Lithium Resources Beneath The Salton Sea

Recursos de litio debajo del mar de Salton

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Hundreds to thousands of ancient “Lake Cahuillas” have formed and evaporated in the Salton Trough rift over the past 4 million years, ever since the growing Colorado River delta cut off the northern part of the rift from the Gulf of California.

The lake has never been stable - it is always forming or drying up.

*El lago nunca ha sido estable, siempre se está formando o secando.*
“Brine Pump”: every time the lake re-forms, it dissolves the salt left over from evaporation of the previous lake and pumps it into the ground.

*Esta bomba de salmuera fuerza la sal en el suelo*

Salt mining in “Salton Sink” 1854-1905

Lake Cahuilla high stand tufa, Santa Rosa Mtns

Pleistocene gypsum/mudstone cycles near Durmid Hills

Pleistocene gypsum (now anhydrite) in deep geothermal drillcore

Restos profundos de lagos evaporados

7,735 foot depth, beneath Bishop Tuff
Over millions of years, this salt has accumulated as a deep basinal NaCl brine normally found at 5-6 km depth.

More recently, magmatic heating has caused the brine to rise buoyantly near the surface in the past few 1000s of years.

El calor ígneo hace que la salmuera profunda se eleve a profundidades poco profundas.
Unaltered rocks:
- sediments
- rhyolites
- evaporites

Buried Na-Cl (salt) brine

Fractured, metamorphosed reservoir rocks

Metalliferous Na-Ca-K-Cl brine
- Li, Mn, Zn, etc.

Magmatic heat & seismicity

Perfect recipe for making hot metal-rich brine:

Receta para hacer salmuera caliente rica en metales:
<table>
<thead>
<tr>
<th>Field</th>
<th>Salton Sea</th>
<th>Imperial L2–28</th>
<th>Cerro Prieto M–5</th>
<th>East Mesa 6–1P</th>
<th>Heber 195</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well</td>
<td>S2–14</td>
<td>L2–28</td>
<td>M–5</td>
<td>~190</td>
<td>~1800</td>
</tr>
<tr>
<td>Temperature(°C):</td>
<td>330</td>
<td>275</td>
<td>300</td>
<td>~190</td>
<td>~195</td>
</tr>
<tr>
<td>Depth (m):</td>
<td>2500–3220</td>
<td>3290–4270</td>
<td>~1200</td>
<td>~2164</td>
<td>~1800</td>
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<tr>
<td>Na</td>
<td>54,800</td>
<td>50,466</td>
<td>5,004</td>
<td>6,362</td>
<td>4,019</td>
</tr>
<tr>
<td>Ca</td>
<td>28,500</td>
<td>18,140</td>
<td>284</td>
<td>759</td>
<td>750</td>
</tr>
<tr>
<td>K</td>
<td>17,700</td>
<td>9,555</td>
<td>1,203</td>
<td>1,124</td>
<td>333</td>
</tr>
<tr>
<td>Fe</td>
<td>1,710</td>
<td>3,219</td>
<td>&lt;1</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Mn</td>
<td>1,500</td>
<td>985</td>
<td>1</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>SiO₂</td>
<td>&gt;588</td>
<td>465</td>
<td>569</td>
<td>257</td>
<td>237</td>
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<tr>
<td>Zn</td>
<td>507</td>
<td>1,155</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Sr</td>
<td>421</td>
<td>1,500</td>
<td>NA</td>
<td>NA</td>
<td>41</td>
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<td>B</td>
<td>271</td>
<td>217</td>
<td>11</td>
<td>NA</td>
<td>4</td>
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<tr>
<td>Ba</td>
<td>~210</td>
<td>2,031</td>
<td>NA</td>
<td>NA</td>
<td>4</td>
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<tr>
<td>Li</td>
<td>209</td>
<td>252</td>
<td>13</td>
<td>NA</td>
<td>7</td>
</tr>
<tr>
<td>Mg</td>
<td>49</td>
<td>299</td>
<td>&lt;1</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>Pb</td>
<td>102</td>
<td>&gt;262</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Cu</td>
<td>7</td>
<td>&gt;1</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Cd</td>
<td>2</td>
<td>4</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>NH₄</td>
<td>330</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>6</td>
</tr>
<tr>
<td>Cl</td>
<td>157,500</td>
<td>131,000</td>
<td>9,370</td>
<td>11,668</td>
<td>7,758</td>
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<tr>
<td>Br</td>
<td>111</td>
<td>NA</td>
<td>31</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>CO₂</td>
<td>1,580</td>
<td>30,000</td>
<td>2,400</td>
<td>NA</td>
<td>186</td>
</tr>
<tr>
<td>HCO₃</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>221</td>
<td>NA</td>
</tr>
<tr>
<td>H₂S</td>
<td>10</td>
<td>&gt;47</td>
<td>180</td>
<td>NA</td>
<td>1</td>
</tr>
<tr>
<td>SO₄</td>
<td>53</td>
<td>NA</td>
<td>4</td>
<td>51</td>
<td>66</td>
</tr>
<tr>
<td>TDS</td>
<td>26.5%</td>
<td>25.0%</td>
<td>1.6%</td>
<td>2.2%</td>
<td>1.3%</td>
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Lithium Resources and the U.S. Supply Chain
Recursos de litio y la cadena de suministro de EE. UU.

<table>
<thead>
<tr>
<th>Compound name</th>
<th>Chemical formula</th>
<th>Molecular weight</th>
<th>kg per Li equivalent</th>
</tr>
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<tbody>
<tr>
<td>Lithium metal</td>
<td>Li</td>
<td>6.94</td>
<td>1.00</td>
</tr>
<tr>
<td>Lithium hydroxide monohydrate</td>
<td>LiOH.H₂O</td>
<td>41.96</td>
<td>6.05</td>
</tr>
<tr>
<td>Lithium carbonate</td>
<td>Li₂CO₃</td>
<td>73.89</td>
<td>5.32</td>
</tr>
</tbody>
</table>

1 ton Li metal = 5.32 tons LCE = 6.05 tons LHME

US has to import most of its lithium (W = <2,000 tons/yr)
La mayor parte del litio en los EE. UU. es importado

Producción mundial de minas

<table>
<thead>
<tr>
<th></th>
<th>Mine production</th>
<th>Reserves⁶</th>
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<tbody>
<tr>
<td></td>
<td>2020</td>
<td>2021*</td>
</tr>
<tr>
<td>United States</td>
<td>W</td>
<td>W</td>
</tr>
<tr>
<td>Argentina</td>
<td>5,900</td>
<td>6,200</td>
</tr>
<tr>
<td>Australia</td>
<td>39,700</td>
<td>55,000</td>
</tr>
<tr>
<td>Brazil</td>
<td>1,420</td>
<td>1,500</td>
</tr>
<tr>
<td>Chile</td>
<td>21,500</td>
<td>26,000</td>
</tr>
<tr>
<td>China</td>
<td>13,300</td>
<td>14,000</td>
</tr>
<tr>
<td>Portugal</td>
<td>348</td>
<td>900</td>
</tr>
<tr>
<td>Zimbabwe</td>
<td>417</td>
<td>1,200</td>
</tr>
<tr>
<td>Other countries³</td>
<td>—</td>
<td>100,000</td>
</tr>
<tr>
<td>World total (rounded)</td>
<td>82,500</td>
<td>100,000</td>
</tr>
</tbody>
</table>

Note: 50,000 miles describes the route, by land and sea, that some materials travel before reaching the car manufacturer as finished battery cells.

This supply chain can be easily interrupted or broken.
Esta cadena de suministro puede interrumpirse o romperse fácilmente.
Our lithium consumption also damages the Atacama Desert’s dry salt flats (salars) in Chile. *Impacto de la minería de litio en los desiertos de Chile.*

Salar de Atacama, Chile – the size of Yosemite National Park (3000 km²)

Financial Post

https://eros.usgs.gov/image-gallery/earthshot/salar-de-atacama-chile
Environmental impacts of traditional salar Li mining in Chile & Argentina: huge footprint, high water loss, lagoon ecology.

Destrucción ambiental causada por enormes estanques de evaporación de litio
Traditional open-pit hard rock Li mines in Australia: blasting, crushing, dust, sulfuric acid, tailings piles and ponds.

Destrucción ambiental por la minería de litio de roca dura
Geothermal brine Li recovery: smallest footprint: closed-loop process, no huge evaporation ponds, no blasting, no pits.

La extracción geotérmica de litio no tiene ninguno de estos problemas

Chilean salar brine:
3,100 acres

Australian hard rock:
465 acres

Geothermal lithium:
50 acres
LBNL-UCR-Geologica Project – 15 months
$1.2M from DOE-GTO

Científicos de la UC intentarán responder muchas preguntas sobre la extracción de litio debajo del Mar de Salton

- How much Li is in the geothermal reservoir?
- How much Li can be recovered?
- Where is the Li coming from?
- How sustainable is the Li production?
- What are the environmental consequences?
How much Li is in the geothermal reservoir?

¿Cuánto Li hay en el depósito geotérmico?

Estimate: brine Li concentration × reservoir porosity × reservoir volume (McKibben, 2021; McKibben et al., 2021). There are ranges in resource area, thickness, porosity and Li concentration. “Conservative” = currently drilled portion of reservoir, porosity of 10%. “Optimistic” = total reservoir volume from Kaspereit et al. (2016) plus a porosity of 20%:

<table>
<thead>
<tr>
<th>Porosity</th>
<th>Reservoir brine volume (km³)</th>
<th>Li in reservoir brines (metric tons of Li metal)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1990s</td>
<td>2016</td>
</tr>
<tr>
<td>10%</td>
<td>5.5 km³</td>
<td>15.5 km³</td>
</tr>
<tr>
<td></td>
<td>“conservative”</td>
<td></td>
</tr>
<tr>
<td>20%</td>
<td>11 km³</td>
<td>33 km³</td>
</tr>
<tr>
<td></td>
<td>“optimistic”</td>
<td></td>
</tr>
</tbody>
</table>

For comparison, Salar de Atacama in Chile contains 6 million metric tons of Li metal (Munk et al. 2016). Reservorio geotérmico puede contener tanto litio como el Salar de Atacama en Chile.
How much Li can be recovered?
¿Cuánto Li se puede recuperar?

For the current field’s production rates:
The total amount of Li contained in produced brine over a year = 120,000,000 x 0.0002 (200 ppm Li) = 24,000 tons Li metal/yr, which is equivalent to 128,000 tons LCE/yr.
Project that by 3x or 4x as geothermal field expands over next decade to meet state power grid mandates:

BHER (210 kt) + ESM (18 kt) + CTR (200 kt) = 428,000 tons LCE/yr?

Equals 2020 world Li production!

¡Puede que produzca tanto litio como el resto del mundo!

Besseling, 2018

BHER leases
Where is the Li coming from?
¿De dónde viene el Li?

Gypsum, mudstones are obvious candidates, but also: rhyolites
¿yeso, lutita, riolita?

We are analyzing brines and rocks for their Li content and Li isotope ratios (to fingerprint rock sources).

Schmitt and Hulen 2008
Wright et al. 2015
Environmental consequences

Consecuencias ambientales

Emissions:

Geothermal power plants emit 10x to 100x less C gases than fossil fuel power plants – coal is the worst.

H₂O and CO₂ (vented into atmosphere) and H₂S (scrubbed) – CO₂ emissions from the Salton Sea plants are already well known:
CO₂ emissions from Li production – depends on process

Pell et al. 2020: geothermal brine extraction is the lowest CO₂ emitter of all Li production methods. Hard rock mining is the worst.

Geothermal electricity can off-set use of fossil fuel electricity for a net carbon loss.

Extracción de salmuera geotérmica es el emisor de CO₂ más bajo de toda la producción de Li métodos.
Example of Li recovery process for Salton Sea geothermal brines:

Proceso de recuperación de Li para salmueras geotérmicas de Salton Sea

Some of the proposed Li brine extraction technologies actually consume CO₂ to make carbonic acid.

Some of them also recover and recycle all acid reagents that are used to release the lithium (e.g. electrodialysis):

Recuperará y reciclará todos los reactivos ácidos que se utilizan para liberar el litio:
Agricultural water distribution is 25 times municipal + industrial distribution in the IID region.

La agricultura recibe 25 veces más agua que las ciudades y la industria.
Municipal versus Geothermal water use

*Uso de agua municipal versus geotérmica*

IID Municipal and Geothermal Water Use
(acre-feet per year, 10 year average)

Municipal 700-9,000 AFY each town vs. Geothermal 10-6,600 AFY each plant.
Totals 34,799 AFY all municipalities vs. 32,635 AFY all geothermal power plants.

*Las ciudades y las plantas geotérmicas reciben cantidades iguales de agua*
Water use estimates for geothermal Li extraction

Estimaciones de uso de agua para la extracción geotérmica de Li

ESM EIR 2021: 3,456 AFY of IID canal water for operations. Comparable to current power plant averages. *La planta de extracción de litio utilizará casi tanta agua como una planta geotérmica.*

BHER and CTR EIRs have yet to be developed and released. BHER has said it will take *50,000 gallons of water to make one ton of Li*, one tenth of that the water needed in Chile.

Potential water sources for geothermal Li extraction:
- IID canal water
- Brackish (non-potable) shallow groundwater (non-IID)
- Steam condensate (self-generated by geothermal operators)
Conclusions

- Geothermal Li extraction is the least destructive of Li production methods and can help secure a stable supply chain for growing U.S. lithium needs.
- The Salton Sea geothermal field’s reservoir brines may contain up to 32 million metric tons of LCE.
- Up to 128,000 metric tons/yr of LCE could be produced from the current plants, if Li extraction methods being piloted now are highly effective and can be scaled up to commercial production.
- Expansion of the field over the next decade could generate over 400,000 metric tons/yr of LCE.
- A LBNL-UCR-Geologica study being conducted over the next year will refine these estimates and evaluate likely environmental impacts from geothermal Li extraction.