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Report Chapter on Lithium resources at the Salton Sea

Chapter 7 from the report "Crisis at the Salton Sea: the vital role of science", 2021, a special report prepared for policymakers and stakeholders by the University of California Riverside Salton Sea Task Force. The entire report as well as the individual chapters can be found here:

https://drive.google.com/drive/folders/17YZYxPSmnnOqeYvX-_fp3fwJhV13jHFP?usp=sharing

Additional submitted attachment is included below.

7

Geothermal Resources

Lithium and Other Geothermal Mineral and Energy Resources Beneath the Salton Sea

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HIGHLIGHTS

- **Salton Sea management plans should consider economic opportunities to expand the region's active geothermal industry, as the receding shoreline opens new land suitable for construction of both wetlands and new geothermal infrastructure.**
- **The existing industry has tremendous potential to become a world-class producer of lithium and other metals, which can be extracted from geothermal brines. Expanding current electrical production would boost California's capacity to meet legal mandates for more renewable energy and lower greenhouse gas emissions.**
- **These efforts would lead to substantial local job creation and increased tax revenues, which would greatly benefit the local economy.**

California has some of the most aggressive greenhouse gas (GHG) mitigation and renewable energy generation targets in the world and will likely mandate even more ambitious goals on both fronts. Key targets include the Renewable Portfolio Standard (RPS), which reduces GHG emissions to 40% below 1990 levels by 2030 and also reduces Short Lived Climate Pollutants. There are several programs in place aimed at helping the State achieve these RPS targets, including the cap-and-trade program, energy efficiency requirements, the Low Carbon Fuel Standard, vehicle-related programs, and vehicle miles traveled targets. Reductions of emissions and increased use of renewable energy will be required across multiple sectors in order to achieve these goals. Under the current RPS established by California Senate Bill 350, the state's

GEOTHERMAL POWER PLANTS at the Salton Sea Geothermal Field. Jonathan Nye

mix of electric power will consist of 40% renewables by 2024 and 50% by 2030. California Senate Bill 100 accelerates the required penetration of renewables into the electricity grid and will achieve a 60% RPS by 2030 and 100% by 2045.

Geothermal electric power production from the Salton Sea Geothermal Field (SSGF) is one source of renewable energy that will help California meet its legislated targets. Potential production of lithium from the SSGF geothermal brines can also reduce import reliance and lower the costs of manufacturing batteries for electrical vehicles and devices, furthering the GHG goals of the state and nation. In 2020 California Assembly Bill 1657 established a Commission on Lithium Extraction in California to review, investigate, and analyze certain issues and potential incentives regarding lithium extraction and use in California.

Current Power Production

CALIFORNIA HOSTS the largest geothermal electrical capacity in the nation and in the world, producing nearly 11,000 GWh of electricity annually, or just over 5% of the total electricity produced in the state from all sources (California Energy Commission, 2019). A total of 43 geothermal power plants in the state have an installed electrical capacity of 2,730 megawatts (MW) of electrical power. The Salton Sea Geothermal Field (SSGF), located at the southeast edge of the Sea, is the second largest geothermal electricity producer in the state, with eleven plants having an installed generating capacity of 432.4 MW (US Energy Information Administration, 2021). These turbines utilize steam with temperatures of up to 250°C from production wells that are typically 1 to 3 km deep. A recent estimate of the SSGF's geothermal reserves to 3 km depth indicates that this reservoir has very large geothermal reserves capable of generating 2,950 MW for 30 years (Kaspereit et al., 2016). As the water level of the Salton Sea continues to drop, additional dry land is exposed suitable for new geothermal development (Figure 7.1).

Unlike solar and wind energy, which are intermittent and sensitive to weather and fires, geothermal resources supply baseload power available 24 hours a day. However, the development of geothermal power has longer lead times and higher capital costs compared to those intermittent renewable energy resources. Despite its huge heat content, development of the SSGF's geothermal resources lagged behind that of other geothermal fields in California because of a unique feature: the unusually high salinity (up to 28 wt. % TDS) of the hot reservoir brines that causes corrosion and scaling and requires management of solids precipitation. This problem was overcome at each of the power plants operating at the SSGF today by creative-but-expensive chemical engineering, mainly the addition of a reactor/clarifier circuit to remove solids from reinjected brines. Because of the huge penetration of relatively inexpensive solar power in California in a competitive power market, new power purchase agreements are more difficult to obtain for more costly geothermal plants at the SSGF. Therefore, all but one of the existing eleven geothermal plants are now between 20 and 38 years old.

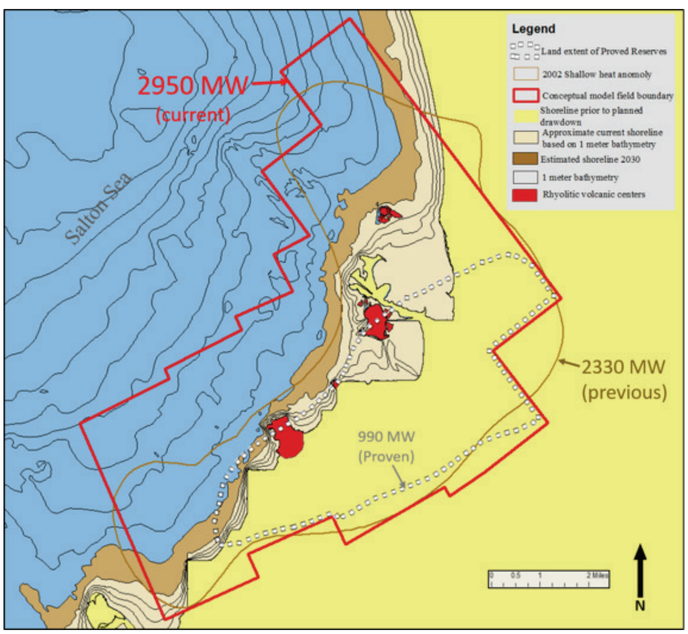


FIGURE 7.1 Outline of previous Salton Sea geothermal reservoir limit based on the shallow heat anomaly shown in brown, with the new boundary based on the new conceptual model shown in red. Proved reserves are shown by the dotted white outline. Light brown is the area (and reserves) that had been exposed by the receding sea as of 2016. By now some of the darker brown area, which is required for a project to be completed, is also exposed. Directional drilling could extend the area by 0.5 mile from pads on the exposed lakebed.
Credit: Kaspereit et al. (2016).

Today, new developments are turning the high dissolved mineral content of the SSGF brines from a liability into an asset. Recently a new geothermal operator, Controlled Thermal Resources, announced its intention to construct a new 300 MW geothermal plant utilizing new wells in the northern part of the SSGF. This expansion has become economically feasible because of the additional revenue that will be generated at this new plant by extracting lithium, manganese, and other metals from the SSGF brines. In recent years, the market for lithium for use in lithium batteries has grown enormously. In 2020 CalEnergy, the operator of ten of the existing geothermal plants at the SSGF, announced that it will spend up to $12 million to build a pilot plant to extract lithium from the SSGF brines, supported by a $6 million grant from the California Energy Commission.

In this paper we review the potential for developing this and other nontraditional sources of revenue from the geothermal brines of the SSGF in the context of likely scenarios for environmental mitigation at the Salton Sea. In addition to the potential revenues from extracting metals, we discuss making geothermal power generation more economically competitive with solar by storing energy at times of day when electricity demand is low by making hydrogen via electrolysis of clean water, and by pumped storage.

Strategic Metals

DISCOVERED IN THE EARLY 1960s and sensationalized for their high concentrations of dissolved salts and metals (White, Anderson, and Grubbs, 1963), the hot, hypersaline brines of the SSGF reservoir typically contain about 26% total dissolved solids including 1500 mg/kg manganese (Mn), 500 mg/kg zinc (Zn), and 200 mg/kg lithium (Li) (Table 7.1). Only the hot brines of the adjacent Imperial/South Brawley geothermal field south of the SSGF contain similar levels of dissolved metals. Metal concentrations in the SSGF reservoir brines vary linearly with the level of chlorine (i.e., chlorinity) of the brines (McKibben and Williams, 1989) and are therefore highly predictable (Figure 7.2).

Lithium concentrations in the reservoir rocks are quite variable but more constrained at depth (Figure 7.3), implying that metamorphic reaction with the brines at high temperature has somewhat homogenized their original sedimentary concentrations. The

TABLE 7.1 Representative flash-corrected chemical compositions of geothermal reservoir fluids in the Imperial and Mexicali Valleys. Credit: McKibben and Hardie, 1997.

Field:	Salton Sea	Imperial	Cerro Prieto	East Mesa	Heber
Well:	S2–14	L2–28	M–5	6–1P	5
Temperature(°C):	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%

average lithium content in the rocks is 40 ppm compared with >200 ppm in the brines (Table 7.1), indicating that the bulk of the recoverable lithium resource in the geothermal field currently resides within the brines rather than the rocks. This is similar to the case for other valuable metals such as manganese, zinc and copper (McKibben and Hardie, 1997).

The total amount of each metal contained within the utilized brine reservoir (like the reserves of a traditional mine: ore grade times tonnage of ore) has been estimated from data on reservoir volume, porosity and brine composition (McKibben et al., 1990; McKibben and Hardie, 1997). The currently exploited volume of the SSGF geothermal brine reservoir to a depth of 2 km contains a conservatively estimated 1013 kg of hypersaline brine. With a density of 1.0 at 300°C, this corresponds to a total of 11 km^3 of brine. The total masses of dissolved metals of economic interest in the brines are thus: 15 million metric tons of manganese, 5 million metric tons of zinc, and 2 million metric tons of lithium. These can be considered the "proven reserves" of dissolved metals in the currently exploited geothermal field (Table 7.2). These resource estimates were conservative because only the known, currently drilled, portion of the SSGF brine reservoir to a depth of 2 km in the mid-1990s was considered, whereas more recently

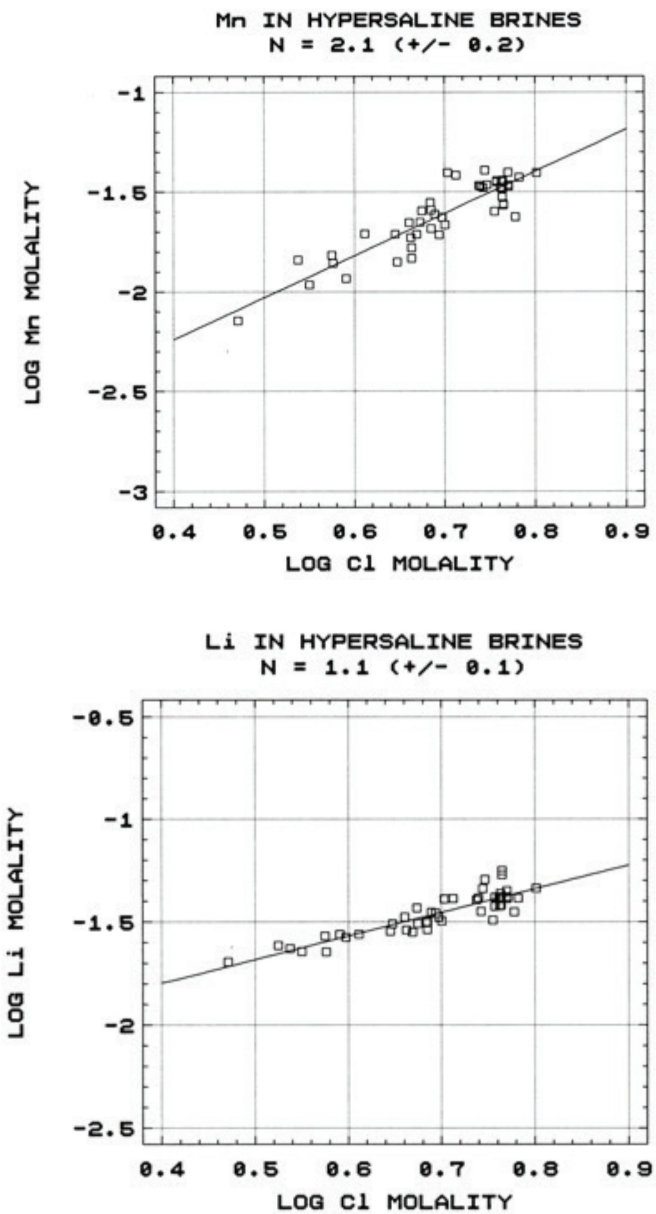


FIGURE 7.2 Variation of dissolved manganese (Mn) and lithium (Li) metal content (in molality: moles of metal per kilogram of brine) as a function of the brine's chlorinity (dissolved chlorine molality) in the Salton Sea Geothermal Field reservoir brines. Credit: Michael McKibben. Source: McKibben and Williams (1989), including unpublished data on lithium.

Kaspereit et al. (2016) estimated the stored energy of the SSGF to a depth of 3 km over a larger area (Figure 7.1). Any expansion of the lateral or deeper dimensions of the brine reservoir would significantly expand these resource estimates. To appreciate the magnitude and significance of these conservative "proven reserves" estimates, it is informative to compare them to the annual global production of these metals from traditional mine sources along with their US production and import reliance (Table 7.2).

Currently, lithium is produced globally from both hard rock mineral mining (mainly in Australia and China) and the evaporation of salt-lake brines (mainly Argentina, Chile, and China). The cost of production from salt-lake brines is about 40% lower than the cost of production from hard rock mines (Canaccord Genuity, 2018). The cost of production of lithium from SSGF geothermal brines has been estimated to be comparable to that for production from salt-lake brines (Besseling, 2018). Production of metals from the SSGF has an added environmental and cost benefit, as these brines are already being brought to the surface to produce steam to generate electricity. The additional circuit needed to extract the metals from these brines would have minimal environmental impacts compared to opening a new hard rock mine (using sulfuric acid) or a new salt-lake brine operation (with high solar water loss).

Hund et al. (2020) estimated for the World Bank that global lithium production would need to increase 500% by 2050 to meet total demand for clean energy technologies, including electric vehicles, batteries for mobile devices, and energy storage batteries. The World Bank predicted that by 2050 cumulative annual lithium demand will grow to ~5,000 metric kilotons and cumulative annual manganese demand will grow to ~7,000 metric kilotons, just for battery technologies alone. Similarly, the United Nations Conference on Trade and Development (2020) reported that the worldwide market for the cathode in lithium ion batteries was estimated at $7 billion in 2018 and is expected to reach $58.8 billion by 2024, a nearly ten-fold increase from today. They also note that in Chile, lithium mining uses nearly 65% of the water in the country's Salar de Atacama region, one of the driest desert areas in the world, to pump out cold salt-lake brines from drilled wells. This has caused groundwater depletion and pollution, forcing local quinoa farmers and llama herders to migrate and abandon ancestral settlements.

Lithium and Other Metals in Geothermal Brines

BOX 7A

ANY SIGNIFICANT PRODUCTION of lithium, manganese and zinc from the SSGF brines could make the United States a significant global producer and reduce its large import reliance on these metals, as well as providing corresponding commodity tax revenues to local, state and federal governments. In the case of lithium, the SSGF could potentially become a major supplier of this metal to the global market, eliminating imports of this strategic metal from South America and China.

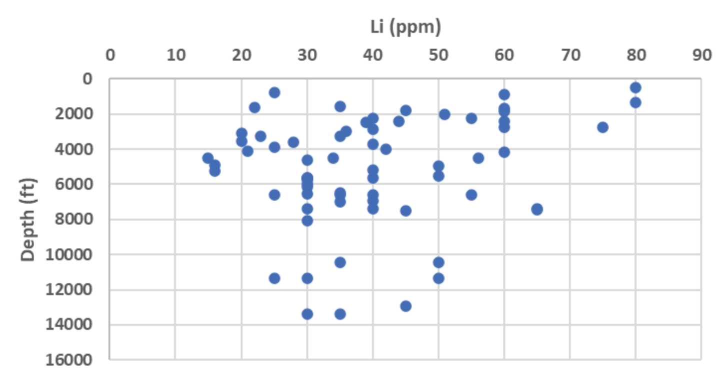


FIGURE 7.3 Variation of lithium (Li) metal content in parts per million (ppm) versus depth for cuttings and core from several drill holes in the Salton Sea Geothermal Field. Credit: Mike McKibben. Source: Unpublished spectrographic data provided to S. D. McDowell, collected in 1971 by D. E. White, L. J. P. Muffler and H. Bastron, USGS.

TABLE 7.2 Total brine metal reserves in the Salton Sea Geothermal Field (SSGF) relative to global production (in metric kilotons), US import reliance and US production. Source: USGS Mineral Commodity Summaries (2020).

Metal	SSGF Proven Reserves	Annual Global Production	U.S. Import Reliance	Annual U.S. Production
Lithium	2,000	77	>25%	Withheld
Zinc	15,000	13,000	87%	900
Manganese	5,000	19,000	100%	None

TABLE 7.3 Potential metal production (in metric kilotons per year, ktpa) from Salton Sea brines based on electrical capacity at nine CalEnergy power plants (Besseling, 2018) relative to US.annual consumption. Source: USGS Mineral Commodity Summaries (2020).

Metal	Current Capacity (350 MW)	Projected Capacity (700 MW)	Annual U.S. Consumption
Lithium	17	40	2
Zinc	32	100	950
Manganese	98	310	740

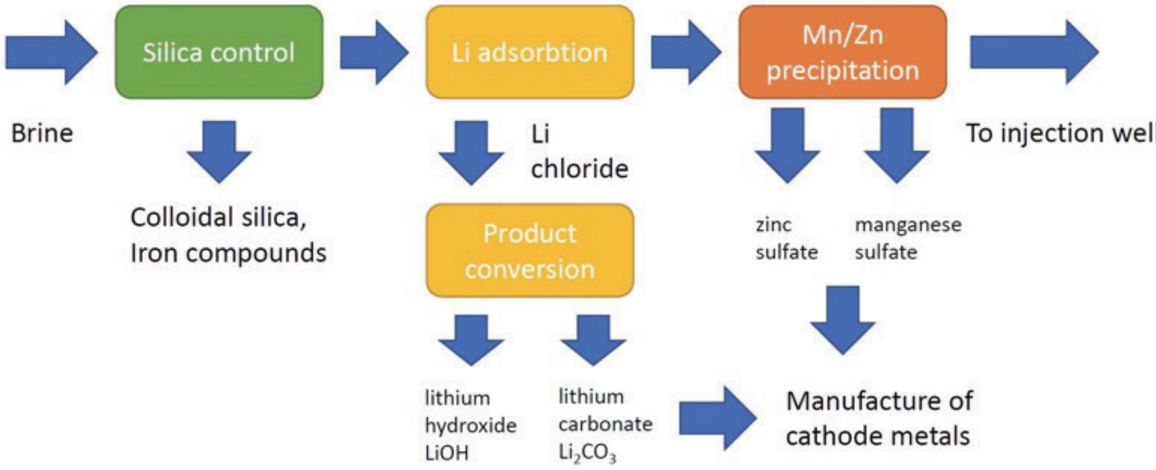


FIGURE 7.4 Scheme for extracting lithium and other valuable chemicals from Salton Sea geothermal brines. Manganese and zinc extraction can precede that of lithium. Credit: Harrison (2010a).

It has also contributed to environmental degradation, landscape damage and soil contamination. Thus, reducing or eliminating US import reliance on lithium by using deeper hot SSGF brines that are already being produced for electricity and then reinjected safely into the geothermal reservoir not only has economic benefits to the United States but also would reduce environmental consequences of traditional mining operations in other locations (Box 7C).

The technology for extracting lithium from saline brines is well known (e.g., Meshram et al., 2014; Murodjon, et al., 2019; Marthi and Smith, 2019; Paranthaman et al., 2017), with direct adsorption/desorption methods being most effective for the hot SSGF brines (California Energy Commission, 2020). Harrison (2010a) describes a sequential scheme for extracting multiple metals from the hot brines (Figure 7.4). Besseling (2018) recently estimated that the nine CalEnergy plants in the SSGF could produce the annual amounts of metals shown in Table 7.3 at both their current electrical installed capacity (350 MWe) and a near future expanded electrical capacity (700 MWe).

Lithium production from the SSGF (17 to 40 ktpa) could easily meet the U.S.'s current demand (2 ktpa) and eliminate its import reliance, as well as supply a significant fraction of the current global production (77 ktpa) (Table 7.2). Obviously, such production levels would have to be approached cautiously so as not cause large price elasticity by flooding the global lithium market. Instead, metal production from the SSGF should be ramped up gradually to keep pace with rapid growing global lithium demand over time as predicted by Hund et al. (2020) and the United Nations Conference on Trade and Development (2020). This approach would also align itself with the stepwise development and refinement of recovery technologies for high volume geothermal brines.

Need for Flexibility

GEOTHERMAL POWER PLANTS generate readily available stable baseload electric power, but the growth of geothermal electric power generation in California has been slowed by the widespread availability and low costs of solar and wind power (Elders et al., 2018, 2019). The extensive penetration of solar power has resulted in circumstances where there can be overgeneration on sunny days, followed by a deficit when the sun sets (Figure 7.5).

This overgeneration can lead to low renewable electricity prices while also resulting in 'curtailment' of excess electricity. The undeveloped part of the geothermal resource of the SSGF is probably the largest known undeveloped geothermal resource in the world. Fully developing the SSGF's estimated 2.7 GWe of resources thus could contribute substantially to the projected 13 GWe ramp in demand for electricity in California when the sun sets (Figure 7.5). However geothermal wells need to flow at a constant rate to remain stable, so the answer to this dilemma is to develop technologies for storage of renewable energy.

These technologies need to be dynamic and capable of providing load-following while also being commercially profitable. The Imperial Irrigation District (IID), the sole electric utility in Imperial County, operates a 30 MWe pumped storage facility at Pilot Knob near the international border with Mexico.

Pumped Storage

THE SSGF HAS THE POTENTIAL to play an important role in providing an essential service to the local community while developing new revenue streams. This benefit could be achieved by taking advantage of the terrain surrounding the Salton Sea to build pumped storage facilities, by using the electricity generated for electrolysis to produce hydrogen and osmosis to produce deionized water, and by cascading the thermal effluent to produce hot and chilled water for district heating or cooling (Shnell et al., 2018; Elders et al., 2018).

We propose an investigation of the feasibility and economics of building large, pumped storage plants that use the water of the Salton Sea and the electricity of the SSGF as the power source. Augmentation of the geothermal electricity produced alone would add to the problem of oversupply when the sun is shining, but during low demand, the geothermally generated electricity could be used to pump water from the Sea to upper storage reservoirs. When the sun sets, this water would flow down back to the Sea and drive hydroelectric turbines that would produce electricity in the evening hours to supply power when demand rises.

If the upper reservoir was sited in a basin in the hills west of Desert Shores, for example, at an elevation greater than 12 m above sea level (the level of the shoreline of ancient Lake Cahuilla), with the surface of the Salton Sea at ~72 m (-236 feet) below sea level, there is the potential for a hydraulic head of more than 84 m. If the intake in the Sea was in the northern deep basin of the Sea, about 10 m below the lake surface, this would have the added advantage of oxygenating some of the bottom water, which exhibits extreme anoxia. Such a scheme might begin with a modest (<50 MW) demonstration plant which, if successful, could be scaled up to the gigawatt level with its operation inte-

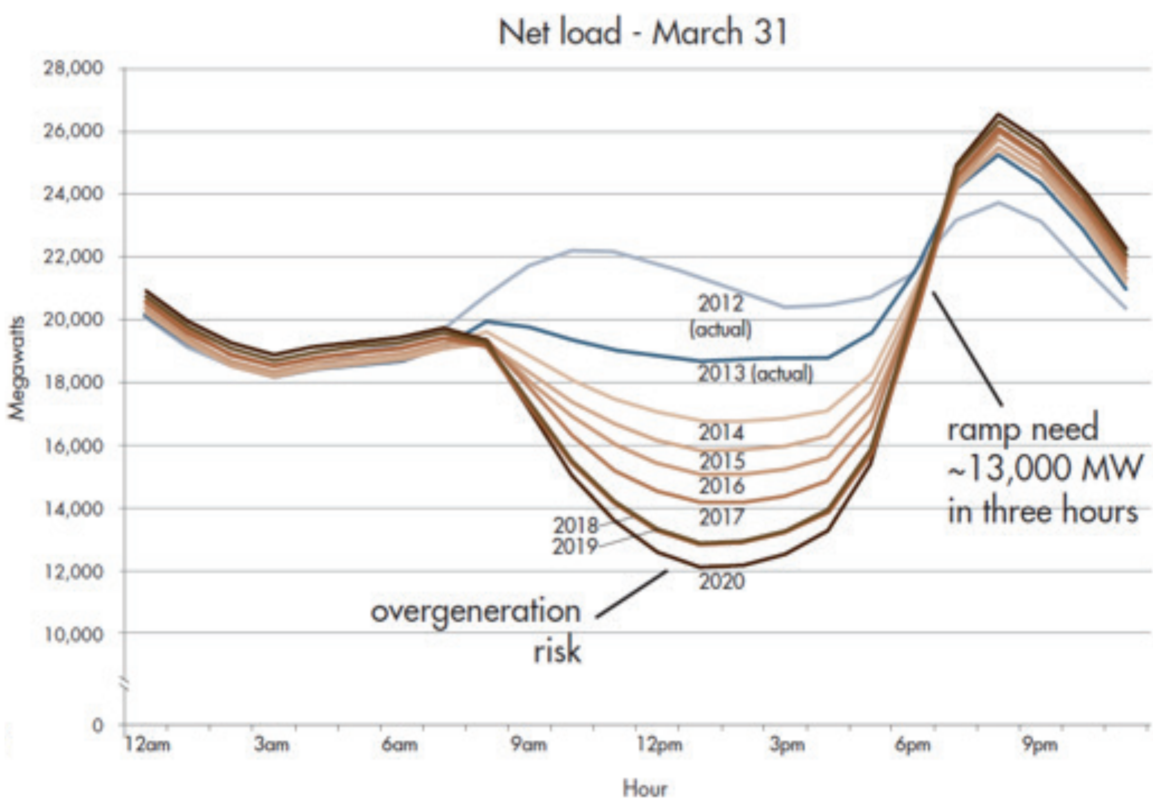


FIGURE 7.5 Projected daily electricity demand, minus wind and solar generation, on a typical spring day in California. There is a risk of overgeneration in the middle of the day and early afternoon. followed by a steep ramp where an additional 13 GWe is needed. Credit: California Energy Commission (2017), Figure ES-4.

grated with the geothermal plants at the south end of the Sea, or possibly using new solar plants. Of course, having the Salton Sea ringed by numerous pumped storage plants would lead to daily fluctuations in lake level that could introduce new environmental issues that would need investigation and mitigation.

Combining Outputs

This concept, shown in Figure 7.6, can be applied to existing or to new wells to be drilled. The SSGF brines would be produced from a reservoir with temperatures of ~300°C, which delivers fluids to the surface at temperatures of about 250°C. Residual brine after use would be re-injected into the geothermal reservoir. The hydrogen produced could be stored on-site, or elsewhere, as a long-term energy storage medium and be used as an energy dense fuel, or used as feedstock for manufacturing salable products such as ammonia fertilizer or hydrochloric acid, to generate additional revenue streams. There are several commercial electrolysis technology providers with most of them being alkaline or polymer electrolyte membrane electrolyzers (Ivy, 2004; Harrison, 2010b). The lack of market penetration for electrolytic hydrogen is primarily due to its higher production cost compared to producing hydrogen from natural gas. The cost of electrolytic hydrogen depends heavily on the cost of electricity. Transportation costs and infrastructure availability/compatibility issues also pose challenges to projects where the hydrogen is not intended for 'captive use'. Although this electrolysis technology was commercialized decades ago, currently it accounts for only ~4% of world hydrogen production (Kelly, 2014). This is primarily due to the higher cost of production by electrolysis and the fact that hydrogen consumption is dominated by large scale industrial processes that require centralized production in high volumes. However, electrolysis using renewable electricity offers an important pathway towards carbon free energy production and usage. Electrolysis also generates very high purity hydrogen and technology options exist for hydrogen production at very high pressures.

High temperature water electrolysis yields higher efficiencies and is a major area of research focus. Detailed reviews of alkaline and solid polymer electrolyte electrolyzers are available in the literature (Kelly, 2014; Millet et al., 2013; Rashid, 2015). Geothermal energy can however be used in a number of hydrogen production configurations using existing commercial technologies. Below are some of the key approaches: (1) utilization of geothermal electricity and heat in alkaline or PEM electrolyzers. (2) utilization of geothermal heat in ther-

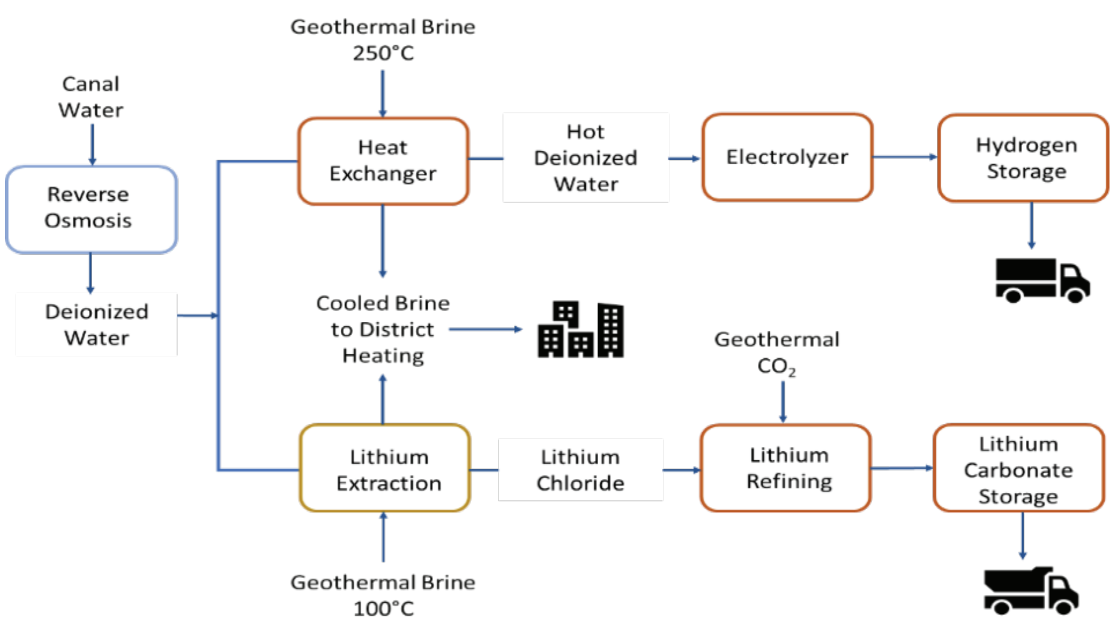


FIGURE 7.6 Conceptual design of lithium and hydrogen extraction from Salton Sea geothermal brines at temperatures of 250°C and 100°C. Direct conversion of lithium chloride to a lithium hydroxide product would be more advantageous for battery manufacture. Credit: Elders et al. (2019).

BOX 7B

RESEARCH HIGHLIGHT: Environmental Analysis

RESEARCHERS WITH THE SUSTAINABLE FUELS INITIATIVE at UC Riverside are working actively to assess the full range of potential environmental impacts of geothermal resource development at the Salton Sea Geothermal Field.

Lithium recovery from geothermal brine involves chemical processing of the spent brine that is produced as part of the geothermal power plant operation. After steam is drawn off to run electrical turbines, the spent brine is clarified and then reinjected deep beneath the ground to replenish the geothermal reservoir and avoid the accumulation of potential contaminants at the surface.

Besides the energy efficiency and recovery cost of lithium, it is important to evaluate the net greenhouse gas (GHG) footprint of the process, the potential air and other emissions, and the net water consumption. Therefore, a Life Cycle Assessment (LCA) of the overall process should be conducted to estimate the fossil and renewable energy consumption, any criteria pollutant and toxic emissions, and GHG emissions. A Techno-Economic Analysis (TEA) is also necessary to calculate the material and energy balances, net water consumption, and anticipated production costs.

Hydrogen production through electrolysis should also be evaluated through LCA and TEA calculations to understand the environmental footprint and commercial viability. A comprehensive analysis that incorporates a multiple product stream may be necessary for facilities that produce power, lithium or other minerals, and hydrogen.

mochemical processes and hybrid cycles, and (3) direct hydrogen production through separation of hydrogen molecules from geothermal gas vents.

Local Economic Benefits

PRODUCTION OF LITHIUM and other metals, electrolytic hydrogen, and pumped energy storage from the SSGF can provide substantial job opportunities and tax revenues in the Imperial Valley. Besseling (2018) recently estimated employment numbers associated with construction and maintenance of lithium extraction facilities, as well as anticipated revenue and county tax receipts (Table 7.4).

Both pumped storage and commercial hydrogen production at the SSGF would help balance the electric grid. If applied in other geothermal fields the global reduction in GHG will depend on the degree of acceptance by the geothermal industry, but could be large and replicable at geothermal plants worldwide (Elders et al., 2018, 2019). We envision ultimately that new fully integrated geothermal plants at the SSGF will become factories producing hydrogen, metals, and water for heating and cooling, while producing electricity, with much of it consumed internally. The reduction in GHG will come from keeping CO_2 out of the atmosphere by: (1) displacing hydrocarbon fuels used for the electricity generated, (2) making hydrogen for energy storage, (3) making hydrogen for transportation and for Syngas, (4) creating a domestic supply of lithium for batteries used in Zero Emission Vehicles, (5) producing metals such as manganese and zinc without smelting, and (6) replacing electricity and natural gas used for air-conditioning and space heating.

Potential Outcomes

GIVEN THAT FURTHER GEOTHERMAL technology infrastructure development at the SSGF will be more feasible if the Sea's level continues to decline and exposes more dry, non-agricultural land on which to build foundations for more power plants and mineral/hydrogen production facilities, it is clear that the most favorable reclamation Scenario for adopting these specific technologies will be Scenario 1 in which the Sea is allowed to shrink. Nonetheless, Scenario 2 (managed wetlands areas in the peripheral portions of the Sea) could also allow for additional geothermal power production with pumped storage and nontraditional metals and hydrogen production if wetland mitigation was designed in a complementary manner to additional geothermal capacity, so as to not preclude further geothermal

TABLE 7.4 Anticipated revenue, county tax receipts, and employment figures associated with construction and maintenance of lithium extraction facilities. Credit: Modified from Besseling (2018).

Construction Employment		**Full Time Employment**	
Construction Period	48 Months	Operations	220
Peak monthly employment	730 workers	Maintenance	130
Average monthly employment	230 workers	Management & Administration	50
			400 Employees
Construction Expenditure		**Contractor Expenditure**	$18M per year
Engineering	$108M		
Procurement	$918M	**Lease Holder Royalties**	$4.5M per year
Construction Management	$72M		
Construction (Disciplines)	$702M	**Imperial County Taxes**	$20M per year
	$1,800M		
Cost of Production		**Annual Revenue**	
Annual Cost of Capital (20%)	$360M		
Annual Operating Expense ($4000/t)	$360M	vs	(90,000t x $10,000/t)
	$720M		$900M

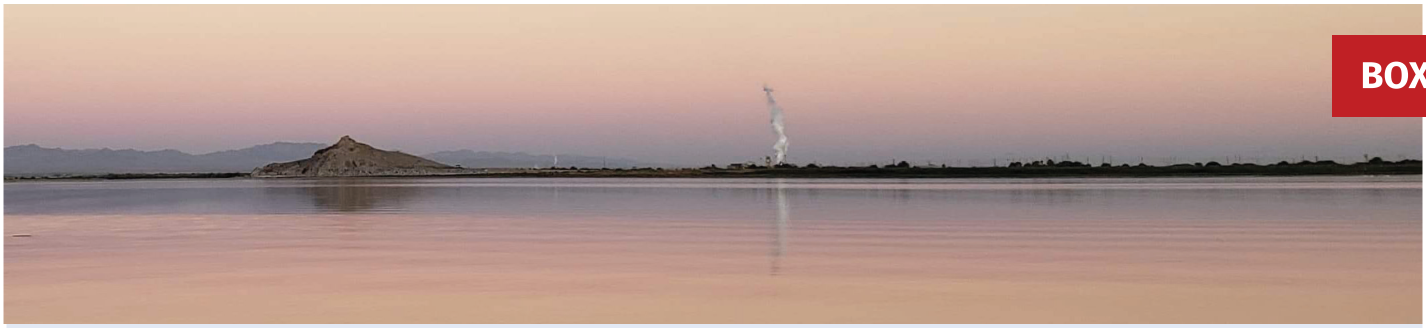
infrastructure development on some of the newly exposed land. Consideration also should be given to the potential impacts of increased traffic and noise, chemical waste disposal, and other environmental factors that are already associated with geothermal development and which would increase if the mineral and energy extraction technologies described above were implemented. All of this will require close cooperation and coordination among the multiple stakeholders involved in reclamation, mitigation, agriculture, and geothermal resource production. Such a "multiple-use optimization" approach to the Salton Sea's final configuration would also maximize local employment opportunities and tax revenues.

Research Needs

TO REMAIN COMPETITIVE with wind and solar energy paired with battery storage, current and expanded geothermal power production from the SSGF should be designed to be integrated with pumped storage to make it more attractive to utility companies facing large fluctuations in daily electrical demand-to-supply ratios. But even more importantly the geothermal plants of the SSGF should generate additional parallel revenue streams from the extraction of critical metals such as lithium, manganese, and zinc as well as the electrolysis of water to produce hydrogen for energy storage and production of salable products. Tremendous research opportunities exist in regard to developing and scaling up these technologies to be commercial. In particular geothermal lithium production could enable the geothermal power companies to become a major net exporter and dominant supplier to the expanding global market.

In the future a factory to construct lithium batteries at the SSGF might also be considered, which would bring more employment to the economically disadvantaged population of the Imperial Valley. Production of such nontraditional mineral and energy coproducts will help California meet legislated mandates on renewable energy targets by 2045, provide local jobs and tax revenues, enhance the ability of the United States to produce electrical storage batteries and electrical vehicles domestically, and reduce reliance on environmentally damaging hard rock metal mining techniques and the manufacture of hydrogen from natural gas. The tax revenues could help facilitate funding of reclamation and mitigation efforts at the Salton Sea

Reclamation and mitigation plans should therefore be developed in coordination with the expansion of geothermal power and nontraditional mineral and energy production. Lack of such coordination could result in lost opportunities for the long-term economic benefit of the local region.



BOX 7C

OBSIDIAN BUTTE (left) and a geothermal plant at sunset. Caroline Hung

Global Environmental Advantages

ANY INDUSTRIAL DEVELOPMENT has an environmental impact that should be considered at local, state, national and global scales. Further industrial development at the Salton Sea is currently underway because the subsurface hot saline brines of the Salton Sea Geothermal Field (SSGF) are unique in the world in having the largest known undeveloped potential for both electricity production and for extraction of lithium and other strategic minerals.

ELECTRICITY GENERATED USING GEOTHERMAL STEAM has an extremely low, or zero, carbon footprint relative to using steam produced by burning hydrocarbon fuels. Electrical generation using steam extracted from SSFG brines to drive turbines has been going on for almost 40 years, with all applicable regulatory environmental requirements being met along the way. From the outset, after steam separation, the spent brine is treated to remove precipitated silica and then injected in deep disposal wells. This silica is a minor component of the brine, but because its precipitate carries traces of heavy metals, it is disposed of in certified toxic waste dumps. At the SSGF there is also a minor component of CO_2 that is extracted from the steam and vented to the atmosphere. If future regulations prevent venting the CO_2, the technology exists to sequester this CO_2 by injecting it in disposal wells where it reacts to form carbonate minerals.

PRODUCING LITHIUM as part of the existing process of electricity generation, rather than importing it, is environmentally beneficial from a global perspective. With burgeoning worldwide demand for lithium batteries for electric cars and other applications, a new industry is developing at the SSGF power plants to extract lithium from the brines. Lithium is present at commercial concentrations accessible with addition of a lithium extraction loop to the existing process of brine production and injection. Lithium extraction from SSGF brines will require a local supply of clean water, which could be generated from steam condensate or from processed saline water that is pumped from shallow wells but is unsuitable for irrigation.

THE MINOR, LOCAL ENVIRONMENTAL IMPACTS of lithium extraction from geothermal brines pale in comparison to the negative consequences of mining, producing, and transporting lithium and lithium battery products from overseas. Currently more than 90% of the lithium used in the United States is imported, with Chile, Australia, and China as the primary producers. In Chile extracting lithium from saline lakes sullies large areas of ecologically sensitive land and consumes fresh water from shallow wells that otherwise could be used for agricultural irrigation. In Australia and China lithium-bearing minerals are produced by hard rock-mining techniques that require blasting and sulfuric acid digestion to make usable lithium products. In addition to the environmental consequences, the considerable carbon footprint to import these products to the United States should not be overlooked.

DEVELOPMENT OF A LITHIUM EXTRACTION INDUSTRY, along with future lithium battery manufacturing, will bring employment to the economically disadvantaged population of the Imperial Valley.

CHAPTER SEVEN - REFERENCES

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