TECHNICAL WHITE PAPER

Unlocking Lithium Brine Production with Ion Exchange

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1. Introduction

The electrification of transportation is a fundamental part of the world's decarbonization efforts. Electric vehicles are powered by batteries that rely on lithium, an indispensable metal that uniquely enables a wide variety of electrode chemistries with high volumetric energy density and fast charging. The broad adoption of electric vehicles therefore requires a substantial increase in lithium production. To realize this electric future, traditional methods of lithium production must be replaced with new technology that can deliver higher rates of production while meeting basic environmental standards.

Brine resources hold a substantial amount of the world's lithium,[1] but until now, the lack of a scalable extraction technology has hindered their development. Essentially all lithium brine projects today rely on evaporation ponds, which are sometimes combined with alumina adsorbents. However, these methods deliver poor performance even for high grade resources, require very large amounts of land and freshwater, and have not kept pace with lithium demand.

The ideal solution for lithium brine extraction is ion exchange (IX), a technology category that leverages various solid materials known as ion exchange media (IXM) to selectively absorb target metals from liquid streams. IX technologies are commonly used in a wide variety of industries, including metals processing, water treatment, pharmaceuticals, and more.

The application of IX technology to lithium would substantially improve the economics and scalability of brine projects. For decades, companies have tried and failed to develop an IXM for lithium with sufficient performance and durability. Recently, proprietary advances in materials and process engineering have now unlocked the IX category for lithium production.

2. The Rising Importance of Lithium

The transition to electric vehicles necessitates a significant expansion in lithium supply. Benchmark Minerals Intelligence previously forecast that lithium demand will grow from 0.9 million tonnes (t) of lithium carbonate equivalent (LCE) in 2023 to approximately 3.1 million t LCE by 2030. To meet this demand growth, Benchmark estimated that $54 billion of investment in lithium supply will be required by 2030.[2]

Ten years ago, brine evaporation projects in South America supplied most of the world's lithium due to their favorable economics, with first quartile operating costs below $6,000/t LCE.[3] However, technical and environmental challenges with incumbent brine extraction technologies have hindered the development of new projects and the expansion of existing projects. As a result, brine resources have struggled to keep pace with rapidly growing demand over the past decade.

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[1] Mineral Commodity Summaries 2024 - Lithium (USGS, January 2024)

[2] Lithium industry needs over $116 billion to meet automaker and policy targets by 2030 (Benchmark Minerals Intelligence, August 2023)

[3] Supply Chain Insights: Lithium, batteries and trade wars (SC Insights, May 2024)

Hard rock resources have emerged to meet the increasing demand for lithium, accounting for up to 90% of new greenfield production since 2015. However, developing these resources is costly, and expenses continue to rise as developers tap into lower-grade deposits. Current operations include high-grade, integrated spodumene projects with operating costs of $7,000-8,000/t LCE, lower-grade, non-integrated Australian and Chinese spodumene projects at $12,000-13,000/t LCE, Chinese lepidolite projects at $14,000-15,000/t LCE, and finally low-grade African lepidolite tailings at around $25,000/t LCE.[4]

Looking forward, compared to the declining grades and rising costs of hard rock projects, brine projects offer fundamental advantages as a source of future lithium supply:

1. **Abundant:** Globally, brine resources total 308 Mt LCE, while hard rock resources amount to only 115M t LCE.
2. **Smaller Environmental Footprint:** Brine production emits three times less greenhouse gases compared to hard rock mining.[5]
3. **Lower Cost:** Pumping brine from reservoirs can present a significant cost advantage over the truck-and-shovel method used in hard rock mining, provided developers use cost-effective technologies for lithium separation and purification.

Given these factors, it is clear that rapid commercial development of brine resources is needed to meet projected lithium demand in a lower-cost and more sustainable way.

3. Historical Challenges with Brine Extraction

To understand the future of lithium brine extraction, it is helpful to examine the technical and environmental challenges that have hindered the development of brine projects over the past decade. This analysis focuses on evaporation ponds and alumina adsorbents, the two incumbent technologies in commercial-scale lithium brine production today.

Evaporation Ponds

The original method for producing lithium from brine resources, which began in the mid-1960s, involves pumping brine from subsurface deposits into large evaporation ponds. Solar irradiation and dry winds gradually evaporate the water, leaving behind solid salt tailings and a concentrated solution that can be processed into lithium chemicals.

This method has been most effective at the Salar de Atacama in Chile, where lithium is present at very high concentrations of over 2,000 mg/L. Outside of the Atacama, evaporation pond projects yield much lower production rates due to lower lithium grades and more challenging brine chemistries. Indeed, over the past decade only two significant evaporation pond projects have come online in South America, at Olaroz and Cauchari, highlighting the difficulty that evaporation pond projects face in achieving commercial deployment compared to hard rock projects.

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[4] Supply Chain Insights: Lithium, batteries and trade wars (SC Insights, May 2024)
[5] Hard rock lithium vs. brine – how do their carbon curves compare? (Benchmark Minerals Intelligence, March 2023)

Evaporation pond projects face numerous technical and environmental challenges that have prevented them from playing a significant part in supply growth over the past decade:

1. **Land footprint:** Projects require vast areas of flat land, making land availability a critical bottleneck. This is particularly true for lower-grade resources, which need larger pond areas to achieve production rates of commercial significance.
2. **Environmental impact:** Evaporation depletes brine aquifers, which can cause subsidence in overlying freshwater aquifers and lead to water access issues in arid regions.
3. **Weather dependency:** Projects depend on arid conditions to efficiently evaporate the brine and must avoid excessive rainfall that can cause process upsets to the open-air system. Outside of South America, these weather conditions rarely coincide with brine resources.
4. **Impurity handling:** The process concentrates not only lithium but also impurities such as magnesium, calcium, and boron, complicating production and increasing costs.
5. **Development timelines:** Projects often face permitting issues associated with their large land footprint. They are also slow to ramp-up, as new projects can need up to a decade before achieving a battery grade product at nameplate capacity. For example, the Olaroz project was under development, construction, and initial commissioning for 7 years from 2008 to 2015, and then took another 9 years from 2015 to 2023 to reach its current maximum production rate of 16,700 tpa LCE, with only 39% at battery grade quality.[6, 7]
6. **Low recoveries:** Projects typically recover only 40-60% of the lithium present in the brine.

Alumina Adsorbents

Alumina adsorbents (AA) are a class of technology used to selectively recover lithium from brines. The technology was first commercialized in 1998 by Livent at the Salar de Hombre Muerto in Argentina, a large and high-grade lithium resource, in an attempt to improve the extraction performance of evaporation ponds.

The AA material is typically a composite with a polymer matrix and an active aluminum-based hydroxide. This hydroxide adsorbs lithium chloride from the brine. To elute the lithium chloride from the adsorbent, large volumes of freshwater are used as a stripping agent.

AA is commonly referred to as an example of direct lithium extraction (DLE) technology, however it appears that in all commercial applications to date the technology has not been directly applied to raw brine. Instead, AA projects in commercial operation need to pre-concentrate the brine prior to adsorption, typically with evaporation ponds. However, even with the help of pre-concentration, the overall lithium recovery of AA projects operating at commercial scale has been extremely poor (calculated to be 42% based on published data, taking into account systemwide lithium losses).[8]

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[6] Annual Report 2023 (Allkem, 2023)

[7] Olaroz Project (Allkem, 2023)

[8] Resource and Reserve Report - Pre-Feasibility Study - Salar del Hombre Muerto (Livent, November 2023)

Calculation Methodology: volume of feed brine produced and associated Li concentration is reported annually, along with Lithium production from the SA Plant. Overall recovery from the wellfield through to the final product was calculated for 2022 using the formula: Overall Recovery = SA Plant Lithium Production (t) / Total Contained Lithium in Brine (t) x 100%.

Over the past 25 years, numerous efforts have been made to adapt AA technology to brines with lower lithium concentrations and higher impurity levels. Some projects in China have achieved production by using AA to process lithium-enriched byproduct streams from potash production. However, these projects generally have modest production volumes due to siting limitations near potash facilities and appear to still rely on pre-concentration of the brine.

Ultimately, existing AA technology in commercial operation today has faced six major challenges that have prevented it from playing a significant part in lithium supply growth over the past decade:

1. **Freshwater consumption:** A significant amount of freshwater is needed to strip lithium chloride from the AA material, even after water recycling is considered. In water-scarce regions like South America's high deserts, where water conservation is critical for local communities, this can limit production rates.
2. **Evaporation required:** Large-scale AA projects in operation today typically rely on evaporation ponds to pre-concentrate brine. At most lithium resources globally, utilizing evaporation is not feasible due to environmental regulations, cost, and brine chemistry.
3. **Poor lithium recovery:** While some AA providers claim high DLE recovery, they often fail to differentiate between economically-viable systems and lab-scale tests optimized for press releases. The economically-viable recovery is the true driver of project economics. Livent’s AA project at Hombre Muerto achieves an overall system recovery of only 42% when considering the aggregate performance of AA and the upstream evaporation ponds used to pre-concentrate the brine (calculated based on published data).[8] The difficulty in economically achieving high lithium recoveries becomes especially pronounced at lower lithium grades.
4. **Brine preheating:** AAs need brine to be heated to between 40-95°C to function optimally[11], increasing energy consumption and GHG emissions. As lithium grades decrease over time with dilution, brine flowrates and corresponding heating costs can increase dramatically.
5. **Impurity tolerance:** AAs are intolerant to arsenic, lead, and other impurities. This leads to lower lithium adsorption capacity and accelerated degradation of the materials. Other anionic species like carbonate and sulfate also interfere with the AA operation. [9, 10, 11]
6. **Poor dilution tolerance:** Reinjection of spent brine can lead to declining lithium grades over the life of a project due to dilution. This poses a major risk to AAs due to their struggles in achieving sustained high recoveries on low-grade brines.

Today, most companies marketing new DLE technologies are offering systems based on AA and claim performance improvements on the existing AA technology that is currently in commercial operation. While these companies have proposed many new AA projects over the last 15 years targeting lower grade salar, geothermal, and oilfield brine resources, none have yet reached commercial production. Of these proposed next generation AA projects, the one most likely to come online first is Eramet’s Centenario Ratones project in Argentina, which is scheduled for commissioning in 2024.

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[9] Y.T. Liu, M.K. Wang, T.Y. Chen, P.N. Chiang, P.M. Huang and J.F. Lee, Environ. Sci. Technol., 2006, 40, 7784

[10] Webinar: Escalating with Aluminate-Optimizing LADH Performance (Forward Water Technologies Corp., March 2024)

[11] Adsorption-type aluminum-based direct lithium extraction: The effect of heat, salinity and lithium content (Desalination, May 2024)

Other Competing Technologies

Numerous other technology companies have attempted to develop novel methods for lithium production from brine resources, such as phosphate precipitation, solvent extraction, and membrane separation. However, none of these technologies appear to have demonstrated compelling unit economics and suitable environmental performance.

Some of these methods show promise for downstream processing of lithium concentrates, especially membrane technologies like bipolar electrodialysis for electrochemical production of lithium hydroxide. However, these downstream applications do not address the critical challenge associated with primary lithium extraction from brines.

4. Unlocking IX Technology for Lithium Extraction

History of Ion Exchange

IX technologies are widely used in industrial applications. Every IX technology utilizes a specialized material called the IXM, which selectively absorbs specific metals from a feed solution. IXM materials, typically based on polymers, have been successfully developed for various purposes including water softening, uranium extraction, and rare earth separations.

The lithium industry has attempted to adapt IX technology for lithium production, but conventional polymer-based IXM materials lack the necessary selectivity for lithium. To achieve high selectivity for lithium, IXM must be constructed from ceramic materials. However, most ceramics suitable for lithium recovery have historically degraded rapidly in the acid needed to release lithium from the ceramic, requiring replacement after tens or low hundreds of absorption cycles.[12,13,14,15] This lack of materials durability led to most lithium companies abandoning IX.

A New Approach to Ion Exchange

In recent years, Lilac Solutions, an IX DLE technology company, successfully developed a novel IXM for lithium extraction. Lilac IXM overcomes the historical challenges of degradation by providing exceptional chemical and mechanical durability. Through eight years of development and testing, Lilac has made significant improvements to the IXM, or “beads”, and to the overall IX system design. These improvements include advancements in IX materials and nano-coatings, porous composite IX media, process design, and equipment optimization. These innovations have unlocked IX technology for lithium production for the first time.

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[12] Molnar et al., Standard Lithium’s Process Development, COM 2020

[13] Zhao, B., Guo, M., Qian, F., Qian, Z., Xu, N., Wu, Z., & Liu, Z. (2020). Hydrothermal synthesis and adsorption behavior of H 4 Ti 5 O 12 nanorods along [100] as lithium ion-sieves. *RSC advances*, 10(58), 35153-35163.

[14] Hossain, S. M., Ibrahim, I., Choo, Y., Razmjou, A., Naidu, G., Tijing, L., ... & Shon, H. K. (2022). Preparation of effective lithium-ion sieve from sludge-generated TiO2. *Desalination, 525*, 115491.

[15] Weng, D., Duan, H., Hou, Y., Huo, J., Chen, L., Zhang, F., & Wang, J. (2020). Introduction of manganese based lithium-ion Sieve-A review. *Progress in Natural Science: Materials International*, 30(2), 139-152.

5. Lilac IX Technology Development

Since Lilac's founding in 2016, Lilac's IX technology has evolved through four distinct generations with a focus on optimizing performance, scalability, and cost. Each generation has built on prior advancements, resulting in cumulative improvements to the technology's performance and reliability. This iterative process has culminated in a breakthrough combination of lithium recovery, impurity rejection, IXM durability, and high module flowrates, to deliver groundbreaking performance and cost competitiveness for a wide variety of projects.

Lilac IX Gen 1 (2017)
Lilac's technology was first demonstrated in 2017, delivering high lithium recovery and impurity rejection, and 300 cycles of durability.

Lilac IX Gen 2 (2020)
Gen 2 improved cycle life to 1,000 cycles. Having achieved technical and operational milestones with the Gen 2 technology, Lilac was able to raise more capital, significantly increase the size of its R&D team, and accelerate innovation.

Lilac IX Gen 3 (2022)
Lilac's Gen 3 technology increased cycle life to approximately 3,000 cycles while improving reliability and operability based on experience with pilot modules. Lilac updated the IX module design to eliminate all custom components, incorporating only off-the-shelf equipment from large suppliers, resulting in both cost savings and increased reliability. Lithium recovery rates remained high during cycling, averaging 80% over 2,800 cycles with low-grade (200 mg/L Li) brine from Argentina, and 81% over 3,200 cycles with high-grade (2,000 mg/L Li) brine from Chile.

Lilac IX Gen 4 (June 2024)
Lilac's Gen 4 technology features another major step change in performance. IXM durability was again improved, with an expected life of 4,000 cycles, even for low-grade brines. Most notably, Gen 4 lithium recoveries were increased to greater than 90% for most brines and the capital cost of the IX system for a project was cut by almost 50% thanks to higher IX module throughput, leading to a lower IX module count. Lastly, Gen 4 reduced acid and base consumption by 10%, further driving down the operating costs of projects.

Lilac IX vs. Alumina Adsorbents

Lilac IX expands the resource base by working effectively with low-grade, complex brines, and having minimal land and freshwater use. The benefits of Lilac IX compared to AA are numerous and significant:

1. **Effective on tough brines:** Lilac IX extracts lithium at sustained high recovery rates, from ultra low-grade 50 mg/L brines to high grade 2,000 mg/L brines, across a wide variety of complex brine chemistries. It achieves this without evaporation ponds or any other form of pre-concentration, reducing land use by up to 30 times.[16]
2. **Low freshwater usage:** Unlike AA, Lilac IX does not use water as a stripping agent. This results in freshwater consumption that is up to 10 times lower than AA.[16]
3. **Streamlined flowsheet:** Lilac IX has a high tolerance for impurities, meaning nanofiltration and carbonate removal is not required. Lilac IX also produces a highly concentrated lithium eluate (2,640 mg/L vs 300-1,200 mg/L for AA[17, 18]) with very low impurity levels, simplifying downstream processing steps and de-risking the production of battery-grade products.
4. **No brine preheating:** Unlike AA, Lilac IX is highly effective at ambient temperatures, eliminating the need for costly and energy-intensive brine heating. Preheating can become a major issue over time as lithium grades decrease with dilution, causing brine flowrates and corresponding heating costs to increase dramatically.
5. **Fast kinetics:** Lilac IX can recover 90% of lithium from a 70 mg/L raw brine with a 200:1 Mg:Li ratio in just one minute. This speed translates into compact modules with high throughput, low capex, and reduced IXM inventory.
6. **Dilution tolerant:** Because Lilac IX is effective at extracting lithium from ultra low-grade brines, it can maintain high lithium recoveries over the entire life of a project, even after lithium concentrations are diluted due to the reinjection of spent brine into the reservoir.
7. **Flowsheet flexibility:** Lilac IX produces either a lithium chloride or sulfate concentrate, enabling compatibility with conventional downstream flowsheets to lithium carbonate or hydroxide.

Together, these attributes unlock lithium projects previously deemed unfeasible and offer lithium producers attractive project economics with higher production rates. The Lilac IX System is optimized for performance and commercial economics to deliver all-in OPEX ranging from $4,000 to $7,000/t LCE, which includes brine pumping through to production of battery-grade lithium. A comparison of the features of Lilac IX relative to AA technologies is presented in Table 1.

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[16] Refer to Table 3 for further information
[17] Lanxess Project DFS (Standard Lithium, 2023)
[18] Prairie Lithium PFS (Arizona Lithium, 2023)

Table 1. Lilac IX Gen 4 vs AA, Under Commercially Relevant Operating Conditions

Parameter	Lilac IX	Alumina Adsorbents
Lithium Recovery (at economically relevant residence times)	80-98%	30-95%*
Lithium Concentration in Raffinate (lithium lost in spent brine, mg/L)	10-30	100-200[19, 20]
Minimum Economic Lithium Grade (mg/L)**	50	300***
Brine Preheating	No	Yes (45-90°C)[21]
Freshwater Consumption (m^3/t LCE)	2-20	100-120[22]
Lithium Chloride Eluate	Yes	Yes
Lithium Sulfate Eluate	Yes	No
Tolerates Fe, Mn	No	No
Tolerates As, Pb, CO_3, SO_4	Yes	No[23, 24, 25]
Acid Requirements in Process (Typical Brine to Li_2CO_3 Flowsheet)	DLE IX Divalent IX	Brine pH Adjustment[26] Divalent IX
Base Requirements in Process (Typical Brine to Li_2CO_3 Flowsheet)	Pre-Treatment DLE IX Ca/Mg Precipitation Divalent IX	Pre-Treatment Ca/Mg Precipitation Divalent IX

* Livent's AA project at Hombre Muerto achieves an overall system recovery of 42% when considering the aggregate performance of AA and the upstream evaporation ponds needed to pre-concentrate the brine (calculated based on published data). It is also understood that recoveries for some AA projects in China are as low as 30%. Companies developing new AA technologies have reported increased recoveries, but this has yet to be proven in commercial production or demonstrated in conditions relevant to commercial production, including extended cycle counts.
** Reflects Lilac's view on the influence of lithium grade on the economic performance of a commercial-scale project related to performance factors including recovery, cycle time, resin durability, and brine heating, amongst others.
*** AA projects in commercial production today operate on brine grades significantly higher than 300 mg/L, however companies developing new AA technologies have reported that they can recover lithium economically from lower grades. This has yet to be proven in commercial production or demonstrated in conditions relevant to commercial production, including extended cycle counts.

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[19] Paranthaman, M., Li L., Luo, J., Hoke, T., Ucar, H., Moyer, B., & Harrison, S. (2017). Recovery of Lithium from Geothermal Brine with Lithium–Aluminum Layered Double Hydroxide Chloride Sorbents. *Environmental Science & Technology*, 51(22), 13481-13486

[20] Resource and Reserve Report - Pre-Feasibility Study - Salar del Hombre Muerto (Livent, November 2023)
Calculation Methodology: implied lithium concentration in raffinate calculated from DLE performance data during years prior to the installation of upstream evaporation ponds.

[21] Adsorption-type aluminum-based direct lithium extraction: The effect of heat, salinity and lithium content (Desalination, May 2024)

[22] Resource and Reserve Report - Pre-Feasibility Study - Salar del Hombre Muerto (Livent, November 2023)
Calculation Methodology: it is reported that in 2022 the process extracted 355 m^3/h of freshwater to produce 26,100 t LCE.

[23] Y.T. Liu, M.K. Wang, T.Y. Chen, P.N. Chiang, P.M. Huang and J.F. Lee, Environ. Sci. Technol., 2006, 40, 7784

[24] Webinar: Escalating with Aluminate-Optimizing LADH Performance (Forward Water Technologies Corp., March 2024)

[25] Adsorption-type aluminum-based direct lithium extraction: The effect of heat, salinity and lithium content (Desalination, May 2024)

[26] South West Arkansas Project PFS (Standard Lithium, 2023)

6. Lilac IX Performance

Lilac has built 60 fully automated, continuous, mini-pilot scale lithium extraction modules at its headquarters in Oakland, California, at scales of 1 to 100 L/h to support optimization of chemical process parameters for a wide variety of brines. Additionally, multiple field pilot plants and demonstration plants have been designed, built, and operated by Lilac. To date, Lilac has tested over 70 different brines from all over the world and logged continuous IX operations totaling more than 550,000 hours and more than 200,000 IX cycles. This obsession with testing and continuous improvement has enabled Lilac to develop and prove industry-leading performance and reliability.

BRINE LIBRARY AT LILAC'S HEADQUARTERS IN OAKLAND, CALIFORNIA

Lilac's Gen 4 IX technology has achieved new heights in lithium recovery and cycle life, while maintaining high impurity rejection, to deliver the best performing lithium extraction technology to date. Lilac IX delivers high lithium recoveries, even from ultra low-grade brines (as low as 50 mg/L Li) with exceptionally high impurities profiles (e.g. Mg:Li ratios of over 170:1). For brines with higher lithium concentrations, recoveries exceed 95%. The Lilac IX System typically rejects 99.9% of impurities, including Na, K, Mg, Ca, B, As, and Pb, and the system performance is independent of total dissolved solids (TDS) in the brine. This breakthrough performance makes Lilac IX effective on a wide variety of brine chemistries, expanding the viability of many resources worldwide.

Lilac IX also has fast kinetics and can recover 90% of lithium from a 70 mg/L raw brine with a 200:1 Mg:Li ratio in just one minute. This speed translates into compact modules with high throughput, low capex, and reduced IXM inventory.

Lilac IX Recovery Rates and Impurity Rejection

For the Lilac IX process, brines require minimal pre-treatment, typically only the removal of suspended solids. The primary challenge for lithium brine production is to reject impurities which typically comprise 99.9% of the brine while obtaining high lithium recovery. Table 2 reports Lilac's industry-leading lithium recoveries and impurity rejections across a wide range of brine chemistries from mini-pilot scale lithium extraction modules. A single charge of IXM is used for the entire duration of each test, without replacement between cycles.

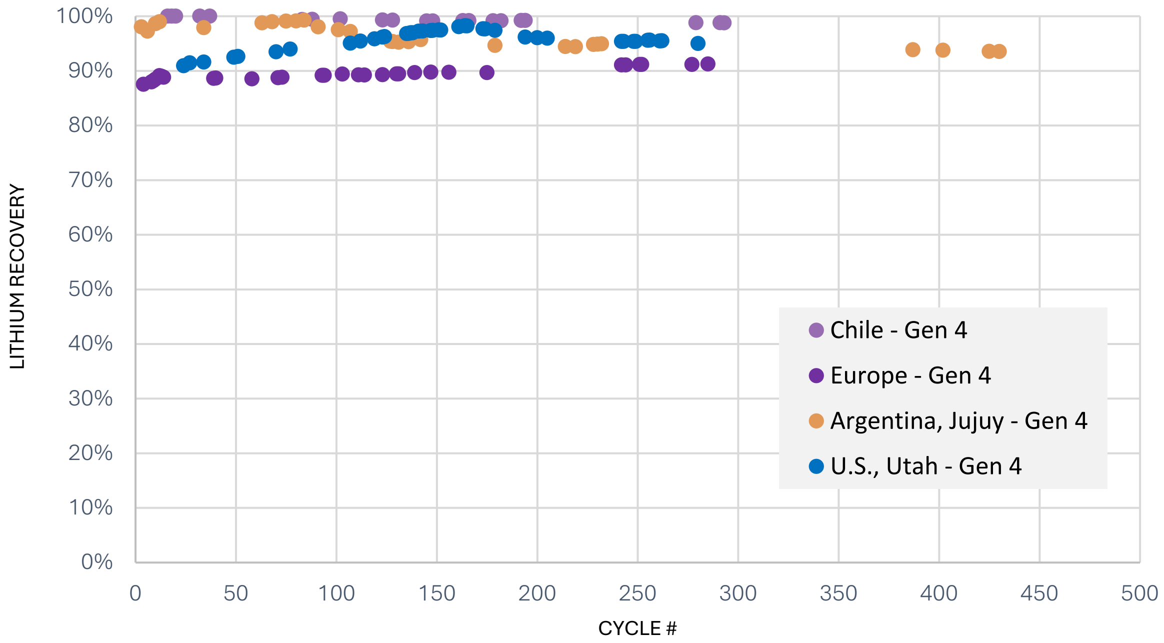
The eluate concentration data presented in Table 2 is measured at the output of the IX system, before any further downstream processing to further reduce impurity levels and increase lithium concentrations. This is an important consideration when comparing the performance of different DLE technologies.

In Table 2, Lithium Recovery Initial represents the average measured recovery over the lifetime of the test to date, and is shown graphically in Figure 1. Expected Long Term Li Recovery, which is always used by Lilac in commercial plant designs, reflects the expected average performance over thousands of cycles.

Table 2. **Lilac IX Gen 4 Technology Lithium Recovery and Impurity Rejections from Four Brine Types Tested on Mini-Pilot Scale Modules**

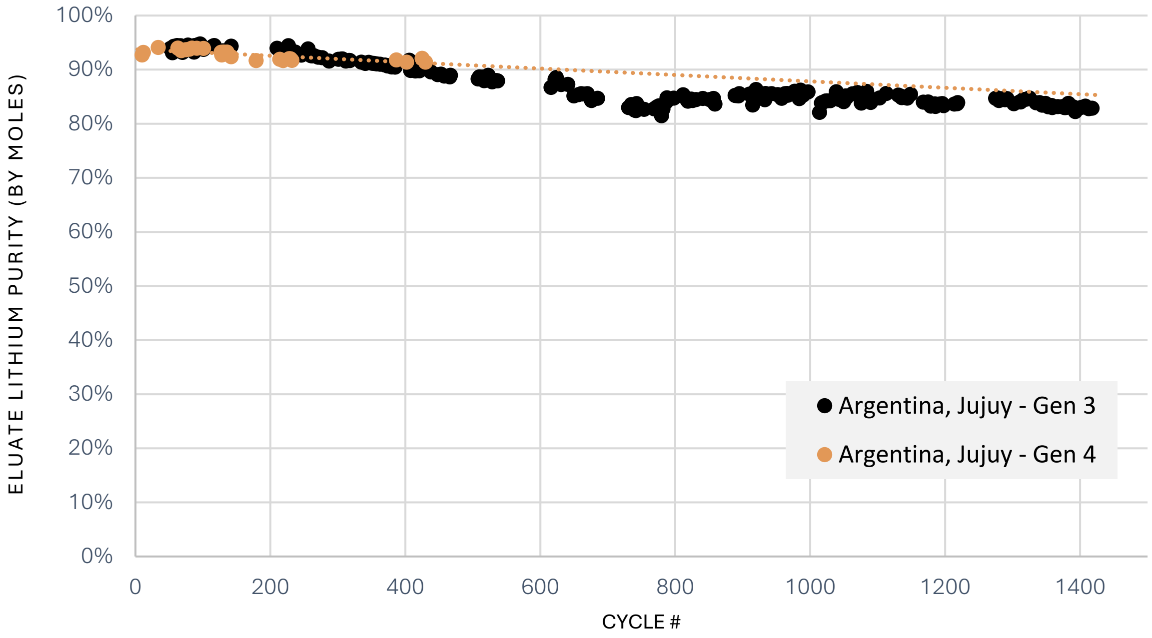
Element	[Li]	[Na]	[Mg]	[Ca]	[K]	[B]
High-Grade Salar Brine (2,200 mg/L Li), Chile Data averaged over initial 293 cycles. Overall impurity rejection: 99.5%.						
Brine Concentration (mg/L)	2,210	82,000	13,400	373	31,000	620
Eluate Concentration (mg/L)	2,570	137	240	137	187	0.5
Lithium Recovery Initial	**99%**					
Expected Long Term Li Recovery	*98%*					
Impurity Rejection		**99.9%**	**98.5%**	**68.9%**	**99.5%**	**99.9%**
Medium-Grade Oil & Gas Brine (400 mg/L Li), Europe, High Calcium Data averaged over initial 285 cycles. Overall impurity rejection: 99.9%.						
Brine Concentration (mg/L)	406	67,100	996	47,300	6,740	231
Eluate Concentration (mg/L)	2,520	172	16	592	12	0.5
Lithium Recovery Initial	**91%**					
Expected Long Term Li Recovery	*89%*					
Impurity Rejection		**99.96%**	**99.8%**	**99.8%**	**99.97%**	**99.9%**
Medium-Grade Salar Brine (300 mg/L Li), Jujuy, Argentina Data averaged over initial 430 cycles. Overall impurity rejection: 99.9%.						
Brine Concentration (mg/L)	324	80,500	1,610	651	6,140	625
Eluate Concentration (mg/L)	2,580	312	95	351	99	1
Lithium Recovery Initial	**94%**					
Expected Long Term Li Recovery	*90%*					
Impurity Rejection		**99.97%**	**99.9%**	**97.7%**	**99.9%**	**99.9%**
Ultra Low-Grade Brine (70 mg/L Li), Great Salt Lake, Utah, U.S. Data averaged over initial 280 cycles. Overall impurity rejection: 99.98%.						
Brine Concentration (mg/L)	71	92,200	10,900	307	6,860	46
Eluate Concentration (mg/L)	2,640	175	314	163	127	0
Lithium Recovery Initial	**95%**					
Expected Long Term Li Recovery	*84%*					
Impurity Rejection		**99.99%**	**99.9%**	**98.6%**	**99.95%**	**100%**

FIGURE 1. Lilac IX Gen 4 Lithium Recoveries from Mini-Pilot Lithium Extraction Modules



Based on several months of Lilac IX Gen 4 testing, projected durability (i.e. cycle life) is virtually identical to Lilac IX Gen 3. The end of life of the Lilac IXM is determined by loss of crystallinity and resulting loss of eluate molar purity. Figure 2 shows Lilac IX Gen 3 and Gen 4 technology delivering comparable molar purity over more than 400 cycles.

FIGURE 2. Comparison of Eluate Lithium Purity between Lilac IX Gen 3 and Lilac IX Gen 4 from Mini-Pilot Lithium Extraction Modules

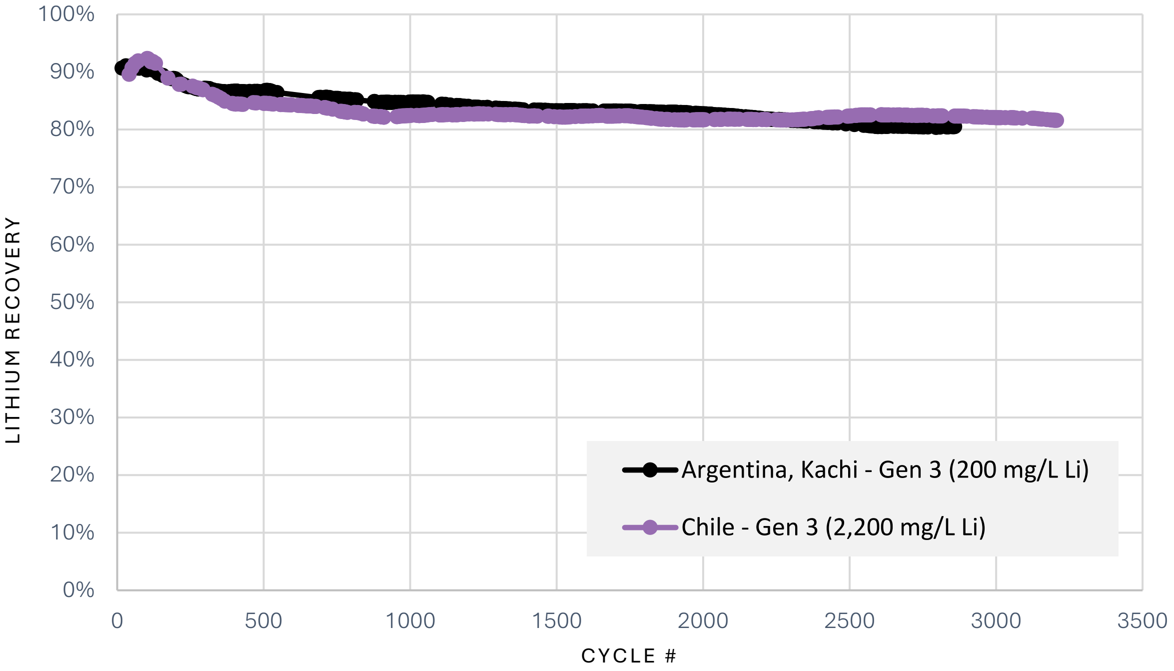


Lilac IXM Durability

The Lilac IXM demonstrates exceptionally high durability, operating continuously for thousands of cycles and over a year before requiring replacement. Lilac's IXM has demonstrated a cycle life exceeding 3,000 cycles, which translates into OPEX that is orders of magnitude lower relative to competing IX providers who require IXM replacement after tens or hundreds of cycles.

Figure 3 demonstrates sustained high recoveries over thousands of cycles with Lilac's Gen 3 technology, reflecting the exceptional durability of the IXM. Each brine was processed continuously on an automated test rig at mini-pilot scale, using a single fill of Lilac IXM, without replacement. Stable recoveries were achieved for over 2,800 cycles with low-grade Argentinian brine and 3,200 cycles with high-grade Chilean brine.

FIGURE 3. Lilac IXM Durability and Cycle Life for Lilac IX Gen 3 Technology from Mini-Pilot Lithium Extraction Modules



Field Pilots and Demonstration Plants: Scalability and Operability

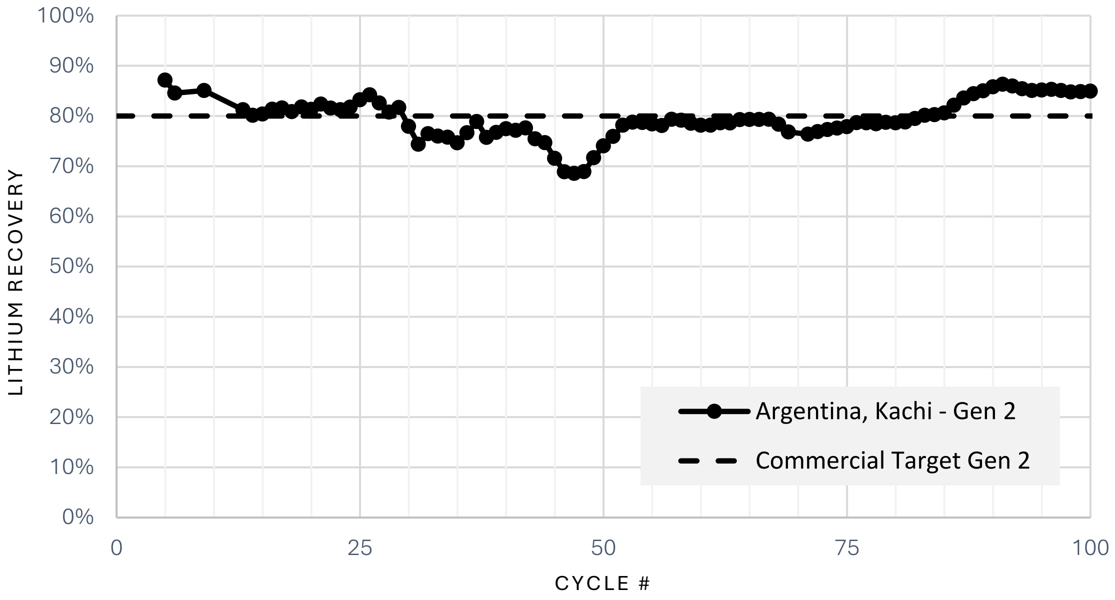
Lilac has successfully completed testing of multiple pilot and demonstration-scale Lilac IX lithium extraction systems deployed to various customer project sites. Of the three pilot plants, two were completed in North America and one in Chile. One demonstration plant was completed at the Kachi project in Catamarca, Argentina in partnership with Australian lithium developer Lake Resources.

KACHI DEMONSTRATION PLANT, CATAMARCA, ARGENTINA, EXTERIOR

KACHI DEMONSTRATION PLANT, CATAMARCA, ARGENTINA, INTERIOR

Data collected from the Kachi and Chile plants demonstrate consistent performance of Lilac's IX technology when scaling from mini pilot to larger plants in the field. In the Kachi demonstration plant, the IX vessel is one-third of commercial scale. Figure 4 compares the lithium recovery from a single fill of Gen 2 IXM that was cycled continuously at the Kachi demonstration plant to the design parameters of a full-scale commercial plant. No measurable loss of IXM performance occurred during this operation.

FIGURE 4. **Lilac IX Gen 2 Lithium Recovery in the Field at the Kachi Demonstration Plant, 200 mg/L Li**



The results demonstrate that the Kachi plant achieved sustained, high lithium recoveries from the Kachi brine, consistent with the design parameters of the full-scale commercial plant at Kachi. The Kachi plant also met the acid consumption design parameters of the full-scale commercial plant, achieving 1.5 t HCl/t LCE.

In addition to the consistent performance metrics outlined above, eluate produced from the Kachi pilot has been successfully converted to battery-grade lithium carbonate. As announced by Lake Resources,[27] independent testing of lithium carbonate produced from Lilac's Kachi Demonstration Plant in Argentina has confirmed grades and purity greater than 99.8%.

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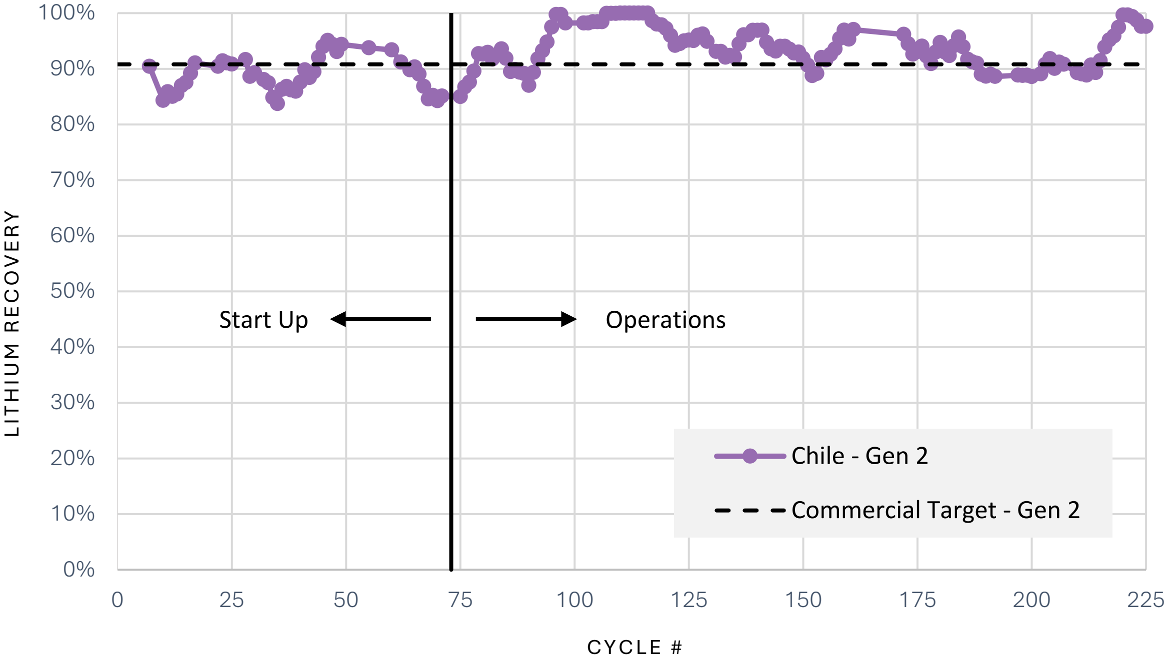
[27] Investor Update (Lake Resources, June 2023)


CHILE FIELD PILOT PLANT

The Chile pilot plant, which featured Lilac's Gen 2 IX technology, similarly achieved sustained high lithium recoveries of 94% on average over steady state production, while having a low acid consumption rate of 1.4 t HCl/t LCE, and a 99% overall impurity rejection rate.

FIGURE 5. **Lilac IX Gen 2 Lithium Recovery in the Chile Pilot Plant**



Lilac is currently commissioning a second demonstration plant in Jujuy, Argentina that will incorporate Lilac's Gen 4 technology, increasing lithium recoveries and reducing acid consumption.

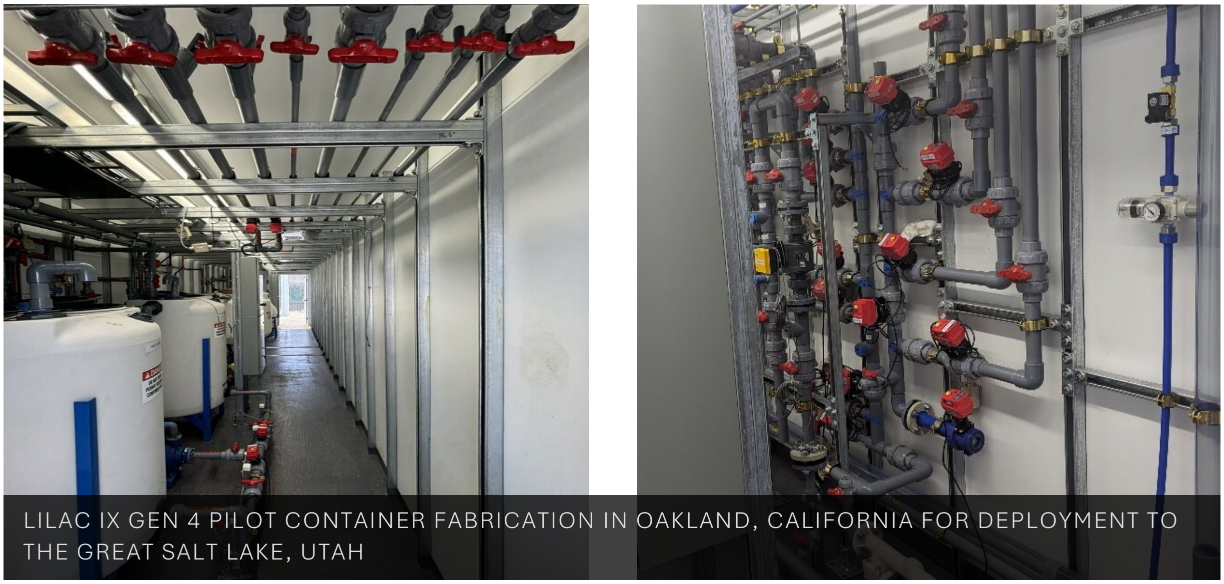
DEMONSTRATION PLANT, JUJUY PROVINCE, ARGENTINA, EXTERIOR

DEMONSTRATION PLANT, JUJUY PROVINCE, ARGENTINA, INTERIOR

Lilac is also constructing a fourth pilot plant that will be deployed to the Great Salt Lake in Utah in the summer of 2024. This system will also feature Lilac's Gen 4 technology.

LILAC PROJECT SITE, GREAT SALT LAKE, UTAH

LILAC IX GEN 4 PILOT CONTAINER FABRICATION IN OAKLAND, CALIFORNIA FOR DEPLOYMENT TO THE GREAT SALT LAKE, UTAH



LILAC IX GEN 4 PILOT CONTAINER FABRICATION IN OAKLAND, CALIFORNIA FOR DEPLOYMENT TO THE GREAT SALT LAKE, UTAH

7. Commercial-Scale Lithium Extraction System Design

IX System Design for Commercial Economics

The Lilac IX System design is highly modular for ease of fabrication, construction, operations, and expansion. Lilac’s system leverages off-the-shelf equipment to minimize project timelines and maximize project economics. Lilac’s modular design removes scale-up risk, allowing project developers to simply add additional units to the system without any concern for changes in performance or throughput.

The fundamental unit of Lilac’s system is the IX vessel, which holds the IX beads. This vessel defines the physics, chemistry, and performance of the technology. Multiple vessels are linked in an array using a standard design to form a module, and each module supports 2,000-7,000 tpa LCE production capacity, depending on the brine chemistry. For a brine with 250 mg/L lithium grade, each module delivers just over 6,000 tpa LCE, and 4 modules combine to form a 25,000 tpa LCE plant.

All equipment used to construct the Lilac IX System is used commonly in industrial applications and available globally from a variety of well-established vendors. Lilac procures and installs this equipment into a unique configuration for lithium extraction.

Lilac has developed full process flowsheets to produce battery-grade lithium carbonate and lithium hydroxide with minimal cost, utilizing conventional equipment and conventional process chemistry for both chloride and sulfate eluates.

Reagents

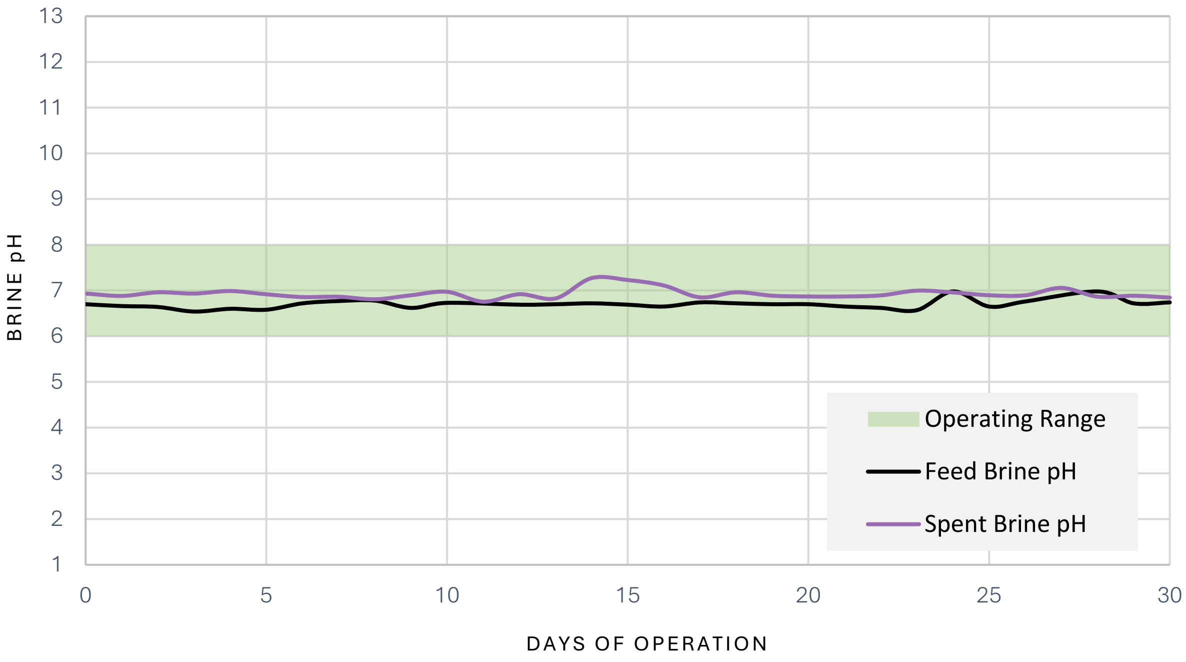
Acid is an essential reagent for the IX process. Lilac's IX System can utilize either hydrochloric acid or sulfuric acid, both commonly used in mining, chemical, and oil and gas industries with comparable EHS considerations. Hydrochloric acid can be produced on-site from sodium chloride using conventional chlor-alkali technology, employed at over 500 industrial sites worldwide, including high-altitude locations. After the hydrochloric acid is consumed, it reverts back into harmless sodium chloride. No acidity is injected into the salar. Sulfuric acid can be sourced from existing supply chains, such as nearby copper operations, or produced on-site through bipolar electrodialysis or sulfur combustion. A base reagent is used to neutralize all acidity, either sodium hydroxide or calcium hydroxide.

Spent Brine

After Lilac IX recovers lithium from the feed brine, the spent brine is chemically identical to the feed brine, except that lithium has been removed and replaced by sodium or calcium, which are already present in high concentrations.

The Lilac IX process does not introduce any exogenous species into the brine. The spent brine pH is readjusted to neutral before reinjection, as required to ensure no acidity is discharged into the environment. This is shown graphically in Figure 6 with pH data from Lilac's Chile pilot plant.

FIGURE 6. **Chile Pilot Plant: Feed Brine pH and Spent Brine pH from the Lilac IX System**



8. Minimal Environmental Footprint

Lilac's technology significantly outperforms competitors on land and water efficiency by eliminating the need for evaporation ponds and reducing water consumption. Lilac's process also operates efficiently at ambient temperatures, resulting in low energy requirements and reduced carbon emissions. Table 3 presents data on environmental performance.

Table 3. **Summary of Environmental Metrics for Lithium Production**

Extraction Method	GHG Emissions (t CO_2/t LCE)	Land Use* (m^2/t LCE)	Freshwater Consumption (t H_2O/t LCE)
Hard Rock – Spodumene	18-20[28]	527[29]	80-193[28, 29]
Brine – Solar Evaporation	3-8[28]	190-950	Freshwater: 16-57[28] Brine: 100-800[30]
Brine – Alumina Adsorbent**	8-13[31]	100-150[32]	100-120[32]
Brine – Lilac DLE***	3-5	5	2-20

* Includes evaporations ponds (if applicable) and processing plant footprint; excludes wellfield.
**Assumes conventional Livent-type AA process for a typical Argentinian salar brine that is preheated and pre-concentrated.
*** Based on FEL-2 study by an independent engineering firm; assumes power supply is 50% solar PV, 50% Argentinian grid.

9. Conclusion

At Lilac, we believe there is a better way to produce lithium from brine resources. Effective and reliable IX technology has long been the holy grail of lithium production and is now a reality. This technology will unlock a wide variety of new brine resources, including in new geographies across the Americas, Europe, and the Middle East. Technology will align increased lithium supply with environmental protection, facilitating permitting and production at unprecedented scale.

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[28] Energy, greenhouse gas, and water life cycle analysis of lithium carbonate and lithium hydroxide monohydrate from brine and ore resources and their use in lithium ion battery cathodes and lithium ion batteries (Kelly, J.C., Wang, M., Dai, Q., Winjobi, O., *Resources, Conservation and Recycling,* 174, 2021)

[29] Minviro Environmental Report (Canadian Mining Journal, 2021)

[30] Environmental impact of direct lithium extraction from brines (Vera, M.L., Torres W.R., Galli C.I., Chagnes A., Flexer V., *Nature Reviews Earth and Environment,* 4, 2023)

[31] 2022 Sustainability Report (Livent, 2022)

[32] Resource and Reserve Report - Pre-Feasibility Study - Salar del Hombre Muerto (Livent, November 2023)
Calculation Methodology: it is reported that in 2022 the process extracted 355 m^3/h of freshwater and used 330 hectares of pre-concentration ponds to produce 26,100 t LCE.