Given the Explosion in Electrical Vehicle Sales, are we in Danger of Running out of Lithium?

by Martin Flusberg

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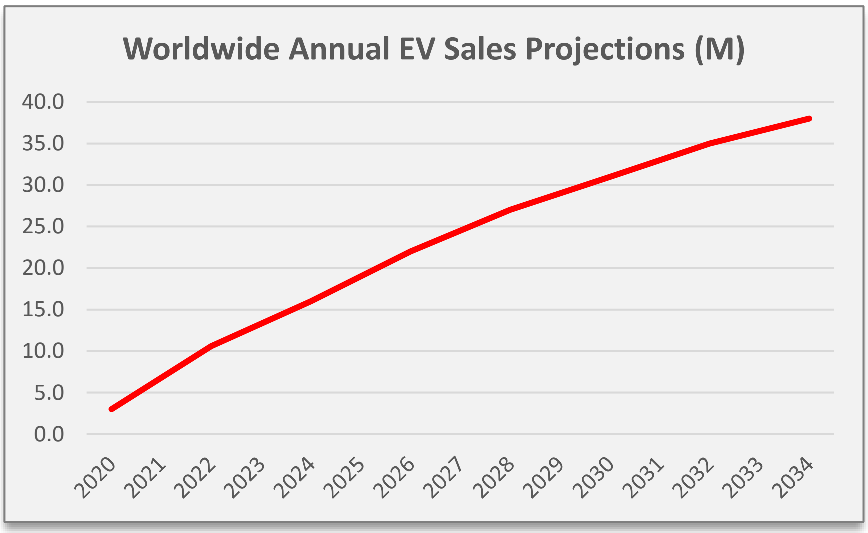
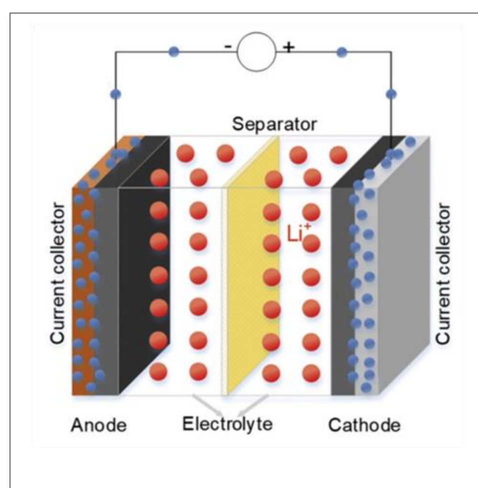
The market for Electric Vehicles has grown significantly in 2022, and with both manufacturers and nations committing to rapidly replacing gas-powered cars with EVs over the next 15 years that trend is likely to accelerate (further accelerated in the US but the Inflation Reduction Act that provides tax rebates for EVs). Projections are that worldwide EV sales will increase from approximately 6.6 million in 2021 (including hybrid vehicles) to 10.6 million in 2022 and more than 35 million annually by 2035, which will represent roughly half of all cars sold.



Source: International Energy Agency

This will dramatically increase the demand for EV batteries. And, this has raised a number of concerns, not the least of which is whether the world has enough lithium to meet this demand. Currently, virtually all EV's use lithium-ion batteries. This is the same type of battery used in mobile phones and other electronic devices (although a smartphone only uses a few grams of lithium vs. at least 8kg for an EV). Numerous articles have appeared in the past year questioning whether we will have enough lithium – or be able to mine it quickly enough – to meet EV demand. For example, the World Economic Forum released a report in July 2022 entitled "the world needs 2 billion electric vehicles to get to net zero, but is there enough lithium to make the batteries?".



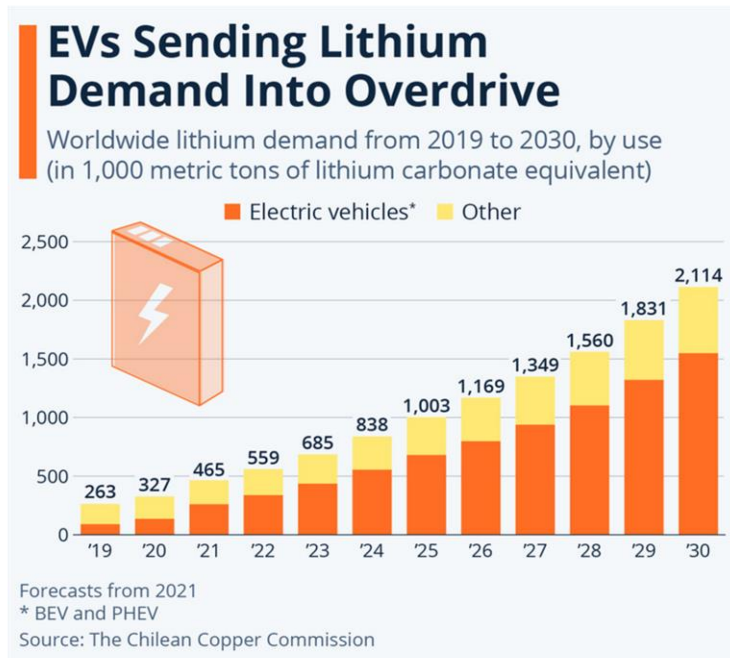
ScienceDirect: Schematic Diagram of Typical Lithium-ion Battery

Lithium is often referred to as a rare element. In fact, it is the 25th most common element on earth (some estimates have it as the 33rd). But that still means that there is a finite supply. Are we in danger of running out soon?

Before trying to answer that question, let's start with a review of current estimates of lithium mining and reserve levels.

Lithium Production and Availability

Unfortunately, there appear to be widely differing estimates of the amount of lithium being mined. For example, the World Economic Forum report noted above estimates that 100,000 metric tons of lithium were mined in 2021. A relatively consistent number was presented by Scotch Creek Ventures, which reported that lithium production in 2020 was 82,000 tons. However, a report from McKinsey estimates that about 540,000 tons were mined in 2021, which is consistent with what is reported in a recent article by ZD Net, citing other sources, which puts the estimate at just over 500,000 tons.



One Estimate of Lithium Requirements - Source: Statista

Moreover, there are wide discrepancies in estimates of lithium reserves. The World Economic Forum estimates lithium reserves in existing mine locations at about 22 million tons. However, a report from Lappeenranta-Lahti University of Technology (LUT) in Finland and the University of Augsburg in Germany, cited in a September 2020 article in PV magazine, examined various models to determine how much lithium remained back then, with estimates varying from 30-95 million tons.

The level of reserves clearly has a huge impact on how quickly we might run out of lithium. The LUT – Augsburg report analyzed a range of scenarios. Their most optimistic forecast assumes 73 Mt of lithium supply existed in 2020 (the group felt that higher estimates of lithium reserves lacked sufficient basis) and further assumes that we significantly increase recycling of lithium (to be discussed below); with these assumptions they projected lithium not being fully depleted until a few years beyond 2100. This forecast assumed that there would be 3M EV's on the road by then, which is almost double the number of total vehicles in the world today. While this suggests that there will be a lithium issue at some point, it is so far in the future that there are many years in which to address the problem.

On the other hand, their most pessimistic forecast assumed that just 26 Mt of lithium existed at the end of 2020 and that recycling efforts would only grow slowly; this forecast had lithium being fully depleted by 2040. Which is still well into the future, but less than 20 years from now.

Interestingly, none of these forecasts appear to take into consideration other potential uses of lithium, such as storage batteries for solar and wind, or for homes, another market that is expected to boom. While many of these batteries do not use lithium-ion, the majority do and therefore these batteries need to also be considered as we look at the issue of lithium availability.

Thus, it is not totally clear when we might run out of lithium, although the answer seems to be not imminently. The question, then, is: are there logical steps that can be – and are being – taken to avoid running out of lithium, or at least delay it significantly? The answer would appear to be yes, as outlined below.

Expanded Lithium Mining

The obvious first reaction to the need for additional lithium is to ramp up lithium mining. Given the huge jump in lithium prices in the past year - surging EV demand has seen lithium prices skyrocket by around 550 percent – there is a major movement to increase production. New mines are being proposed, but concerns about the environmental implications means it will take a while for new mines to be in production, so most of the near-term increase in mining will occur in existing mines.

While the vast majority of lithium-ion battery manufacturing (65%) is done in China, Australia leads the way in lithium mining, currently responsible for about 50% of all lithium production, with South America responsible for more than 40%. But developments are happening throughout the world that are likely to result in broader lithium mining and battery manufacturing.

Silver Creek Lithium Mine

The US lags far behind on both, but that looks like it is starting to change. The only operating lithium mine in the US is Silver Creek in Nevada (a former silver mine), operated by a major lithium mining company called Albermale. Silver Peak had been supplying about 5,000 metric tons per year, with no expectation of major future growth. Now it's invested $60 million in an expansion and is on track to make 10,000 metric tons a year by 2024.

At Silver Creek, the metal is extracted from brine, a liquid found beneath the ground. Brine extraction is much greener than hard-rock extraction. It demands more water and has a larger physical footprint, but uses less harmful chemicals and, since it relies on solar evaporation, less energy. Albermale is also working to reopen a lithium mine in Kings Mountain, N.C., and plans to build a refinery in the Southeast.

Overall, dozens of lithium mines are in various stages of development in the United States – including locations in California, Tennessee, and Oregon. The requirement in the Inflation Reduction Act for domestic production is already beginning to have an impact.

There is also a lot of movement related to lithium mining in Canada. Canada has made it a mission to become a major source of raw materials and components for electric vehicles. But most of these projects are years away from production.

One Canadian project that should move forward much more quickly is a deep mining pit located about 350 miles northwest of Montreal that has changed hands repeatedly and been in bankruptcy, but now could become a major source of lithium.

If the mine, now operated by Australian company Sayona Mining, opens on schedule early next year, it will only be the second North American source of lithium after Silver Creek. After the price of lithium fell by half from 2017 to 2020, the mine's previous owner, the Chinese battery maker CATL, shut down operations and declared bankruptcy. Sayona, working with a lithium mining and processing company based in Belmont, N.C. called Piedmont Lithium, bought the operation last year and is working on ramping up production.

And expansion is underway in other countries as well. But, the majority of known reserves, about 60%, are actually in multiple South American countries, and that is where the largest near term ramp up of mining might be expected.

The salt flats of the so-called lithium triangle—made up of Argentina, Chile, and Bolivia—contain roughly half the world's known lithium. Last year, these countries produced over 40 percent of the world's lithium. Lithium is typically extracted from the salt flats by pumping brine into ponds and processing the lithium salts that crystallize once the water has evaporated. It requires time and investment to set up, but thereafter production is cheaper – and as noted earlier much less energy intensive - than the hard-rock mining practiced in Australia.

But, both Chile, the second largest lithium producer which reportedly produced over 100,000 metric tons of lithium carbonate in 2021, and Bolivia, have imposed state controls that may limit the amount of lithium that might be mined in the short-term.

Chile considers lithium a strategic resource and does not allow mine operators to own any of the lithium they find. While they can apply for a special license to extract lithium, in practice all they can do is lease from the state, which only two lithium mining companies—Albemarle and SQM—have done. No new mines have been opened in the past 30 years. Expansion plans have been complicated by local objections about the use of so much water in a desert region, and scandals involving Albemarle and SQM allegedly extracting more brine than allowed. As a result, the mining companies have focused on extracting lithium more efficiently from the same amount of liquid and, while production has grown, it has not grown as fast as it could have if they were pumping more brine, too. Chile's new government is creating a state lithium company that is intended to extract lithium in alliance with private companies, while paying greater attention to the demands of local communities. But it is expected that any such joint ventures will take a long time to develop.

Bolivia has more lithium resources than any other country, but 14 years after the state declared its intent to industrialize its salt flats, large-scale production has yet to begin. YLB, Bolivia's state lithium company, has dug ponds to pursue the same extraction method as Chile and says it will produce 15,000 metric tons a year starting in 2023. But that sounds optimistic since Bolivia has yet to start building the required water treatment plant. Moreover, Bolivia's salt flats have relatively low concentrations of lithium, high levels of impurities, and a rainy season that lasts several months — all of which complicate the proposed method of extraction. YLB is now considering direct lithium extraction (DLE) technologies that pull lithium straight from the brine, potentially without the need for solar evaporation. But DLE technologies are relatively unproven; there are just 5 operations using DLE technologies: 1 in Argentina and 4 in China. None of these use DLE alone but rather combine it with solar evaporation.

That leaves Argentina, which has taken a liberal approach to developing its lithium industry, with little state involvement, low taxes, and permissive regulation, to be the location where a major expansion of lithium mining can be expected in the near-term. There has been significant investment from international companies since lithium prices began to climb in mid-2020. Two new projects are already producing roughly 40,000 metric tons of lithium carbonate; another is set to become active before the end of the year; and almost 40 others are at some stage of development. So, Argentina is set to be a major player in the race to expand lithium production.

Another avenue of research and investment is the potential to use improved technology to extract lithium from the brine used at geothermal power plants. Because the brine is already being pumped, and no large evaporation ponds would be required, it promises a much smaller environmental footprint - if companies can pull it off.

It appears that it will take a while for lithium mining to begin to produce significantly more lithium, but the process is clearly underway.

Recycling

While increasing lithium production is one way to ward off a shortage, another approach is to recycle lithium from existing batteries as they reach end-of-life.

However, currently there is *virtually no* recycling of lithium.

A study earlier this year in the *Journal of the Indian Institute of Science* found that less than 1 percent of Lithium-ion batteries get recycled in the US and EU compared to 99 percent of lead-acid batteries. The study cited recycling challenges such as evolving battery technology, costly shipping of dangerous materials, and inadequate government regulation.

Recycling of lithium is not easy because of the way that batteries are made. For example, it's difficult to disassemble the battery and extract the lithium and and various gases may escape in the process.

However, the reticence to recycle appears to be starting to change. According to a recent United States Geological Survey report, about two dozen companies in North America and Europe are recycling lithium batteries or have plans to—up from a single company and facility just a few years ago. This growth has been made possible by changes in the recycling process for Li-ion batteries.

- For example, Northvolt, a Swedish battery maker, has a process that involves dismantling the batteries down to the level of modules before beginning any crushing, shredding, or chemical processes. A year ago, Northvolt produced its first battery from using only recycled material. The company hopes to heavily automate most of the dismantling process in the near future.

- American Battery Technology Company (ABTC) has an automated "de-manufacturing" process to make chemical extraction easier. Their two-part recycling process involves the disassembly of the batteries, followed by a hydrometallurgical, or chemical, process to accomplish recycling. ABTC is currently building its first facility in northern Nevada, scheduled to be completed at the end of 2022, which they say has the potential to recover battery-grade materials in under three hours. The company claims that this facility will the able to take in 20,000 metric tons of recyclable material per year.

- Canadian firm Li-Cycle, one of the first companies to focus exclusively on lithium-ion battery recycling, will shortly begin constructing a $175 million plant in Rochester, N.Y., When completed, it will be the largest lithium-ion battery-recycling plant in North America. The plant will have an eventual capacity of 25 metric kilotons of input material, projected to recover 95% or more of the cobalt, nickel, lithium, and other valuable elements through the company's zero-wastewater, zero-emissions process - with zero diversion to a landfill, no wastewater, and no direct emissions. Li-Cycle has focused on improving on traditional hydrometallurgical recycling; for instance, rather than dismantling an EV battery pack into cells and discharging them, they separate the pack into larger modules and process them without discharging. The process involves the decentralized disassembly of batteries into their fundamental building blocks, followed by shredding into inert products. From there, materials like plastic, copper, and aluminum go to local recycling streams. The remaining intermediate product, a wet fine powder called black mass, is shipped to a central hub where it's refined to extract lithium, nickel, etc.

- Tesla is developing an electric-car-battery recycling system at its Gigafactory 1 battery production plant in Reno, Nevada. The plan is to process manufacturing scrap and end-of-life batteries into raw materials to be reused by the company

The bottom line: recycling has the potential for becoming a major source of lithium supply. It won't happen in the short-term, because it will take a while until there are enough batteries to recycle, but it will become a more important source as we begin to further deplete lithium reserves.

Lithium Replacement

Thus far we have focused on what is being done to expand the supply of lithium. But there are also multiple efforts aimed at replacing lithium in EV batteries entirely. This has even more importance since the mining of lithium requires a significant amount of energy and has a range of environmental impacts. Moreover, material extraction is only the first step; processing of minerals like lithium usually requires toxic chemicals and refineries typically dispose of waste in tailings piles or evaporation ponds from which poisonous fluids can leak into the environment, potentially contaminating the soil and water.[1]

One example is ***Alsym Energy***, based in Woburn, MA, who says they've built a new kind of rechargeable battery that doesn't contain lithium or cobalt and delivers the performance of lithium-ion cells at half the cost. Alsym has been in stealth mode since its founding in 2015 and is extremely secretive about the chemistry that makes the battery work. What has been reported is that the electrolyte — the material that carries energy between the two electrodes —contains water mixed with some solvents, and that one of the electrodes is mostly made of manganese oxide. Nothing has been reported about the other electrode.

Alsym has reportedly signed major orders with shipping companies that plan to use the batteries as an auxiliary power source. They also signed a deal with one of India's biggest carmakers to provide electric car batteries.

It will probably take a few years to determine how effective these batteries are, but an Alsym factory has already begun building prototypes. Since Alsym batteries can be made using the same equipment found at any lithium-ion battery plant; only the materials inside the batteries are different. That means existing battery plants could quickly switch over, if and when the Alsym batteries prove their worth.

Revolution Power Inc. dba ***Powerit,*** is a metal-air battery designer and manufacturer that uses non-lithium materials. They claim that their metal-air technologies dramatically increase power/kg over existing battery technologies, cost less to produce, and improve overall battery safety. They report that they have successfully developed a proprietary, safe, recyclable first-of-its-kind air-charger that is ready for market introduction.

On another front, sodium has been proposed as a replacement for lithium. For about a decade, scientists and engineers have been developing sodium batteries, which replace both lithium and cobalt used in current lithium-ion batteries with cheaper, more environmentally friendly sodium. Unfortunately, in earlier sodium batteries, a component called the anode would tend to grow needle-like filaments (called dendrites) that can cause the battery to electrically short and even catch fire or explode.

[1] There are also a number of companies developing ways to make lithium production less energy intensive. One example is 6K, which uses a microwave plasma approach. Another is Energy Exploration Technologies (EnergyX), which offers a direct lithium extraction and processing technology designed to increase lithium yields, reduce the need for heavy chemicals, metals, and large amounts of water. They claim they are able to produce lithium at a much faster rate than current methods

More recently, University of Texas at Austin researchers have created a new sodium-based battery material that is highly stable, capable of recharging as quickly as a traditional lithium-ion battery, and may deliver more energy than current battery technologies.

In one of two recent sodium battery advances from UT Austin, the new material appears to solve the dendrite problem and recharges as quickly as a lithium-ion battery. The team published their results in the journal Advanced Materials.

And what better place to find sodium/salt than seawater? A team at the Karlsruhe Institute of Technology in Germany has developed a prototype battery based on seawater, with the sodium that is naturally dissolved in it carrying the charge.

There are also a number of other approaches that have been proposed for lithium replacement, with development at various stages. These will clearly take years to develop, but they offer another way to address lithium shortages. Examples of other proposed lithium alternatives include:

- **Glass batteries -** The University of Porto in Portugal has been working on a battery design with John Goodenough, the inventor of the Li-on battery. The key component is the electrolyte, which is made of glass spiked with sodium ions, which can travel through it. Every material needed is easy to source. The University claims that the battery can outperform lithium-based batteries, but others are have reported issues replicating this approach.

- **Calcium -** Calcium can deliver twice as many electrons per ion between electrodes as can lithium-ions, so calcium batteries could offer a higher capacity than lithium batteries. Calcium is also reported to be 10,000 more abundant on the earth's crust than lithium. However, a lack of suitable electrolytes has limited research. Recently, a team of Korean university researchers has reported that calcium can be used in place of lithium for EV batteries. The researchers, who worked with the Argonne National Laboratory in a project sponsored by the US Department of Energy, conducted quantum mechanics simulations to determine which metals could work in a calcium-based ion battery.

- **Magnesium -** Lithium and sodium ions can only carry an electrical charge of +1. Magnesium carries a +2 charge and several research teams are working using magnesium. That being said, it is clearly still early days for magnesium research.

- **Fuel cells -** Fuel cells can be thought of as batteries that you charge by adding fuel. RMIT University in Melbourne, Australia, has been developing one that splits protons from water, which are then stored inside the battery. To release this power, oxygen from air is fed through the machine, which combines with the protons to produce water and electricity.

- **Liquid batteries -** Otherwise known as flow batteries, these work on a similar principle to regular batteries, but all the components are dissolved in liquids. The University of Glasgow has developed one such battery based on an enormous tungsten-containing molecule. The advantage is that a charged-up liquid battery could be pumped into an electric car quickly. The main barrier appears to be that the electrical charge makes the liquid electrolyte sticky and therefore difficult to pump.

- **Solid-state batteries -** The development of solid-state batteries that can be manufactured at a large scale is a key goal of some manufacturers. The intent is to develop solid-state batteries that are suitable for use in electric vehicles but surpass the performance, safety, and processing limitations of lithium-ion batteries. In contrast to research into lithium-ion batteries, which will provide incremental gains in performance towards theoretical limits, research into solid-state batteries is long-term and high risk but has the potential to bring high rewards.

Bottom Line

Given the vastly different numbers being presented for lithium production levels and reserves – not to mention the as yet unknown actual pace of EV rollouts - there is no clearcut picture of if and when we are danger of running out of lithium.

But; the world is not standing still while it begins to run out of lithium. As noted above, there are major activities underway to expand lithium mining, begin to recycle lithium as batteries end their useful lives, and replace lithium entirely. While nothing is going to happen overnight, with all of this activity we should be able to avoid reaching a point anytime soon where limitations on battery production becomes a barrier to EV production.