

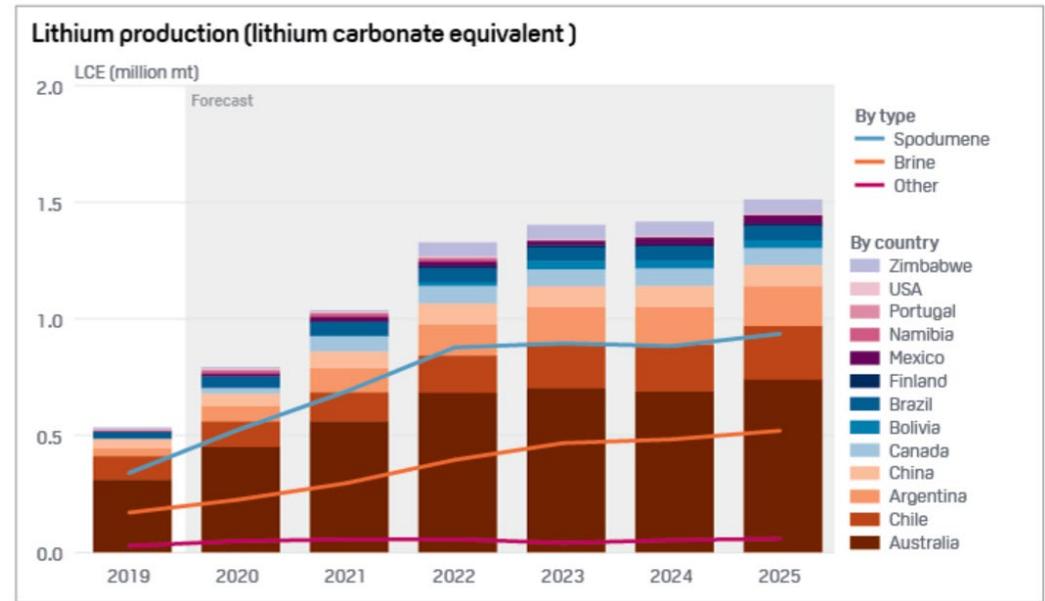
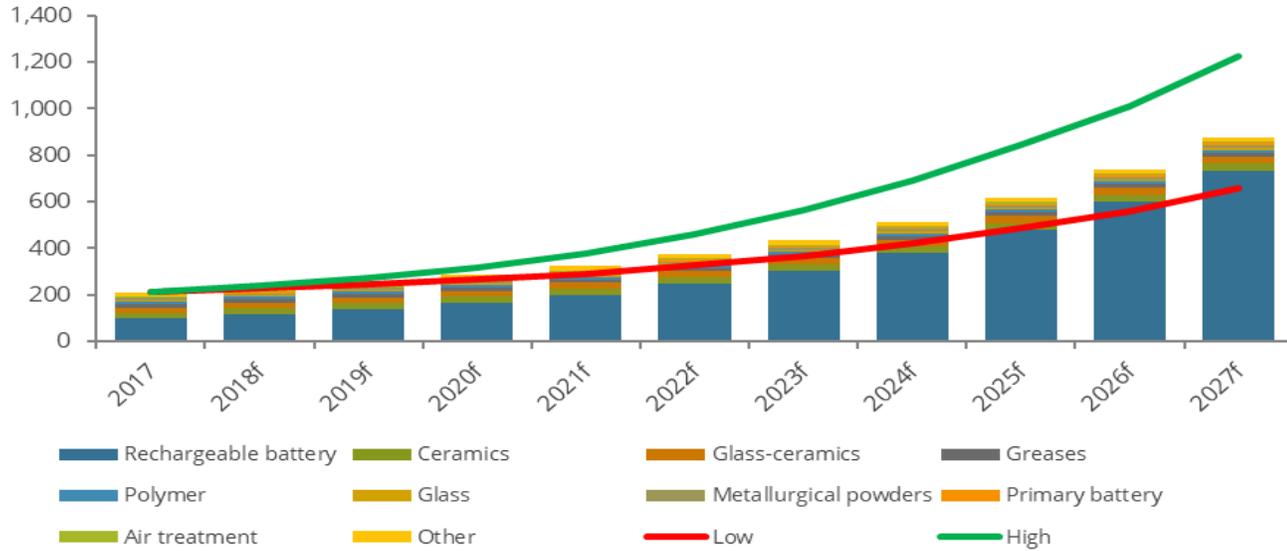
Lithium Recovery from Geothermal Brine and Minerals

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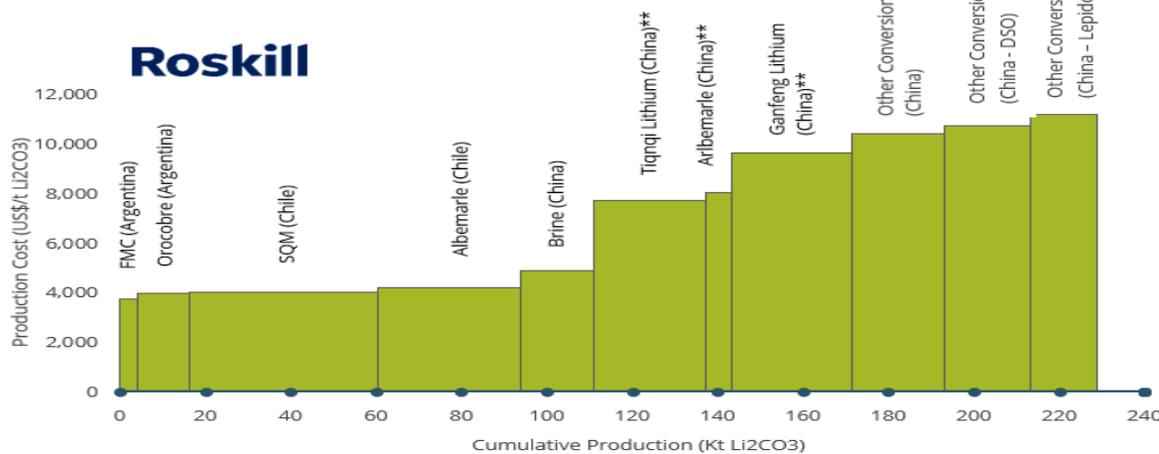
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Lithium forecast (x 1000t LCE)



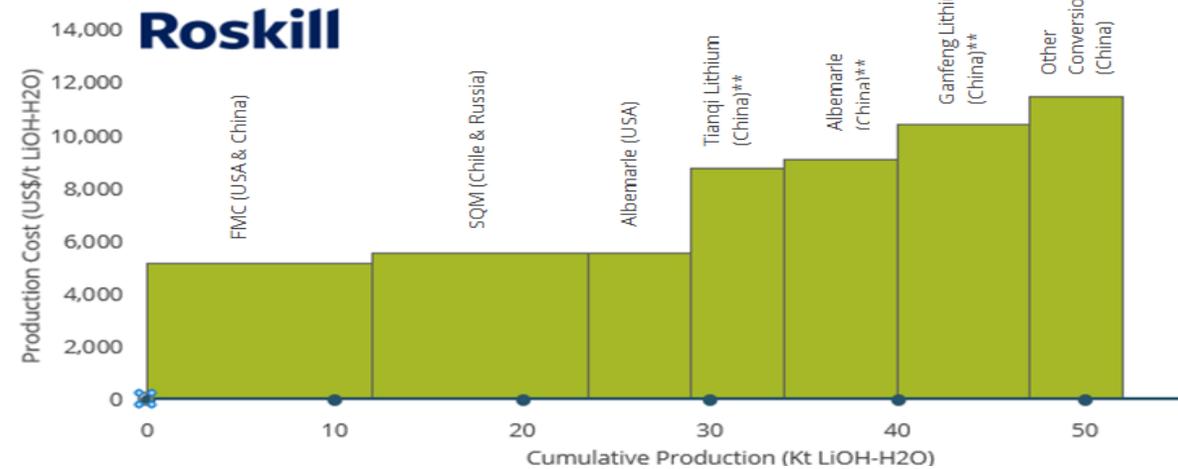
https://www.spglobal.com/_division_assets/images/articles/lithium-supply-is-set-to-triple-by-2025.-will-it-be-enough/lithium-mines.jpg

Li₂CO₃, LCE cost (2018)



Source: Roskill (2018) Lithium: Global Industry, Markets and Outlook

LiOH, Lithium hydroxide cost (2018)



Benchmark Mineral Intelligence (BMI)'s assessment puts the mid-point of Chinese lithium carbonate prices in December at \$39,250 a tonne, a gain of 485.8% from the same period a year ago. The range was \$36,575 to \$41,925 a tonne.

Types of lithium resources

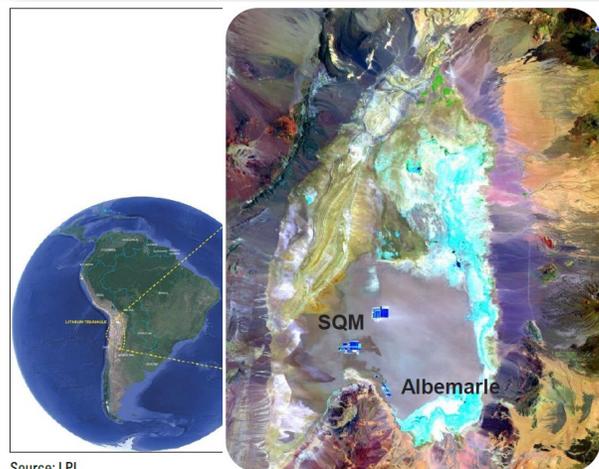
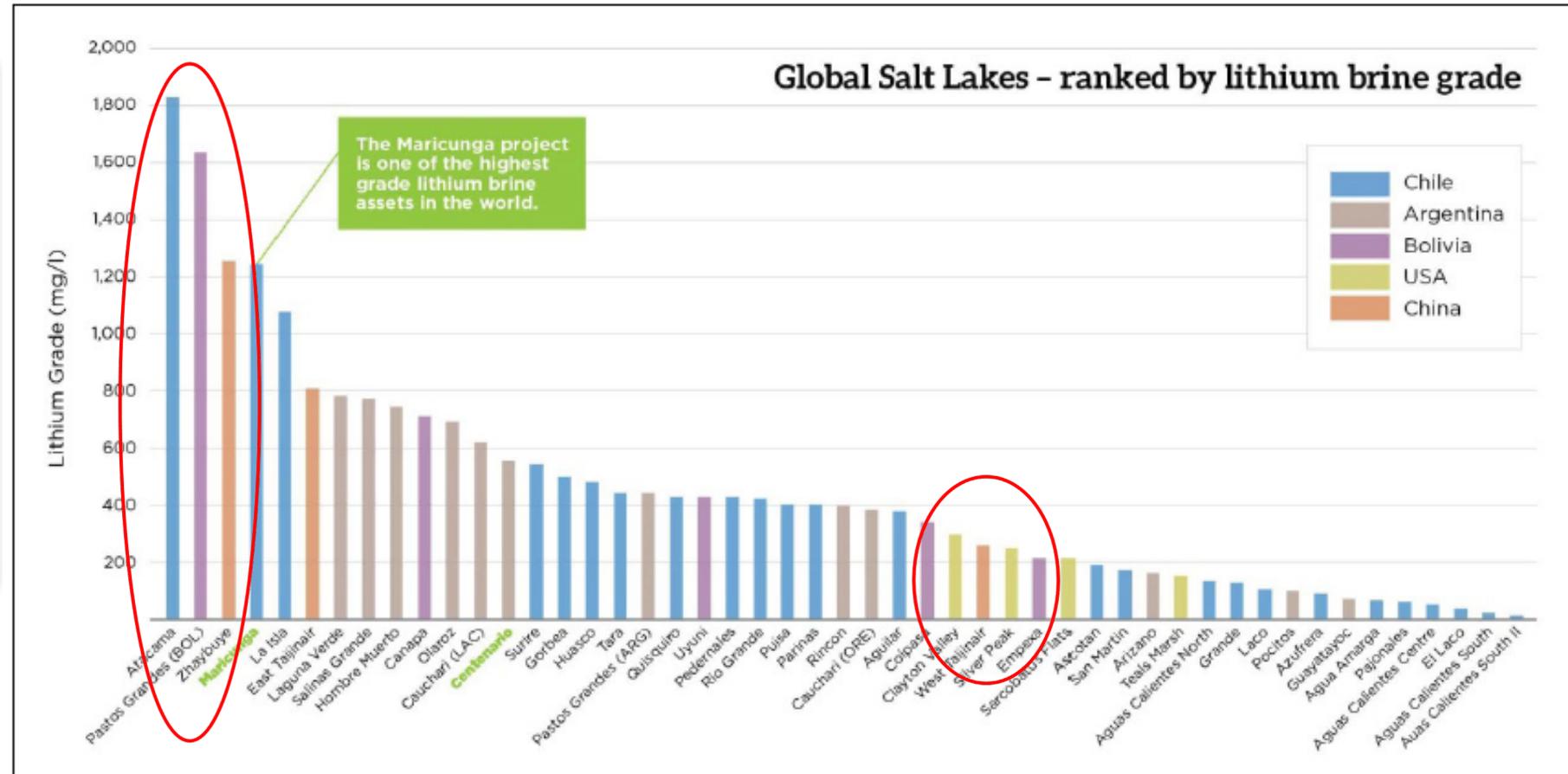
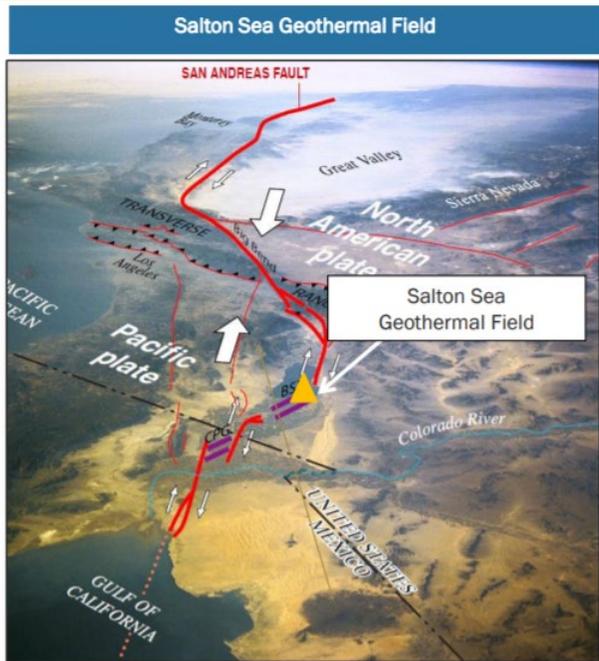
- Minerals (2,300 – 18,000 ppm)
 - About 145 mineralogical species; few commercial sources (e.g., spodumene (lithium aluminosilicate), petalite (castorite) and lepidolite)
 - Sedimentary clays (e.g., Hectorites; Boron CA in USA y jaderites in Serbia)(2,000 – 3,000 ppm)
 - Sea water (0.17 ppm)

Lithium minerals from pegmatite (from Harben (2002) and USGS (2010)).

Mineral	Formula	% Li ₂ O	Resource
Spodumene	LiAlSi ₂ O ₆	8.0	Australia, China, Canada, Zimbabwe, Portugal and Finland
Petalite	LiAlSi ₄ O ₁₀	4.9	Zimbabwe, Namibia and Canada
Lepidolite	K(Li,Al) ₃ (Si,Al) ₄ O ₁₀ (OH,F) ₂	6.2	Zimbabwe
Amblygonite	LiAlPO ₄ (F,OH)	10.3	Zimbabwe
Bikitaite	LiAlSi ₂ O ₆ H ₂ O	11.8	Zimbabwe
Eucryptite	LiAlSiO ₄	11.9	Zimbabwe
Montebrasite	Li ₂ O·Al ₂ O ₃ ·2SiO ₂	7	Canada
Jadarite	LiNaSiB ₃ O ₇ (OH)	3.16	Serbia – at feasibility stage
Zinnwaldite	KLiFeAl(AlSi ₃)O ₁₀ (F·OH) ₂	2.5-5	No current exploitation

- Recycling of lithium-ion batteries

Global comparison: Li grade in salt lakes



Source: LPI

Source: LPI

Estimates: 10.6 M MT of LCE at Salton Sea 100 km² field; Mn, Zn and K can be recovered as well

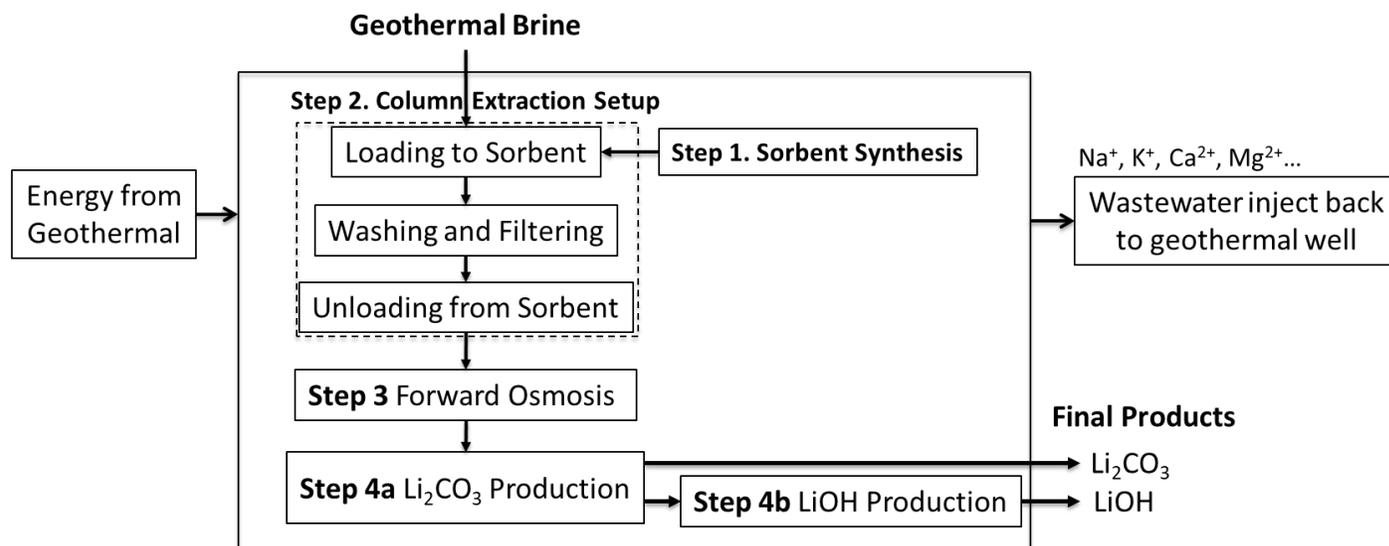
LDH sorbents and forward osmosis reduce environmental impacts

• Achievement

- Life cycle analysis (LCA) of LiOH and Li₂CO₃ production from geothermal brines shows up to 91% reduction in environmental impacts compared to mining or salar brine.

• Significance and impact

- LDH sorbents recover >91% of LiCl from geothermal brines.
- Forward osmosis membrane technology concentrates 3% LiCl eluate to 20%.
- Li₂CO₃ produced from geothermal brines has a carbon footprint that is 34% lower than production from salt flats and 26% lower than production from the mineral spodumene.
- LiOH production from geothermal brines can achieve 48% reduction on greenhouse gas emissions.



LCA schematic of lithium recovery from geothermal brines using CMI innovations in sorbent and membrane technology.

Details and next steps

- This work is coupled with techno-economic analysis and extended to recovery of lithium from other sources.

Tai-Yuan Huang, Jesus Ramon Perez-Cardona, Fu Zhao, John W. Sutherland, and Mariappan Parans Paranthaman, "Life Cycle Assessment and Techno-economic Analysis of Lithium Recovery from Geothermal Brine" *ACS Sustainable Chem. Engg.* 9, 6551-6560, 2021. <https://doi.org/10.1021/acssuschemeng.0c08733>

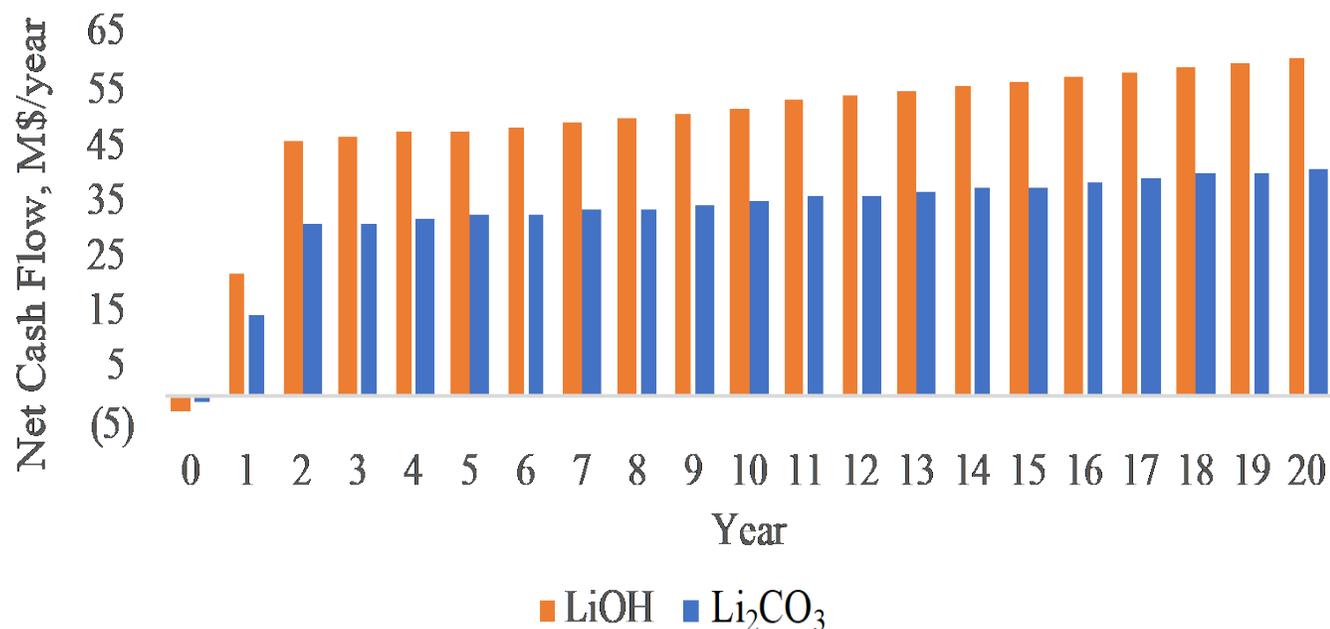
CMI sorbents and forward osmosis boost lithium economics

- Achievement

- Techno economic analysis (TEA) of LiOH and Li₂CO₃ production using CMI sorbent and membrane technologies points to a green and profitable approach for recovering lithium from geothermal brines.

- Significance and impact

- Geothermal brine is one of the promising resources to enable a sufficient domestic supply of lithium for batteries for electric vehicles.
- Based on the CAPEX and OPEX, the pay back period is only one year.



Net Cash Flow for LiOH and Li₂CO₃ production (for augmented geothermal plant across its life).

- TEA coupled with LCA project the respective production of Li₂CO₃ and LiOH to be 16,000 tpa and 10,372 tpa by assuming plant operation of 330 days in a year and plant life of 20 year for each 50 MW geothermal plant.

Details and next steps

- This work has been extended to recovery of lithium from clay minerals.