Lithium Resources Beneath The Salton Sea
Recursos de litio debajo del mar de Salton

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The Origin of Hot Brines Beneath the Salton Sea

El origen de las salmueras calientes debajo del mar de Salton

Sources: University of Redlands, USGS NCT/CAL

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.

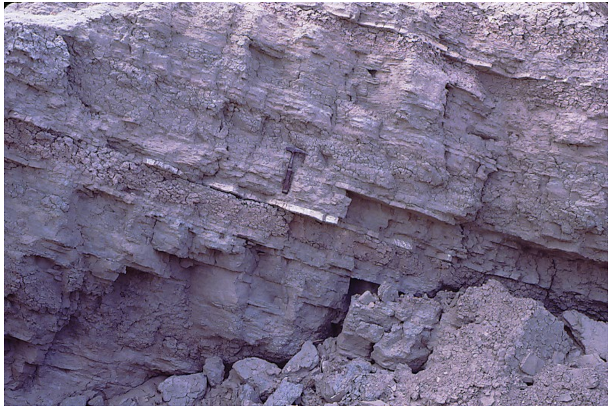
"Brine Pump": every time the lake re-forms, it dissolves the salt left over from evaporation of the previous lake and pumps it into the ground.

Esta bomba de salmuera fuerza la sal en el suelo

Salt mining in "Salton Sink" 1854-1905

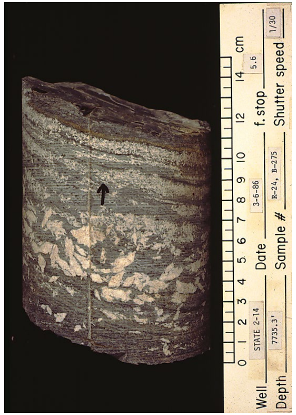
Lake Cahuilla high stand tufa, Santa Rosa Mtns

Pleistocene gypsum/mudstone cycles near Durmid Hills



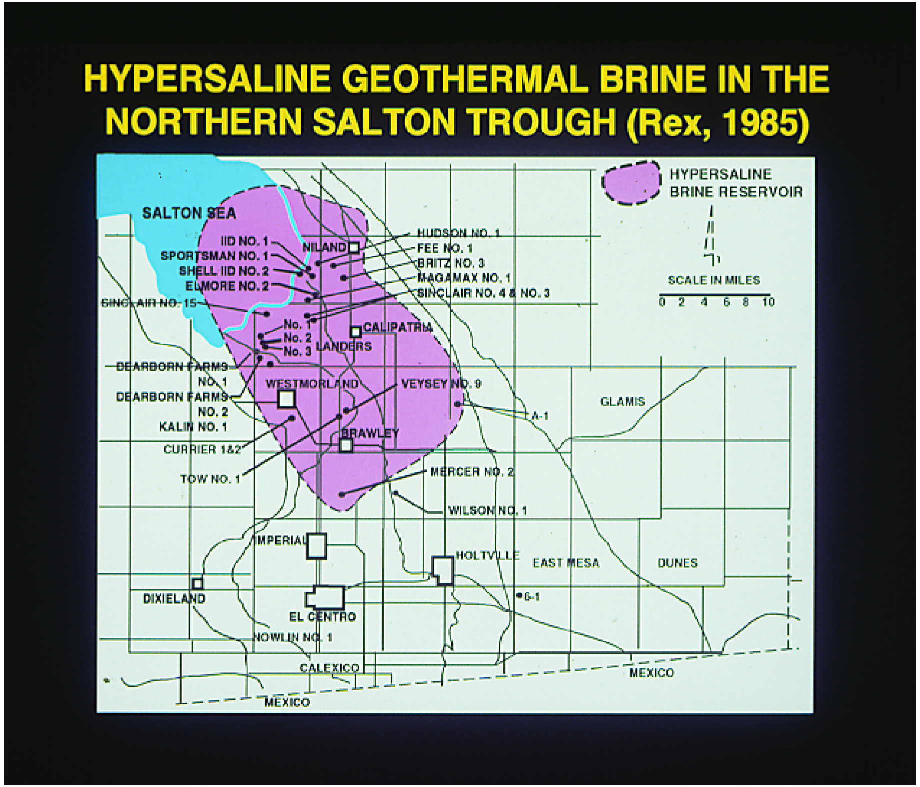
Restos profundos de lagos evaporados

Pleistocene gypsum (now anhydrite) in deep geothermal drillcore

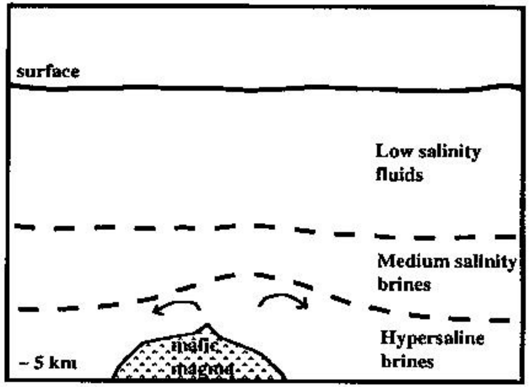


7,735 foot depth, beneath Bishop Tuff

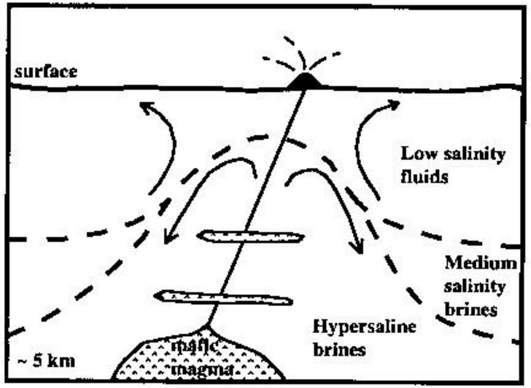
Over millions of years, this salt has accumulated as a deep basinal NaCl brine normally found at 5-6 km depth.



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



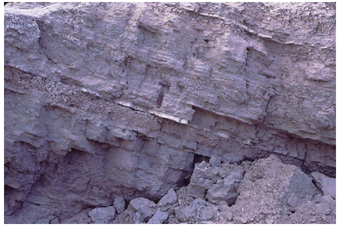
Basalt and rhyolite intrusions



Hot brine diapir

El calor ígneo hace que la salmuera profunda se eleve a profundidades poco profundas.

Perfect recipe for making hot metal-rich brine:
Receta para hacer salmuera caliente rica en metales:



Unaltered rocks:
sediments
rhyolites
evaporites

+

Buried Na-Cl (salt) brine

+

Magmatic heat & seismicity

→

Fractured, metamorphosed reservoir rocks

Metalliferous Na-Ca-K-Cl brine

Li, Mn, Zn, etc.

Valuable Critical Metals in Salton Sea and South Brawley geothermal brines

Valiosos metales críticos en las salmueras geotérmicas de Salton Sea

Field:	***Salton Sea***	***Imperial***	***Cerro Prieto***	***East Mesa***	***Heber***
Well:	***S2–14***	***L2–28***	***M–5***	***6–1P***	***5***
Temperature(℃):	***330***	***275***	***300***	***~ 190***	***195***
Depth (m):	***2500–3220***	***3290–4270***	***~ 1200***	***~ 2164***	***~ 1800***
Na	54,800	50,466	5,004	6,362	4,019
Ca	28,500	18,140	284	759	750
K	17,700	9,555	1,203	1,124	333
Fe	1,710	3,219	<1	NA	NA
Mn	1,500	985	1	NA	NA
SiO_2	>588	465	569	257	237
Zn	507	1,155	NA	NA	NA
Sr	421	1,500	NA	NA	41
B	271	217	11	NA	4
Ba	~ 210	2,031	NA	NA	4
Li	209	252	13	NA	7
Mg	49	299	<1	9	2
Pb	102	>262	NA	NA	NA
Cu	7	>1	NA	NA	NA
Cd	2	4	NA	NA	NA
NH_4	330	NA	NA	NA	6
Cl	157,500	131,000	9,370	11,668	7,758
Br	111	NA	31	NA	NA
CO_2	1,580	30,000	2,400	NA	186
HCO_3	NA	NA	NA	221	NA
H_2S	10	>47	180	NA	1
SO_4	53	NA	4	51	66
TDS	26.5%	25.0%	1.6%	2.2%	1.3%

Lithium Resources and the U.S. Supply Chain

Recursos de litio y la cadena de suministro de EE. UU.

Compound name	Chemical formula	Molecular weight	kg per Li equivalent
Lithium metal	Li	6.94	1.00
Lithium hydroxide monohydrate	$LiOH \cdot H_2O$	41.96	6.05
Lithium carbonate	Li_2CO_3	73.89	5.32

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)

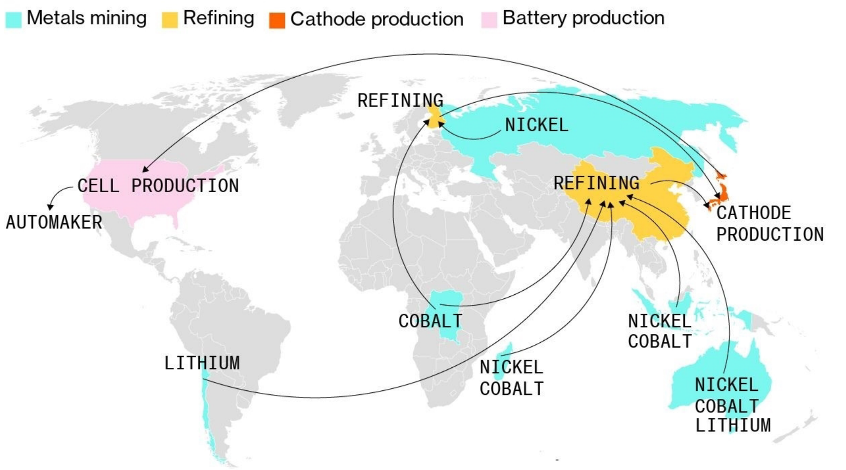
La mayor parte del litio en los EE. UU. es importado

World Mine Production and Reserves: Reserves for Argentina, Australia, and "Other countries" were revised based on new information from Government and industry sources.

Producción mundial de minas

	Mine production 2020	Mine production 2021[e]	Reserves[6]
United States	W	W	750,000
Argentina	5,900	6,200	2,200,000
Australia	39,700	55,000	[7]5,700,000
Brazil	1,420	1,500	95,000
Chile	21,500	26,000	9,200,000
China	13,300	14,000	1,500,000
Portugal	348	900	60,000
Zimbabwe	417	1,200	220,000
Other countries[8]	—	—	2,700,000
World total (rounded)	[9]82,500	[9]100,000	22,000,000

Data in metric tons of Li metal, USGS MCS 2022



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

Bloomberg

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 km^2)

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.



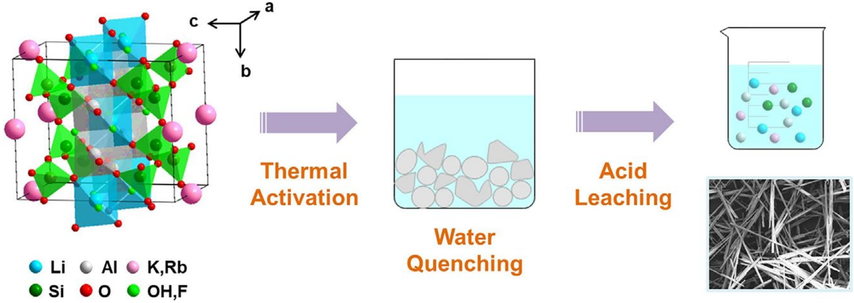


SQM; Lithium Americas; Millennial Lithium

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.

Tianqi Lithium; samcotech.com, cat-engines.blogspot.com



Solid lithium mineral

Liu et al., 2022

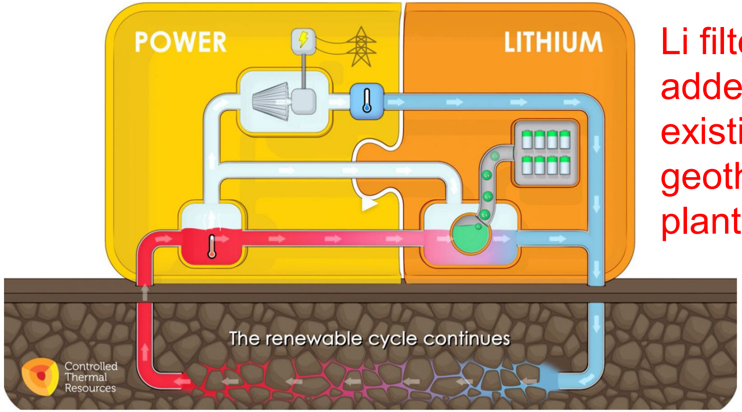
Destrucción ambiental por la minería de litio de roca dura

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

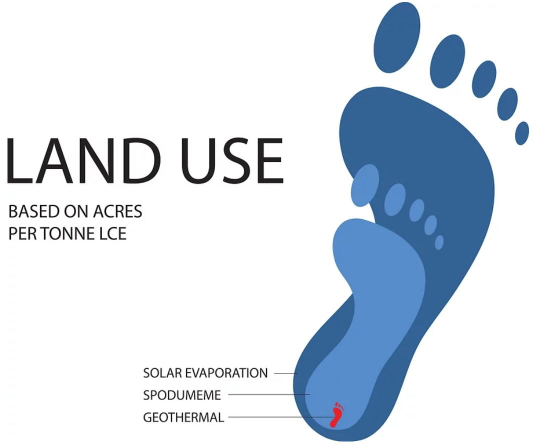
ESM

BHER



Li filter added to existing geothermal plant

CTR



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%:

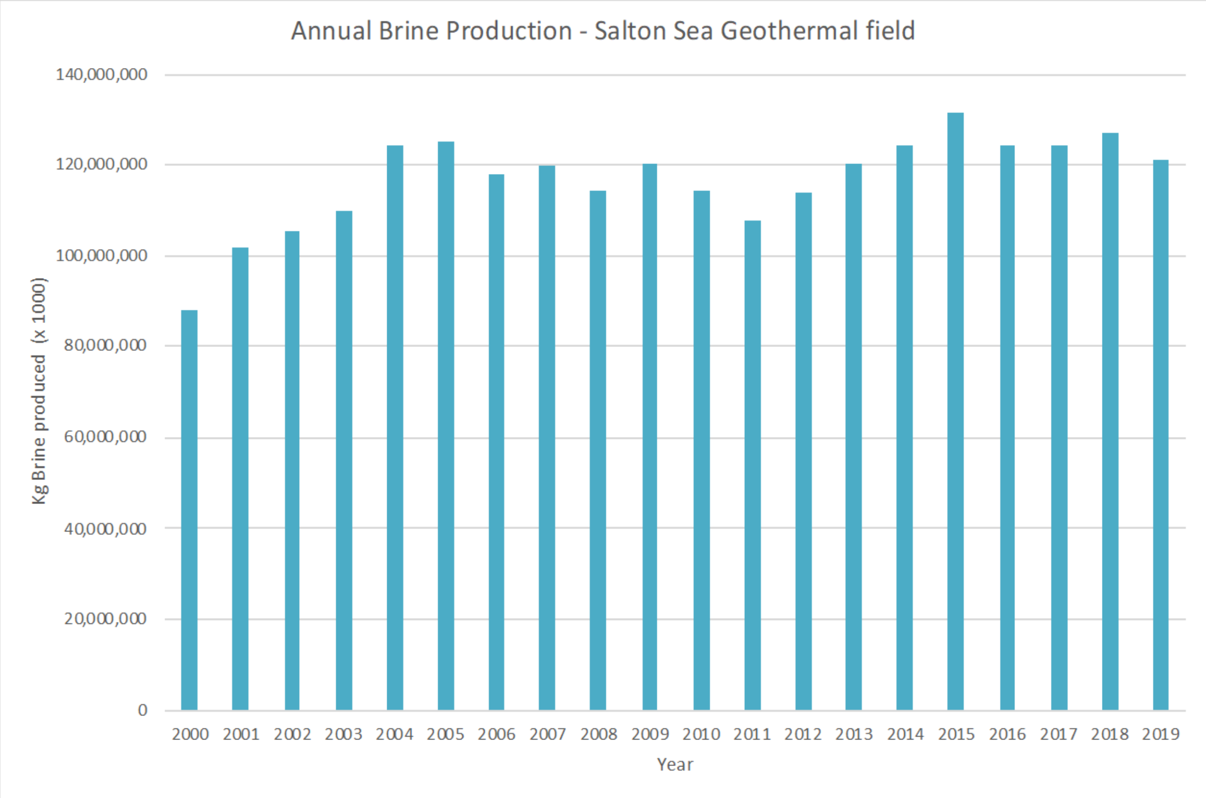
	Reservoir brine volume (km^3)	
Porosity	1990s	2016
10%	5.5 km^3 "conservative"	15.5 km^3
20%	11 km^3	33 km^3 "optimistic"

	Li in reservoir brines (metric tons of Li metal)	
Porosity	1990s	2016
10%	1,000,000 "conservative"	3,000,000
20%	2,000,000	6,000,000 "optimistic"

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

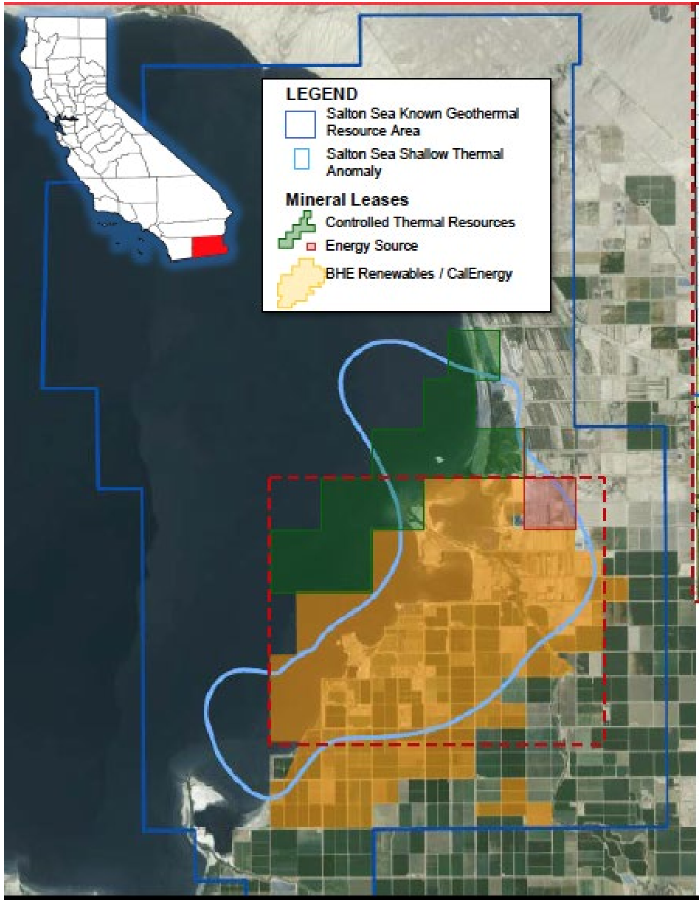
How much Li can be recovered?
¿Cuánto Li se puede recuperar?

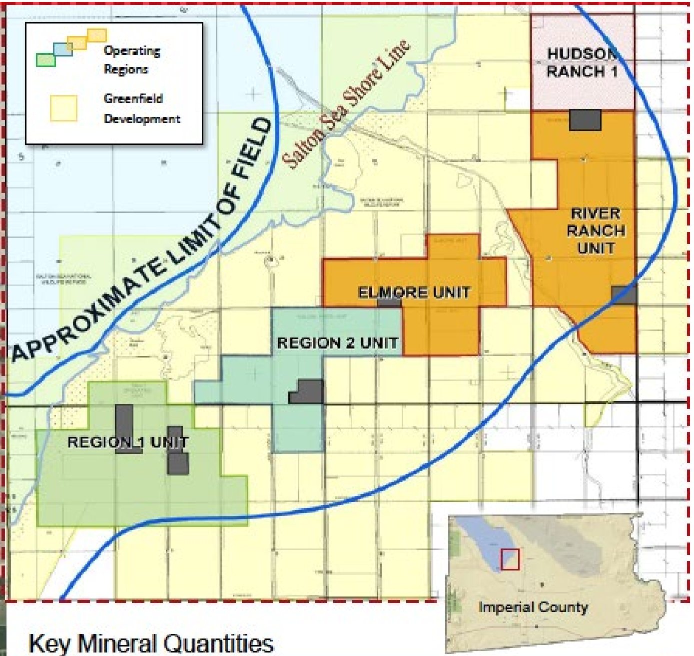


Annual cumulative brine production rates (CA Dept. of Conservation, 2021).

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:





Key Mineral Quantities

CalEnergy Resources	Power MW	Potential Annual Mineral Production			
		Li_2CO_3 (ktpa)	Zn (ktpa)	Mn (ktpa)	KCl (ktpa)
Operating	350	90	32	98	2,480
Greenfield	700	210	100	310	5,370

5

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).

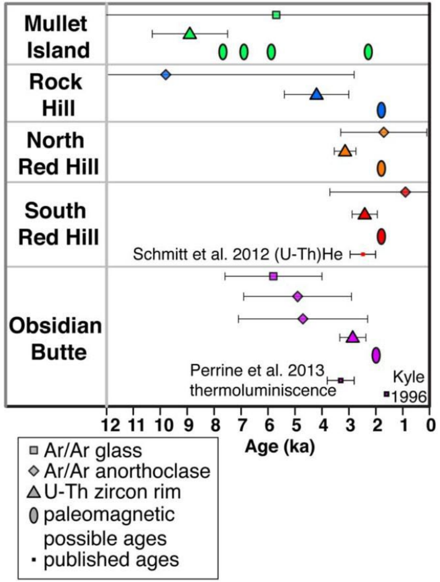


Figure 8. Compilation of $^{40}Ar/^{39}Ar$ and ^{238}U-^{230}Th age results (with 2 sigma uncertainties for Ar ages and 95% confidence intervals for U-Th ages) from this study, including permissible ages for paleomagnetic data within uncertainty limits of other age determinations and previously published age constraints for Salton Buttes surface domes.

Wright et al. 2015

710 *A.K. Schmitt, J.B. Hulen / Journal of Volcanology*

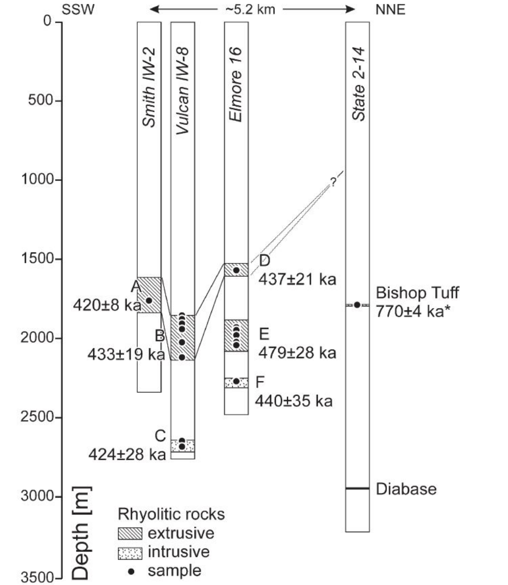


Fig. 2. Schematic well logs showing presence of volcanic rocks in studied Salton Sea Geothermal Field wells (after Hulen and Pulka, 2001; Hulen, unpublished data; Herzig and Elders, 1988). All ages are U–Pb zircon-model ages, except for (*) which is the $^{40}Ar/^{39}Ar$ sanidine age for Bishop Tuff (Sarna-Wojcicki et al., 2000, recalculated by Crowley et al., 2007). Letters refer to panels in Fig. 4. All age uncertainties quoted at 2σ level.

Schmitt and Hulen 2008

Environmental consequences

Consecuencias ambientales

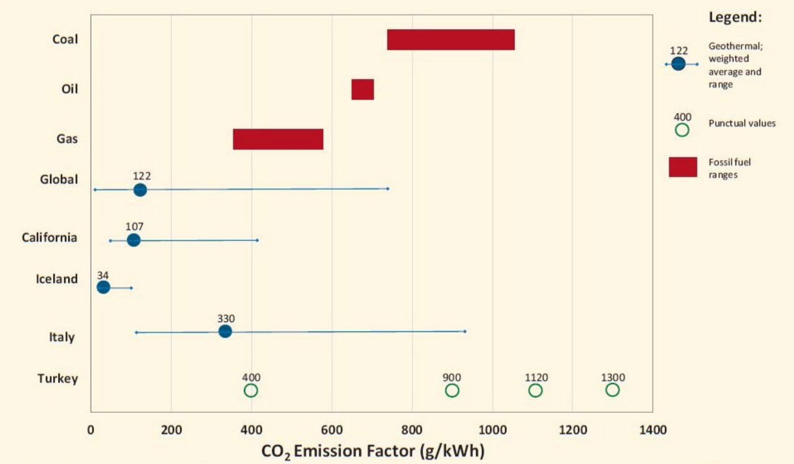
<u>Emissions</u>:

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

H_2O and CO_2 (vented into atmosphere) and H_2S (scrubbed) – CO_2 emissions from the Salton Sea plants are already well known:

FIGURE 5.1
Emission Factors of Geothermal Power Compared to Fossil Fuel

World Bank 2016



Note | Emission factors for fossil fuels are from World Bank (2015); global geothermal emission factors are from Bertani and Thain (2002); and emission factors for California apply to 2014 and are provided by Ben Matek (per. comm., 2016). The California emission factors are based on emission data for 2014 from California Air Resources Board (CARB) and power generation data from the US Energy Information Administration (EIA). Icelandic geothermal emission factors apply to 2012 and are based on unpublished data from Icelandic geothermal power producers. Italian geothermal emission factors apply to 2013 and were computed from data from ARPAT, and Turkish geothermal emission factors are from Aksoy (2014).

Annual Summary of GHG Mandatory Reporting
Non-Confidential Data for Calendar Year 2019

CALIFORNIA AIR RESOURCES BOARD

See the "Introduction" tab and the "Column Descriptions" tab for important information about the data shown.

ARB ID	Facility Name	Report Year	Total Emissions (metric tons CO_2e): Total CO_2e (combustion, process, vented, and supplier)	AEL	Emitter CO2e from Non-Biogenic Sources and CH4 and N2O from Biogenic Fuels
100692	CalEnergy Operating Corporation - J J Elmore - Geothermal	2019	7,716	No	7,716
100703	CalEnergy Operating Corporation - J M Leathers - Geothermal	2019	21,456	No	21,456
100712	CalEnergy Operating Corporation - Region 1 - Geothermal	2019	70,992	No	70,992
100716	CalEnergy Operating Corporation - Region 2 - Geothermal	2019	35,590	No	35,590
104346	Hudson Ranch Power I - Geothermal	2019	24,890	No	0

CARB 2019

Hudson Ranch I Project
Geothermal Gases in Produced Brine

Noncondensable Gases	Nominal Concentrations (ppmw)
Carbon Dioxide (CO2)	1,532.00
Hydrogen Sulfide (H2S)	13.00
Ammonia (NH3)	47.00
Methane (CH4)	1.90
Nitrogen (N2)	4.70
Hydrogen (H2)	0.13
Argon (Ar)	0.02
Benzene (C6H6)	0.04
Total	1,598.79

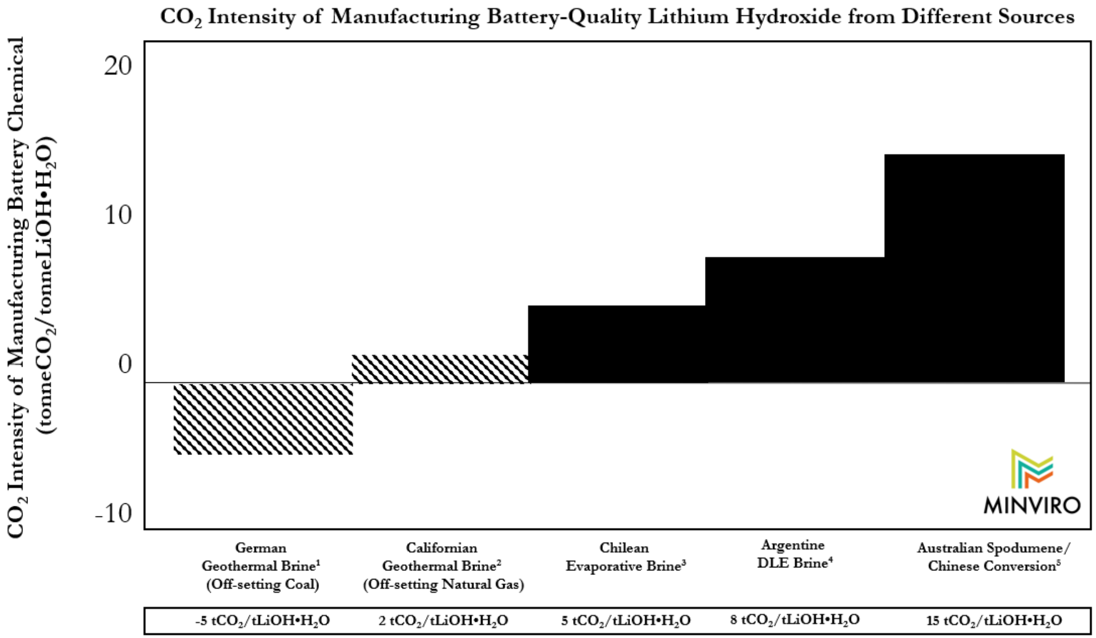
CA RWQCB 2013

CO_2 emissions from Li production – depends on process

Pell et al. 2020: geothermal brine extraction is the lowest CO_2 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 CO_2 más bajo de toda la producción de Li métodos



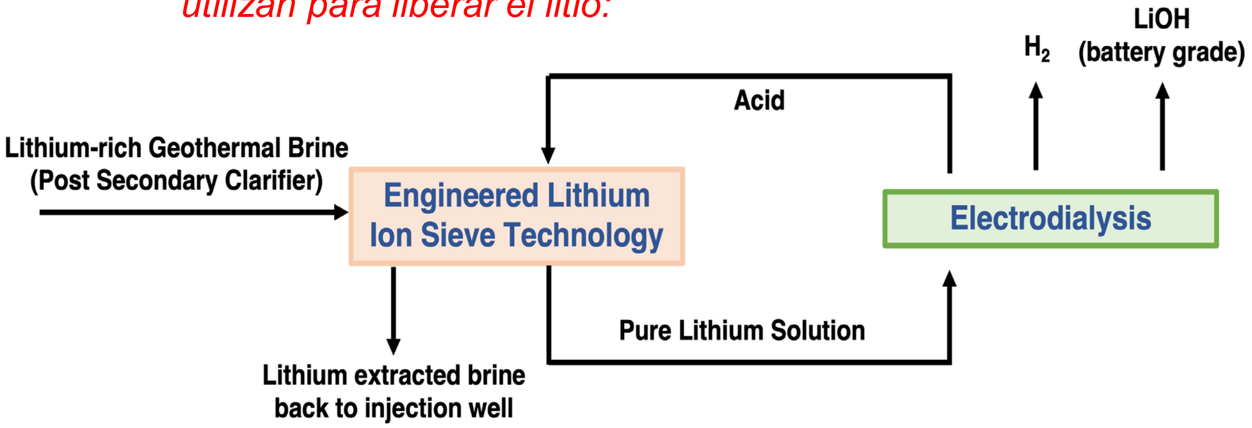
[1] Pre-Commercial Scoping Study Stage with Power Offsets
[2] Pre-Commercial Feasibility Study Stage with Power Offsets
[3] Commercial Operation, Technical Grade, Not Battery Quality
[4] Commercial Operation
[5] Commercial Operation

Example of Li recovery process for Salton Sea geothermal brines:
Proceso de recuperación de Li para salmueras geotérmicas de Salton Sea

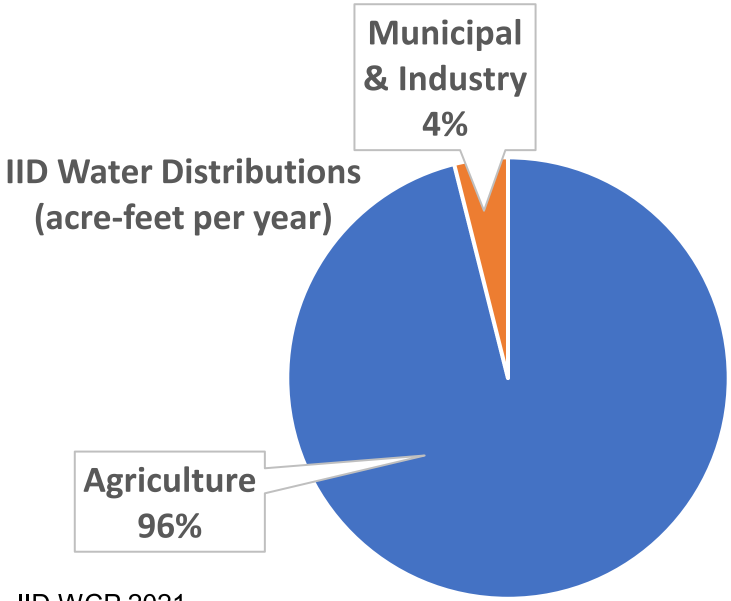
Some of the proposed Li brine extraction technologies actually *consume* CO_2 to make carbonic acid.

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:



Water usage
El consumo de agua



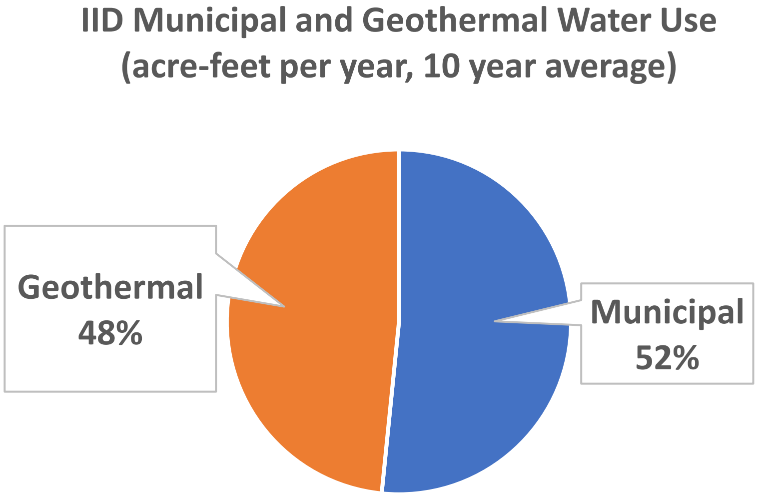
IID WCP 2021

Context:

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



Imperial Co. IRWMP 2012

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.*

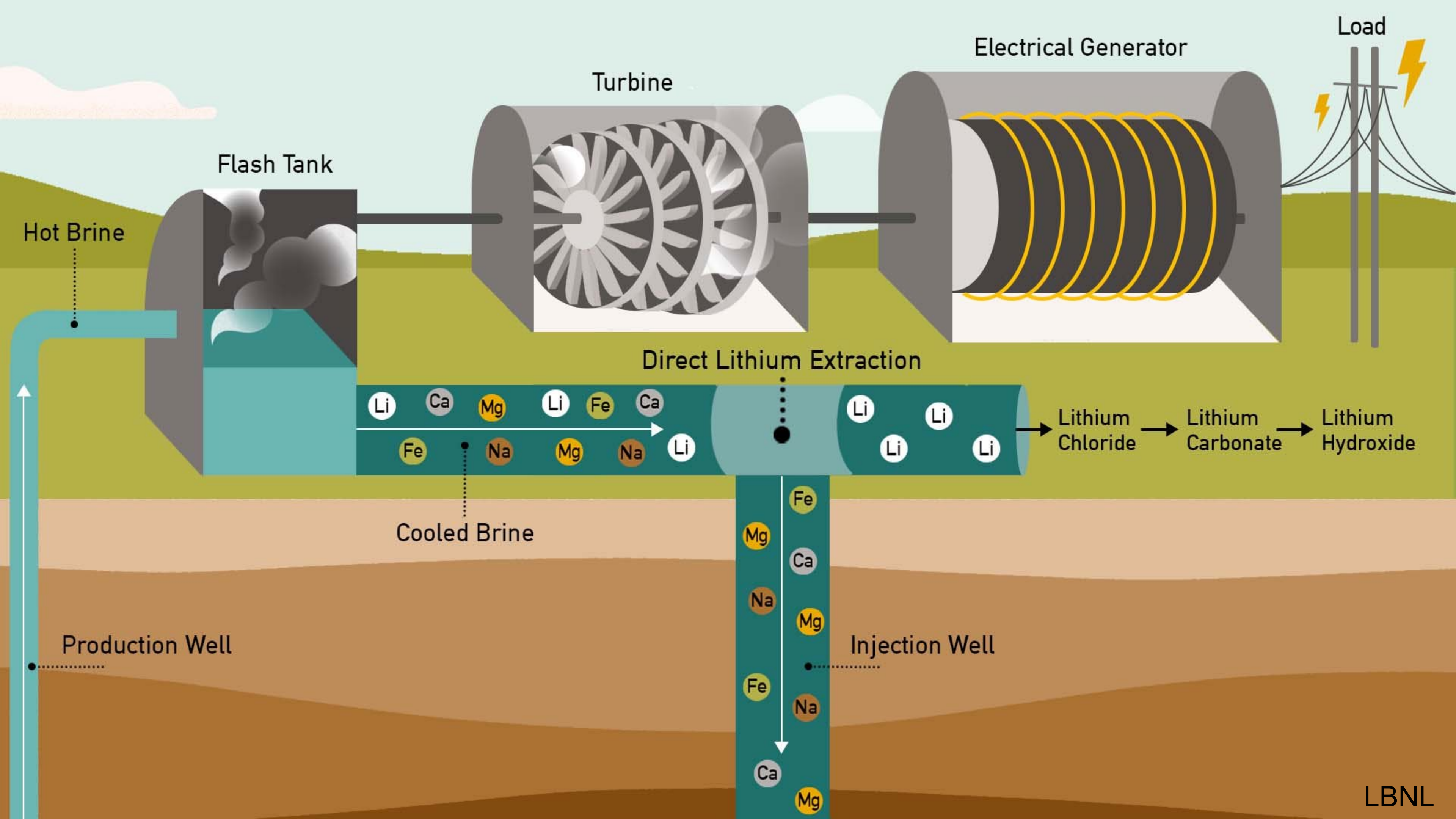
BHER and CTR EIRs have yet to be developed and released. BHER has said it will take 50,000 gallons of water to make one ton of Li, one tenth of that the water needed in Chile.

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.



Load
Electrical Generator
Turbine
Flash Tank
Hot Brine
Direct Lithium Extraction
Li
Ca
Mg
Fe
Na
Lithium Chloride
Lithium Carbonate
Lithium Hydroxide
Cooled Brine
Production Well
Injection Well
LBNL