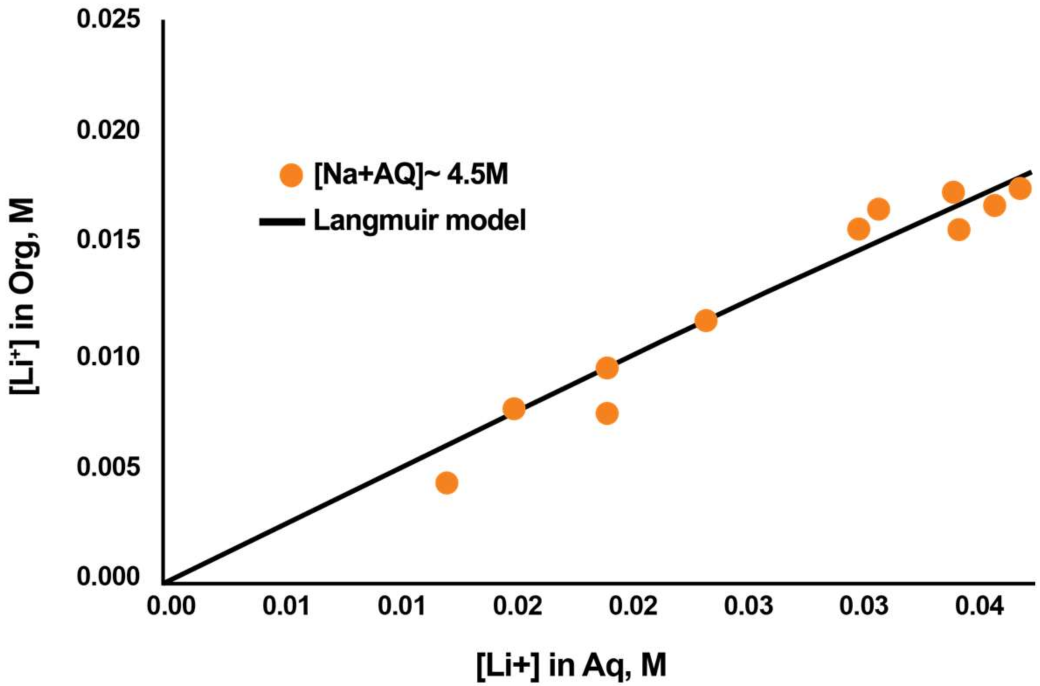
EKOSOLVE DISTRIBUTION RATIOS AND LANGMUIR ISOTHERM

The EKOSOLVE process shows distribution ratios (K_d), the concentration of a solute in the organic phase divided by its concentration in the aqueous phase) of the order of 0.53. The distribution ratio, represented as a Langmuir isotherm, is shown in the figure.



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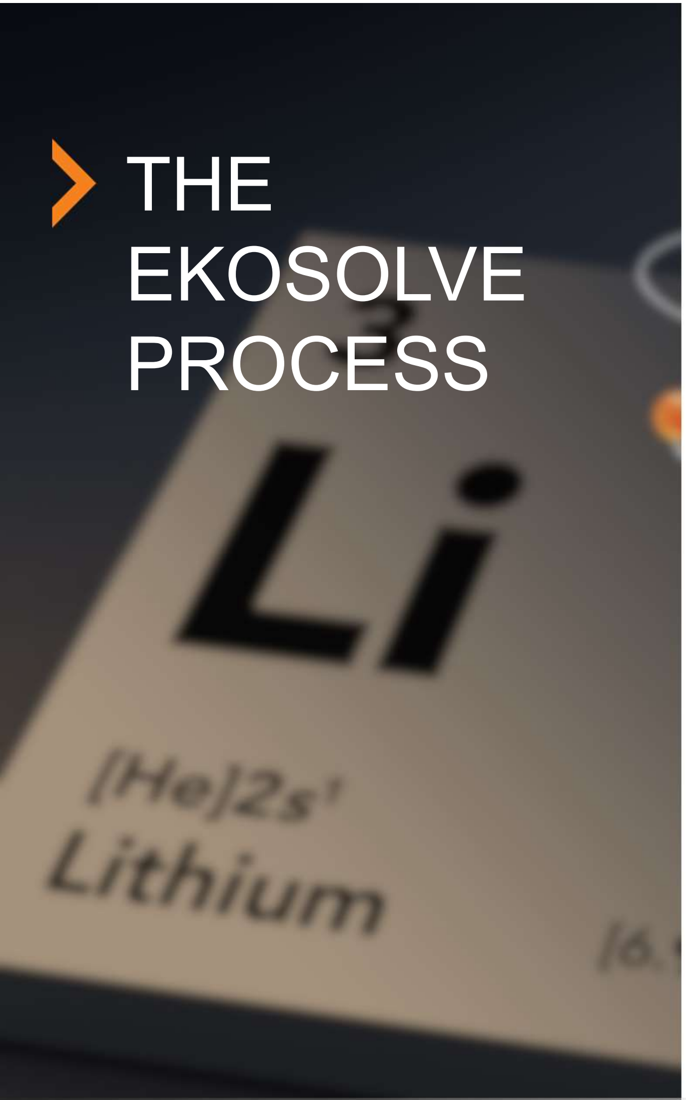
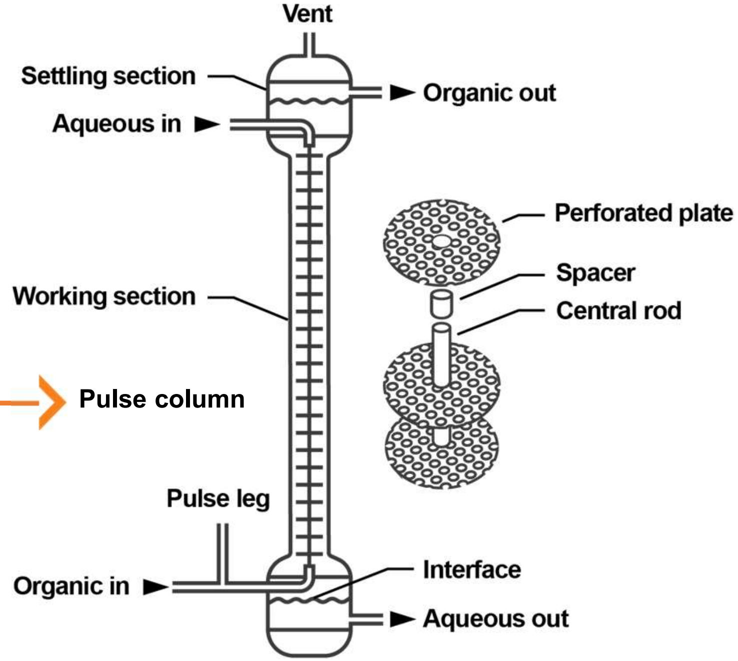
THE EKOSOLVE PROCESS



The EKOSOLVE process occurs in several sequential pulsed extraction columns, each consisting of a large diameter vertical column filled alternatively with disc and doughnut-shaped baffles, which facilitate contact between the immiscible liquids as they pass through the column.

- The aqueous phase enters through a disperser at the top of the column.
- The solvent phase enters through a similar device near the bottom.
- A decanter at each end of the column permits the liquids to coalesce and be poured out separately.
- When the solvent phase is continuous, the interface between the phases is in the lower decanter, and when the aqueous phase is continuous, it is in the upper decanter



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EKOSOLVE RECOVERY

A recovery of 96% of the lithium was achieved from the lithium brines at Incahuasi salar, Argentina.

The testwork indicates that EKOSOLVE will recover Li economically from lithium-rich brines above 72 mg Li/L.

Once extracted, the exhausted raffinate from Stage 1 is fed to Stage 2, where the extraction is repeated.

The exhausted raffinate from Stage 2 is fed to Stage 3, and the extraction is repeated. As necessary. The overall recovery can be expressed as:

$$\rho_n = \sum_{i=1}^{n} \left([Li^+]_i \bullet \rho \right)$$

ρ is the recovery, expressed as a fraction of 1, such that $0 \leq \rho \leq 1$;

n is the total number of stages;

i is the ordinal for each stage;

ρ_n is the total recovery after *n*-stages; and

$[Li^+]_i$ is the concentration of the metal in the feed of the *i*-stage.

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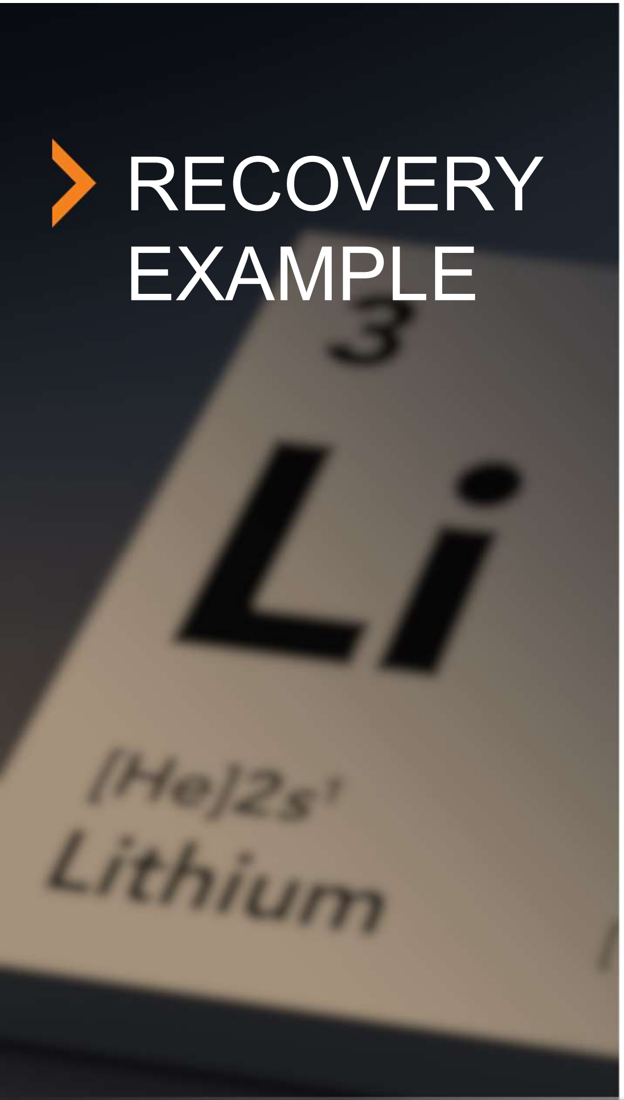
RECOVERY EXAMPLE



An example of the process' recovery, based on actual test measurements performed on natural brines, is summarized below:

Recovered			
	Feed	**Raffinate**	**Recovered Li**
		mg Li^+ / L	
Stage 1	100.0	30.7	69.3
Stage 2	30.7	9.4	21.3
Stage 3	9.4	2.9	6.5
Total recovery			97.1

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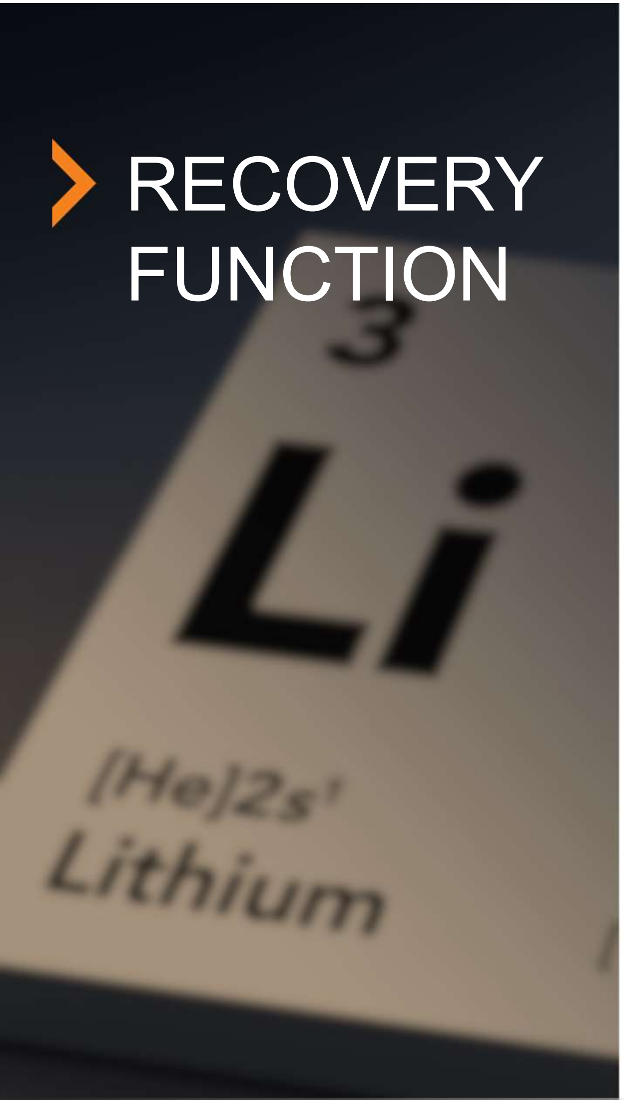
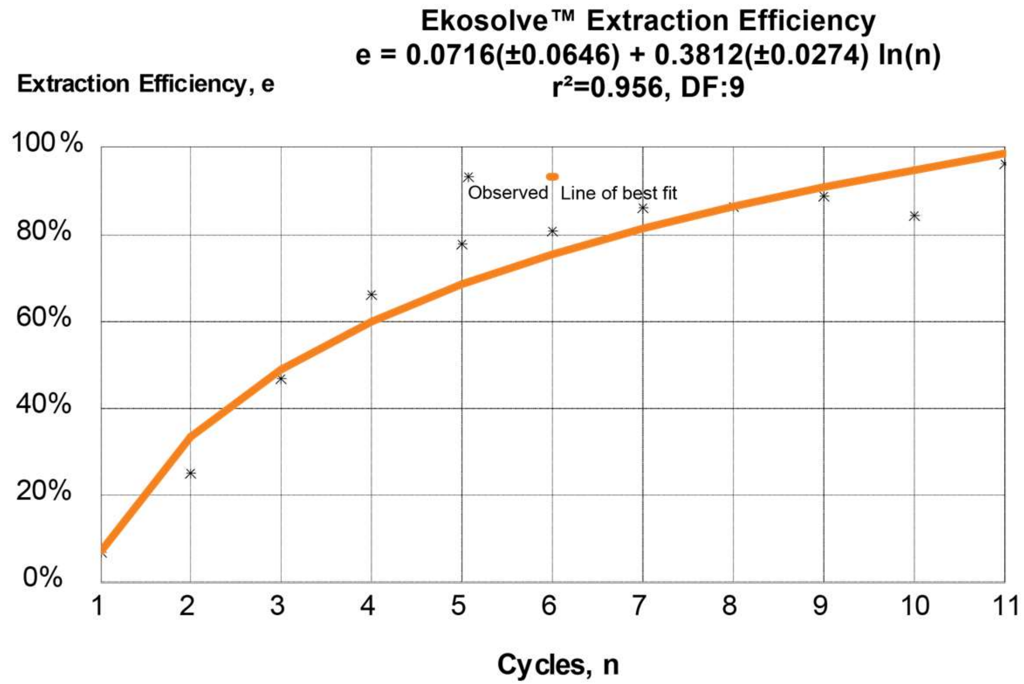
RECOVERY FUNCTION



As the number of stages increases, the lithium recovery approaches asymptotically to 100%.

However, after several stages, the recovery is marginally economic and does not compensate for the costs incurred.

The graph shows the course of this recovery function.



Lithium is recovered as Li_2CO_3 with a purity exceeding 99%

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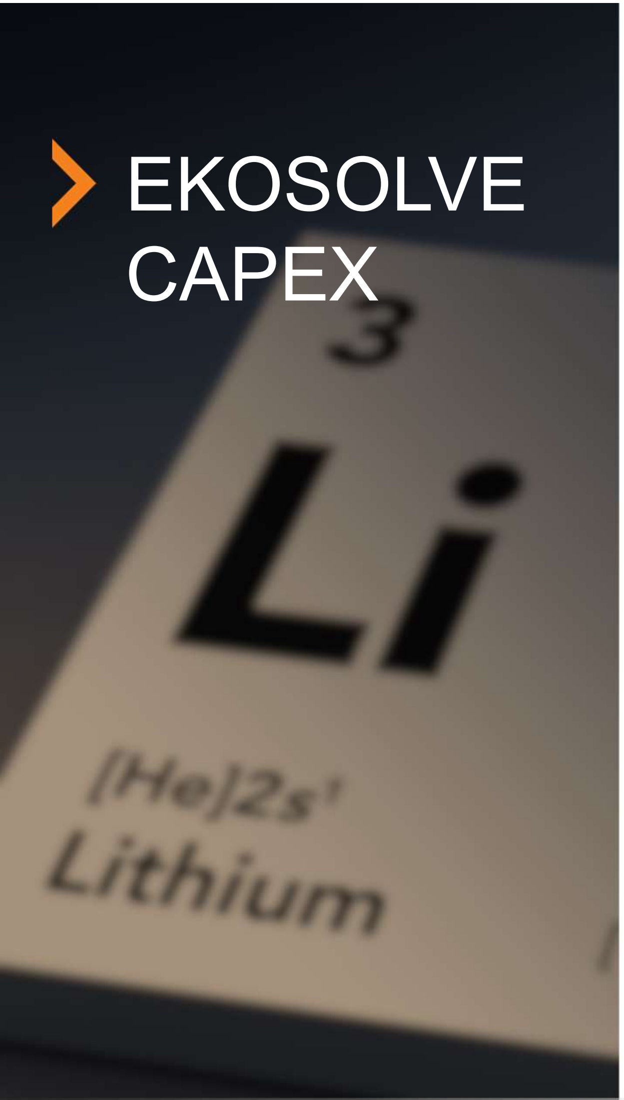
ESTIMATES OF CAPITAL AND OPERATING COSTS

Capital and Operating Costs have been appraised as an AACE's Class 2 Estimate, based on detailed unit costs with forced detailed take-off, an estimate with uncertainty in the range from -15% to +37%

The estimates are based on February 2022 prices for a plant capable of producing 20,000 tonnes per year of Battery Grade Lithium Carbonate.

The estimates do not include financial costs, fiscal taxes and royalties and do not account for inflation since 1 Jul 2021.

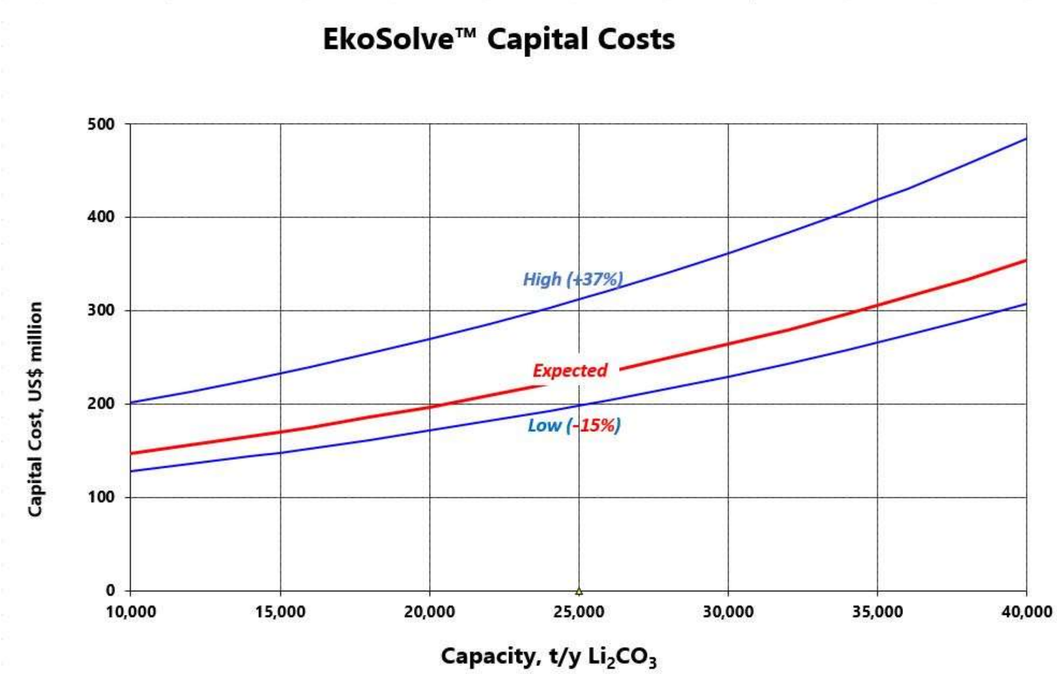
EKOSOLVE CAPEX



The capital investment required for a plant capable of producing 20,000 Li_2CO_3 per year is expected to be US$197M, ranging from a low of US$171M to a maximum of US$270 million.

This uncertainty arises from the conditions of each project, such as ease of access, power availability, reagents' import duties, etc.

The figure below shows estimates for several plant capacities.



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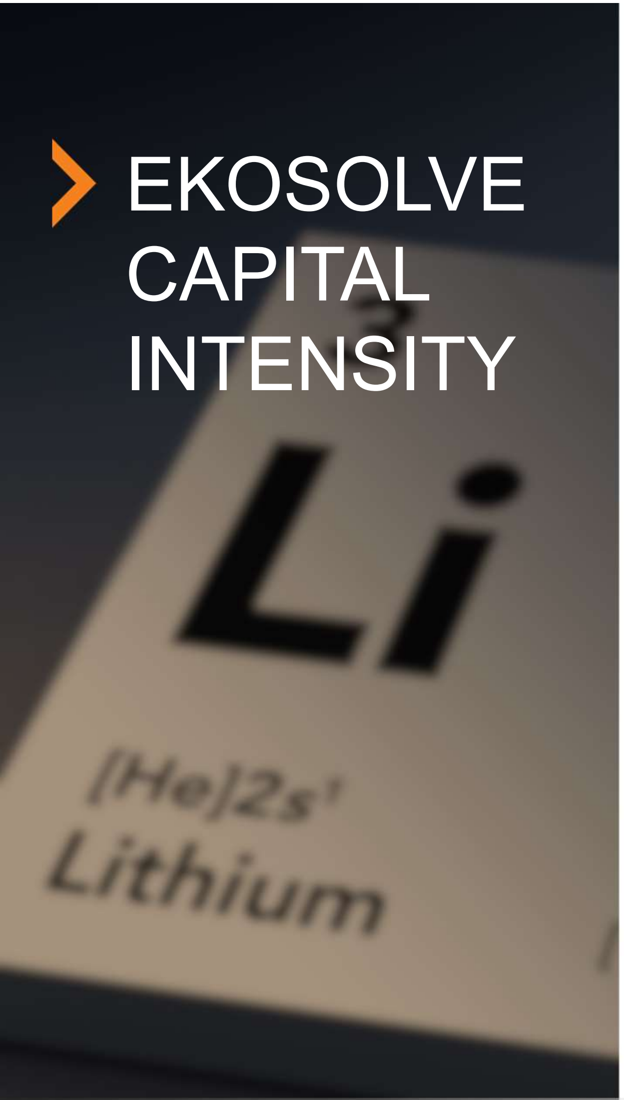

EKOSOLVE CAPITAL INTENSITY

Capital Costs can be amortised over the annual production to estimate the unit costs per tonne of Li_2CO_3 produced, a Capital Intensity that allows for a comparison of relative capital requirements between EKOSOLVE and other brine projects.

EkoSolve™ Capital Intensity, US$ per tonne of Li_2CO_3 produced annually

	Low	Expected	High
Pulsating extraction column	2,985	3,431	4,701
Initial reagent load	2,902	3,336	4,570
Plant civil installations	746	858	1,175
Generators & power works	580	667	914
Mobile plant	332	381	522
Caustic electrolytic plant	249	286	392
ECPM	779	896	1,227
Recovered	**8,573**	**9,855**	**13,501**

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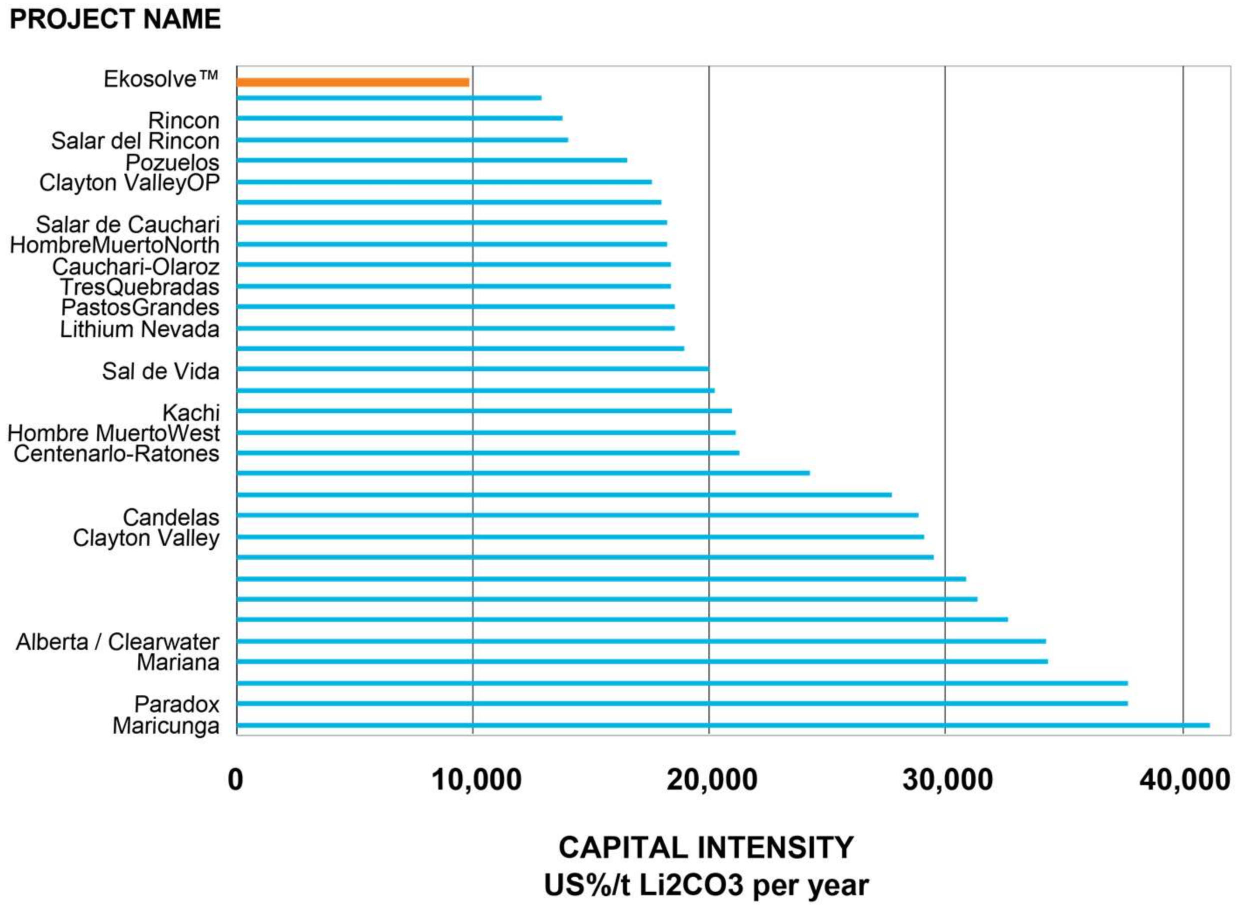
EKOSOLVE CAPITAL INTENSITY

With a Capital Intensity of US$ 9,855 per tonne of Li_2CO_3 produced annually, EKOSOLVE compares well with the capital intensity of other proposed brine projects.

Even at its maximum estimated Capital Intensity of US$13,500, EKOSOLVE is still positioned as one of the lowest investments required to develop a Li-rich brine project.

Capital Intensity of 31 proposed Li-rich Brine projects



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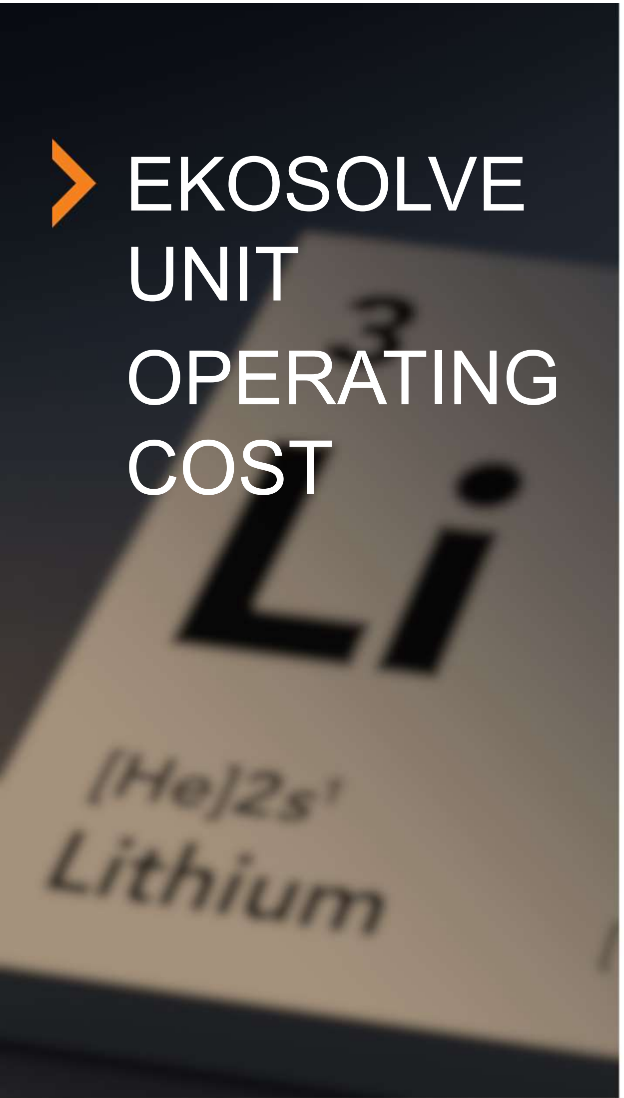
EKOSOLVE UNIT OPERATING COST



The EkoSolve operating costs can be estimated at US$2,710 per ton of battery-grade of Lithium Carbonate produced.

The opex has been averaged over ten years; that is to say, it includes commissioning expenses.

This Opex does not include the amortisation of the plant capital costs or its maintenance.

Operating costs amortized over 10 years of production, US$/t

	Low	Estimated	High
Reagents	1750	2060	2820
Fuels and Energy	460	540	740
Labour	90	110	150
Operating Costs total	**2300**	**2710**	**3710**

THE EKOSOLVE ADVANTAGES

- High recovery of Li from brines as Lithium Chloride
- Produces Battery Grade Lithium Carbonate
- Circumvents problems of brine contaminants such as Mg, Ca and B that can interfere with the recovery and quality of Battery Grade Lithium Carbonate
- Eliminates the need for solar evaporation
- No requirement for large water volumes
- Single continuous process
- Low operating costs – 98.8% of solvent and reagents recovered
- Low capital costs
- Environmentally friendly process

WHO HAS SIGNED CONTRACTS?

SPEY Resources Corp (CSE:SPEY) project in Incahuasi Salar, 10,000-tonne plant, 10,000 tonne plant in Pocitos Salar – Ekosolve processing licence agreement signed

Recharge Resources Corp (CSE:RR) project in Pocitos, previously drilled –contract being reviewed, subject to production well results and capital raising

C29 Metals Ltd (ASX:C29) in Pocitos Salar - Ekosolve processing licence agreement signed

510 Ontario – investigating lithium brines in oil wells -Ekosolve processing licence agreement signed

634 Ontario – investigating geothermal and oil well brines - Ekosolve processing licence agreement signed

Patagonia Lithium Limited (ASX:PL3) Formentera project, the contract being reviewed, subject to production well results and capital raising

Two other corporations reviewing contracts

EKOSOLVE TECHNOLGY REVIEW

An analysis of the risks of Direct Lithium Extraction systems showed that overall EkoSolve was in the lowest risk category the DLE technologies evaluated.

	Capital	Operation Complexity	Lithium Recovery	Development time	Operating Expenditure	Environment	Reagent Supply	Reagent Recovery	Safety
EKOSOLVE®	Low	Low	Low	Medium	Low	Low	Medium	Low	Low
A - Solvent/Ion Exchange	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
B - Adsorption	Medium	High	Low	Medium	High	High	Medium	High	Medium
C- Adsorption Combination	High	High	Medium	Medium	Medium	Medium	Medium	High	Medium
D - Ion Exchange/Rev Osmosis	High	Medium	Medium	Medium	Medium	Medium	High	Low	High
E - Ion Exchange	Medium	Low	Medium	Medium	Low	Medium	Medium	Low	Medium
F - Conventional	High	Low	High	High	Low	High	Low	High	Medium

Low Risk | Medium Risk | High Risk

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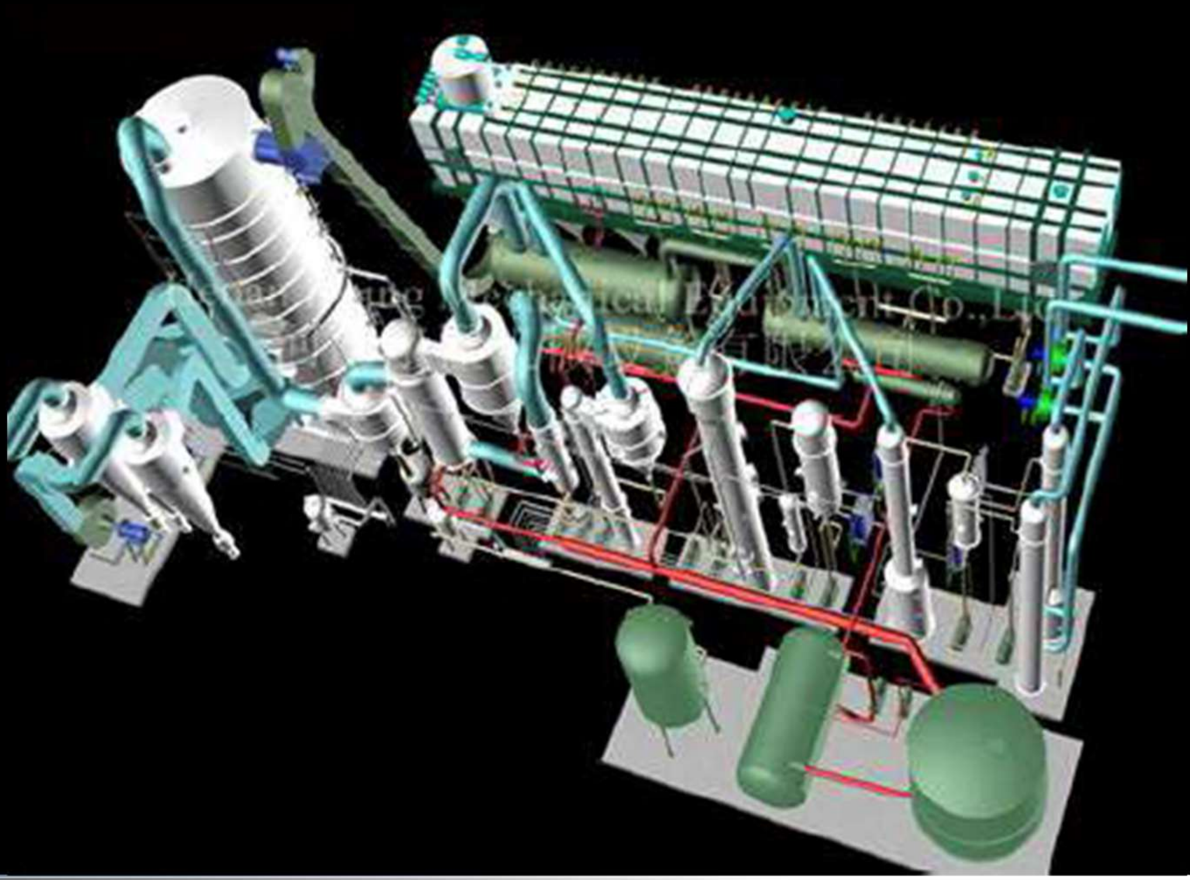
3-D OF A TYPICAL SOLVENT EXTRACTION PLANT



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Thank you

Don’t hesitate to get in touch with us for further information or a proposal to build a plant for your lithium project. admin@ekosolve.com.au

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