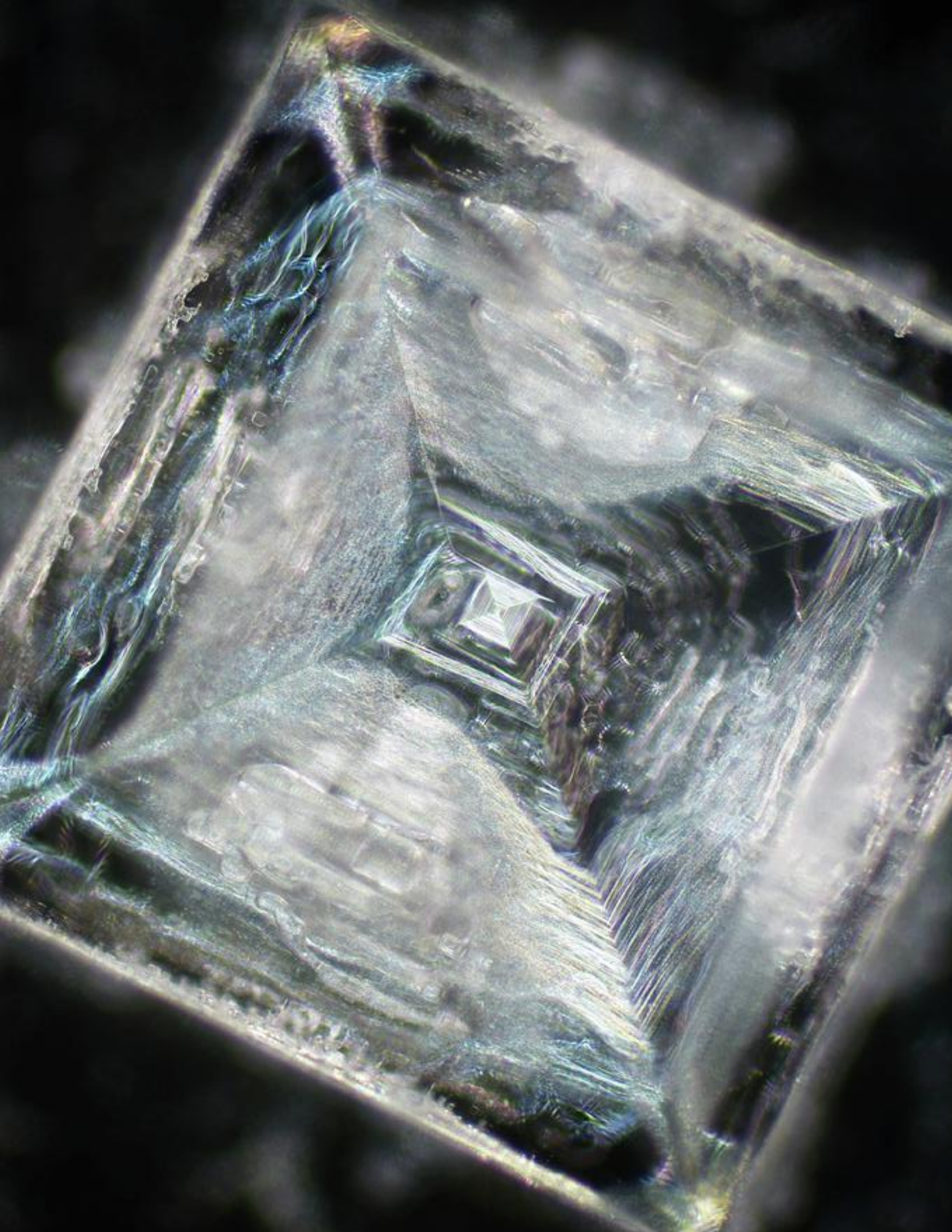

# Inside Tesla's Lithium Clay Salt Extraction Process

*Or, Can You Really Say That It Won't Work?*

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“So, my antagonist said, "Is it impossible that there are flying saucers? Can you prove that it's impossible?" "No", I said, "I can't prove it's impossible. It's just very unlikely". At that he said, "You are very unscientific. If you can't prove it impossible then how can you say that it's unlikely?" But that is the way that is scientific. It is scientific only to say what is more likely and what less likely, and not to be proving all the time the possible and impossible.”

— Richard Feynman

On 22 September 2020, Tesla announced at its "Battery Day" a series of technical advancements it was working on that when combined, could reduce the cost of energy storage in its homemade lithium-ion batteries by over 50%. Some of those announcements were impressive, some were surprising, some were obvious, but some were received with shock by lithium-ion battery supply chain stakeholders.[1] Notably, the company's "acid-free saline extraction" lithium production process development for sedimentary clays in Nevada. In the screenshot below, Elon Musk says, "Lithium is not like oil – there is a massive amount of it pretty much everywhere."


**Drew Baglino and Elon Musk at Tesla Battery Day (22 Sept 2020)** JADE COVE PARTNERS

The lithium industry reacted negatively to this proposition, with some industry analysts suggesting it could be a ruse to threaten lithium companies into lowering their prices, considering a new season of supply contracts was to come in the near future.[2] Another common criticism was that it would take years to delineate any resource and receive project permits, and no one yet knows if this has already been started.

**Sedimentary Clay Resources**

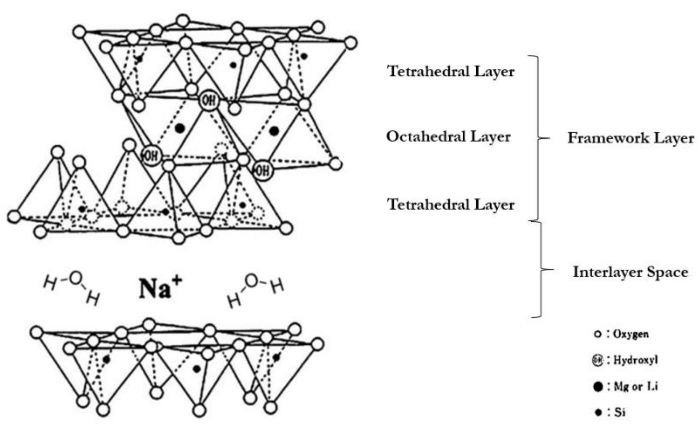
Skepticism of the technical feasibility of "saline extraction from clay" has multiple layers. First, a significant fraction of the lithium industry does not consider sedimentary clays to be an economic source of lithium chemicals. They believe this because sediments typically contain lower grades compared to pegmatitic "hard rock" minerals such as spodumene, and the impurities in a sediment extraction process are much more complex than those from a spodumene extraction process. This population in the industry will likely be proved wrong in the 2030s, since a number of sedimentary deposits across North America are reaching late stages of development, including the Rhyolite Ridge, Thacker Pass, and Sonora projects. We published an article on these projects in November 2019.[3]

Beyond skepticism of sediments in general, Tesla's announcement provoked significant skepticism that "table salt," or sodium chloride, could be used to extract lithium from a sedimentary clay at all, notably without the use of any acid. Two of the three projects listed above are planning on building sulfuric acid plants to extract lithium from their sediments at low pH, while the third plans to roast their material at a high temperature with a cocktail of reagents to enable lithium extraction with water. There are currently no ex-China projects in development that have published on an economic "saline extraction" technique. However, these comments left a lot of unknowns on the table, and the technical team developing the process would likely be able to describe it much better than two executives could.

Tesla has articulated a broad thesis beyond just lithium that using sulfate intermediates to manufacture chemicals is not an optimized flow path for atoms like lithium and nickel coming from nature to reach their batteries. Tesla has claimed to have consulted first principles to develop new processes to manufacture lithium chemicals from sedimentary clays. So, what do first principles have to say about the concept of a "saline extraction"? Perhaps others in the lithium industry have not been successful at making it work before using particular technical teams with particular ideas and testing with particular mineralogies. However, is it fundamentally physically impossible to extract lithium from a sedimentary clay with sodium chloride and no acid? The concept of a non-acidic, neutral, or basic pH extraction process for sediments is compelling because it could keep non-lithium impurities in the mineral from dissolving. Minimizing mineral dissolution could mean that other reagents are not required to separate the impurities later on. This is a desirable outcome as it lowers the costs and $CO_2$ emissions of the process. So, taking Tesla's claims at face value, is saline extraction of lithium from sedimentary clays possible?

**Clay Mineralogy and Ion Transport**

Clay minerals consist of microscopic framework layers composed of Li, Na, K, Al, Si, Mg, Ca, Fe, O, and/or OH, and inter-layer spaces through which cations like Li, Na, K, and Mg may be conducted in water or other electrolytes (like "books on a bookshelf", Tesla's metaphor for lithium in cathode materials). The position of the lithium atom in this mineral structure makes all the difference for how it can be extracted, e.g. if the lithium is found within the framework layer or floating in the interlayer.




Structure of Hectorite - A Common Lithium-Bearing Clay Mineral

We believe the mechanism for how a saline extraction could work would fall into one of two categories. First, the mechanism could be a chemical reaction between NaCl (or a product of NaCl) and the sedimentary clay mineral, which could degrade or modify the framework layer structure to liberate lithium. Second, the mechanism could be an ion exchange-type process that swaps the lithium for a sodium ion, ending with a LiCl solution and a sodiated clay with minimal modifications to the framework layer.

Below is a list of five theoretical mechanistic contributions that we believe are plausible pieces of the puzzle for explaining how a saline leach process could work. It is possible that not one of them in isolation is sufficient to explain a saline leach, but combined, they could constitute a viable mechanism to explain how Tesla's saline extraction could work.

**1. Octahedral Layer Site Exchange**

The octahedral layer within the framework layer (such as in hectorite) is restrictive to ion diffusion and exchange. The reason being is that a monovalent cation would need to be sufficiently small to diffuse through the silicate layer, or through the edges of the layer, while also adopting a favorable octahedral geometry. A $LiO_6$ unit may exist in the octahedral layer because the radius ratio of Li:O is sufficiently small. However, the larger Na:O radius ratio is slightly above the boundary between an octahedron, but does form $NaO_6$ in several other mineral cases (such as wulffite and meieranite). A more favorable Na:O radius ratio in clays could occur at an elevated temperature where O gets larger, decreasing the radius ratio to allow $NaO_6$ into the octahedral layer.[4] In conjunction with high sodium concentration to get over the Donnan Potential barrier, sodium could then exchange into the octahedral layer, liberating lithium in the process. Upon cooling, the $NaO_6$ site would be unstable. The octahedral site's instability could present a situation for lithium diffusion back into its original site. This has process design implications that could compromise the relevance of "cook and look" bench-scale extraction experiments.

**2. Interlayer Site Exchange**

If lithium resides in the interlayer spaces of the clay and it is mobile, then mixing it with a very high concentration NaCl solution could provide an entropic driving force to imbue the same ratio of Li/Na in the solution and in the clay interlayer. For example, if the interlayer spaces were in fluid communication with the bulk solution, then with enough time, the Li/Na ratio in each could end up being the same both within the interlayer and in the bulk fluid. It is possible to control that ratio, meaning the lithium could be cajoled out of the interlayer. There could be steric and other surface chemistry factors that could affect how this diffusive process would work both thermodynamically and kinetically. Considering that much more aggressive leaching techniques have been advanced by most sediment projects in development, we think it's unlikely that a significant fraction of the lithium is mobile in the interlayer, however it is not impossible that Tesla could have identified a unique mineralogy in which this is the case.

**3. Differences Between Enthalpies of Hydration**

Lithium has a higher enthalpy of hydration than sodium, meaning it holds onto water more strongly under common conditions as chlorides. This is the basis for sodium chloride and potassium chloride crystallization in evaporation ponds. Lithium chloride holds onto water more tightly than the other monovalent chlorides, so when water is removed by evaporation, the other metal chloride salts crystallize first. Tesla could leverage this effect in a saline leach. If the clay mineral was modified, or made less stable using heat or reagents to a certain point that it was possible to extract lithium (from either the framework layers or interlayers, in exchange for sodium or otherwise), lithium's enthalpic driving force to complex water molecules could be a driver for it to enter solution, i.e. to be extracted from the mineral into a leachate. This driving force would be reduced if the total dissolved solids of the leach (extractant fluid) was too high, and the lithium ion had to compete with too many sodium ions for water molecules to complex. The Gibbs free energy change of extracting lithium from the octahedral layer may be positive, but the Gibbs free energy change of solvation or whatever else happens in solution must also be considered in the total Gibbs free energy change, i.e. to judge if the process would occur spontaneously or not.[5]

**4. An Inverse Hofmann-Klemen Process**

If the mineral is hectorite, then negative structural charge of the clay ensures that the concentration of sodium at the framework layer surface is much higher than that of chlorine if in solution. This would suggest that it is more likely that sodium is the active agent in an aqueous sodium chloride extraction. However, sodium would not dissolve the aluminosilicate octahedral layer like an acid would. A possibility for sodium to liberate lithium from the octahedral sheet could be the use of an inverse Hofmann-Klemen process, in which sodium replaces magnesium in the octahedral sheet. This could destabilize the mineral structure and result in a simultaneous expulsion of lithium. A similar possibility is that sodium could enter a vacancy in the octahedral layer, expelling lithium in order to maintain charge balance. This means that sodium doesn't necessarily need to ion exchange with lithium directly in order to liberate lithium, but if other cations were exchanged first, it could mean those other cations could constitute more impurities in the leachate, similar to an acid leach.[6]

**5. Chlorination by Calcination**

The melting point of sodium chloride is 801°C. Tesla could heat a dry mixture of salt and clay to near or above this temperature, causing the sodium chloride to melt and/or potentially becoming much more reactive. This could result in chloride ions disintegrating the framework layer of the clay mineral, liberating lithium in the process, and allowing it to be washed out with water. This could work similarly to the "sulfation" extraction process which is being pushed forward by the Sonora sedimentary clay project in Mexico, in which $CaCO_3$ and $CaSO_4 \cdot 2H_2O$ is calcined with the clay to liberate lithium. This process was originally developed by the US Department of the Interior, and was also the chosen flowsheet for the Thacker Pass project until it was switched to an acid extraction process.[7] The equipment required for a calcination process could look similar to a cement kiln. If Tesla is already working on high temperature processes for cathode manufacturing, then they might be able to leverage some of their learnings from that processing to develop a high temperature salt roast process for sedimentary lithium extraction.[8]

Though we do not claim that Tesla's saline extraction process works, applies to any particular sedimentary clay material, or works economically, we believe that some of the mechanisms described above could be useful for explaining how it could work. We believe it is highly likely that their process includes high temperature processing and/or other reagents not mentioned at Battery Day.

**Engineering, Environmental Impacts, and Conclusion**

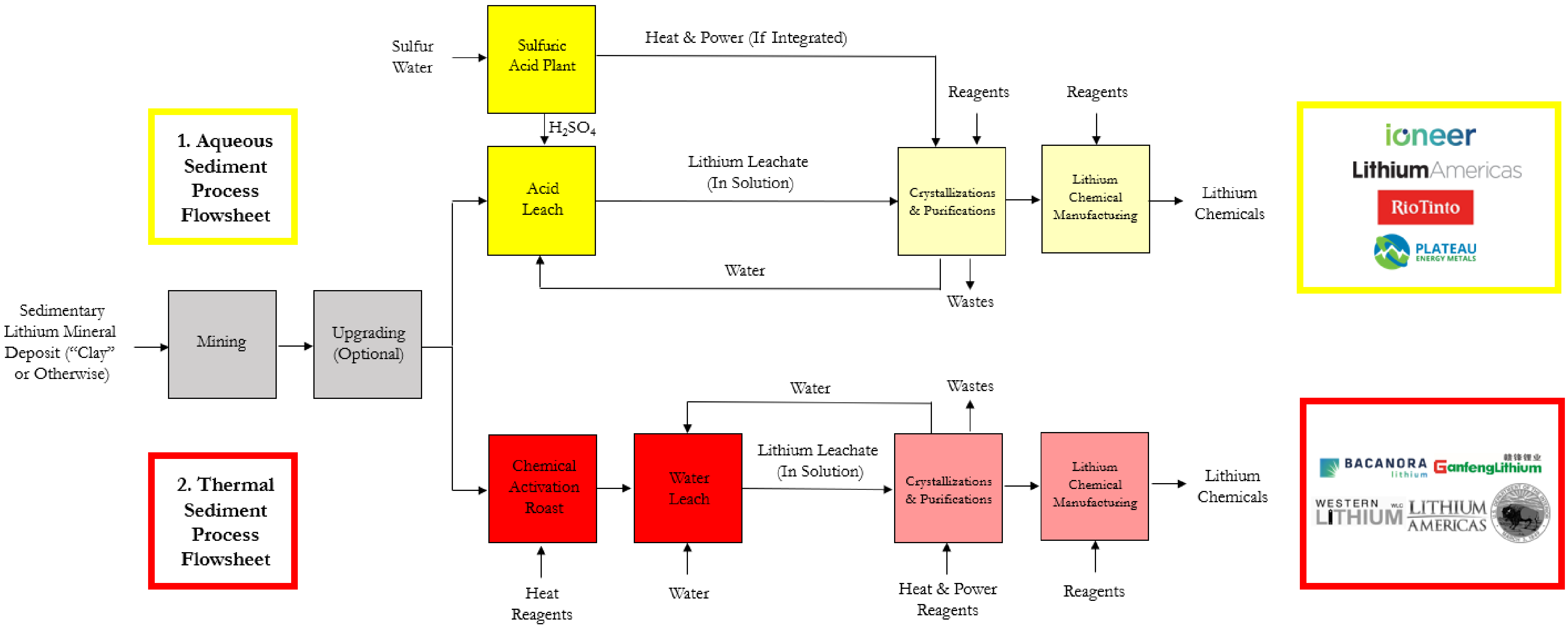
There was a lot that was not said about the saline extraction process at Battery Day. For example, we do not know if it includes high temperature processing, bases, oxidative or reductive chemicals, ultra-fine grinding or milling, beneficiation/upgrading, or other processes proposed to be used in sedimentary clay extraction. We do not know what kind of sedimentary clay mineral Tesla is working with, of which there are many variations, and they can vary dramatically in chemical behavior between different deposits. For example, this process could work on one sedimentary clay deposit and not work on another.

The process used to convert the lithium leachates from the extraction process into lithium hydroxide monohydrate or lithium carbonate could look quite different depending on the mechanism of the extraction process and its performance. For example, if in the extracted lithium solution, Li/Na >> 1, then it may be possible to produce the chemicals needed to make cathodes with minimal further processing. If Li/Na << 1, then another lithium-sodium separation process may be required before a suitable lithium chemical can be made. This may involve a series of crystallizations but that would require energy. It could also involve the use of a direct lithium extraction (DLE) technology to produce a higher concentration, higher purity lithium concentrate from the leachate. From there, the high NaCl concentration de-lithiated leachate could be recycled to extract more lithium from fresh clay, meaning the net consumption of NaCl and water could be low.

It is also not yet possible to clearly conclude that this process would have superior environmental performance in any impact categories like $CO_2$ emissions, human toxicity, water use, or land footprint. In fact, two of the three sedimentary projects in late-stage development in Western North America propose to produce all their heat and electricity from waste heat in their sulfuric acid plants, meaning the Scope 1 and 2 $CO_2$ emissions of their operations may be low. Energy needs to be bought if a sulfuric acid plant or other exothermic process is not employed, and this energy could make the process uneconomic and high $CO_2$ intensity unless concentrated solar power is used directly.

Below, we show a high-level outline of how these processes compare with respect to their overall flowsheets. Tesla's proposed process could be an aqueous or thermal extraction process, and could share characteristics with what is being done for other projects depending on the process route. If their process is thermal, then it could not be so much of a (salt+water)+clay=lithium, but perhaps a (salt+clay)+water=lithium process, similar to Bacanora's Sonora process and the "original" Department of the Interior process. Further, it could be advantageous to avoid a sulfuric acid process since there has been some (unscientific) NIMBY-esque resistance to sulfur use at sediment projects,[9] because "acid" is a scary word to some people even if it is a common chemical. Though there may be process advantages associated with not using acid, the optical benefits of being "acid-free" may be valuable for Tesla to leverage in acquiring their environmental and social licenses to operate.

The burden of proof rests with Tesla to demonstrate that this process works if they require any sort of third-party validation for development of the process. But if their process and project development is funded internally, they don't owe the world disclosure until regulatory bodies have something to say about it. Despite all the uncertainties about what Tesla is doing, we do believe that the lithium industry should pay attention. At the very least to Tesla's focus on first principles to build more optimized lithium extraction processes.




**Schematic of Sedimentary Lithium Mineral Processes in Late Stages of Development**

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