Estrazione di Minerali da Brine Geotermica: Come Condurre uno Studio di Fattibilità

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Innovazione e Sostenibilità per la Geotermia del Futuro

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WHO'S STEAM?

- We are an **Italian consultancy company** with a 35-year history in geothermal
- Our experts will become your team for **geology, geochemistry, geophysics and engineering**
- We support our customers with end-to-end services:
  - Resource assessment and management
  - Drilling engineering and supervision
  - Feasibility studies and environment assessments
  - Engineering and construction management
  - O&M support and capacity building

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STEAM's presence in international geothermal markets is increasingly that of a global player.

IN THE LAST 8 YEARS

25+ NATIONS

20+ FEASIBILITY STUDIES

30+ RESOURCE ASSESSMENTS

40+ WELLS COMMISSIONED

10+ DRILLING SUPERVISIONS

80+ KMs OF GATHERING SYSTEMS ENGINEERED

220+ PLANT MWs SUPERVISED

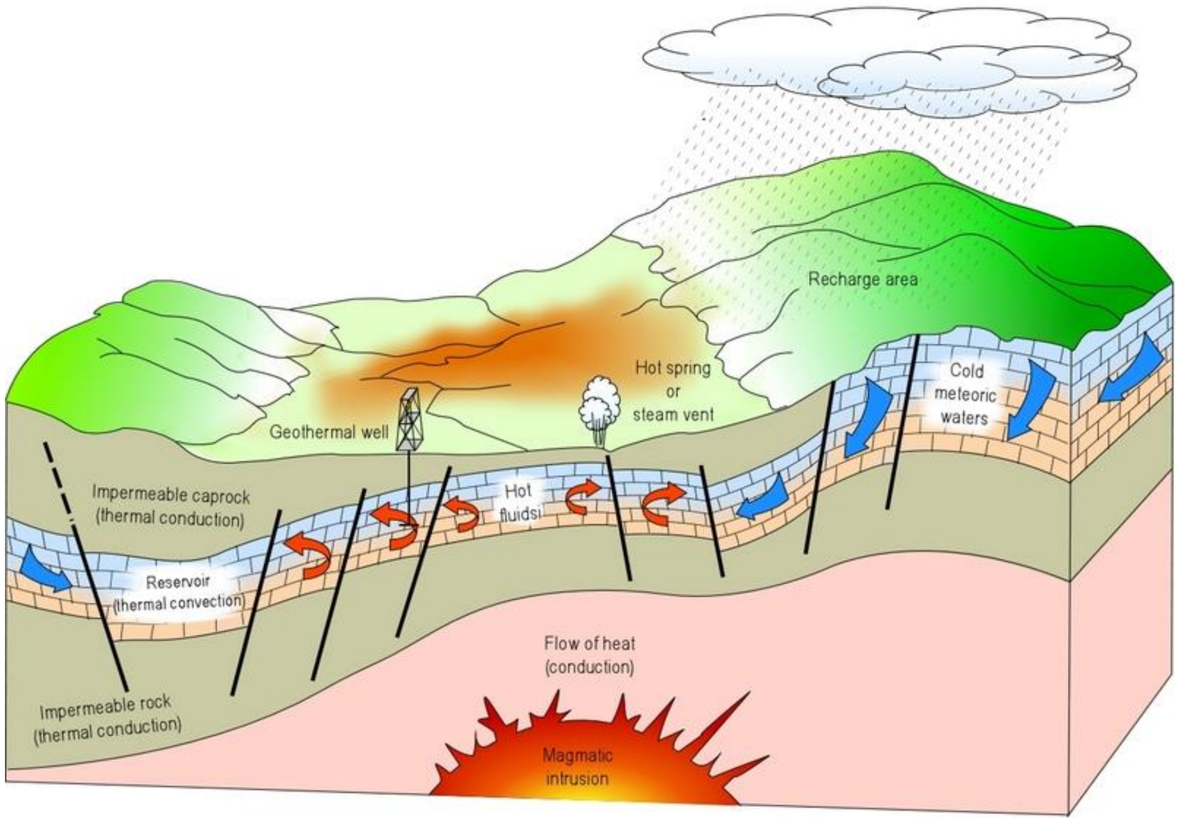
375+ PLANT MWs ENGINEERED

GENERAL DESCRIPTION OF THE GEOTHERMAL ENERGY AND SYSTEM

A common geothermal field consist of three parts:

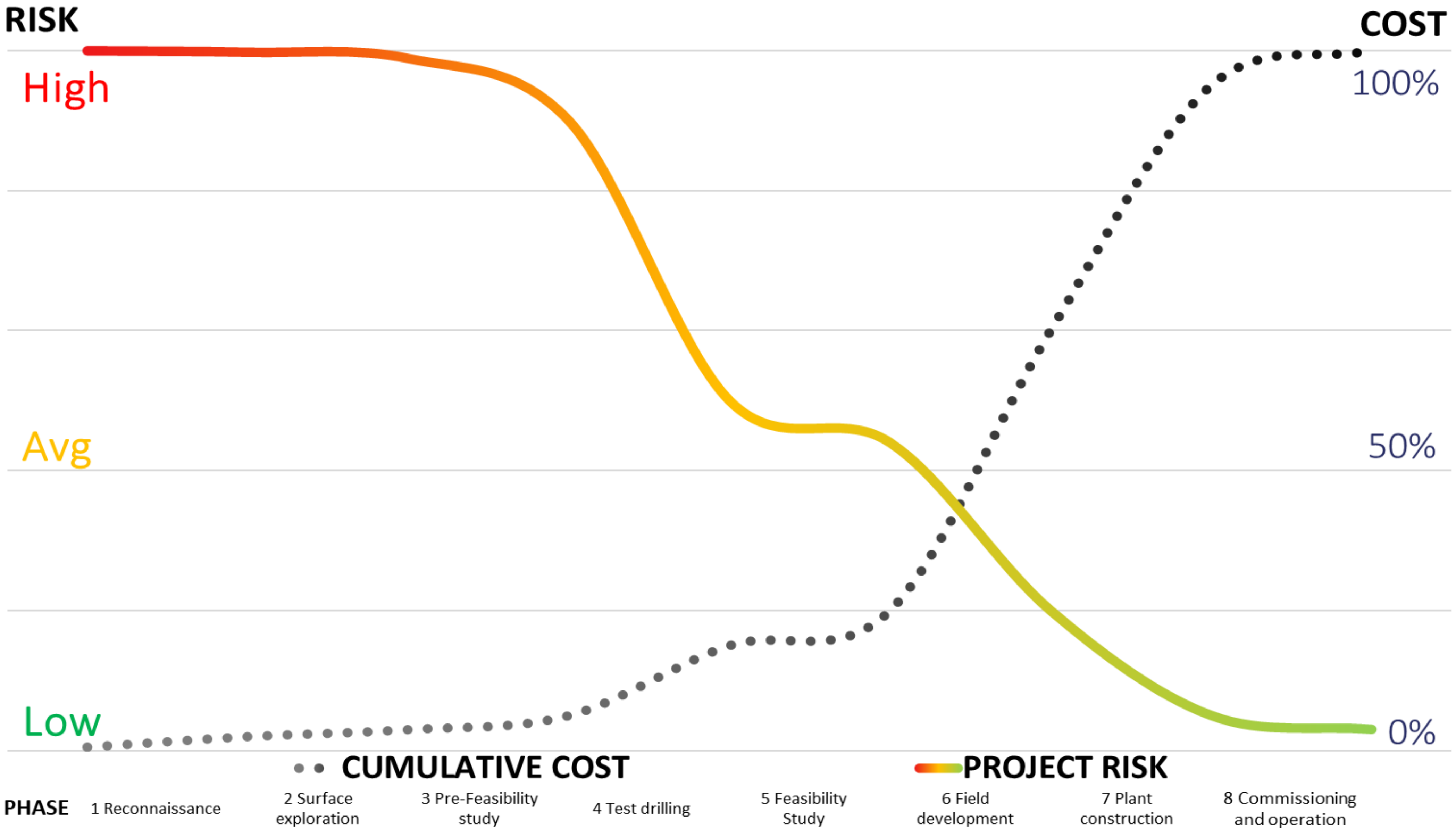
- Thermal source
- Reservoir
- Fluid

Do we need all of them for a project of mineral extraction from geothermal brine?



ROADMAP OF A GEOTHERMAL PROJECT DEVELOPMENT

GEOTHERMAL PROJECT DEVELOPMENT – RISK vs COST CURVE



FEASIBILITY OF MINERAL EXTRACTION

Mineral extraction is an **opportunity** for:

- **Additional revenues** in a power generation project
- **Harvesting existing resources** which are not suitable/feasible for power generation only
- **Developing new geothermal fields** which are not sustainable for power generation only

Today we talk about **Feasibility**: the evaluated field must have **existing wells and/or available literature data**

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FEASIBILITY OF MINERAL EXTRACTION

A **Feasibility study** is composed of:

1. **Evaluation** of the **resource**
2. **Assessment** of the **demand**
   i. Supply chain identification
   ii. Market evaluation
3. **Technical feasibility**
   i. Selection of the extraction process
   ii. Environmental impact assessment
   iii. Cost estimation
4. **Economic and Financial** analysis
5. **Environmental and social** evaluation
6. **Regulatory Framework** assessment

1. EVALUATION OF THE RESOURCE

The **resource** will be **assessed** as follows:

- Identification of the **required data**
  - Concentration of minerals (quality)
  - Available brine flow (quantity)
  - Reserve (sustainability in time)
- **Literature review**
- **Data collection** and **analysis**
  - List of available data
  - Identification of the sources of potential additional data
  - Gap analysis
- **Identification** of the **most promising resources** in terms of mineral content
- **Detailed chemical analysis** to fill the gaps

Examples of mineral composition

Item	Salton Sea	Coso	Dixie Valley	Cerro Prieto
Temp., °C	296	274	246	340
Silica, mg/kg	>461	>711	>599	>864
Boron, mg/kg	257	119	9.9	9.4
Lithium, mg/kg	194-230	45	2-4	27
Zinc, mg/kg	438	0.03	NA	NA

Bourcier et al, 2003 and Gallup, 1998

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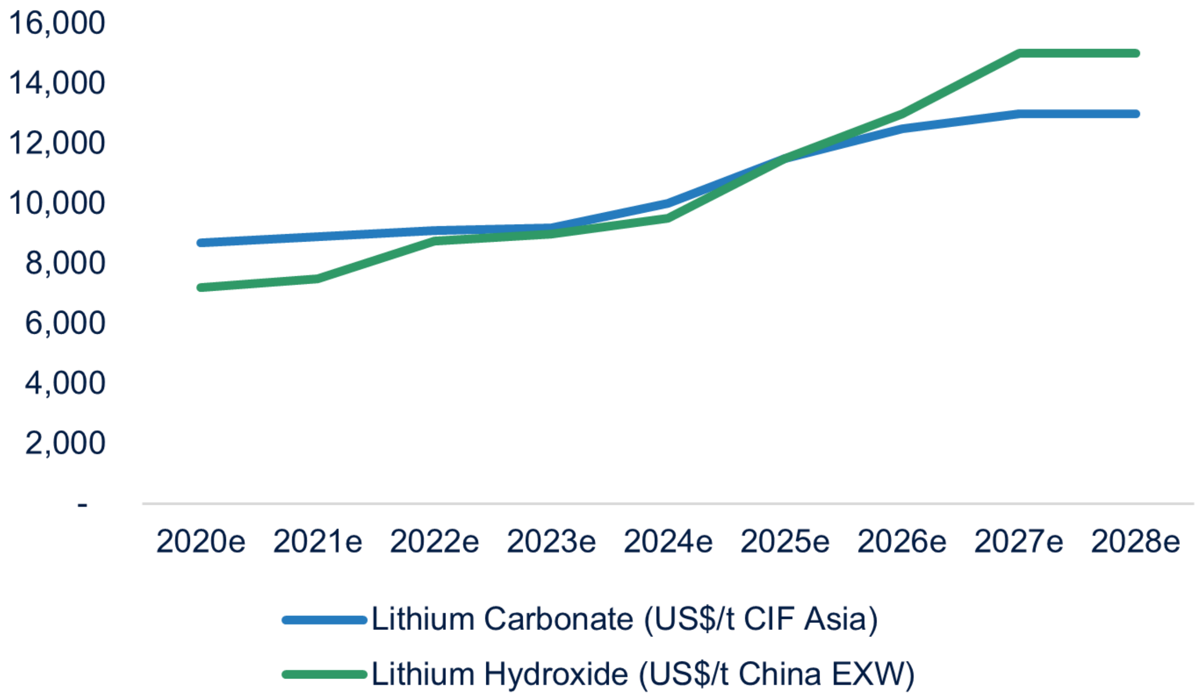
2. ASSESSMENT OF THE DEMAND

For each **potentially interesting mineral,** the market appetite will be assessed:

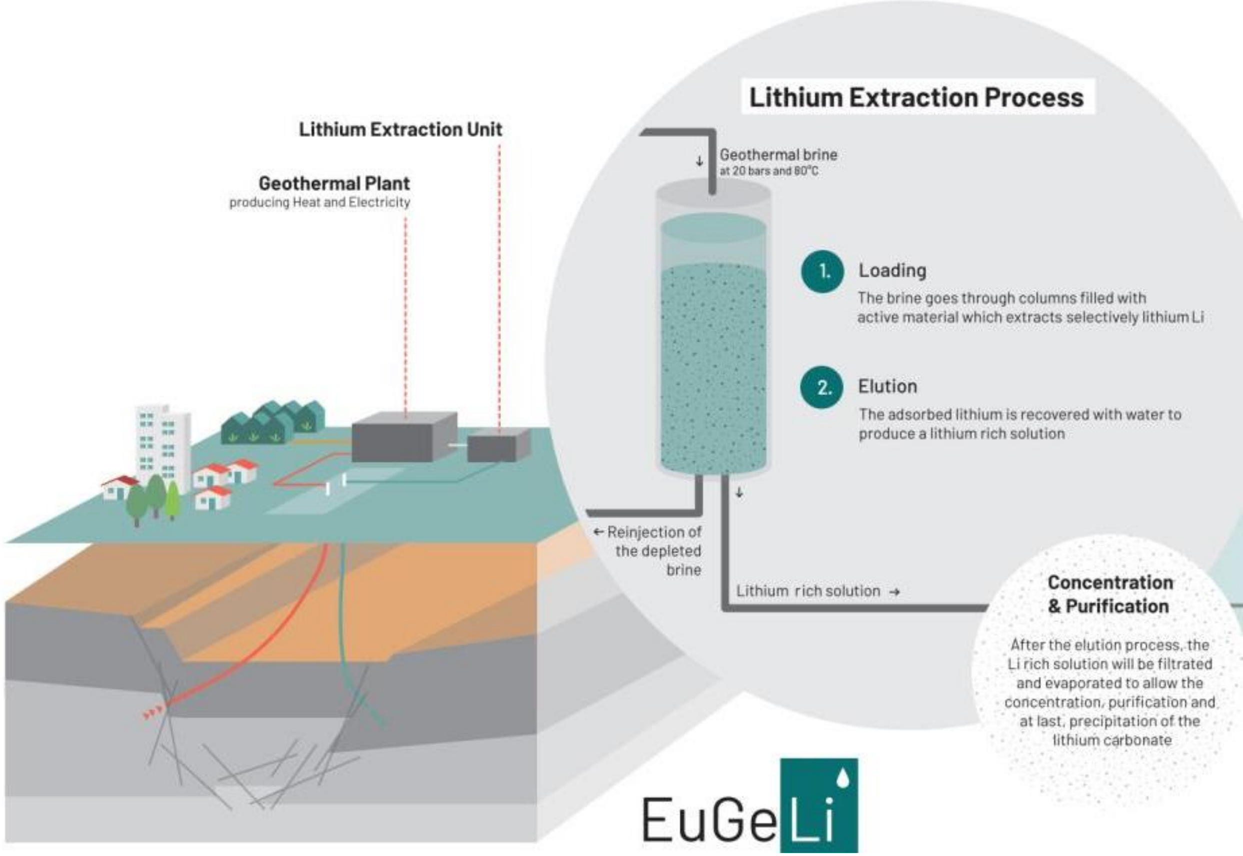
- The mineral **may not be a commodity**
    - Identify the **final uses**
    - Detect the **supply chain**
    - Assess the **requested quality** (purity, compounds, …)
    - Understand the **logistics**
- **Calculate the value** of the mineral or its compound
- Evaluate the **historical trends** in its value
- Assess the **effective local demand** in terms of quality, quantity, price and risk



3. TECHNICAL FEASIBILITY

For each **selected mineral,** the following technical features are assessed:

- **Availability** of one or more commercial or experimental **extraction technologies**
- **Limiting factors** of the identified technologies (e.g. minimum capacity)
- **Quality** of the product of such technology
- **Technical needs** of the technologies (e.g. fresh water, solvents, special membranes,…)
- **Environmental impact** of the technologies (e.g. byproducts, pollution,…)
- **Matching** of **resource** and **technology**
- **CAPEX, OPEX** and **schedule** estimate



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4. ECONOMIC AND FINANCIAL ANALYSIS

Starting from the results of the previous activities, it is possible to:

- **Collect detailed information** on the project as applied in its location, for example
  - Cost of labor
  - Price of commodities
  - Availability of specialized personnel
- Construct a **business plan**
- Conduct a **sensitivity analysis** on the revenues, CAPEX and OPEX
- Evaluate the **main risks and opportunities**
- Identify **financing schemes**

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5. ENVIRONMENTAL AND SOCIAL IMPACT ASSESSMENT

The environmental and social assessment builds up on the results of the technical feasibility, by investigating:

- A matrix of potential **environmental** impacts of the selected technology, e.g. on
  - Air quality
  - Water quality
  - Soil occupation
- A matrix of potential **social** impacts of the selected technology, e.g. on
  - Workforce (capacity building, occupation)
  - Health
- Identify **risks, mitigation measures** and **opportunities**

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6. REGULATORY FRAMEWORK ASSESSMENT

In parallel to the technical and environmental analyses, the **regulatory framework** shall be assessed:

- Assess the **legislative framework** in which the project develops (Geothermal? Mining? How to combine them?)
- Identify the **regulatory barriers**
- Refer to **international best practices**
- Make a plan to **resolve or mitigate the barriers** in cooperation with the institutions

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CONCLUSION

As presented, the **feasibility study** of **mineral extraction** from a **geothermal** resource is based on a number of activities:

1. **Assessment** of the **resource**
2. **Technical feasibility**
3. **Assessment** of the **demand**
4. **Economic and Financial** analysis
5. **Environmental and social** evaluation
6. **Regulatory Framework** assessment

The feasibility study will be summarized a report stating the **technical-economic feasibility**, the **risks** and the **opportunities**, including a **SWOT** analysis.

EXAMPLE (1/4)

National Renewable Energy Laboratory (NREL)

Techno-Economic Analysis of Lithium Extraction from Geothermal Brines, Ian Warren

Resource evaluation

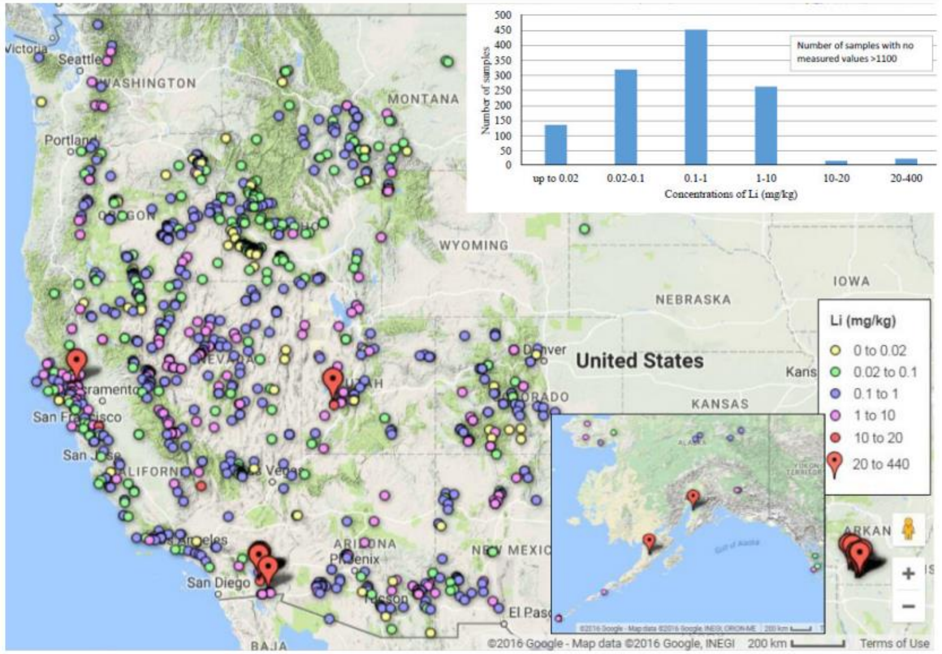


Figure 2. Lithium concentrations in geothermal fluids of the western United States

Table 1. Composition of Select Production Fluids from the Salton Sea KGRA

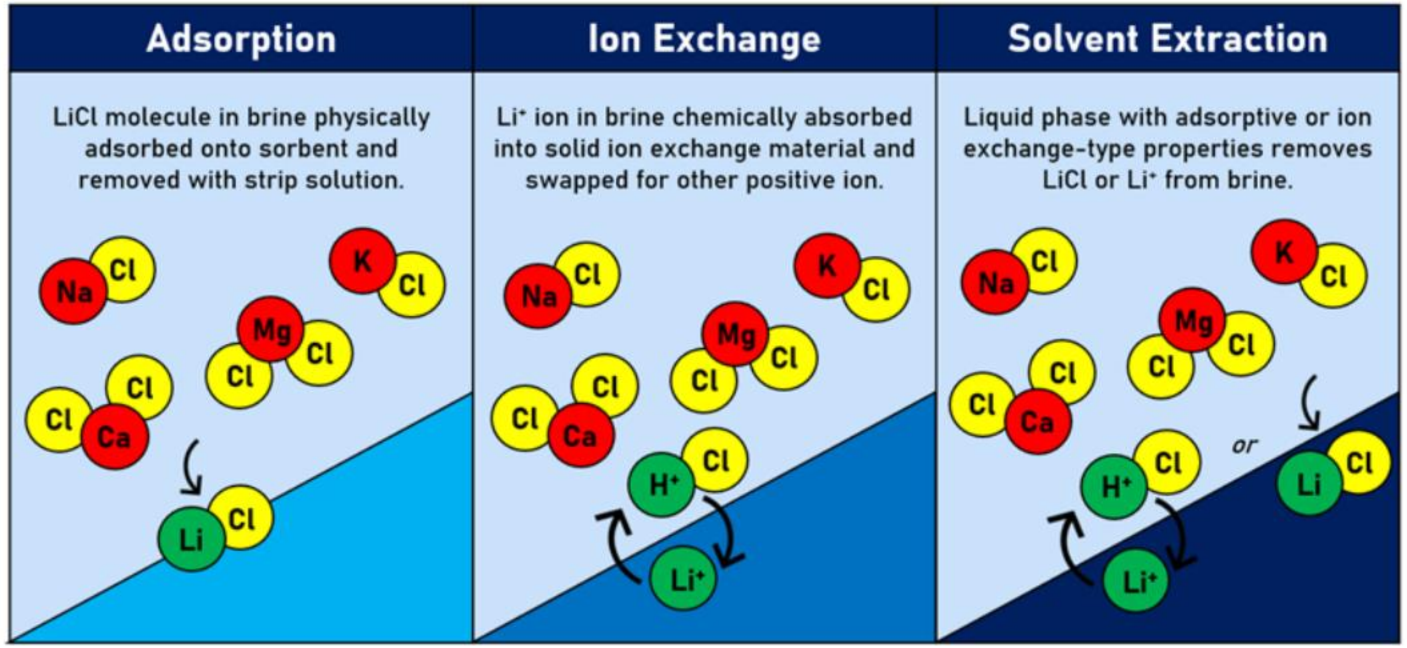
Well Name	SSSDP State 2-14	SSSDP State 2-142	SSSDP State 2-143	Well 11b	Well 10	Unnamed Well	Magmamax 1	Magmamax 14	Hudson Ranch Well	IID-1	IID-2	Sinclair #4	Fee 5	Fee 6
Date sampled	12/1/1985	3/1/1986	6/1/1988				7/1/1979	8/1/1976		4/21/1966			8/15/1984	3/1/1985
Depth (m)	1,850-1,890	2,500-3,220	1,830-2,200	660-1,070	700-1,070		855	855		1,595	1,776	1,615	~3,500	~3,500
T°C	305	330	320	300	295			215		340	332	260	~300	~300
pH	5.4	5.1	5.3	5.2	5.3	5.3		5.2		5.2		5.3		
Units	ppm	ppm	ppm	ppm	ppm	ppm	mg/L	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Na	53,000	54,800	53,700	46,200	41,400	52,700	43,000	42,000	56,275	50,400	53,000	58,443	43,500	48,100
Ca	27,400	28,500	26,300	22,800	20,900	26,500	22,300	20,000	29,778	28,000	27,800	26,992	27,700	28,700
K	16,700	17,700	17,100	12,500	11,800	16,500	7,550	8,600	18,006	17,500	16,500	14,918	16,200	14,500
Fe	1,560	1,710	1,620	582	969	1,550	220	256	1,411	2,090	2,000	1,148	1,890	1,920
Mn	1,450	1,500	1,470	801	855	1,390	420	690	1,700	1,560	1,370	1,025	1,430	1,650
SiO2	>461	>588	>840	>336	>404	475		432	437	400	400	90	354	243
Al	2					3		1		4.2				1.8
Rb	170							64		137	70			
Zn	518	507	510	321	323	506	105	361	487	790	500		551	558
Ag						2				0.8	2			
As						5			12	12		10		
Sr	411	421	410	376	345		460	388	316	609	440	434	426	489
B	257	271	380	204	197	268			563	390	390	332	319	274
Ba	203	<353	218	183	156	194	130	118	167	235	250		270	300
Li	194	209	215	157	152	230	170	141	228	215	210	287	228	216
Mg	33	49	43	19	33	36	150	80	43	54	10	736	96	81
Pb	100	102	107	69	67	91	50	78	108	84	80		63	111
Cu	5.9	6.8	5.8	NA	2		2.5	1	0.9	8	3		3.9	2.3
Cd	2.2	2.3	2.2	1	1.4								2.2	2.2
Cs	20	NA	23	NA	NA					16	20			
NH4	333	330	356	339	341		335	45		409				
Cl	151,000	157,500	152,000	128,000	116,000	174,900	115,200	121,000	165,442	155,000	155,000	154,590	139,000	127,000
F	15								7.2	15		14		
Br	99	111	111	95	78					120		25	94	90
I	20									18		13		
SO4	65	53	123	100	53					5.4		19	35	74
TDS (%)	25.6	26.5	25.6	21.4	20	29.5	21.5	20.8	27.9	25.8	25.9	26.7	23.8	23
References	Williams and McKibben 1989; McKibben and Hardie 1997	Williams and McKibben 1989; McKibben and Hardie 1997	Williams and McKibben 1989; McKibben and Hardie 1997	Williams and McKibben 1989; McKibben and Hardie 1997	Williams and McKibben 1989; McKibben and Hardie 1997	Duyvesteyn 1992	Featherstone and Powell 1981	Maimoni 1982	CA regional water quality control board Order R7-2013-0059	Skinner et al. 1967; Blake 1974; Palmer 1975	Skinner et al. 1967; Palmer 1975	Palmer 1975	Zukin et al. 1987	Zukin et al. 1987
Comments	Flash corrected brine analyses	Flash corrected brine analyses; may be contaminated by drilling fluids	Flash corrected brine analyses; may be contaminated by drilling fluids	Flash corrected brine analyses	Flash corrected brine analyses				Average produced brine composition (production wells 13-1, 13-2, & 13-3)	Corrected for steam loss	Average analysis, corrected for steam loss	Average analysis, corrected for steam loss	Flash corrected brine analyses	Flash corrected brine analyses

EXAMPLE (2/4)

National Renewable Energy Laboratory (NREL)

Techno-Economic Analysis of Lithium Extraction from Geothermal Brines, Ian Warren

Technology selection



Direct Lithium Extraction Techniques
Precipitation
Organic sorbents
Organic ion-exchange resins
Ion-imprinted polymers and other organic sorbents
Inorganic sorbents
Aluminum hydroxides
Manganese oxides
Titanium oxides
Other inorganic sorbents (various metal oxides)
Organic solvents
Crown ethers
Multicomponent
Extractant, co-extractant, diluent
Alternative diluents —ionic liquids, supercritical CO_2
Supported liquid membranes
Membranes
Reverse osmosis
Nanofiltration
Electrochemical separation
Electrodialysis
Combination with membrane and ion-exchange processes

EXAMPLE (3/4)

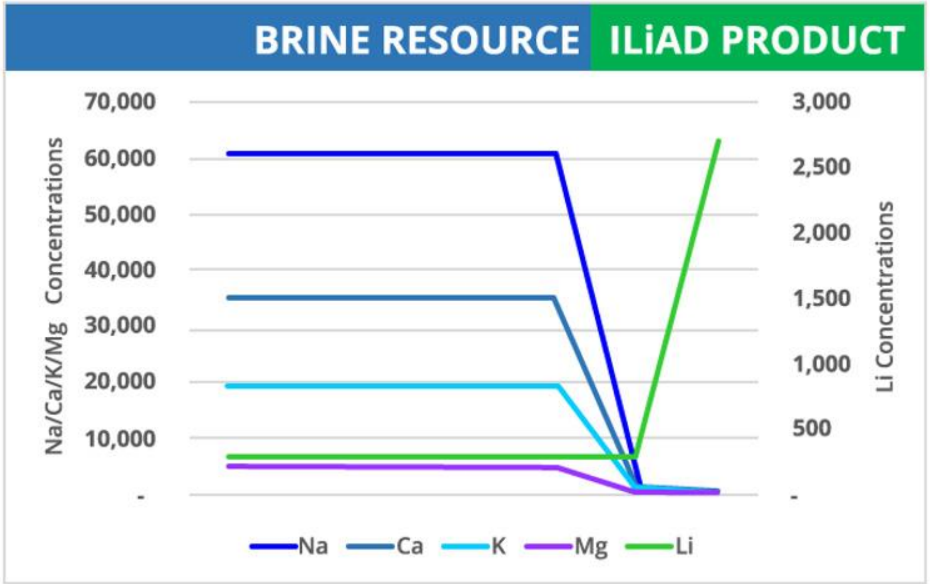
National Renewable Energy Laboratory (NREL)

Techno-Economic Analysis of Lithium Extraction from Geothermal Brines, Ian Warren

Market and product assessment for certain technologies

Table 2. Lithium Species Conversion Factors

		Conversion Factors		
Species	Molecular Weight (g/mol)	Li_2CO_3	LiCl	$LiOH$-H_2O
Lithium Carbonate (Li_2CO_3)	73.882	1.000	1.147	1.136
Lithium Chloride (LiCl)	42.384	0.872	1.000	0.990
Lithium Hydroxide Monohydrate ($LiOH$-H_2O)	41.960	0.880	1.010	1.000
Lithium	6.938	5.324	6.109	6.048



EXAMPLE (4/4)

National Renewable Energy Laboratory (NREL)

Techno-Economic Analysis of Lithium Extraction from Geothermal Brines, Ian Warren

Economic analysis

Table 3. Summary of DLE Project Economics

Company	SRI International	Vulcan Energy Resources	Standard Lithium	E3 Metals Corp	Anson Resources	Pure Energy Minerals	Lake Resources
Project	Salton Sea	Upper Rhine Valley	Lanxess Smackover	Clearwater	Paradox Stage 3 (Li)*	Clayton Valley	Kachi
Location	California, USA	SW Germany	Arkansas, USA	Alberta, Canada	Utah, USA	Nevada, USA	Argentina
Document	DOE, CEC reports	PFS	PEA	PEA	PEA	PEA	PFS
Brine type	Geothermal	Geothermal	Evaporite (Br tail brine)	Oilfield	Evaporite	Evaporite	Salar
Resource (1,000 kg LCE)	NA	15,850,000	3,140,000	2,200,000	192,000	217,700	1,010,000
Lithium concentration (mg/L)	400	181	168	74.6	100–500	65–221	289
Production (mt/yr)	20,000**	40,000	20,900	20,000	15,000	11,500	25,500
Production cost ($/mt)	3,845	3,217***	4,319	3,656****	4,545	3,217*****	4,178
CAPEX ($1,000)	52,300	1,287,600	437,162	602,000	120,000	358,601	544,000
OPEX ($1,000/yr)	76,900	128,688	90,259	73,200	68,180	36,516	106,539
Modeled product price ($/mt)	12,000	14,925	13,550	15,160	13,000	12,267	11,000
Pre-tax IRR (%)	268	31	41.8	32	106	24	25
Technology	Ion exchange	Adsorption	Ion exchange	Ion exchange	Ion exchange	Solvent extraction******	Ion exchange
Lithium recovery	90%	90%	90%	>90%	75%	90%	83.20%
Product	Li2CO3	LiOH·H2O	Li2CO3	LiOH·H2O	Li2CO3	LiOH·H2O	Li2CO3
Comments	Bench-scale testing and ASPEN modeling of hybrid sorbent with nanostructured manganese oxide embedded within Li-imprinted polymer beads using synthetic brine.	Known geothermal resource with measured chemistry and temperature. Bench-scale testing of two commercially available adsorbents using Upper Rhine Valley brine.	Bench- and mini-pilot-scale confirmation of process using ceramic adsorbent and crystallization process to convert concentrated LiCl into high-purity Li2CO3.	Bench-scale testing demonstrated high Li selectivity and recovery. Full process yet to be tested.	Multi-stage development with stage 3 producing 60,000 mt/yr NaBr and 15,000 mt/yr Li2CO3. Production cost reported as All-in Sustaining Cost.	Bench-scale testing of brine and synthetic equivalents informed the solvent extraction process developed by Tenova.	Nano-coated, porous ion exchange beads, tailored composition, and continuous column process.

*Estimated based on lithium component of operations; Phase 3 PEA retracted in June 2020 due to amounts of inferred resources. This does not affect estimates of CAPEX and OPEX.

**Estimated commercial production with costs and performance informed by bench-scale experiments and ASPEN modeling (Ventura et al. 2020).

***Euro to USD exchange rate 1.2; $3,656/mt Li2CO3.

****$4,155/mt Li2CO3

****$3,656/mt Li2CO3

*****An ion exchange polishing step might be required prior to electrolysis to convert Li2SO4 to LiOH.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