OCEAN WALL

THE CASE ON LITHIUM

September 2020

INTRODUCTION

Lithium is one of the most critical metals in modern industry, with uses ranging from aeronautics with light lithium alloys to medicine. The most important usage nowadays is Lithium-ion Batteries (LIBs), offering long term relevance. Lithium has been gaining investor interest, largely due to forecast demand growth in the rechargeable LIBs market. The price of lithium has been falling since its peak in April 2018 (*Figure 1*) at $20,000 per Metric Ton, due to speculated oversupply and a slower rise of demand than predicted.

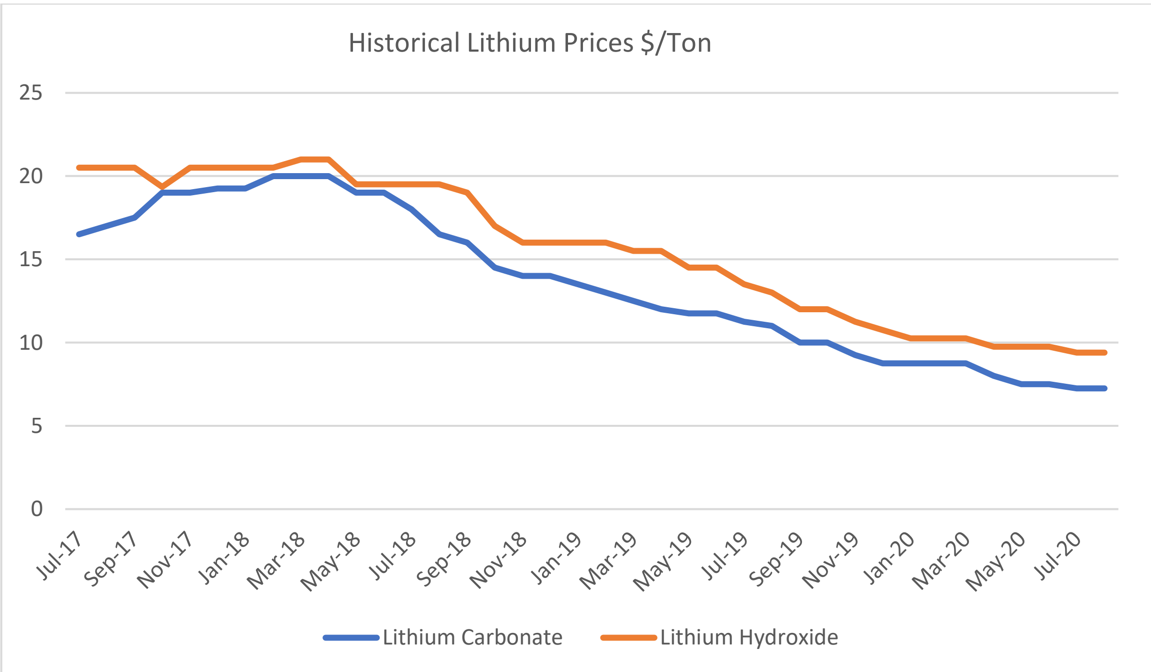


Figure 1. *Price of Lithium Carbonate and Lithium Hydroxide July 2017 to present*

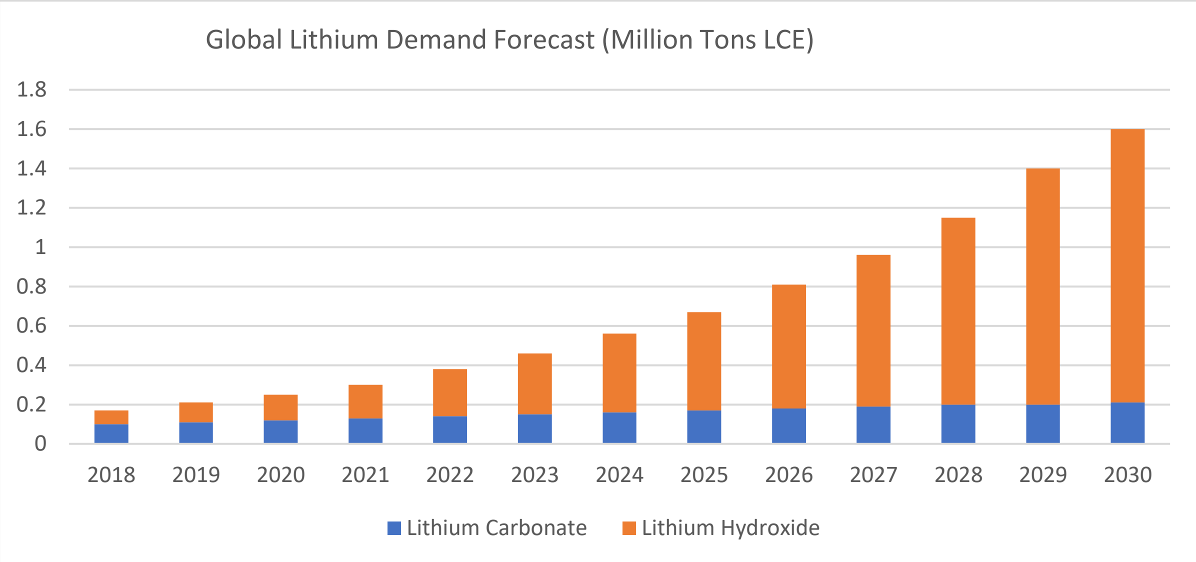
This report gives an overview of the lithium industry: what lithium is and what its uses are; the extraction methods, innovations in the extraction market and the various lithium products; where the lithium resources are; alternatives to lithium in LIBs and renewable energy storage; future lithium demand and the investment case, with respect to the supply and demand factors in the market.

OVERVIEW

LOCATION OF RESERVES

	Reserves, Million tons (Mt)	Economically viable reserves, Mt	% of total reserves that are economically viable
Bolivia	21	0	0
Argentina	17	1.7	10
Chile	9	8.6	96
USA	7.3	0.63	9
Australia	6.3	2.8	44
China	4.5	1	22

GLOBAL DEMAND



CORPORATES

MAJOR MINERS

	Mkt Cap bn$	Country	Main Resources	
Jiangxi Ganfeng Lithium	9.1	China	Australia, Argentina, China, Ireland	
Tianqi Lithium	4.45	China	Australia, China	51% owner of Greenbushes
Albemarle	10.44	US	Australia, Chile	49% owner of Greenbushes
Sociedad Quimica y Minera (SQM)	4.0	US	Chile, Argentina	24% owned by Tianqi
Livent	1.3	US	Argentina	

TECHNOLOGY

	Country	Technology
Summit Nanotech	Canada	Cleantech innovator in Direct Lithium Extraction.
Lilac Solutions	US	Ion exchange technology for Lithium producers.
Energy X	US	Breakthrough Direct Lithium Extraction technologies.
Primus Power	US	Energy storage solutions
ESS	US	Energy storage solutions

LITHIUM PRICES

Lithium prices have continued their 2-year bear run throughout 2020 and the benchmark Fastmarket prices are currently at $7,250 per ton for Lithium Carbonate and $9,400 per ton for Lithium Hydroxide.

In their report of Oct 2019 Goldman Sachs in attempting to call the bottom of the Lithium price cycle suggested that falls from the levels then of $9,000/t and $11,000/t would result in a significant contraction in supply as marginal producers ceased production.

While we make no attempt here to call the low there is a growing feeling that prices are at least flattening off and further significant weakness is unlikely as supply chains and margins are already fragile.

Lithium production to date has been focussed on the relatively easy to store and transport Lithium Carbonate, however as battery technology advances the increased demand is emerging as being for Lithium Hydroxide hence the significantly higher price. Demand growth is anticipated at a CAGR OF 10-14% to 2027 for Lithium Carbonate and a CAGR of 25-29% to 2027 for Lithium Hydroxide as shown above. In Australia the development of 2 plants close to the Greenbushes mine which will process Spodumene directly into Lithium Hydroxide, the technological advances being made in the processing of South American brine directly into Lithium Hydroxide and the more advanced processing of Lithium Carbonate into Hydroxide should, combined, result in this differential contracting over the medium term.

Demand for batteries for the EV market is expected to triple to 2027 valuing it at $310.8 bn from $113.4 bn now, though accurate demand numbers for Lithium are few and far between, we can safely assume that demand will catch up with available supply by 2028 at the latest and significantly earlier than that without some strengthening of prices.

That aside, the key for producers will be keeping production costs as low as possible while ensuring that environmental impact is minimised, and social welfare is maintained.

There is also a significant increase in demand for energy storage solutions for the renewable energy market in order to flatten off the intra-day supply curve. While current battery technology is proving to be very difficult to align with this short-term storage there are huge advances being made and, in most cases, the underlying battery technology is Lithium based.

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USES FOR LITHIUM

Lithium is one of the most critical metals in modern industry. Even before electric cars, lithium was a hot commodity with uses ranging from pharmaceutical, with lithium-based bipolar disorder treatment drugs, to aeronautics, with light lithium alloys and shock resistant glass. Lithium has physical properties that make it different from other metals. Unique properties make lithium and its compounds capable of energy density – the ability to pack a lot of power into a very small space. As a result, lithium has become an extremely important component of batteries for laptops, phone and other digital devices. Therefore, the most prominent usage nowadays is in Lithium-ion Batteries (LIBs) in both consumer electronics, such as laptops or cell phones, and electric vehicles, EVs.

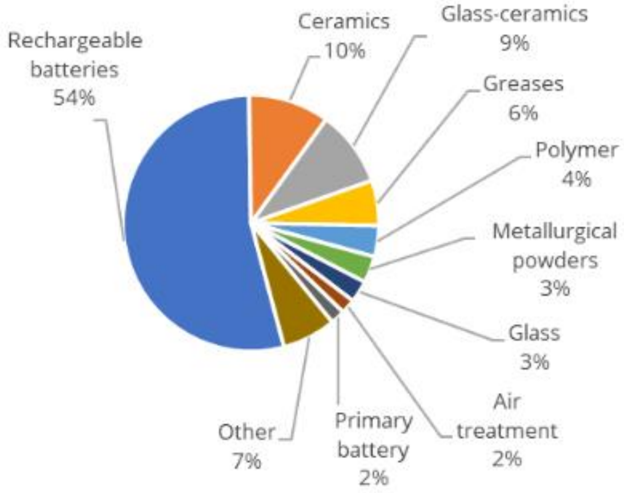


Figure 2. *Lithium demand by end-use industry, 2019 (%)*

Among those uses, LIBs show the highest percentage growth rate and are expected to play an even bigger part in the lithium industry (see Lithium Demand). Lithium carbonate (Li2CO3) and lithium hydroxide (LiOH) are the two primary lithium compounds that are used in LIBs.

LITHIUM EXTRACTION

Lithium is an alkali metal; the lightest of all metals and the least dense of any elements that are solids at room temperature. Because of its inherent instability and reactivity, it never occurs freely in nature. Lithium salts are found in underground deposits of brine, mineral ore, and clay, as well as in seawater and geothermal well brines/water. A set of chemical processes are required to extract and isolate the lithium to be converted to a saleable form of the metal.

The resources of lithium are primarily divided into three categories. The first are brines. They are, by far, the main source of lithium with more than 60% of the global identified reserves (GIRs). Among the brines, the salars, which are dried salt lakes, hold 78% of the lithium brine reserves. The second source, by amount of lithium available, is minerals in the form of pegmatites. Extracting lithium from minerals is called hard rock/spodumene lithium extraction. Recent estimations evaluate mineral reserves as 23% to 30% of the lithium GIRs. The third source is Sediment-Hosted Deposits, such as clay, which represents less than 3% of the lithium GIRs.

LITHIUM BRINES

Lithium brine deposits are accumulations of saline groundwater that are enriched in dissolved lithium. These are common in nature, but there are only select regions in the world which contain brines in closed basins in arid regions; conditions which must be met to extract lithium salts at a profit. There are also Geothermal (accounting for circa 3%) and Oil Field (also accounting for circa 3%) brine resources, but these account for a small percentage of deposits. Drilling is required to access the underground salar brine deposits, which typically contain around 200 to 1,600 milligrams per Litre (mg/L) Li. The brine is then pumped to the surface and distributed into evaporation ponds. The brine remains in the evaporation ponds for a period of months or years, depending on the climate, until most of the liquid water content has been removed through solar evaporation, each pond in the chain having a greater Li concentration. A concentrate of 1 to 2 percent Lithium is required to start processing in a chemical plant with calcium carbonate to extract the lithium products, such as lithium carbonate and lithium metal. The requirements for Lithium brine are as follows: an arid climate with a closed dried up basin, geothermal activity with suitable lithium source-rocks, one or more adequate aquifers (underground layers of water) and sufficient time to concentrate the brine economically. These conditions result in suitable lithium brine reserves being in very specific regions. The salars of Chile and Argentina have the highest lithium concentration in the 680-1570 mg/L range.

Figure 3. *Brine mining in the Salar de Atacama*

HARD ROCK MINING

While accounting for a relatively smaller share of the world's lithium deposits, mineral ore deposits yield nearly 20 million tons of lithium annually. Hard rock or mineral resources are far more homogeneously distributed on Earth with deposits located on each continent. But still, only a few sites are currently producing in Canada, Australia and China. Well over 100 different minerals contain some amount of lithium, however, only five are actively mined for lithium production. These include spodumene, which is the most common by far, as well as lepidolite, petalite, amblygonite, and eucryptite. Spodumene offers a theoretical Li content of 3.73%, whereas raw minerals in nature typically offer 1 to 2% Li with some notable exceptions such as Greenbushes, Australia which offers a high rate of 3.10% Li . Some mines have higher yields than others. Mineral ore deposits are often richer in lithium content, i.e. are higher quality, than are salar brines, however, they are costly to access since they must be mined from hard rock formations. Spodumene deposits are commonly hosted in pegmatites, and are mined by conventional open cut mining, followed by crushing and grinding, and extraction using a mixture of gravity, heavy media separation, magnetic separation and flotation to produce a concentrate, largely comprised of spodumene. The spodumene concentrate is then usually sold and shipped to lithium hydroxide or carbonate conversion plants, mostly located in Asia, where it is converted to these respective lithium chemical products. Hard rock lithium mining relies on traditional methods of drilling and processing.

OTHER EXTRACTION METHODS

- Hectorite clay:
  - Extensive research and development has been invested into developing effective clay processing techniques, including acid, alkaline, chloride and sulphate leaching, as well as water disaggregation and hydrothermal treatment. To date, none of these technologies has proven economically viable for extracting lithium from clay.
- Seawater:
  - While seawater is actually a brine, it differs from traditional lithium source brines (e.g. salars) in that the lithium concentration in seawater is much lower. A commercial lithium production operation usually extracts the metal from source brines with a lithium concentration of 800 to 1600 mg/L. By contrast, seawater contains less than 1 mg/L of lithium. While existing processes have succeeded in extracting lithium from seawater, it is not economically viable to do so.

BRINE VS HARD ROCK COSTS AND MARGINS

Lithium is abundant around the planet, but it most often occurs in low concentrations that are not economic to start production.

If suitable hard rock reserves are found it presents a great opportunity for countries to develop their own sources of lithium and for investors of hard rock lithium explorers and developers. Currently only a few sites are currently producing through hard rock mines in Canada, Australia and China.

The largest reserves of lithium are in brine deposits and these reserves are primarily found in the Salars of the Lithium Triangle – Chile, Argentina and Bolivia.

EXPLORATION

In general, lithium brine deposits are easier to explore, faster to put into production and require less capital to mine. From exploration through to development and production hard rock can cost from US$300m – US$2bn and take up to 10 years versus brine which will take half that time and cost US$150-US$300m. New technologies involving direct extraction from brine could reduce those costs even further.

***Table 2**. Comparisons between hard rock and lithium brine for development, location and exploration*[7]

Hard Rock Mining	*Lithium Brine*
Global Identified Reserves - %	
23-30%	60%
Location Setting	
• The setting and location of typical mining deposits can vary greatly • Access can be easy or hard depending on where the mineral is found	• Lithium brine deposits occur in salt flats, specifically in the "Lithium Triangle" • Fewer logistical or topological challenges, easier to ship after evaporation
Prospecting and Exploration	
• Claims may be harder to gain for hard rock mining • Diamond core drilling (to test targets) 5,000 metres total usually required • Advanced field programs and geophysical surveys required	• Flat and arid land make exploration cheaper • Softer rock and less geological complexity makes prospecting cheaper, being liquid compares it to drilling water • Lithium brine is not as deep as most hard rock deposits, so can be done to a shallower depth
Development	
• Diamond core drilling, >100,000 metres over the project lifetime • Metallurgical Test Work, and permitting	• Environmental studies less involved than hard rock • Resource expansion requires fewer metres of drilling

PRODUCTION COSTS

What is produced at a hard rock mine and a brine mine is also different. Hard Rock mines produce a spodumene concentrate which then requires further processing to produce lithium carbonate or lithium hydroxide; whilst the brines produce lithium carbonate which requires no further processing. Advancing technologies mean, in the future, that brines should also be able to produce lithium hydroxide too if required.

The cost of producing the spodumene concentrate at hard-rock lithium mines is generally around US$2,540/t.

The cost of producing lithium carbonate from brine will be around US$5,580/t.

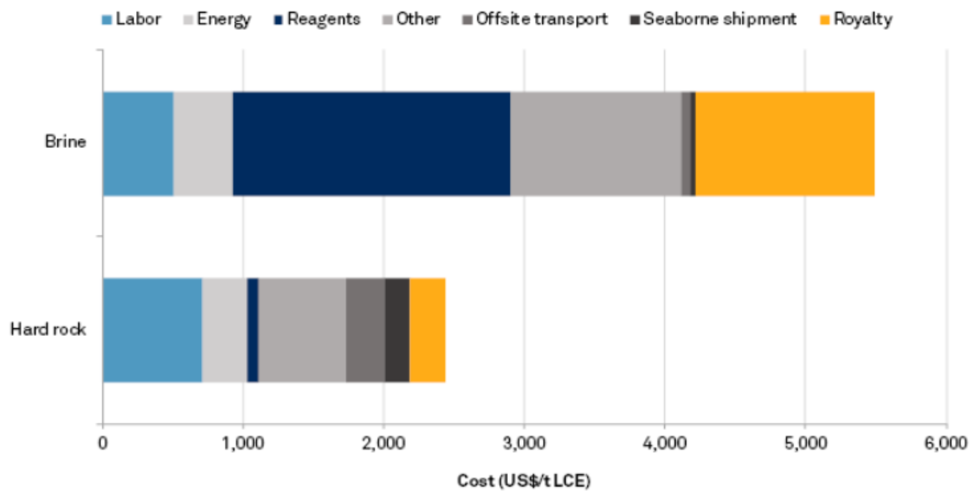


Figure 4. *Costs for both brine and hard rock extraction, May 2019*

PRODUCTION PRICES

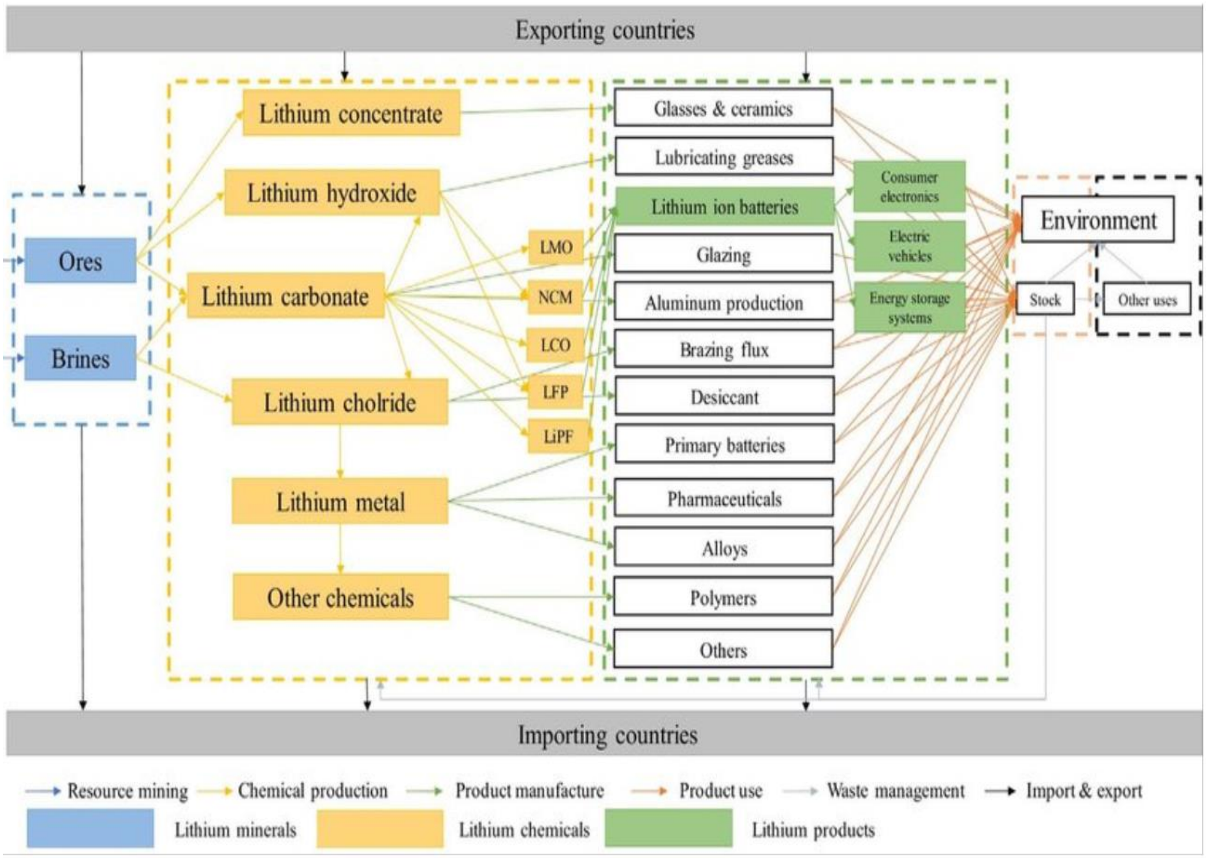
Although hard-rock producers have lower costs, the price (average: US$ 4,619/t) they receive for their end product, spodumene concentrate, is significantly lower than that received for lithium carbonate, chloride and hydroxide (saleable compounds). Brine producers receive a considerably higher price (range: US$8,552/t to US$12,500/t) for the lithium carbonate which is produced at brine operations (see *Figure 6*).

Once the spodumene concentrate is purchased it must then be transported away from the mine to processing plants (mainly located in China). The facility is likely to have to remove impurities first, then the lithium second. The lower price for the spodumene concentrate reflects the cost involved in the transportation and conversion to lithium hydroxide or carbonate.

Another factor to consider in production costs is the concentration of lithium in the stream. The higher the concentration of lithium, the less amount of ore and brine processing the facility is required do, which also reduces secondary wastes and overall cost. Mineral ore deposits are often richer in lithium content i.e are higher quality than salar brines, however, they are costly to access since they must be mined from hard rock formations. Due to the added energy consumption, chemicals, and materials involved in extracting lithium from mineral ore, the process can run twice the cost of brine recovery, a factor that has contributed to its smaller market share along with a smaller natural reserve.

There are additional risks to brine extraction. Evaporation of brine is far more susceptible to uncontrollable external factors such as changes in weather, which will have a severe effect on the solar evaporation process. This risk is potentially mitigated through innovations in lithium brine extraction methods, as discussed later.

As shown below *Figure 5* demonstrates the connectivity of different products in the industry, and how some are feed stock into different products.



Most lithium products are traded using long-term contracts, and prices vary based on both the lithium content and impurities and the price-negotiating strategies of the operating company.

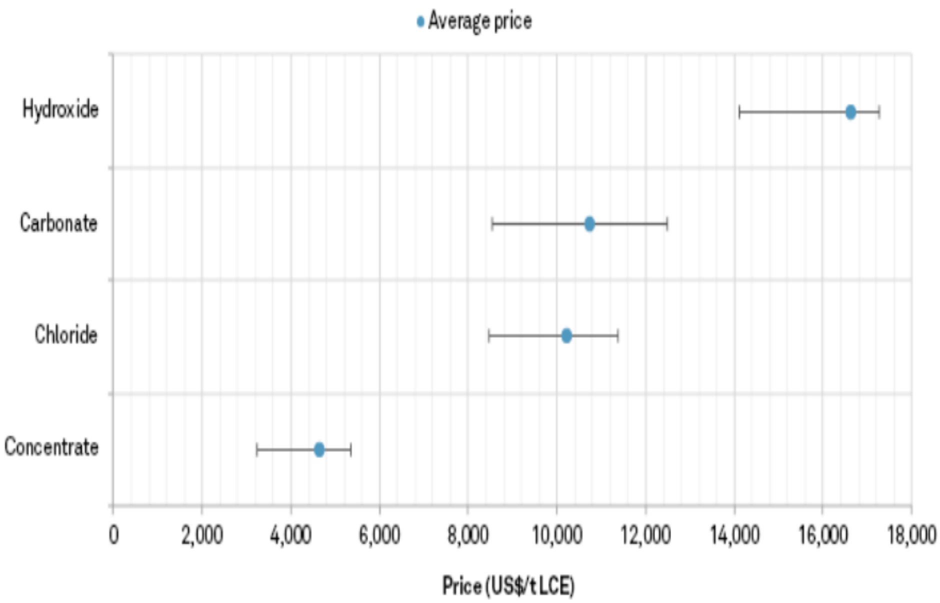


Figure 6. *Prices of spodumene concentrate, lithium carbonate, chloride and hydroxide, 2019*

PRODUCTION MARGINS

Using the 2019 forecast figures in Figure 6 we have set out a table below showing production, price and margins – this demonstrates that brine producers, on average, are expected to achieve a margin, which is over double that of hard-rock producers.

	Hard Rock Mining	***Lithium Brine***
	(produces spodumene concentrate)	(produces lithium carbonate)
	US$/t	US$/t
Avg Cost of Production	2,540	5,580
Avg Price Obtained (2019)	4,619	10,800
Avg Margin (2019)	2,079	5,220

The one notable exception to this trend will be the margin for lithium hydroxide that will be produced at Greenbushes, a hard-rock mine that currently produces a spodumene concentrate. Two lithium hydroxide conversion facilities are being constructed in Western Australia to convert a portion of this spodumene concentrate to lithium hydroxide. The additional cost of converting the spodumene concentrate to lithium hydroxide is expected to be US$2,456/t. This will take their production costs to approximately US$5,000/t. However, lithium hydroxide had an avg price obtained (2019) of US$17,274/t. This will lead to a higher margin for the lithium hydroxide produced at Greenbushes. Phase One of the Tianqi Lithium plant's construction was completed in October 2019 but the expansion phase has now been put on hold. Albemarle's plant is under construction and expected to be completed at the end of 2021.

Also to be considered is that lithium carbonate is more stable than lithium hydroxide, has a considerably longer 'shelf life', is easy to transport and store. Lithium carbonate can easily be processed into lithium hydroxide at an additional cost.

ROYALTY COSTS

State development agency Corfo struck deals with top miners SQM and Albemarle in previous years that set a sliding scale for royalties, depending on the price of the metal, as shown in table 3. For any price above 10,001$/tonne LCE you pay 40% of the current price i.e i.e. if the price is 20,000$/tonne LCE you pay 40% so $8,000. In a move to help grow state revenues from mineral production, a bill proposing a 3% royalty on lithium production has been presented to Chile's lower house. For now, the proposed 3% royalty would only impact the country's top lithium producer SQM who is estimated to have produced around 55kt LCE in 2019. The 3% royalty would have a relatively marginal impact on producers as shown in *Figure 7*.

***Table 3**. Royalty Rate Table – Chile*

Price ($/tonne LCE)	Royalty (%)
0	6.80
4001	8.00
5001	10.00
6001	17.00
7001	25.00
10001	40.00

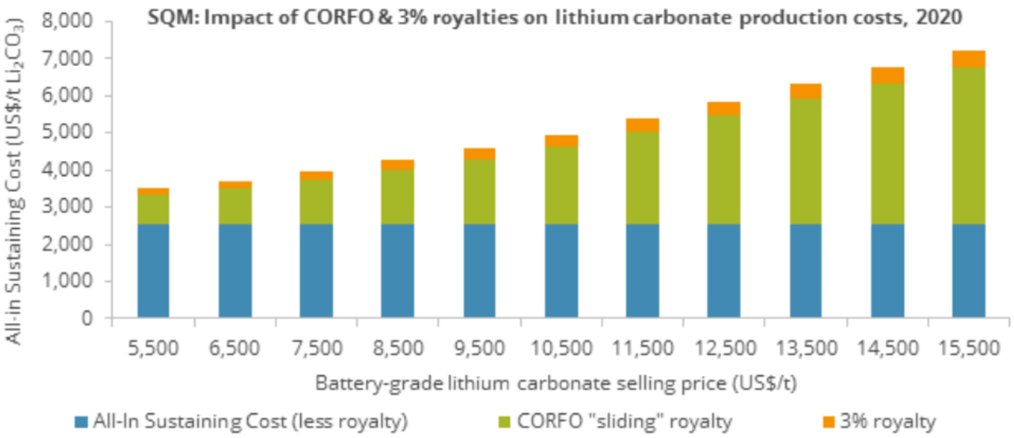


***Figure 7**. Costs of lithium mine production, including "sliding" royalty and 3% royalty, 2020*[41]

ENVIRONMENTAL IMPACT OF BRINE EXTRACTION

One of the side effects of lithium mining is water pollution: the process of mining can affect local water supplies, potentially poisoning communities. According to the report, the Tilopozo meadow in Chile used to be a shelter for shepherds traveling at night yet has become barren due to lack of grass or water. That puts a severe strain on local farmers. Chemical leakage is also a major concern when it comes to lithium mining. A chemical leak from the Ganzizhou Rongda Lithium mine wreaked havoc with the local ecosystem, killing fish, yak and cows through contaminated water. It was the third such incident in the space of seven years in the area. The lithium carbonate extraction process harms the soil and can cause air pollution. It should, however, be noted that new technology is currently being developed which has demonstrated a 90% reduction in the environmental impact of Lithium extraction from brine.

LITHIUM-ION RECYCLING

LIBs contain useful high-grade metals other than Lithium such as copper, aluminium, cobalt and nickel. To prevent future shortage of cobalt and nickel, and to enable a sustainable life cycle of these technologies, recycling is required. Recycling processes today recover approximately 25% to 96% of the materials of a lithium-ion battery cell, depending on the separation technology. In order to achieve this goal, several steps are combined into complex process chains, especially considering the task to recover high rates of valuable materials with regard to involved safety issues.

As of 2019, the recycling of Li-Ion batteries in most cases does not extract lithium since lithium-ion battery technology continuously changes and processes to recycle these batteries can thus be outdated in a couple of years. Another reason why it isn't being done on a large scale is because the extraction of lithium from old batteries is approximately 5x more expensive than mined lithium. However, it is already being done on a small scale (by some companies), clearly an industry being developed in expectation of large quantities of disused batteries to come.

Tesla supposedly recycles all of its produced batteries, through a vast network of partners around the world. Tesla wishes to close the loop and recycle all the batteries it produces in house and is developing a unique battery recycling system at its Nevada Gigafactory.

A Finnish company, Fortum, announced it has reached a recycling rate of 80 percent for EV batteries, using a hydrometallurgical recycling process. It will be the first company in Europe to offer industrial scale hydrometallurgical process for recovering cobalt, manganese, nickel and lithium.

Canadian Li-Cycle can achieve a recycling rate of 80 to 100% of materials in LIB's, the company claims. The two-phase process involves first shredding the batteries and removing plastic and metals. Then a chemistry process, hydrometallurgy, removes the individual valuable components, so lithium carbonate, lithium, cobalt, copper, aluminium, graphite and iron. The company has 5000 tonnes of shredding side capacity but needs to scale up the second part of the process to reach full scale.

EMERGING EXTRACTION TECHNOLOGIES

SUMMIT NANOTECH

Summit Nanotech has designed an innovative new extraction method to generate battery grade Lithium Carbonate or Lithium Hydroxide direct from brine sustainably. This extraction process is called Direct Lithium Extraction (DLE) – denaLi – and is currently the most green lithium extraction technology in the world. This DLE process is scalable, requires no fresh water, doubles yield and reduces the use of chemicals and production of waste by 90% while rapidly producing high-purity lithium products.

Generation 1 of the field unit will focus on isolation and concentration stages of lithium extraction. Subsequent generations will include innovations in the purification, carbonation, and crystallization steps as well. Being a relatively small operation, they are unable to bring too many new systems to the field all at once. As of August 2020, Summit Nanotech signed a letter of intent with 3PL (for its Nevada Lithium based mine) and are on schedule for the commissioning and operation of a pilot extraction unit in 2021.

With questions regarding the supply and demand predictions, as well as being able to provide their technology as a service to existing producers or new producers, Summit Nanotech are relying on society, EV buyers and the likes of Elon Musk wanting to source their lithium supply from sustainably extracted processes. "Green" lithium will be at the top of the list.

LILAC SOLUTIONS

Bill Gates-backed Breakthrough Energy Ventures is among the investors to inject $20m into California-based Lilac Solutions' lithium project, again developing technology for brine extraction. The $1bn Breakthrough Energy Ventures fund is also backed by Jeff Bezos, Jack Ma and Mark Zuckerberg among others.

Lilac Solutions' ethos of "Lithium is here to stay" is backed up by its belief that Lithium is irreplaceable for the high-energy batteries that power portable electronics and EVs, and that even the new battery technology will be based on lithium metal and lithium silicon anodes.

Lilac Solutions has developed a new continuous ion exchange technology to address the challenges faced by lithium producers working in the brines. Lilac's technology cuts capital and operating costs, accelerates project start-ups, boosts lithium recovery, and unlocks new resources.

***Figure 8**. Lilac's continuous extraction process*

ENERGYX

EnergyX has a patented LiTAS technology that is a type of filtering nanotechnology. The membrane accelerates the lithium extraction process and makes lithium production more affordable and orders of magnitude for efficient than brine and hard rock extraction approaches in the past.

Lithium Ion Transport and Separation (LiTAS™) is EnergyX's proprietary technology that stems from nanoparticles capable of selectively separating lithium from the rest of the brine. Comparing to conventional ponds, the technology has a 90% Lithium recovery rate as opposed to 30% and takes 1-2 days in continuous processing as opposed to 18 months. It also uses minimal fresh water compared to 18,000 gallons/ton in conventional pond methods. They are confident that the new method will completely replace traditional mining.

EnergyX also believes this technology could have applications for solid-state separators, a component in LIBs.

LITHIUM RESOURCES

Figures for lithium resources and reserves differ considerably accordingly to the source, although there is a unanimous agreement that lithium resources in brine are much larger than those in hard rock. The lithium production was, until recently, dominated by the Salt Lake brines, because of their cheaper production cost. The ever-growing demand in lithium compounds led to the regaining of interest for another source, after the lithium price increased. This other source, lithium rich minerals or hard rock mining, now accounts for 50% of the world's lithium production.

Owing to continuing exploration, identified lithium resources have increased substantially worldwide and total about 80 Mt Li. Lithium resources in the United States—from continental brines, geothermal brines, hectorite, oilfield brines, and pegmatites—are an estimated 6.8 Mt. The US withheld production numbers to avoid disclosing proprietary company data. Its only output last year came from a Nevada-based brine operation, most likely in the Clayton Valley, which hosts Albemarle's Silver Peak mine. The vast majority of lithium in the U.S is in reserves; therefore, production numbers are not usually recognised.

The total lithium resources in other countries excluding the U.S is 73 million tons. Total lithium resources represent lithium that is not yet economic to mine today but has potential to become economic at some point in the future. Lithium resources, in descending order, are: Bolivia, 21 million tons; Argentina, 17 million tons; Chile, 9 million tons; Australia, 6.3 million tons; China, 4.5 million tons; Congo (Kinshasa), 3 million tons; Germany, 2.5 million tons; Canada and Mexico, 1.7 million tons each; Czechia, 1.3 million tons; Mali, Russia, and Serbia, 1 million tons each; Zimbabwe, 540,000 tons; Brazil, 400,000 tons; Spain, 300,000 tons; Portugal, 250,000 tons; Peru, 130,000 tons; Austria, Finland and Kazakhstan, 50,000 tons each; and Namibia, 9,000 tons[17].

Lithium extraction in Bolivia is not deemed economically viable. Its resources are not as easily accessible as those in neighbouring Chile and Argentina. The primary source of Bolivian lithium, Salar de Uyuni, is inhibited by frequent rains and high magnesium/ potassium levels (reducing magnesium is crucial in producing high-purity lithium), meaning huge foreign capital and advanced technology is needed to extract usable lithium. China, after negotiations with Bolivia for the Belt and Road Initiative, has secured an initial US$ 2.3 billion investment venture in a Bolivian state company, expandable according to market demand. Without regard for market forces and with an active interest in securing global commodity reserves, China has secured a foothold in the Bolivian reserves despite them being uneconomically viable at this point in time. “China is a guaranteed market for the production of batteries” said the president when signing the agreement, “as it will require 800,000 tonnes of lithium per year by 2025 to keep up with battery demand”. The locals of the region in Bolivia are in support of the decision and believe they have been deceived by the industrialisation taking longer than promised.

Although the Bolivian government states that it would like to attract more FDI, it has done little to do so and remains highly corrupt (123rd out of 179 in the Corruption Perceptions Index). The instability of the legal framework, corruption, the weakness of the rule of law and the prohibition to resort to international arbitration are elements which continue to affect the business environment. However, the odds of this continental brine seeing commercial production are low for several reasons, including the fact that Bolivia is keen on keeping its natural resources under state control. Therefore, it has thus been discredited as a viable option for investment and from any comparisons made.

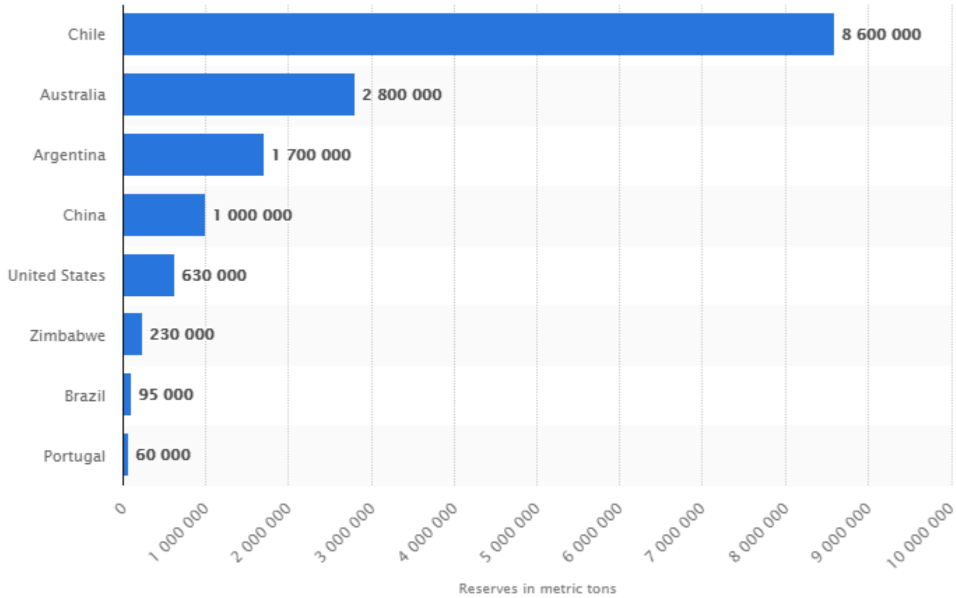


***Figure 9**. Countries with the largest lithium reserves worldwide, 2019*

Figure 9 shows the countries with the largest lithium reserves in the world. USGS (Source) lithium reserves follow a definition known as proven and probable reserves. A country's lithium reserves represent the segment of the country's lithium resources that are economic to mine today, using today's technology. Chile has the greatest lithium reserves by a large margin. However, Argentina, at 17 million tons, has a larger lithium resource than Chile, at 9 million tons, which could potentially become economically viable in the future.

***Figure 10**. Location of the mineral triangle*[19]

Figure 11 shows the largest countries in worldwide lithium mine production from 2014 to 2019. The majority of global lithium reserves exist in continental lithium brine deposits in what is known as the "Lithium Triangle" — a region of the Andes mountains that includes parts of Argentina, Chile and Bolivia (see *Figure 10*). These figures are accurate to around 1,000 metric tons, through comparing to different sources. New spodumene facilities were ramped up through the year to boost production from 40,000 tonnes in 2017.

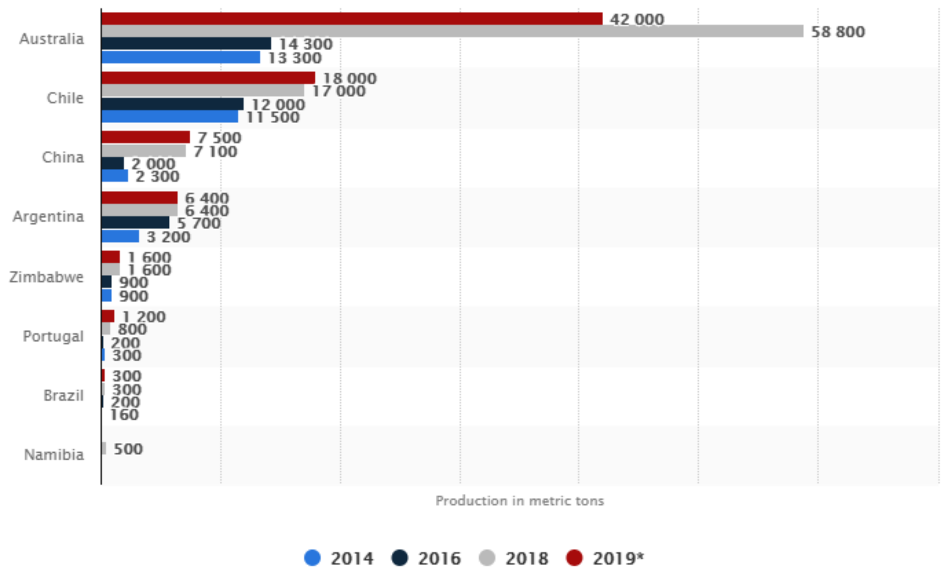


***Figure 11**. Major countries in worldwide lithium mine production, 2014 to 2019*

Australia has the largest percentage of current lithium production, but is the country using the largest percentage of its reserves. In future, to meet upcoming demand, this may not be an issue as lithium is not a scarce commodity, as discussed later. Chile has a comparatively low production volume compared to its reserves (resources currently economically viable to extract). Argentina has a higher production level as a percentage of estimated reserves, however, has significantly larger resources which are yet to be economically viable to extract.

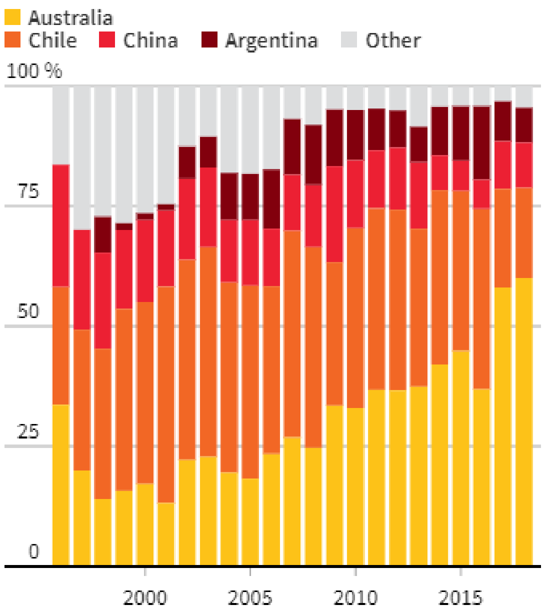


Figure 12*. The top four lithium producers as a percentage of total world output, 1996 to 2018*

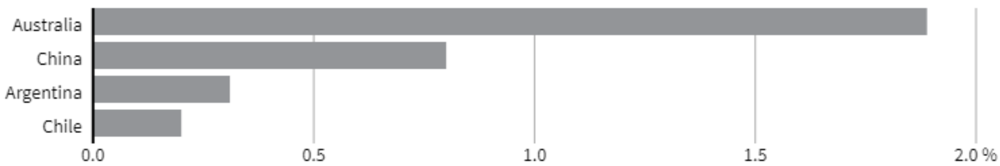


Figure 13*. Production as a percentage of country's estimated reserves, 2019*

The current global reserve of lithium is hard to determine but it is most likely that we will not run out of lithium. Lithium reserves are estimated at up to 80 million tons. There's around 63kg of lithium in a 70kWh Tesla Model S battery pack. With an estimated 1.2 billion cars in the world, even if every one were to convert, it would take years and years to run out of lithium. Whether or not we can extract it quickly enough to meet sudden demand – whilst being mindful of the environmental consequences – might be the real issue.

COBALT RISKS

At the other end of the battery metals spectrum is cobalt. The world is dependent on the Democratic Republic of Congo (DRC) for supply of the rare mineral, which makes it unpredictable and highly susceptible to political risks. There have been claims of children toiling in hand-dug mines and facing serious health risks in the DRC. Cobalt is mainly produced as a by-product of copper and nickel. Most cobalt in the DRC comes from an area known as the Copperbelt. It holds one-third of global cobalt reserves and accounts for 40 to 50 percent of cobalt output in the DRC.

DRC is aware of the critical role its mines now play in the market for battery metals and last year it labelled cobalt a "strategic" substance in order to justify tripling mining royalties.

"Global cobalt mine supply is at risk of disappearing in 2020," said Benedikt Sobotka, CEO of Eurasian Resources Group. "Some of this will be replenished with ramp-ups at major industrial projects, but not enough to close the gap. Some may be supplied by existing stockpiles, but these are held in stable hands and will fall to critical levels over the course of 2020."

Breakthrough Energy Ventures, a $1 billion Bill Gates-led fund, recently invested in Kobold, a Silicon Valley start-up looking to deploy artificial intelligence to find cobalt reserves in parts of the world where labour and environmental laws are stricter than those found in the Congo.

LITHIUM ALTERNATIVES

The most prominent use for lithium is in Lithium-Ion Batteries, whilst also showing the highest percentage growth rate. Although there are other uses for lithium, we can assume those to be comparably negligible to the growth and relevance to lithium demand in the future.

LITHIUM-ION BATTERY ALTERNATIVES

While there are many different batteries out there, the Li-ion battery is the only rechargeable battery that is used on a large scale and this is due to its ease of fabrication, good (but not excellent) properties, long usable lifetime, being relatively safe and the ability to be produced at scale.

The two most common metrics for comparing batteries is the energy density in watt-hours per kilogram (Wh/kg), the amount of energy the battery can store with respect to its mass, and power density in watts per kilogram (W/kg), the amount of power that can be generated by the battery with respect to its mass. Lithium, being highly reactive can store a lot of energy in its atomic bonds thus has both high energy and power density. A typical LIB can store 150 watt-hours of electricity in 1 kilogram, many multiples greater than alternatives such as Nickel-Metal Hydride batteries or lead-acid batteries.

Material development in lithium ion batteries is being driven by the need for improved battery capacity, lower cost (for automotive applications), improved safety, and improved capacity retention after cycling of the battery.

Despite this, there has been a steep decrease in Li-ion prices due to technology improvements and economies of scale. Fierce competition between manufacturers has also been a large factor.

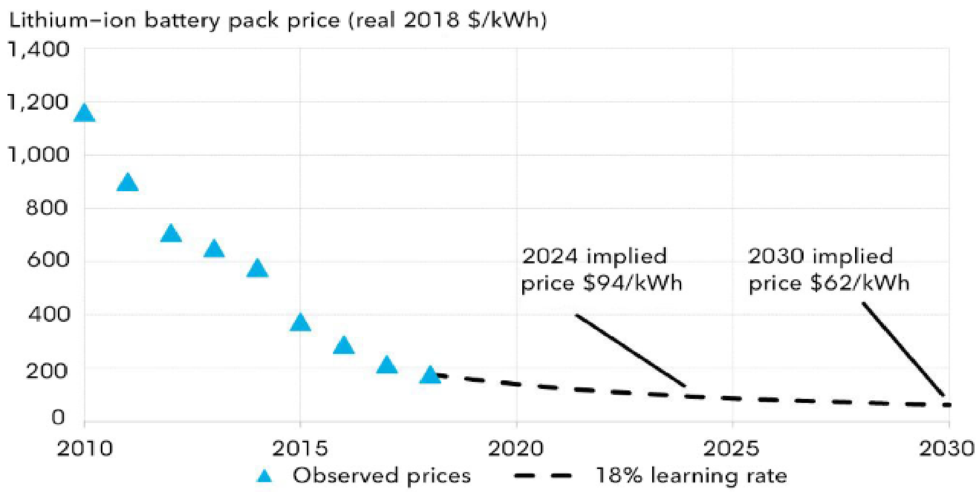


Figure 14. *Lithium-ion battery price outlook*

Most of the recent advances in lithium-ion energy density have come from manipulating the relative quantities of materials such as cobalt, manganese, nickel and aluminium in cathodes. However, the technical merits are not the only factor dictating material selection. Currently, almost 80% of sales of EV batteries use cobalt to some extent. Several manufacturers are attempting to completely phase out cobalt.

There are many other batteries out there which have much higher theoretical energy densities than Li-ion batteries, see *Figure 15*.

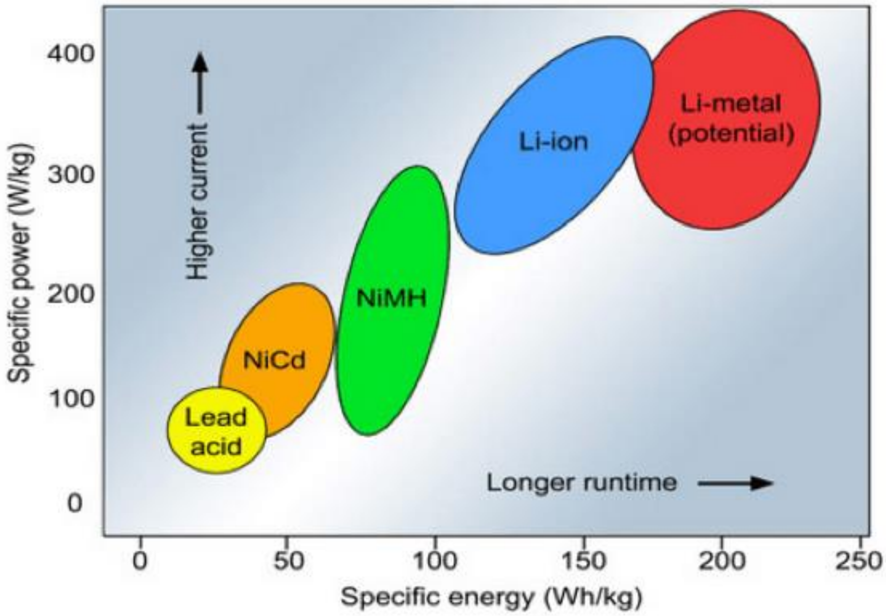


Figure 15. Specific power against specific energy of different battery technologies

ALTERNATIVE TECHNOLOGIES:

- Magnesium:
  - Magnesium as an anode in place of lithium has a theoretical energy density almost 5x that of lithium. But this has stalled due to the lack of practical materials to use as electrolytes and a cathode.
- Lithium Air:
  - Has demonstrated energy density at over 5 times that of current Li-ion batteries. There are still challenges to the development of Li-O, including the cathode.
- Silicone Anode Lithium Ion batteries:

  Looking to overcome the problem of unstable silicon in lithium-ion batteries, a hybrid anode with silicon and carbon has been developed. The aim is to remove graphite with silicone. University of Eastern Finland.
- Lithium-Sulphur:
  - Monash University researchers have developed a lithium-sulphur battery that can power a smartphone for 5 days, outperforming lithium-ion. The researchers have fabricated this battery, have patents and the interest of manufacturers. The environmental impact compared to lithium-ion will be less.

  - OXIS Energy is building a Li-Sulfur battery plant with an initial capacity of 2M cells/year. There is a theoretical energy density 5 times greater than Li-ion. Lithium is used for the anode, the cathode is Sulfur based. OXIS has customers including Airbus, Seat, Renault, Nissan and many more. Investors include Umicore and Samsung.
  - The main drawback is the formation of unwanted ions within the battery, which release into the electrolyte and reduce the long-term efficiency and stability of the battery.
  - Will not be too long to see commercialisation, but adoption of mass production may be a while.
- Flexible Solid-State Lithium Batteries:
  - Instead of using a liquid electrolyte solution to regulate flow of lithium ions, a solid electrolyte could be used instead. Using a solid electrolyte will provide a smaller size with higher energy density, longer lifespan, and increased safety. Dyson has attempted to manufacture an EV with this technology. Fisker patented its solid-state batteries and revealed an EV in 2018 with the technology. Less cobalt is used than in traditional Lithium-Ion batteries, making it comparably cheaper.
  - The batteries can be manufactured with the same processing equipment as lithium-ion batteries.
  - Solid Power has partnerships with Ford, Hyundai and BMW Group.
  - Dyson shut down its electric car project due to production of the car not being economically viable. He claims all large manufacturers like BMW, Mercedes, Audi and JLR are making huge losses on every electric car they sell as they are so expensive to make, they are doing it to lower their average CO and NO emissions overall, helping to comply with EU legislation. He stated that the company would "*concentrate on the formidable task of manufacturing solid-state batteries*". The company acquired solid-state battery tech company Sakti3, and then walked away from that technology in favour of another one it has reportedly developed internally. A Dyson spokesperson has stated "*We remain committed to investing £1bn in battery technology over the coming years, and Sakti3 is an essential and exciting part of that program.".*
- Metal-air batteries:
  - Log 9 Materials technology just uses water, air and aluminium to run. The electrode is made of graphene, filtering out CO2 so that oxygen can oxidise the aluminium and create power. It runs on a bottle of water every few hundred kilometres. It can never explode, hold multiple days charge and doesn't need to be recharged.
  - Zinc8 Energy solutions has developed innovative battery technology using zinc and air as fuel. It is able to be scaled easily and can solve the issue for renewable energy generation methods.
- Hydrogen Fuel Cells:
  - Hydrogen doesn't occur naturally, it has to be extracted, then compressed in fuel tanks. There are numerous methods of extracting hydrogen, but none are easy to execute, therefore there is a large efficiency loss in the process. Most hydrogen is made from methane in a process that produces CO2 but can also be produced using electrolysis which requires electricity, an issue that can be addressed by diverting renewable energy sources to H2 plants but hasn't been fully explored.
  - This is the technology of the future but is stuck in a chicken-and-egg situation of supply and demand. The cars are built in small numbers (4,293 units in 2017) and are extremely expensive to buy because there are no economies of scale. In addition, there are nowhere near enough hydrogen filling stations. This leads to a low demand for hydrogen, which means that little money is being invested into the new technologies for extracting hydrogen. The lack of 'push' from legislators further hinders the progress of the hydrogen fuel cell car.

- Nickel Metal Hydride Batteries:
    - Toyota uses these in the Prius, which are not as energy dense as lithium ion packs but have the advantage of longer usable lifespans and lower production costs.

FUTURE BATTERY MARKET OUTLOOK

Near Term: Improving Lithium Ion

- New anode and cathode materials
- Stable and higher quality electrolytes and additives
- Better pack design and materials
- Advanced control

Mid-Term: Era of Diminishing Gains

- Any advancements are minimal before switch-over to next gen batteries

Long Term: Beyond Lithium Ion

- Battery cost and performance breakthrough
- Solid state as an alternative to liquid electrolyte
- Li-Air, Li-S as an alternative to Li-ion
- Next gen liquid, gel, polymer electrolytes to enhance performance of new anode and cathode materials

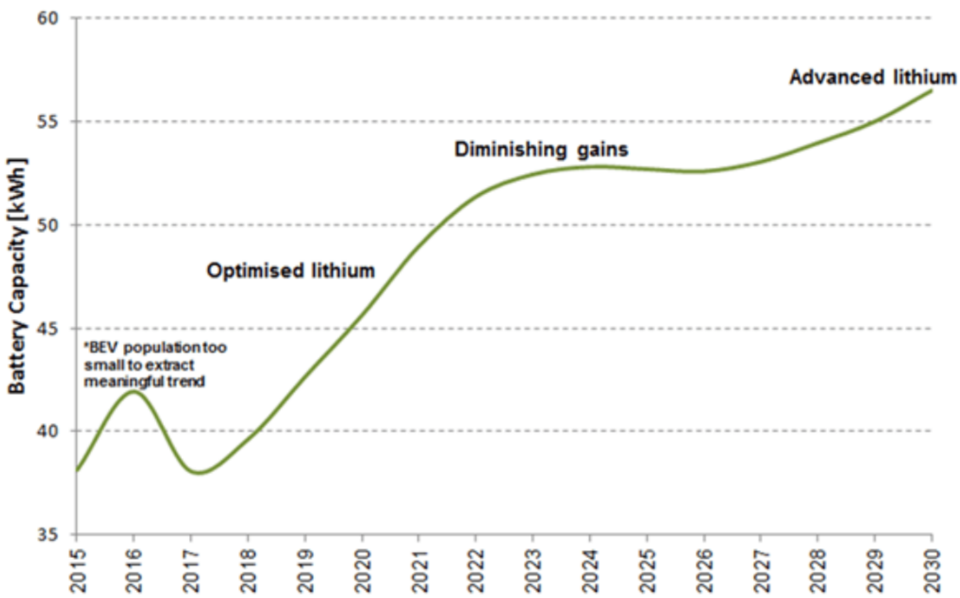


Figure 16. EV Battery Capacity Trend – weighted average by global volumes

There are current claims of battery cell price per kWh as low as $113, but this figure does not include the cost of the battery pack. While pack price has dropped significantly over the last decade, future gains will be harder to find and we don't expect a pack price figure of $100/kWh, giving cost parity with internal combustion engines, before the middle of the next decade. Even at this stage, batteries will still be compromised by range and charging-time limitations. For that to change, a technology breakthrough, such as solid state, would be required. Naturally, there is a risk that this assumed breakthrough will not come to fruition. If that is true, it may be the catalyst for the move to hydrogen fuel cells, widely recognised as the most sustainable powertrain solution.

Lithium-ion battery technology is the most reliable, stable and safest solution in the foreseeable future for e-mobility. The economies of scale exist to meet current and reasonably anticipated future demand. In short, it's as close as you get to a sure bet in an industry long in hyperbole. Most experts agree that no other chemistry is going to disrupt lithium-ion for at least another decade or more.

RENEWABLE ENERGY STORAGE

Solar and wind power costs have continued to fall, complementing the more mature bioenergy, geothermal and hydropower renewable technologies. Solar photovoltaics (PV) shows the sharpest cost decline over 2010-2019 at 82%, followed by concentrating solar power (CSP) at 47%, onshore wind at 40% and offshore wind at 29%. The main issue facing renewables is ensuring there is always energy on demand, for when the renewable energy source runs out. Finding a cost competitive and reliable energy storage is crucial to its adoption.

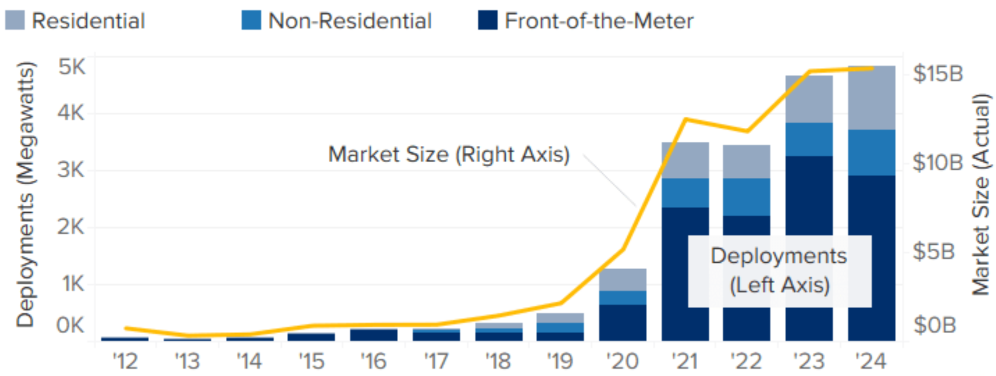


Figure 18. *Energy storage annual deployments, 2012 to 2024*

CHEMICAL BASED STORAGE SYSTEMS

- Li-ion: Tesla's Powerwall and utility-scale system Powerpack
  - Prices are dropping but are currently too expensive for electrical grid applications. Li-ion cannot store power for more than 4 hours at an economical price point. They also are deemed too unsafe and a fire risk.
  - Tesla built the largest Li-Ion battery paired to a wind farm, to deliver energy at peak hours. But it remains to be price competitive.
- Flow Batteries:
  - Primus Power has developed a Stable, non-toxic zinc bromide flow battery which uses a liquid electrolyte to offer a long-duration, fade-free energy storage solution. It shifts mid-day oversupply of renewable energy generation to evening peak periods. It has received more than $100M in equity capital and over $30M from government grants. Supply energy pods that have 25kW capacity, supplying 5-7 homes 5 peak hours. Multiple pods can be used to boost capacity. It has supplied to Microsoft, a military base and a Chinese Wind Turbine manufacturer. Currently supplies to solar plus storage facilities or larger commercial enterprises but could be economical for the grid.

  - ESS, backed by Softbank group, Gates-led Breakthrough Energy and crucially insurance company Munich RE. It has developed a storage unit called Energy Warehouses which can supply 100kW for 4 hours, with a lifespan of 20 years.
  - These technologies still rely on Lithium, so will face material cost challenges to achieve 100 hours storage capacity.

NON-CHEMICAL BASED ALTERNATIVES

- Pumped Hydro
  - Currently supplies 96% of worlds energy storage. Excess energy from the grid pumps water up to an elevated reservoir, then releases the water during high demand hours. This requires large amounts of land; it disturbs the environment and can only work in specific locations.
- Gravity based energy storage
  - Energy Vault uses cranes and wires to move 35 ton bricks up and down a tower, depending on whether energy is required to be stored or not. In times of excess energy, motors in the crane will move the heavy bricks up the tower and store gravitational potential energy. 20 towers could provide 350MWh capacity, powering 40,000 homes for 24 hours. These tall towers could not be built in a city, and have very low energy density compared to chemical-based storage systems.
- Flywheel energy storage
  - ABB Powerstore Flywheel uses the inertial properties of a flywheel to store energy.
  - This was implemented in an Alaskan island to integrate more renewable energy and stabilize power supply.
- Thermal energy storage
  - Antora Energy uses excess energy to heat up cheap carbon blocks. When energy is required, it is converted back to electricity.
- Compressed air energy storage
  - Instead of pumping water, ambient air is compressed and stored under pressure in underground caverns to store energy. The pressurised air is heated and expanded in a turbine driving a generator for power production in peak demand times.

With many niches in the energy storage market, how successful each technology is depending on the application. Battery technology, including Li-Ion, is likely to be crucial for residential and commercial areas. Costs that remain high are among the reasons preventing a surge in lithium-ion battery grid integration. They are not suitable for longer term energy storage and have safety issues. Alternative types of energy storage, including types that can be scaled such as gravity or compressed air, will potentially be economic in utility scale and grid scale energy storage. Government policies and incentives will be a major player in making innovative methods economically viable.

LITHIUM DEMAND

DETERMINING LITHIUM PRICES

Unlike other metals used to make electric cars such as copper, there is currently no traded price for lithium. The London Metal Exchange is working to develop a tradeable price and is already publishing reference prices in conjunction with Fastmarkets, but until then, the industry's investors are left without a full sense of the global market. Some of the banks are not keen to get involved as they can't hedge their price risk. Prices on spodumene, hydroxide or carbonate and battery prices are all used to estimate the price of lithium.

The price of lithium depends largely on the purity of the product, what other impurities are present in the product, and what contracts are in place for long standing supply chain agreements. Today, lithium prices range from \$6000–\$11,000 USD/tonne LCE for the 97% pure Tier 3 Li2CO3 product.

Tier 3 lithium products are those that come from the mine and have a purity of 97%. Technical Grade Lithium (Tier 2) is lithium with less than 99% purity. Technical grade product is useful in the manufacture of glass, frits, other ceramics, and a variety of specialized applications. Battery Grade Lithium (Tier 1) is a free-flowing, odourless white powder with guaranteed 99.5% purity and a relatively fine particle size. Battery grade is a superior purity grade product that is a required precursor for critical battery materials. Battery metal purity is incredibly important because the end product would create a safety hazard if impurities exist in the final product.

Spot prices in China have dropped double digits due to uncertainty around the country's electric vehicle subsidies. But such prices only reflect a portion of global demand. "Investors are valuing the industry based on the worst they're hearing from only a handful of companies, because they don't have a benchmark price to base analysis around," said Ernie Ortiz, president of Lithium Royalty Corp, an affiliate of Waratah Capital Advisors, which buys lithium royalty rights.

Neo Lithium Corp, Lioneer, Standard Lithium Ltd, Sigma Lithium Resources Corp and other prospective lithium projects have all struggled to attract investors largely due to that price uncertainty.

FALLING LITHIUM PRICES

Global uncertainty from the U.S.-China trade war, reduction in Chinese EV subsidies thus a reduction in EV sales in China, consumers reducing lithium inventories, along with introduction of new supply has seen a gradual correction in the lithium market over the past 18 months, as shown since the peak in 2018 in *Figure 1*. Despite this the majority of new chemical projects have been slow to deliver, share prices and investor sentiment remain tied to short-term price trends rather than underlying market fundamentals. This was before coronavirus disrupted the economy and may put lithium under pressure due to fears of a protracted recession. President Donald Trump's aggressive stance against China may result in a shift away from Chinese sources of lithium, potentially increasing prices.

After expecting an EV boom, there has been overinvestment in lithium supply, slashing prices of lithium carbonate. But battery packs are actually less sensitive to the prices of commodity materials than typically assumed – instead, much of the cost comes from manufacturing inefficiencies.

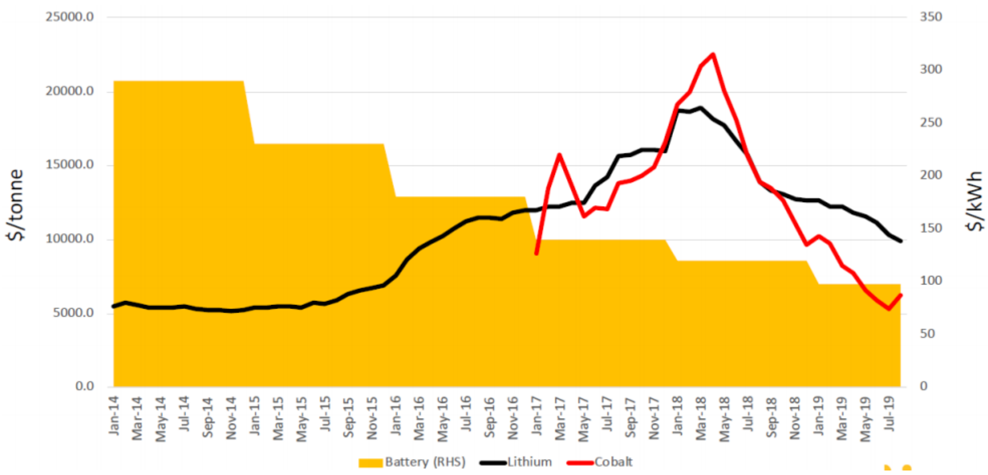


***Figure 19**. Lithium-Ion battery costs have continued to fall despite raw material cost volatility, 2014 to 2019*

EV GROWTH

Electric car deployment has been growing rapidly over the past ten years, with the global stock of electric passenger cars passing 5 million in 2018, an increase of 63% from the previous year. Around 45% of electric cars on the road in 2018 were in China – a total of 2.3 million. In comparison, Europe accounted for 24% of the global fleet, and the United States 22%. There are long-term signals to the auto industry and consumers from governments that support the transition to Electric Vehicles, including zero-emission vehicles mandates and fuel economy standards.

Electric models are seen accounting for 3% of global car sales in 2020, rising to 7% in 2023, at some 5.4 million units. Many analysts including BloombergNEF believe that by 2040, the global EV market could exceed 60 million vehicles sold per year accounting for 58% of new passenger car sales globally.

Sales of electric passenger vehicles are forecast to fall 18% in 2020, to 1.7 million worldwide – with the coronavirus crisis interrupting ten successive years of strong growth. However, sales of combustion engine cars are set to drop even faster this year (by 23%), proving EV sales being more resilient.

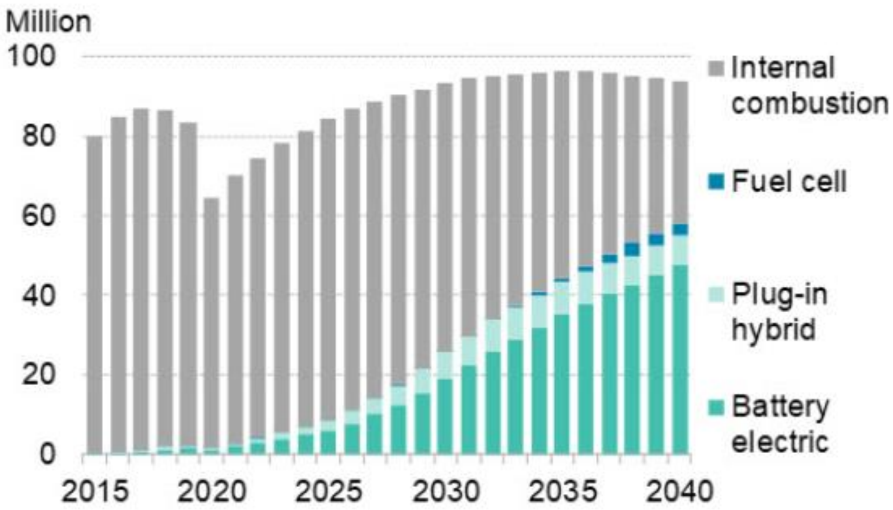


Figure 20. *Projected global annual passenger vehicles sales by drivetrain, 2015 – 2040. Note: Electric share of annual sales includes battery electric and plug-in hybrid*

These figures are historically impressive, but electric cars accounted for 2.6% of global car sales and around 1% of global car stock in 2019.

CARBONATE VS HYDROXIDE

The battery market size value in 2020 is USD 113.4 Billion. The revenue forecast in 2027 is expected to be USD 310.8 billion. As battery applications extend their dominance of lithium demand, the market is expected to become more focussed on providing products to meet specifications for automotive batteries. The shift towards high-nickel cathode materials, to increase battery energy density, is accelerating demand growth for lithium hydroxide, though its cost premium over lithium carbonate has made some consumers reluctant to switch feedstock. Lithium hydroxide is expected to become the dominant lithium chemistry consumed, though the balance between lithium carbonate and lithium hydroxide remains highly dependent on lithium-ion cathode requirements. To increase EV range, producers are switching to higher nickel content battery's, which require lithium hydroxide due to temperature restrictions of lithium carbonate during manufacture. Demand for lithium carbonate is expected to rise at a compound annual growth rate (CAGR) of 10-14pc in 2018-27, while lithium hydroxide demand is seen rising at a 25-29pc CAGR. Other expanding markets for lithium usage include Lithium-Aluminium alloys for aircraft and energy storage for renewable energy sources.

Spodumene is the main source of lithium hydroxide, with producers able to use this to process either carbonate or hydroxide for approximately the same cost. A few companies are looking into conversion plants for brine directly into hydroxide. The process of producing lithium hydroxide from brine is processing the brine to make lithium carbonate, then converting the carbonate into lithium hydroxide. Brine producers will continue to do this process but are looking for ways to reduce costs. SQM is expanding its lithium carbonate capacity in stages to 180,000 t/yr from 70,000 t/yr, while it has received permits to expand its lithium hydroxide capacity to 32,000 t/yr from 13,500 t/yr.

Greenbushes is the world's biggest hard rock lithium mine. Albemarle, which holds a 49% stake in Talison, is planning a lithium hydroxide manufacturing plant, outside of Greenbushes, capable of producing up to 100,000 tonnes per year of lithium hydroxide monohydrate from five 20,000 tonnes per year process trains and up to 1.1-million tonnes a year of tailings. China's Tianqi, which has a 51% interest in Talison, is constructing a 24 000 t/y lithium hydroxide plant in Kwinana, just 40 km from Perth.

Infinity Lithium Corporation Ltd is seeking to develop its 75% owned San Jose Industrial Lithium Project in Spain. The goal is to develop a hard rock mine and refine ore onsite to produce lithium hydroxide. The Infinity Lithium pre-feasibility study estimates a total revenue from Lithium Hydroxide of US$6Bn from the proposed largest open pit-based project in the world. However, this project is 3 years away from commission.

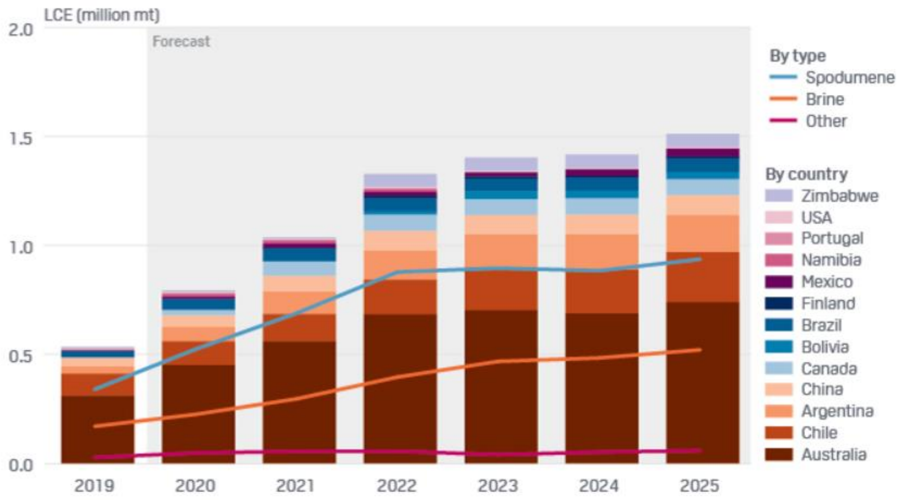


Figure 21. *Forecasted lithium production (lithium carbonate equivalent), 2019 to 2025*[36]

FUTURE DEMAND

Lithium consumption for batteries will increase significantly because rechargeable lithium batteries are used extensively in the growing market for portable electronic devices, electric tools, electric vehicles, and grid storage applications. This is coupled with concerns over CO2 pollution from Internal Combustion Engines. Although innovative battery technologies may take over Li-Ion in the next 10 years, Lithium is likely to play a part in those future technologies and will continue to be dominant in the battery market until then. It can be assumed that all other products made from lithium will have a comparably negligible effect to lithium-ion batteries.

Countries policies towards Lithium will greatly affect the demand in the future. *Figure 22* shows predicted Lithium Metal demand in 2030 for both NPS schemes and the EV30@30 scheme. NPS (New Policies Scenario) provides a sense of direction in which todays policy ambitions would take the energy sector. EV30@30 is a scheme planning to increase EV sales to 30% by 2030 signed by multiple countries.

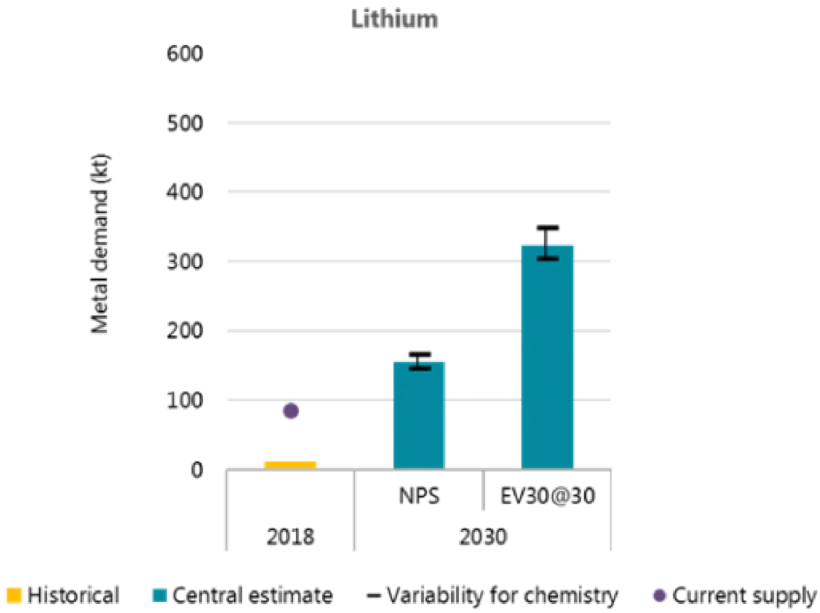


Figure 22. *Increased annual demand for lithium for batteries from deployment of electric vehicles by scenario, 2018-30*

GROSS INDUSTRY OUTLOOK

For the past 2 to 3 years, prices have been falling due to both an over-supply which was fuelled by substantial investment into production facilities which lead to an increase in supply and lower than expected increase in demand due to a lower than expected increase in EV sales in China. Although demand will undeniably increase, the supply surplus is likely to continue for the near future (3-5 years).

EV cars are evidently of increasing relevance to both the battery and thus the lithium market. It is forecast that demand of EV's will increase almost exponentially in the 20 to 30 year horizon logically increasing lithium demand in the longer term. Demand in the near future is less than investors expect. The dependence of lithium on EV's is increasing, but EV's only account for 2.6% of car sales globally. The effects of consumers widely adopting EV's is yet to be passed onto lithium but should happen in the future. There are conflicting opinions on where future demand and supply will be, but the majority of industry analysts predict an oversupply of the market into 2025. Granted, supply will need to increase to meet the undeniable future demand, however both existing investment into lithium production assets along with the potential adoption of new efficiency improving technologies will oversupply the market for the near term.

Figure 24 shows the Supply Demand forecast prepared by Bloomberg in October 2018. As a result of COVID this graph will likely shift along the X-axis, but the trend will stay the same. The dotted line is the top down demand curve for lithium-based manufacturing volumes and the bar graph is a bottom up analysis of demand.

This analysis is intended to identify the difference between the nameplate supply capacity and the derisked supply of lithium. Nameplate capacity is the intended full-load sustained output of all facilities in the market. The derisked supply chain includes optimized manufacturing and supply networks to manage risk. As shown, the demand implied by the volume of manufacturing is, for the near future, higher than bottom up predicted demand.

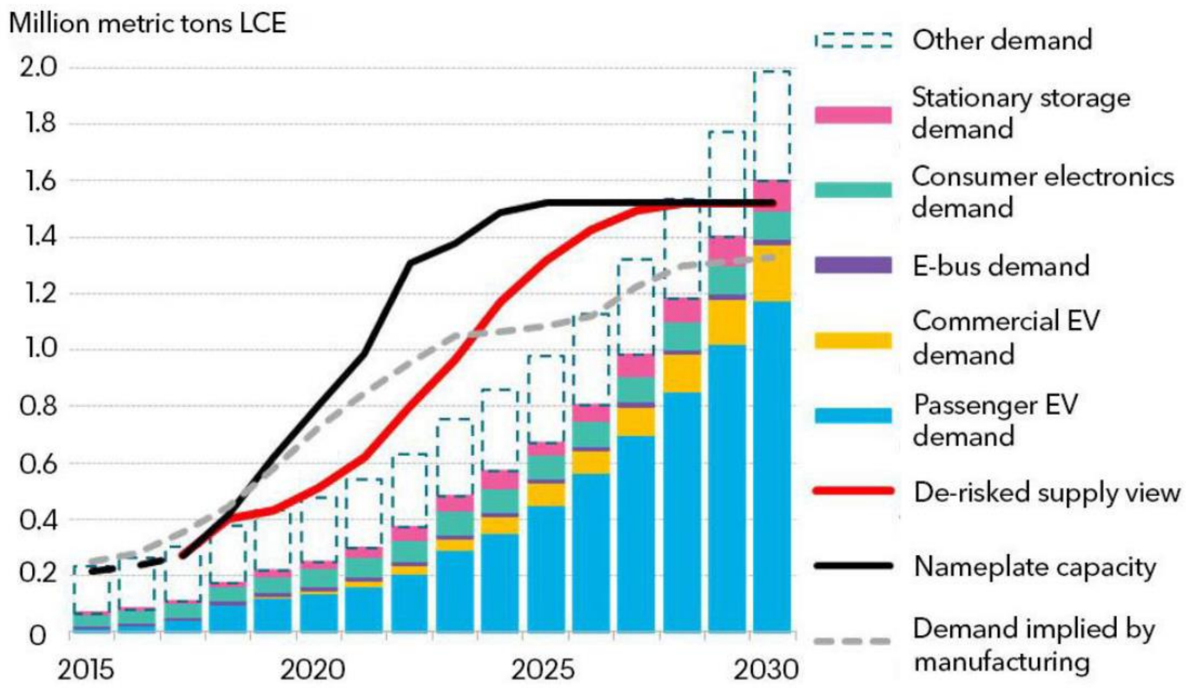


Figure 23*. Global Lithium Supply and Demand Forecast, Comparing Methodologies*

Some experts are predicting that prices won't fall any lower because the producers are currently selling at cost however there is anticipation of another year of low prices. Regardless, price drops can cause problems for producers when an 18-month production cycle drives production rates and weather (i.e. rainy periods) can interrupt supply by diluting the resource in the ponds. This may potentially be mitigated by new technology such as Summit Nanotech.

Despite this outlook of the lithium market in the near future, the increase in production facilities still require investment. This may lead to investment opportunities in the market. We foresee any downtrend in prices as being short lived as lithium will play a central role in future technologies over the next ten years.

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