Lithium Extraction from Oil Field Brines: Outlook, Opportunities, and Challenges

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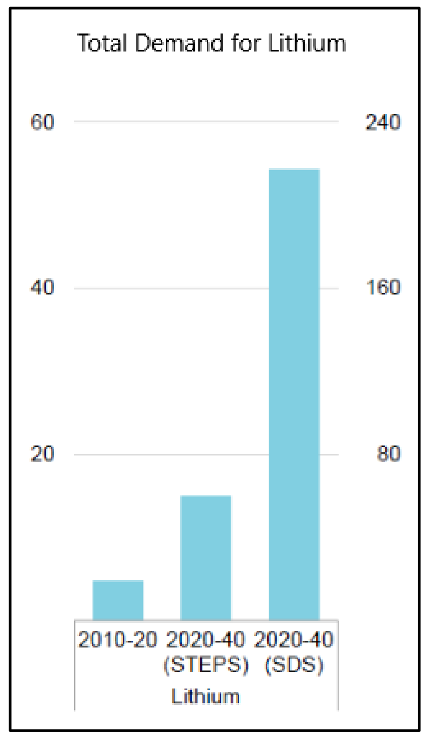
Lithium extraction from oil field brines, known as lithium brine extraction, has garnered significant attention in recent years. The number of scientific publications on lithium extraction from various sources is steadily increasing, but data on specific processes or technologies for recovering lithium from oil-field brines are scarce.[1] The lithium extraction process provides a potential source of lithium to meet the rising demand for lithium-ion batteries, commonly utilized in electric vehicles and renewable energy storage systems.

The most significant and widely known use of lithium is in rechargeable batteries. Lithium-ion batteries power various devices, from smartphones and laptops to electric vehicles (EVs) and energy storage systems. Lithium's high energy density and lightweight properties make it ideal for these applications.

Lithium-ion batteries are also used in grid-scale energy storage systems, allowing excess energy generated from renewable sources like solar and wind to be stored and used during periods of high demand or when renewable sources are not producing electricity.

An average EV battery typically contains approximately 8 kilograms of lithium, 14 kilograms of cobalt, and 20 kilograms of manganese. However, the specific composition may vary based on the battery size. For instance, a Tesla Model S battery incorporates approximately 138 pounds of lithium.

As the pace of energy transitions accelerates, the energy sector is becoming a major player in mineral consumption. Forecasts suggest that lithium demand will undergo significant changes, with a threefold increase expected in a Sustainable Development Scenario in line with the Paris Agreement and a doubling anticipated under a Stated Policies Scenario. The latter scenario provides insight into the potential trajectory of the energy sector based on existing policy measures and plans. Emerging technologies, like the direct extraction of lithium from oil field rines, have the potential to increase future supply volumes significantly.[2] Current lithium demand is approximately 2,000 metric tonnes/yr.[3]



IEA, Total demand for lithium by end use in the Net Zero Scenario, 2021-2050, IEA, Paris

While oil field brines are primarily recognized for their lithium potential, they can also contain trace amounts of other elements, including some rare earth elements (REEs). However, the

[1] Knapik, E.; Rotko, G.; Marszałek, M. Recovery of Lithium from Oilfield Brines—Current Achievements and Future Perspectives: A Mini Review. Energies 2023, 16, 6628. https://doi.org/10.3390/en16186628

[2] IEA (2021), The Role of Critical Minerals in Clean Energy Transitions, IEA, Paris https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions, License: CC BY 4.0

[3] Mackey, J., Kutchko, B., & Stuckman, M. (2023). Lithium Resources from Oilfield Produced Water. National Energy Technology Laboratory (NETL), Pittsburgh, PA, Morgantown, WV, and Albany, OR (United States).

concentration of these REEs in brines typically remains quite low compared to lithium and other sources, such as geothermal, mining operations and ore deposits.

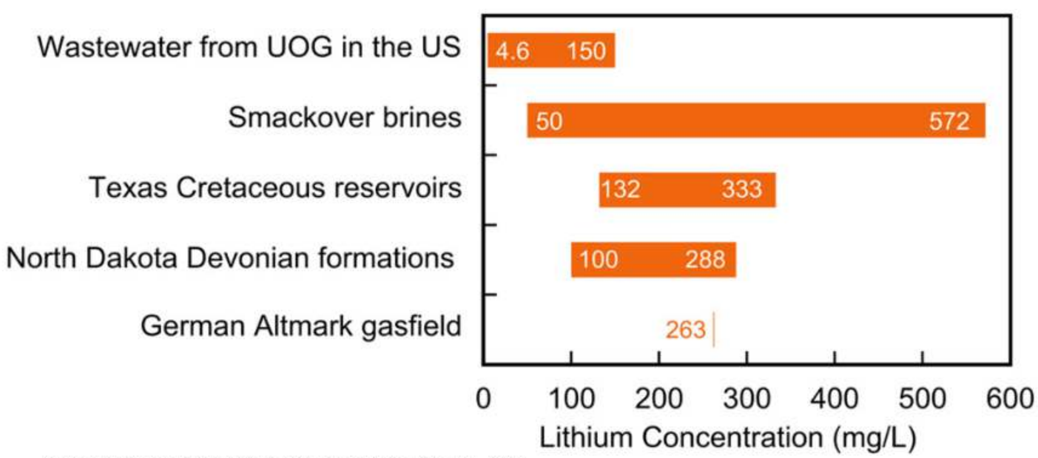
Lithium Content in Oil Field Brines

Oil field brine extraction is a naturally occurring aspect of oil and gas production. In some cases, underground reservoirs of saline water can hold substantial concentrations of dissolved lithium. Conducting a thorough geological and geochemical assessment of oil and gas basins is essential to determine lithium extraction's feasibility and economic viability.

Oil field brine compositions can vary, but those with high lithium concentrations are of value. The lithium content in oil field brines can significantly differ from one location to another, with some brines being more lithium-rich, making them economically more feasible for extraction.

The figure below shows that certain oil field brines around the world contain high lithium concentrations. The United States boasts some of the most notable oil-field brines known for their lithium content. Within the Williston Basin of North Dakota, waters from Devonian formations contain lithium levels ranging from 100 to 288 mg of Li+ per liter.[4] Marcellus Shale wells in Appalachia have lithium content ranging from 30 to 185 mg/L.[5]

Meanwhile, in the Gulf of Mexico's Jurassic Smackover Formation (found in Texas and Arkansas), lithium concentrations vary from 50 to 572 mg/L.[6] Yu et al.'s[7] latest research validates the presence of fluctuating Li+ concentrations, ranging between 7.5 and 150 mg/L, within the Qianjiang Formation located in central China.



Source: Amit Kumar et al, ACS Energy Letters 2019 4 (6), 1471-1474

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[4] IBID

[5] Personal analytical data from two Marcellus Shale wells in Appalachia with lithium content ranging 30 to 185 mg/L.

[6] IBID

[7] Yu, X., Wang, C., Huang, H. et al. Lithium and brine geochemistry in the Qianjiang Formation of the Jianghan Basin, central China. Sci Rep 13, 4445 (2023). https://doi.org/10.1038/s41598-023-31421-1

Lithium Extraction

Lithium extraction from brines presents both positive and negative environmental implications:

Positive Environmental Considerations:

- The brine extraction process often leverages existing oil and gas infrastructure, such as wells and pipelines, reducing the need for new infrastructure development and related environmental impacts.
- The utilization of renewable energy sources, such as solar or wind power, can mitigate carbon emissions tied to lithium extraction operations.
- Lithium brine extraction is generally recognized as more resource-efficient than traditional hard rock mining for lithium, as it typically requires less energy and water, thus reducing its environmental footprint.
- Employing existing infrastructure and avoiding energy-intensive processes related to hard rock mining can lower greenhouse gas emissions per unit of lithium produced.

Negative Environmental Considerations:

- The environmental impacts of lithium extraction from brines hinge on the specific extraction process employed.
- Brine extraction often necessitates substantial water usage, potentially depleting local water sources and adversely affecting aquatic ecosystems if not managed properly.
- Using chemicals such as acids and solvents in lithium extraction from brines can lead to groundwater and surface water contamination if not handled or disposed of correctly.
- After lithium extraction, the remaining brine may contain concentrated salts and other impurities, posing challenges for proper disposal that must adhere to environmental regulations.
- Although brine extraction is generally less energy-intensive than hard rock mining, it still requires pumping, processing, and transportation energy. The source of this energy can influence the environmental impact, with fossil fuel-based sources contributing to carbon emissions.

Brines from naturally occurring saline water reservoirs alongside oil and gas deposits often flow to the surface as drilling activities progress. The volume of brine produced during oil and gas drilling can be substantial, often exceeding the volume of oil and gas extracted.

Traditionally, brine has been regarded as a waste product, incurring disposal costs for the oil and gas industry. Common disposal methods encompass reinjection into deep wells, discharge into surface waters following treatment, or storage in evaporation ponds, each associated with costs and environmental considerations.

The emergence of lithium extraction from oil field brines transformed the perspective on the value of these brines within the oil and gas industry. Instead of regarding brine as a waste product, the industry can extract valuable lithium, creating additional revenue streams and diversifying income sources.

This approach is appealing from an environmental standpoint as it offers a more sustainable and environmentally friendly alternative to simply disposing of the brine, repurposing a waste product into a valuable resource, and potentially reducing the environmental footprint associated with brine disposal.

Lithium extraction from brines can occur at various stages in the production process, and the extraction location can vary based on project-specific and logistical considerations.

The decision regarding lithium extraction from oil field brine, whether it occurs at individual wells, well pads, or a centralized collection and disposal site, depends on several factors. These factors encompass the brine's characteristics, economic aspects, environmental implications, and regulatory requirements. In some states, obtaining a special waste treatment permit is necessary for treating and extracting lithium from oil field brines due to their classification as waste materials.

Opting for extraction operations at a centralized collection and disposal site offers the advantage of capitalizing on economies of scale, potentially lowering the per-unit operating costs for lithium production. Conversely, smaller-scale operations centered around individual wells may incur higher per-unit costs but can still be viable, especially if the brine's quality boasts exceptionally high lithium content.

One approach to dealing with lithium-rich brine involves transporting the brine from multiple wellheads to a central processing facility equipped with the requisite infrastructure and technology for efficient lithium extraction. Depending on distance and volume considerations, brine water can be conveyed through pipelines or tanker trucks.

Alternatively, if the brine contains substantial lithium concentrations and represents the primary target for extraction, specialized equipment and processes can be installed at the wellhead. This method, often referred to as "direct lithium extraction," allows for on-site extraction of lithium before further transportation or processing.

Mobile lithium extraction units may also be deployed to various well sites as needed. These units can be transported to different locations to process brine water on-site, eliminating the need for extensive transportation infrastructure.

Various techniques and process strategies have been put forth for directly extracting lithium from geothermal and other brines. These approaches are generally classified into adsorption, ion exchange, and solvent extraction. Among these technologies, the ones currently progressing toward pilot- and near-commercial-scale demonstrations primarily encompass adsorption and ion exchange techniques.

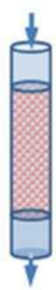
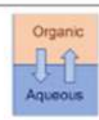
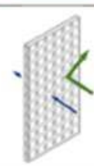
The extraction location and method choice depend on the brine's lithium concentration, the operation's scale, logistical factors, and economic considerations.

- Solar evaporation and carbonation can produce pure lithium compounds. Still, only at concentrations greater than 500 mg/L, and it requires more than one year to concentrate the lithium sufficiently to ensure effective precipitation of lithium carbonate upon adding sodium carbonate (soda ash). Evaporitic technology is not applicable to these more diluted oil field brines.

- Chemical treatment may be employed to enhance lithium extraction efficiency. Commonly used chemicals include sodium carbonate and lime, which help precipitate impurities, facilitating more effective lithium separation.

- Various technologies can isolate and recover the lithium from the brine. Common methods are solvent extraction, ion exchange, and membrane separation. In ion exchange, resin beads selectively adsorb lithium ions from the brine, while membrane separation uses specialized membranes to separate lithium from other ions in the brine. This approach necessitates significantly stricter water pretreatment compared to sorption or solvent extraction methods.

  Once extracted, lithium is further processed to produce lithium carbonate or lithium hydroxide, the primary forms used in battery production. For lithium to be suitable for commercial applications in lithium-ion batteries, it must have minimal traces of other metal impurities.

Technology	Mechanism		Developer
Solar evaporation		Lithium-containing solutions in ponds are concentrated by solar heating; lithium carbonate precipitated on addition of soda ash (sodium carbonate). $2LiCl + Na_2CO_3 \rightarrow Li_2CO_3 + 2NaCl$	Conventional
Phosphate precipitation		Lithium phosphate precipitated on addition of phosphoric acid. $3LiCl + H_3PO_4 \rightarrow Li_3PO_4 + 3HCl$	POSCO[8-10]
Ion exchange resin		Lithium ions intercalated into layers of aluminum hydroxide on ion exchange resins. $LiCl{+}NaCl \cdot 2Al(OH)_3 \cdot nH_2O \rightarrow NaCl{+}LiCl \cdot 2Al(OH)_3 \cdot nH_2O$	Dow[11-13]
Aluminum based adsorbent		Lithium ions adsorbed onto aluminum hydroxide with the almost same mechanism as ion exchange resin above.	FMC[14-16] Simbol[17,18] Eramet[19]
Manganese based adsorbent		Lithium ions adsorbed within layers of manganese oxide such as $H_{1.6}Mn_{1.6}O_4$ and λ-MnO_2.	JOGMEC[20]
Titanium based adsorbent		Lithium ions adsorbed into layers of titanium oxide such as H_2TiO_3.	Neometals[21]
Solvent extraction		Lithium ions extracted from water phase by oil phase. $R\text{-}H_{sol} + LiCl_{aq} \rightarrow R\text{-}Li_{sol} + HCl_{aq}$	Tenova[22,23]
Nanofiltration		Lithium ions concentrated through differences in ion rejection ratios and water flow rejection by membrane	MGX[24,25]

Lithium Recovery from Oil and Gas Produced Water: A Need for a Growing Energy Industry Amit Kumar, Hiroki Fukuda, T. Alan Hatton, and John H. Lienhard V ACS Energy Letters 2019 4 (6), 1471-1474
DOI: 10.1021/acsenergylett.9b00779

Techno-Economics of Lithium Extraction

Publicly available cost and performance data for assessing the techno-economics of lithium extraction from oil field brine are currently limited. Nevertheless, ongoing demonstrations are expected to provide more comprehensive insights for future analyses.
A review of the economics of direct lithium extraction projects suggests that economically viable lithium concentrations should ideally fall within the range of 65 to 160 ppm. These concentrations yield a pre-tax internal rate of return ranging from 24 to 41 percent.[8] This is assuming a lithium recovery of 90 percent.

Starting from mid-2018, the spot market prices for lithium carbonate have fluctuated between roughly $20,000/metric ton t to $7,500/mt, while lithium hydroxide monohydrate prices have ranged from $21,000/mt to $10,000/mt. The lowest prices were observed during the global economic downturn caused by the COVID-19 pandemic, which reduced demand.[9]

Benchmark lithium prices in September 2023 are about $28,000/mt, but they averaged roughly $55,000/mt over the past year.

Comprehensive Services for Oil Field Brine Lithium Extraction

Environmental consultants play a crucial role in supporting lithium extraction from oil field brines by helping to conduct the process in an environmentally responsible and sustainable manner. Consultants bring expertise in adopting best practices and technologies for mitigating environmental impacts associated with brine extraction and lithium processing. Incorporating environmental considerations in the early stages of project planning can contribute to maintaining sustainable practices throughout the entire project life cycle.

Your environmental consultants and engineers can offer a range of services for evaluating direct lithium extraction from oil field brine.

- Consultants can conduct feasibility studies to assess lithium extraction projects' technical, economic, and environmental viability.
- They can analyze the brine resource and provide estimates of lithium reserves and potential production rates. This can include sampling and testing oil-field brine.
- Consultants can assess various lithium extraction technologies, such as adsorption, ion exchange, and solvent extraction, to determine the most suitable approach for a specific oil field brine.
- They can help design the extraction process, including the equipment, facilities, and infrastructure required for efficient lithium recovery.
- They can evaluate the environmental implications of lithium extraction and propose mitigation strategies to ensure sustainable practices.
- They can assist in navigating the regulatory requirements and permitting processes associated with lithium extraction, helping to ensure that projects comply with local, state, and federal regulations.

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[8] Warren, Ian. 2021. Techno-Economic Analysis of Lithium Extraction from Geothermal Brines. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5700-79178. https://www.nrel.gov/docs/fy21osti/799178.pdf.
[9] IBID

Lithium Extraction Pilot Plants and Projects

Pilot plants for lithium recovery from oil-field brines have been established in the USA, Canada, China, and Russia up to this point.

- Standard Lithium is engaged in testing and proving the commercial viability of lithium extraction from over 150,000 acres of permitted brine operations in southern Arkansas. They are also pursuing the resource development of over 30,000 acres of separate brine leases in southwest Arkansas, referred to as the South West Arkansas Lithium Project, and approximately 45,000 acres of mineral leases in the Mojave Desert in San Bernardino County, California.[10]

- In early 2023, ExxonMobil acquired the rights to 120,000 gross acres of the Smackover formation in southern Arkansas, considered one of North America's most prolific lithium resources. Following the application of conventional oil and gas drilling techniques to access lithium-enriched saltwater from reservoirs located approximately 10,000 feet below the surface, ExxonMobil will employ direct lithium extraction technology for the purpose of isolating lithium from the saltwater.[11]

- POSCO Holdings (a Korean company) has teamed with Invest Alberta Corporation of Canada to develop lithium resources from oil-field brine in Alberta. POSCO is conducting research and development on the commercialization of oil-field brine lithium projects based on its accumulated lithium extraction technology and business capabilities through a brine lithium business in Argentina and an ore lithium business in Australia.[12]

- PetroChina Southwest Oil & Gasfield Company has developed a pilot plant for lithium extraction with an annual lithium carbonate output expected to reach 50 tons.[13]

It is essential to note that the economic viability of lithium extraction from oil field brines hinges on factors such as the lithium concentration in the brine, extraction, and processing costs, market lithium prices, and regulatory considerations. Additionally, the oil and gas industry will likely invest in innovative technologies and expertise to extract lithium from these brines more efficiently.

As the global shift toward clean energy sources accelerates and the demand for lithium-ion batteries continues to rise, the value of oil field brines as a source of lithium will increase. This transformation has the potential to reshape how oil and gas companies perceive and manage these brines, shifting them from being a disposal cost to a valuable resource.

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[10] https://www.standardlithium.com/investors/news-events/press-releases/detail/113/standard-lithium-and-lanxess-finalize-plan-for-first

[11] https://corporate.exxonmobil.com/news/news-releases/2023/1113_exxonmobil-drilling-first-lithium-well-in-arkansas

[12] https://newsroom.posco.com/en/posco-holdings-secures-lithium-from-oil-field-brine-in-canada/#:~:text=POSCO%20HOLDINGS%20has%20joined%20forces,contains%20minerals%20such%20as%20lithium.

[13] https://www.globaltimes.cn/page/202301/1283176.shtml