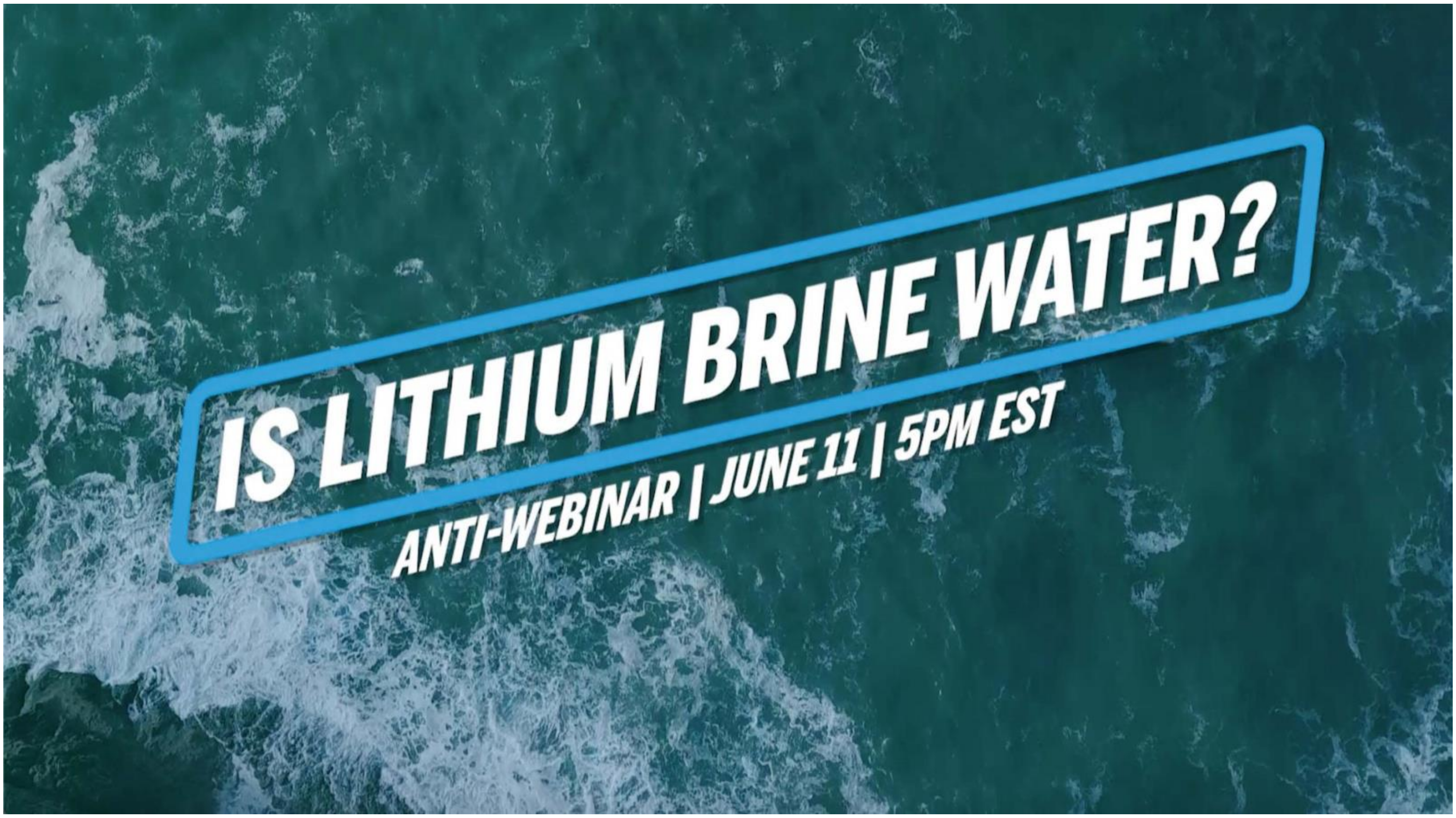
IS LITHIUM BRINE WATER?
ANTI-WEBINAR | JUNE 11 | 5PM EST

Summary and Conclusions of the “Is Lithium Brine Water?” Anti-Webinar

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Foreword

On 11 June, 2020, the Minerals Manhattan Project hosted an online "anti-webinar" to discuss one of the most controversial but important questions in the lithium industry: **is lithium brine water?** We decided to publish a summary of our conversation here in a tidy, concise format. We assembled a team from across the industry with different experiences and viewpoints, but all who want the South American lithium brine industry to flourish and to foster a greater understanding of environment impacts by the many stakeholders who tuned into the webinar and those it has yet to reach.

Alex Grant, Principal at Jade Cove Partners, is an engineer who advises projects, investors, and governments on advanced lithium extraction technologies like direct lithium extraction (DLE). He co-founded a technology company backed by Bill Gates called Lilac Solutions.

Emily Hersh, Managing Partner at DCDB Research, is an economist focused on Latin American resource development, and founder of The Minerals Manhattan Project.

Carlos Galli is an industrial engineer who has been a part of developing brine projects across the Argentine Puna, where he has studied process development, hydrogeology, and infrastructure.

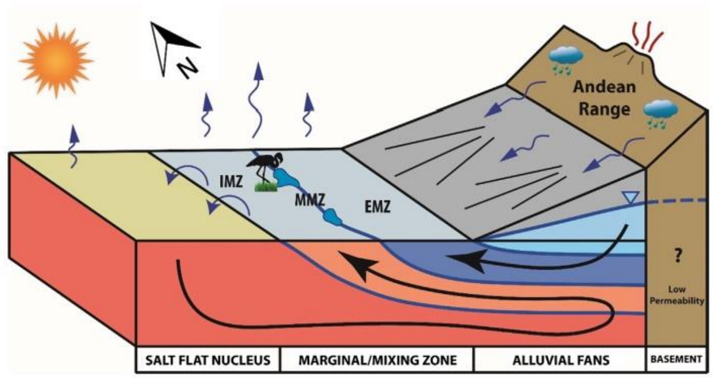
Daniel Jimenez, Partner at iLi Markets, where he advises investors and other stakeholders in the lithium industry about pricing, markets, and project development. He worked at SQM for 29 years.

Murray Brooker, head hydrogeologist at Zelandez & Hydrominex, is a consultant across the lithium and potash industries, who has studied brine/water hydraulic systems for more than a decade.

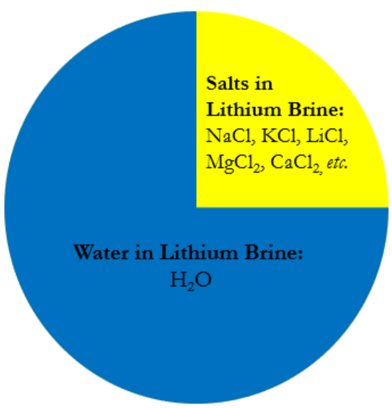
On the anti-webinar itself we did not actually answer the question "is lithium brine water?", and instead focused on real questions about environmental impacts and possible futures for the brine industry, because the question "is lithium brine water?" is a silly question.

What is Lithium Brine?

Over millions of years, rainwater falls onto mountains around arid "endorheic" basins, which are depressions in which the only way out for water is through evaporation or infiltration into deeper aquifers. Salts dissolve into that water and flow into closed basins where it collects and concentrates as water evaporates. This is how salars and brine aquifers are formed. These brines, such as those found at the Atacama, are around 25% dissolved salts, and 75% water by mass. This is in contrast to seawater, which is around 3% salts and 97% water, while drinking water is typically below 0.1% salts by mass.



When they are processed to produce lithium, they are pumped from underneath the salar, and they are subject to processes that include concentration, impurity removal and synthesis of battery chemicals like Li_2CO_3 and $LiOH \cdot H_2O$. A common concentration process is using evaporation ponds, where the impurity salts are sequentially crystallized out from the brine, producing a LiCl concentrate which is further processed into the final products. In other cases, direct lithium extraction (DLE) technologies can be used to extract the lithium directly from the brine, producing a concentrate which can be further processed to make lithium chemicals with minimum evaporation of water from the brine. However, this also requires returning (re-injecting or re-infiltrating) the brine without lithium in it somewhere else in the basin.



Hydrogeology is the study of how the brines move through the basin and under the surface of the salar. Hydrogeologists build mathematical models which can be used to predict how the brine moves, and if brine pumping will impact other aquifers. When brine is produced from an aquifer and evaporated like at the Atacama in Chile, there is concern that lower salt content water sitting on top of the brine, around the margins of the salar, may also be pulled into the salar, potentially disrupting ecosystems and water availability for humans, plants and animals. In 2019, an environmental court rejected SQM's application to produce more brine from the Atacama because there was not enough data demonstrating that these aquifer interactions were not happening. It is possible that DLE with brine re-injection could mitigate these impacts if they are demonstrated to be happening, however this is very project-specific. Almost all public data collected on brine hydrogeology and lithium project evolution over time comes from the Salar de Atacama in Chile, where there is 30 years of operation history, although Livent's Hombre Muerto operation in Argentina has also been operating for two decades. Recent academic studies of the Atacama hydrogeology are providing important understanding on the salar hydrogeology and a number of salars are in development across South America, however there is little public information on their hydrogeology.

Part 1: How Did We Get Here?

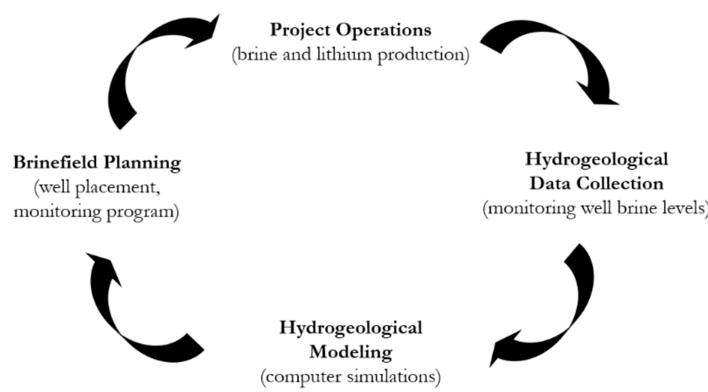
Lithium buyers and people who buy electric vehicles (thus the batteries in those electric vehicles and the lithium in those batteries) are concerned that aquifer interactions are impacting water availability for wildlife and humans in Chile and Argentina. Some of them believe that purchasing lithium from brine resources may not be socially responsible, and Alex pointed out that some have even decided to stop buying all lithium products derived from South American brines.

SQM's application to pump more brine from the Salar de Atacama was rejected in Chilean environmental court last year because they were unable to conclusively demonstrate that a higher rate of brine extraction would not impact the less salty aquifers on the East side of the Atacama. This is after 25+ years of operation there producing mainly potash, and using the most advanced hydrogeological models and monitoring well data of any lithium brine operation in the world. There appears to still not be enough data to determine if aquifer interactions are causing major issues, or if brine extraction does cause impacts, on what time scale we may expect to observe them. The audience also pointed out that water in these brackish aquifers evaporates naturally already, and some flows into the salar. So, the question is not "if" this water is lost, but "how much" and "how fast".

The lithium industry has struggled to communicate this reality to investors, customers, and other stakeholders. On one hand, there is no such thing as truly "sustainable" extraction of any mineral, because the lithium atoms in the resource do not replenish themselves indefinitely. This is true for both brines and other mineral resources. An extraction project that is properly managed should target minimized environmental impacts, but can never achieve no environmental impacts. Emily wondered who is in charge of determining what an acceptable (maximum) environmental impact looks like in the lithium brine context, and what role data and scientific literature has to play in determining this. We all agreed that quantification of environmental impacts and a focus on real data was a critical aspect of making these evaluations. An important part of this is quantifying the different types of water impacts. For example, water is lost from the brine, water may be consumed from freshwater aquifers, and aquifer interactions may cause freshwater to be lost into brine aquifers. All three impact categories are different and should be treated differently.

Part 2: Who Owns the Truth?

It is challenging to quantify and map the environmental impacts of lithium brine extraction because brine hydrogeology is complex. Hydrogeological models are built to predict how brine and water move underground using advanced mathematics and a variety of assumptions. However, it is challenging to make these models accurate since "all models are wrong but some are useful". To make them accurate, thus more useful for planning a brinefield (e.g. where to put wells and what needs to be monitored), lots of information needs to be collected on brine and water flow in the salar's aquifers. The best data comes from operating a project (i.e. brine has to be moving around), however some data can be generated before operations begin at commercial scale. Murray pointed out that operations have to start before we are able to very clearly understand how they will progress and end. Pumping tests can be used to get data to start hydrogeological modeling, and simple models can be used to plan a preliminary brinefield, but ultimately the model will evolve over time and so must the brinefield design. Active monitoring and project adjustment is critical to ensuring brine extraction does not impact other water aquifers. Data collection is key. Environmental impact statements thus can never be perfect at the start of a project, but potentially should be redone periodically throughout the life of a project. This information should be made public on the internet as Chile already does on its Snifa web portal. Some audience members expressed a desire for these documents to be made more transparent/searchable.



Daniel posited that the brine extraction companies know that they will not be able to operate indefinitely if they don't operate within acceptable ranges of environmental impacts. Emily disagreed though, and pointed to a number of mining operations around the world that cut corners to increase margins in the short term. Two examples were Vale's tailings dam collapse in Brazil and Rio Tinto's destruction of an anthropological site in Australia. Alex argued that governments should be in charge of monitoring and regulating brine extraction projects, since they may most accurately represent all stakeholders' concerns. The panel counter-argued that in many places, the government does not have good enough information or resources to regulate these types of industries, and that some governments are not stable or reliable enough to perform this task reliably.

The panel agreed that it is important for brine operators to be proactive about collecting data for getting a better understanding of hydrogeology, and mitigating environmental impacts. Daniel suggested that management teams of companies which cause unacceptable environmental damage should be fired. The panel agreed that this should be an important aspect of a mining company's governance strategy. Another important question is how the information about brine extraction impacts is communicated and to who. Most people in the world do not have adequate technical training to understand how brine/water systems work, and the key findings must be distilled with clear curation of data that most people can understand.

Part 3: What Happens Next?

Brines are an excellent source of low CO_2 intensity lithium because they are already in solution, while hard rock resources must first be roasted, then leached to make a lithium solution. The panel pointed out that technically, hard rock processing actually consumes more freshwater compared to Atacama-style evaporative brine processes, where the freshwater is used for washing the final product. The whole panel was in favor of brine development so that these resources can decarbonize the energy transition as thoroughly as possible. However, we recognized that the South American brine "industry" is severely fragmented and its social license to operate challenged. In fact, it has already lost out on growth in the lithium market because projects could not be built and expanded fast enough. Alex argued that DLE brine projects like oilfields and geothermals in California, Alberta, Arkansas, and Germany will capture much more of the growth in the market unless the perception of the South American brine industry changes.

We discussed the appeal of DLE applied to salar brine resources, since it could allow for lithium depleted brine to be returned to the salar, decreasing decline in the brine level in the salar and increasing the height of brine near brackish or freshwater aquifers, preventing changes in aquifer interactions. We also discussed the challenges of reinjecting spent brine in DLE projects, since brine without lithium in it must be returned to the salar in a way that it somehow does not mix with the depleted brine, which could affect the lithium resource. Carlos admitted he has always been skeptical that brine reinjection is possible, but we discussed that new strategies could be developed to make it possible. We also discussed the reality that DLE technologies must be developed for specific brine chemistries and subject to available infrastructure and other characteristics, and that "copy and paste" typically does not work well. Carlos mentioned the importance of recovery (quantity of lithium as final product related to the total lithium in the brine extracted) as a resource in itself that can help reducing the brine pumping intensity of projects, and Emily asked if this could be done at the expense of higher water consumption ("killing Peter to save Paul"). The panel agreed that recovery is one of several indicators (as freshwater and energy consumption) that have to be evaluated and optimized. It is well known that DLE does not necessarily decrease freshwater consumption for brine projects.

One of the panel's central conclusions to answering the question "is lithium brine water?" is that lithium producers like SQM, Albemarle, Livent, and Orocobre should share information that can form the principles of "best practices" for hydrogeology of lithium brine extraction. Further, governments should make environmental impact statements more public and accessible. We acknowledge that lithium companies are not used to collaborating with each other since they are competitors, but we think that in the absence of other "adults in the room", the lithium brine industry should work together to ensure that water impact communication strategies are professional, that all stakeholders are properly educated, and that best practices in hydrogeology are shared in order to minimize environmental impacts. A "lithium brine industry" does not truly exist yet in the same way that the oil industry exists, but we hope that this will be the beginning of a more transparent, curious, and collaborative community of lithium brine resource development.

So, Is Lithium Brine Water?

Though we don't agree on everything and our experiences of the world are very different (we were all raised in different countries and we all do different things), we still came together for a constructive and collaborative conversation about this difficult topic. We hope that lithium industry stakeholders can do more of this in the future. At the end of the day, we all ultimately desire for the lithium industry to scale effectively with the battery industry, allowing for rapid decarbonization of transport and other industries to mitigate climate change. For completeness, we decided to answer the question of the hour. If we had to answer Yes/No, with a short explanation, we would each say…

Alex Grant (Engineer)	**Yes.** But "Is lithium brine water?" is a silly question and a much better question is "Does brine extraction impact water availability for things which we value?". However, if I had to choose, I'd say that it "is" water because brine is an aqueous resource that is 25% salt and 75% water by mass. The ocean is also water even if you can't drink it. Brine is an aqueous resource just like freshwater and they are all connected, but their impacts must be modeled clearly as separate categories. The lithium brine industry needs to develop better water impact communication strategies based on these realities. Better geophysical measurements and monitoring are required to build better brinefield intelligence over the life of projects.
Emily Hersh (Economist)	**No.** I think it's a bad question though. Brine undoubtably contains water, and is physically connected to other water deposits that may support plant, animal, or human life. This is not a black and white issue, and we need to understand how brine extraction impacts water availability in other areas. Oversimplification fuels non-science based emotional responses that threaten to damage the social license - and thus long-term viability - of lithium extraction from brines.
Carlos Galli (Engineer)	**Yes.** Brine is a type of water with such a high content of other elements as total dissolved solids (TDS) that can´t be used directly for humans, plants or multicellular organisms, and has a value that is related to the quantity and quality of some of those other elements, including lithium.
Daniel Jimenez (Market Expert)	**No**. It contains water but will never become water again naturally unless it evaporates. The relevant question is whether extraction of brines affects availability of freshwater. After 35+ years of brine extraction in Atacama, there is no serious data confirming fresh water availability has been affected. Evaporation of brines occurs naturally, and therefore each salar has a level of forced evaporation up to where no effects on the surrounding availability of freshwater will be experienced. Hydrogeological modeling is key to understand the long-term behavior.
Murray Brooker (Hydrogeologist)	**Yes.** It is the extreme end member in the spectrum that is water. The huge content of dissolved salts, makes it unsuitable for consumption by man or animal and a lot of the brine naturally evaporates over time from near the salar surface.