Trinity Student Managed Fund
Research Team

Outlook On The Lithium-Ion Battery Market

FEB 2024

Summary

- Lithium-ion batteries will be a critical pillar in the global transition to a carbon-free economy
- A combination of technological, geopolitical, and supply chain challenges threaten to compromise LIB's future as the dominant force in electric vehicles and energy storage.
- This report details these challenges and presents an outlook for the battery technology

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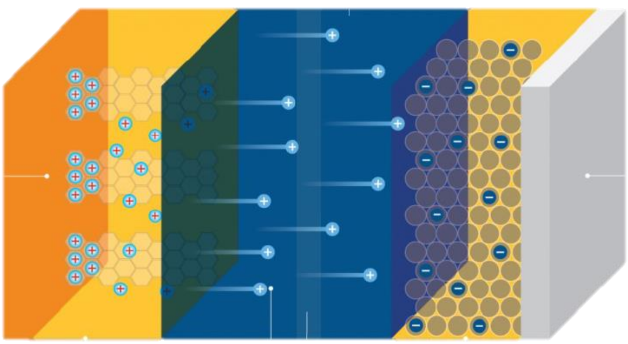
Overview of the Li-ion Battery

The lithium-ion (Li-ion) battery (LIB) is the most popular form of rechargeable battery available on the market today. Demand for these sources of power continues to rise exponentially, fueled by the booming EV market.

WHAT'S INSIDE THE BATTERY AND HOW DOES IT FUNCTION?

The battery's main components consist of the cathode and anode which store the lithium, electrolyte, separator, and positive and negative current collectors. The liquid electrolyte carries the positively charged lithium ions from the anode to the cathode through the separator. Meanwhile, the separator is a thin layer of insulating material that stands between the cathode and anode. It allows the lithium ions to pass through whilst blocking the electrons. These free electrons that remain in the anode then create a charge at the positive current collector, resulting in a flow of current. When Li-ion batteries are being charged, the process reverses. Lithium ions are released by the cathode and received by the anode.



ADVANTAGES OF LI-ION BATTERIES

Once the rechargeable battery of choice, the lead-acid battery has now been replaced by the Li-ion battery which has several technical advantages. The lithium-ion battery is significantly higher energy density, meaning more energy can be stored using the same physical space. This results in the ability for energy to be discharged from the battery for longer. Furthermore, Li-ion batteries have an average depth of discharge (the percentage of the battery that can be safely drained during each use without negatively impacting a rechargeable battery's lifespan) of 85%, compared to lead acid's 50%. (1) A higher depth of discharge coupled with higher energy density results in an even higher effective capacity for LIBs. Lastly, lithium-ion batteries last multiple lead-acid battery lifespans.

DISADVANTAGES OF LI-ION BATTERIES

Li-ion batteries present certain safety hazards as they are vulnerable to higher temperatures. The electrolyte located inside the battery is highly flammable and exposure to high temperatures can lead to thermal runaway, resulting in combustion. The upfront costs of LIBs are also far greater than lead-acid batteries. In the long run, however, they are far more economically viable than lead-acid batteries for a multitude of reasons including longer lifespan and higher effective capacity. There are also environmental concerns regarding lithium's extraction process and the other minerals used in the batteries such as cobalt.

APPLICATIONS OF LI-ION BATTERIES

Li-ion batteries have played a pivotal role in overhauling the global energy and transport systems to reduce reliance on fossil fuels. This battery technology has been used in a variety of different applications, however, its predominant use cases consist of powering electric vehicles (EV) and storing renewable energy. LIBs are the main component of battery energy storage systems (BESS) and the universal EV battery type. Their relatively high energy density means that Li-ion batteries are useful for energy storage when space and weight are a concern. Li-ion batteries are highly efficient, resulting in minimal energy loss during storage and discharge processes. LIB's compact and lightweight nature and their considerable lifespan make them highly suited for use in BESS and EVs. Battery energy storage solutions allow energy to be stored during periods of high-volume energy generation and to supply the grid during peak usage times. The systems can also aid in stabilizing energy grids and provide arbitrage opportunities, as energy can be stored during times of low energy costs and dispatched when prices are high, ultimately leading to savings. A total of 77% of energy storage systems in the US that operate to stabilize the grid rely on Li-ion batteries. (2)

The Li-ion Battery Supply Chain

The Li-ion supply chain can be broken down into four key stages: upstream, midstream, downstream, and end-of-life. Each of these stages is critical in ensuring the efficient and responsible production and distribution of lithium-ion batteries.

UPSTREAM

In the upstream phase of lithium-ion battery production, essential raw materials are extracted from mines. However, concerns regarding the ability to extract these materials quickly enough to meet the escalating demand have risen. Additionally, mining operations have been associated with issues of human rights abuses and environmental degradation. Raw materials including lithium, graphite, nickel, manganese, and cobalt are associated with Li-ion batteries.

Lithium

Lithium, the lightest metal, is a key component in the form of lithium carbonate in battery cathodes and anodes. It generates electricity through chemical reactions. The mining of lithium is associated with environmental concerns such as air and water pollution, as well as land and water contamination. Typically, lithium extraction involves pumping brine (underwater saltwater reserves) to the surface, where it is evaporated to extract lithium and other minerals. The extraction involves substantial water consumption, with approximately half a million tons of water needed to produce one ton of lithium. However, while the process is energy-intensive, it is worth noting that these concerns result in significantly lower emissions compared to fossil fuel production, a major source of global carbon dioxide emissions.

Graphite

Graphite is a critical mineral for lithium-ion batteries. Natural graphite is sourced from mineral deposits. Synthetic graphite is manufactured using high temperatures with petroleum coke and coal tar, resulting in a higher carbon footprint and emissions. Natural graphite is the preferred choice due to its lower carbon footprint and cost-effectiveness. China dominates the graphite industry, accounting for approximately 80% of global production in 2021. (3) The United States heavily depends on imports from countries such as China, Mexico, Canada, and India.

Nickel

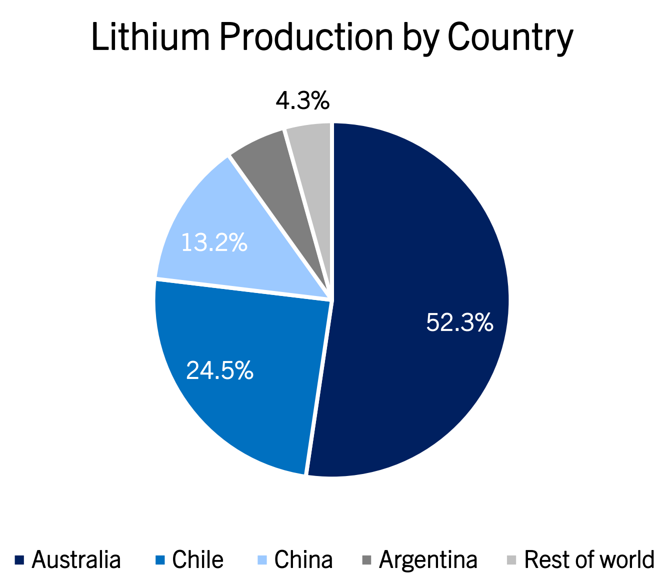
Nickel is a well-suited metal for rechargeable batteries due to its corrosion resistance, high-temperature tolerance, and excellent electrical conductivity. Although it tends to be pricier than alternative materials, the remarkable performance characteristics of nickel lead to reduced future maintenance costs. It is highly reactive, making it a cost-effective choice for Li-ion batteries, offering increased energy density and storage capacity. It is important to note that nickel mining is associated with environmental concerns such as pollution spills and deforestation, along with the risk of atmospheric deposition, impacting both wildlife and water supply. Indonesia is the leading nickel mining country, followed by Australia, Russia, South Africa, and Canada.

Manganese

Manganese serves as a stabilizing component in Li-ion battery cathodes, ensuring optimal performance at elevated temperatures. It is more abundant and less costly than some of the other metals like cobalt. Manganese extraction typically involves shallow open-pit mining, which is considered more ethical. Alternatively, underground mining can yield high-grade manganese but is more expensive. Most of the world's manganese reserves are found in South Africa, China, Gabon, and Australia, with South Africa contributing over 30% of global production. (4)

Cobalt

Cobalt is a relatively expensive component of Li-ion batteries, and its limited supply necessitates the exploration of alternatives. Cobalt is primarily sourced as a by-product of nickel and copper mining, often entangled in environmentally detrimental practices and human rights controversies. Most of the world's cobalt originates from the Democratic Republic of the Congo, where mining operations lack regulation. China is the leading producer of refined cobalt with a substantial portion imported from Congo. To reduce reliance on cobalt, auto manufacturers are actively exploring alternative battery technologies.



MIDSTREAM

The midstream section purifies raw materials with processors and refiners to create active anode and cathode materials, which are then assembled into battery cells. Commodity traders facilitate the buying and selling of these materials to producers responsible for battery assembly. Dominant players in this phase are primarily located in Asia, including China, South Korea, and Japan. China holds a prominent position, producing approximately 75% of all lithium-ion batteries while processing and refining more than 50% of the world's lithium, cobalt, and graphite. (5) Geographical concentrations in battery manufacturing pose a significant threat to supply chain stability. Europe is facing a significant bottleneck in its battery supply chain, affecting its competitiveness compared to the US and Asia. Midstream companies are vital for the future of the Li-ion battery supply chain as they have the leverage to enhance traceability and ensure ethical sourcing of materials. Implementing strong due diligence procedures and audits for these companies could encourage responsible sourcing, compelling mines to improve their practices or face significant financial losses.

KEY PLAYERS – UPSTREAM & MIDSTREAM

Albemarle

Albemarle is the largest lithium miner in the world with a market cap of $13.97 billion. (6) Albemarle operates three mines located in Chile, Australia, and the USA. Silver Peak, Albemarle's mine in Nevada is the only active lithium mine in the US. (7) In both the US and Chile, lithium is extracted using brine pools while in Australia it is extracted from the rock. Albemarle has processing plants in Chile and Australia, and in 2022 announced plans to build a $1.3B processing plant in the United States. (8) This processing plant will be of huge importance to Albemarle as it will double its current Lithium processing capacity and allow increased supply to US EV manufacturers. Due to this, Albemarle is likely to be the leading supplier of Lithium to US battery manufacturers and has already joined many companies including Tesla to promote EVs in the US.

Ganfeng Lithium Group

Ganfeng is a Chinese lithium producer with a market cap of $11.29 billion and is dual-listed on both the Shenzhen and Hong Kong Stock Exchanges. (9) Ganfeng has mines in Australia, Argentina, Mexico, and China. Ganfeng is unique to its competitors in that its business segments cover upstream, midstream, and downstream. Like Tianqi, the majority of Ganfeng's processing and manufacturing facilities are in China. Ganfeng is also recognised globally for its efforts as a sustainable lithium miner.

Tianqi Lithium Corporation

Tianqi is the world's largest hard rock lithium producer and has stakes in some of the biggest lithium mines in the world. Tianqi primarily operates in China and Australia. Tianqi acquired Greenbushes, in Australia in 2012 however has since sold 49% to Albemarle and another 24.9% to IGO, an Australian lithium miner. (10) In 2018 Tianqi purchased a 23.77% stake in the Chilean firm SQM which has now increased to 25.88%. Tianqi has 3 chemical plants, all located in China.

Sociedad Química y Minera de Chile (SQM)

SQM is a Chilean lithium producer with a market cap of $13.77 billion. The majority of SQM's operations are in Chile, in the Salar de Atamanca salt flats, the third largest salt flats in the world. In contrast to Albemarle, SQM's business is less geographically diversified and is extremely reliant on Chile. This has meant that SQM has been in a vulnerable position since Chile announced that they would be looking to nationalize the Lithium mining industry. In July 2022 SQM signed an agreement to earn a stake in the Dorchap Lithium project in Victoria, Australia.

DOWNSTREAM

The downstream phase involves battery manufacturers assembling battery cells into modules and subsequently packaging and selling them. Manufacturers stack battery cells either in series or in parallel within a protective metal frame to safeguard the cells against shocks and vibrations. These battery modules are then inserted into the battery pack. Downstream operations are primarily concentrated in China, South Korea, and Japan. This is due to China's significant investments and focus on battery production, while South Korea and Japan leverage their extensive experience in manufacturing consumer electronics. Meanwhile, the US has boosted its investments in clean energy manufacturing initiatives, allocating over $70 billion into electric vehicle and battery supply chain projects. (11)

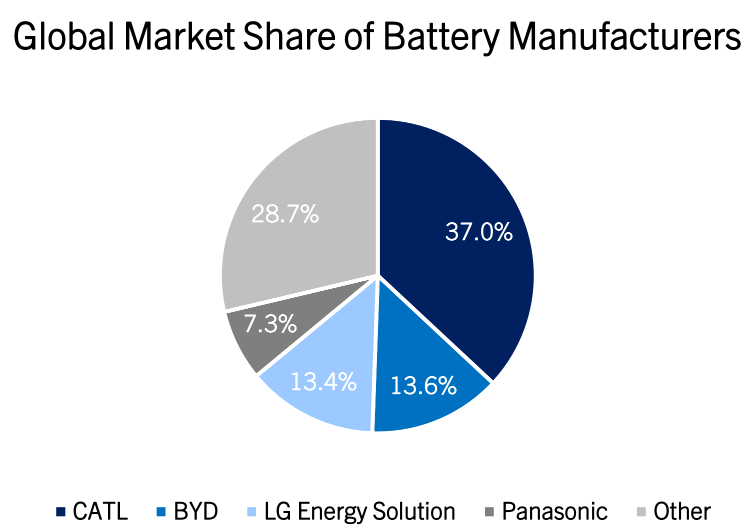
KEY PLAYERS – DOWNSTREAM

CATL

CATL is by far the most dominant player when it comes to the manufacturing of Lithium-ion batteries. CATL is a global corporation, it accounts for almost half of the Chinese battery market, 27.47% of the European market, and 14.12% of the US market. CATL provides batteries for commercial vehicles, passenger vehicles, and energy storage systems. Additionally, they own Brunp, a pioneer in the battery recycling industry. This is part of CATL's efforts to achieve their carbon neutrality by 2025 targets and offset environmental concerns concerning the recyclability of Li-ion batteries. Aside from the Li-ion battery, CATL announced their first sodium-ion battery in 2021.

BYD

BYD originated as a battery company but has become the 4th largest supplier of EVs in the world with a 9.4% market share. To date, BYD's strategy has focused on the EV market in China, which has proved successful given China's demand for electric vehicles. Despite being a key player in China, BYD has a far smaller footprint in the Western world. The Chinese company manufactures commercial vehicles and electric buses in the US and has continued to increase its footprint in the western world.



LG Energy

Established in 1992, LG Energy Solution is a South Korean company offering commercial and passenger vehicles in addition to energy storage solutions. LG Energy Solution has benefited from obstacles that have prevented Chinese companies' efforts to dominate the European and US markets. They are the most dominant player in Europe, with a 39.12% market share and hold a 17.78% share in the US market. (12)

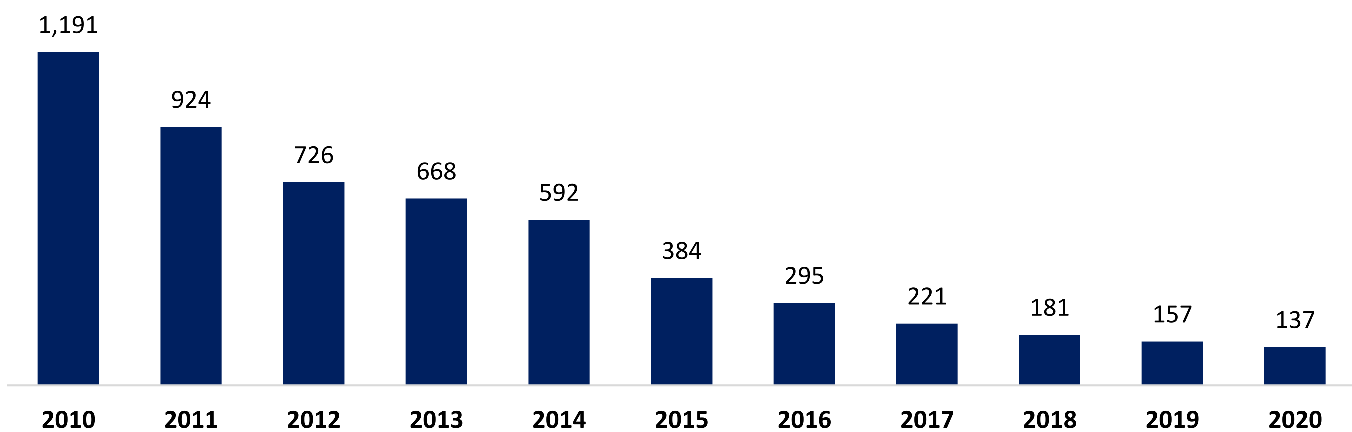
Panasonic

Panasonic is currently the largest battery manufacturer in the United States. Despite holding only 7.3% of the global battery market, the Japanese company account for 45.32% of the US market. (12) Panasonic operates Giga Nevada alongside Tesla, which is one of the largest battery factories in the US. Outside of the US Panasonic also has battery manufacturing plants in Japan, China, Thailand, Indonesia, and South America.

END OF LIFE

Batteries at the end of their life have depleted their utility and lifespan, leaving them unable to function at a satisfactory capacity. Nevertheless, they have the potential for repurposing as second-life batteries in less demanding roles, like energy storage. If a battery isn't suitable for a secondary application, its components may be recycled. The process of battery recycling aims to recover as many materials as possible, all while maintaining any structural integrity and quality the batteries still hold.

Volume Weighted Average Price of Li-ion Batteries (USD)



Alternative Battery Technology

LITHIUM IRON PHOSPHATE (LFP) BATTERY

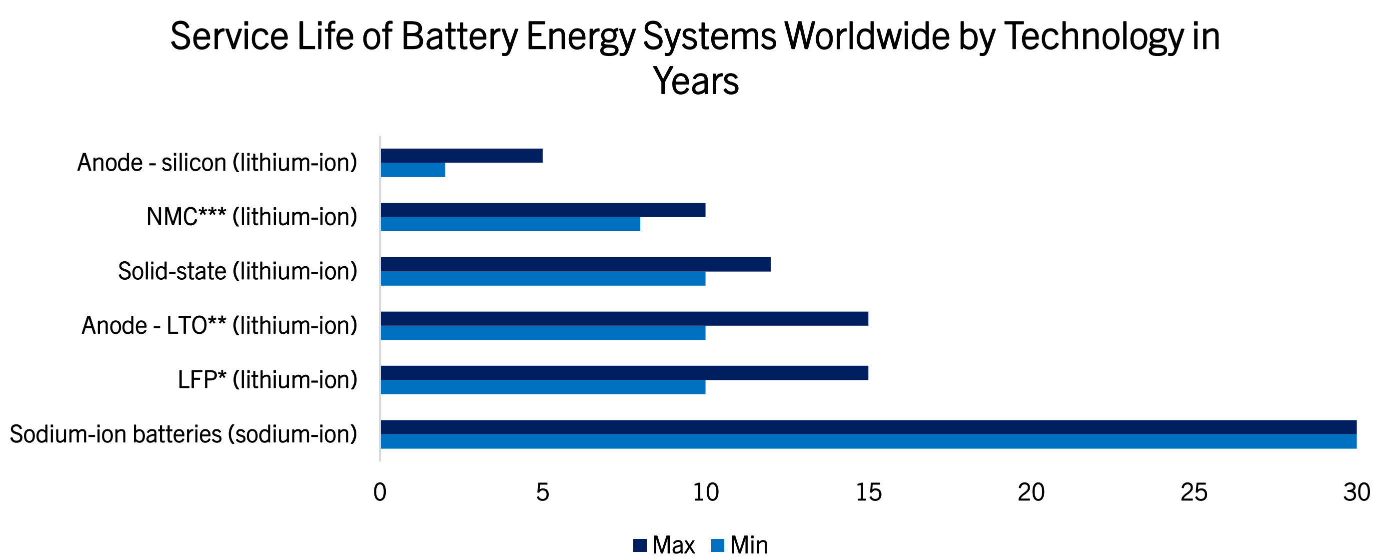
Lithium iron phosphate is increasingly becoming the rechargeable battery technology of choice, due to a variety of technological advantages, but most notably its low cost. Cobalt and nickel are replaced with iron and phosphate in the latest generation of the lithium-ion battery. This change makes the battery relatively lighter, safer, and more stable than previous versions. On the other hand, nickel and cobalt are highly energy-dense and efficient raw materials, and as such, the LFP battery has a lower energy density than LIBs. Whilst lithium-ion batteries typically last 3-5 years, LFP batteries offer a longer lifespan with the ability to last up to 10 years in the right conditions, primarily due to their lower voltage. Another differentiating feature of LFP batteries is their ability to function normally in extreme conditions, unlike LIBs which are susceptible to thermal runaway and vulnerable at freezing temperatures. The LiFePO4 battery is the Li-ion battery's strongest competitor in the EV production market, with the new technology accounting for about half of the battery capacity of EVs sold in China last year (13). LFP cells are primarily used for shorter-range EVs due to their lower energy density. Tesla has been one of the first automakers to embrace the use of LFP cells and has been selling the Model 3 SR+ with a lithium iron phosphate battery for just under a year.

SODIUM-ION BATTERY

The declining supply of lithium, as well as other essential raw materials such as cobalt, nickel, and copper, has put unprecedented pressure on the supply chain, prompting manufacturers to consider alternative options to li-ion batteries. At a price of only 1-3% of that of lithium, with remarkably similar chemical properties, sodium, a far more abundant material, is increasingly becoming a feasible option for rechargeable batteries. (14) Advances in battery cell technology have meant these batteries can now be recharged daily for years and their energy capacity has also been improved. Furthermore, they retain almost all their charge when temperatures fall far below freezing, unlike lithium batteries. The latest generations of sodium batteries do not require cobalt or nickel; two raw materials which have been in scarce supply recently and whose extraction processes are surrounded by controversy. Very few adjustments to EV production lines are required to facilitate this change in battery technology, as manufacturers have managed to design these cells to be so like lithium battery cells that they can both be produced with the same equipment. This translates to much lower required capital investment, hence lower battery costs, as well as faster time to market.

SOLID-STATE BATTERY

Often dubbed as the "holy grail" of electric vehicles by many in the industry, solid-state batteries have long been regarded as a potential game-changer for EVs. The main innovation this battery type provides is the use of a solid electrolyte as opposed to the liquid version used in LIBs; lithium is still the predominant raw material used within these batteries. A solid electrolyte brings increased stability, enables ions to move quicker and is far more resilient to higher voltages and temperatures. This is a huge development for the safety of rechargeable batteries, due to the highly flammable nature of the liquid electrolyte used in LIBs. One of the primary concerns for consumers considering the switch to EVs is range anxiety: the worry about the adequacy of EV batteries' charge to complete a required journey. Solid-state batteries have the potential to make range anxiety a concern of the past due to their much higher energy density than LIBs. This also enables reduced charging times, with Toyota expecting its solid-state battery would have a charging time of 10 minutes. The automaker also anticipates it won't have to compromise on the typical trade-off of solid-state batteries: shorter battery life. (15)



The Fragility of the Li-ion Battery Supply Chain

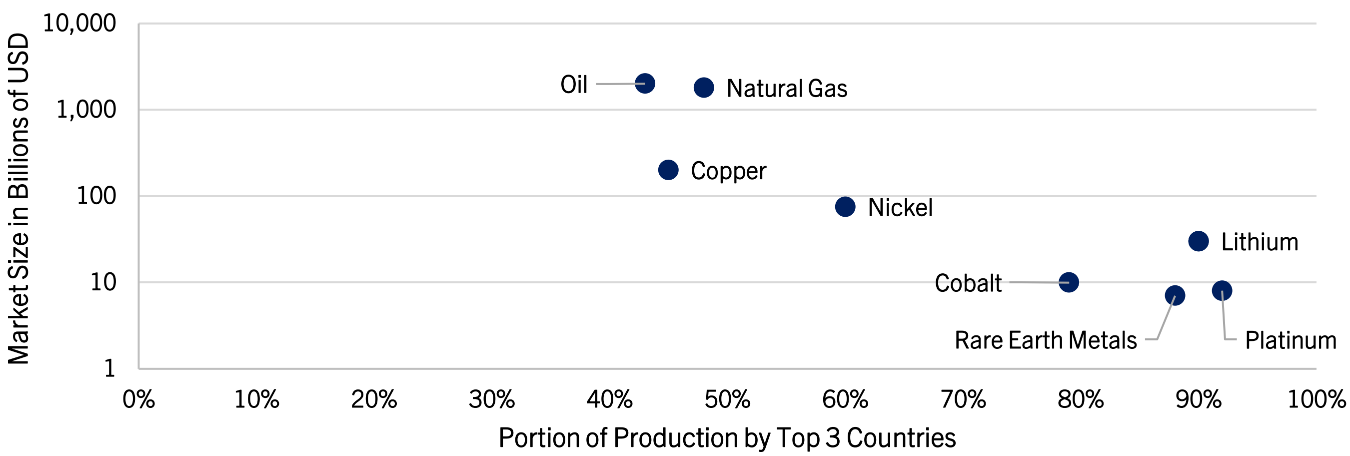
As demand for Li-ion batteries rises exponentially over the coming decades, automakers will be faced with a wide array of supply chain risks that threaten to impede forecasted growth in the industry unless addressed. As manufacturers scramble to scale production to meet this surging demand, several challenges face the LIB supply chain, including the need to reduce exposure to high-risk geographies and address ESG concerns.

GEOPOLITICAL RISKS

Control of each stage of the supply chain is concentrated amongst a very small cohort of nations, from the upstream to downstream phase. To add a layer of complexity, these countries are prone to political instability and/or are subject to diplomatic tensions. Strategic dominance of the upstream segment of the supply chain requires access to or ownership of critical raw material deposits, which are determined by the geographical characteristics of an area. Lithium, cobalt, nickel, and graphite are critical in the production of LIBs. In 2022, 90% of lithium extracted originated from three countries: Chile, Australia, and China; 74% of the cobalt supply was mined in the Democratic Republic of Congo; 49% of the world's nickel was sourced from Indonesia. (16) Consequentially, EV automakers are exposed to political and economic developments within these high-risk geographies.

The midstream phase of the supply chain is currently dominated by Asia, but most notably China which currently controls 60% of the world's lithium refining capacity. (17) In 2022, the country accounted for the refinement of 74% of the world's cobalt, 100% of graphite, and 42% of copper. (18) A further 43% of the world's nickel refinement is restricted to Indonesia. (19) Yet again, we have a division of the supply chain which is highly concentrated within certain high-risk nations, however, unlike the upstream phase whose dominance is restricted by geography, western nations are optimistic they can leapfrog Asia and upscale their refinement operations.

Concentration of Commodities Production



Asia's supply chain dominance extends to the downstream segment too, with China accounting for 73.3% of global lithium-ion battery manufacturing capacity as of May 2023. (20) The region’s refining capability is a huge factor behind its manufacturing superiority. The cost competitiveness of Chinese-manufactured LIBs can be attributed to refinement and manufacturing operations being run simultaneously. The West believes relocating the downstream phase of Li-ion battery production will enable them to regain a competitive advantage.

MITIGATION OF GEOPOLITICAL RISKS

The Western world is cognizant of its vulnerability to political instability in the high-risk geographies where most of the Li-ion battery supply chain is concentrated. Manufacturers are focusing on vertical integration, strategic partnerships, and supply chain localization to mitigate the risks. Both Europe and the US contain varying amounts of critical battery materials, but nothing in comparison to the volume of reserves belonging to the nations currently controlling the upstream phase. Nevertheless, various new exploration and extraction projects have been launched in the West, facilitated by green subsidies, as the Western world takes a U-turn on its Not In My Back Yard (NIMBY) approach to raw materials mining. Automakers are also heavily investing in battery technology R&D to reduce reliance on these scarce battery materials. The most widespread approach being adopted is a combination of vertical integration far outside their business model and forging long-term supply agreements. GM's investment of $650mn in a lithium mine in Nevada together with Lithium Americas highlights a growing trend of automakers investing in raw material mines to stabilize their supply chain. (21) As mentioned, the midstream and downstream segments can be de-risked most effectively. The refinement and production processes are not restricted by geography, even though it's an important consideration when looking to reduce costs. Countries are increasingly prepared to invest in localizing these segments of the supply chain. America's Inflation Reduction Act (IRA) and Europe's Green Deal Industrial Plan are instrumental fiscal legislations subsidizing the cost of localization. Biden's flagship act was introduced in August of 2022 and sought to establish the US as a green tech powerhouse. It included a range of tax credits and funding to incentivize green energy technology projects. The act provides support for any project that is based in the US, incentivizing foreign clean tech firms to establish operations in the states. This has been a huge cause of concern in Europe, where policymakers worry their brightest talent will relocate across the pond in search of lucrative tax breaks. Europe's response to the US legislation is the Green Deal Industrial Plan, which includes three acts, all of which share the end goal of establishing Europe as a global frontrunner in cutting carbon dioxide emissions and a leading producer of clean technologies. Both policies have helped kickstart a wave of localization of the mid to downstream phases of the Li-ion battery supply chain. Over $90bn of new battery-related projects were announced in the US in the year that followed the introduction of the IRA. (22) Just this month, Stellantis announced a $3.2bn investment in conjunction with Korean battery maker Samsung SDI to develop a battery facility located in Indiana. (23) Europe's Gigabat project aims to significantly expand the EU's lithium-ion battery production capacity. Power Co, Volkswagen's battery subsidiary, Verkor and Comau, Stellantis's equipment manufacturer, are all involved in the project.

Lastly, LFP batteries are increasingly being considered as a viable solution for reducing exposure to high-risk countries. This is because they replace the critical materials of cobalt and nickel with phosphate and iron, which are supplied by lower-risk nations. Tesla is just one of the many automakers that see this technology as a suitable option to stabilize their supply chain.

ESG RISKS: THE DARK SIDE OF LITHIUM MINING

Lithium has a crucial role to play in the decarbonization of our planet, yet its extraction process is plagued with controversy. Removing any raw materials from the planet has a detrimental impact on the surrounding environment, and lithium is no different. Biodiversity loss, air contamination, soil degradation, and damage to ecosystem functions are all direct consequences of natural resource extraction. A significant portion of the world's lithium reserves are concentrated within the "Lithium Triangle" of Chile, Bolivia, and Argentina. This region is characterized by a very arid climate, making access to water a struggle for the indigenous people who inhabit the lands surrounding the salt flat mines where the lithium is extracted. The climate is so harsh it is used by NASA to test their Mars rovers. Furthermore, lithium mining is incredibly water-intensive, and the resulting situation is already scarce water supplies being diverted away from local communities and being consumed in the mining process. Approximately 2.2 million litres of water is needed to produce one ton of lithium. (24) The extraction process also contaminates local water supplies, further impacting essential access to clean water. Local conflicts have ignited over access to water supplies. Multinationals SQM and Albemarle, the two largest players in the extraction of lithium in Chile have come under scrutiny from activists and politicians who are advocating to protect the salt flats from rampant extraction. A changing political landscape in Chile may see the indigenous peoples' concerns answered, however, the situation remains complex.

Key Economic and Political Developments

THE GREEN SUBSIDIES WAR

The announcement of Biden's Inflation Reduction Act was a cause for celebration in the renewable energy and electric vehicle industry; Brussels, however, reacted slightly differently. Bloc leaders quickly came to the consensus that the US fiscal legislation could have a damaging effect on Europe's green industry, incentivizing the brightest EU green tech start-ups to relocate their operations to the US, in search of generous tax breaks and subsidies. However, we are now just over a year since the flagship legislation was signed into effect, and so far, there is little evidence to show that Europe's worst fears were realized. The attractiveness of the tax breaks the IRA offered European companies was largely overstated. One European decision that helped prevent this outflow of firms was the move to relax its state aid rules allowing member states to match the amount of subsidies companies would otherwise have received if they were operating in the US. The Net Zero Industry and the Critical Raw Materials Acts are two pieces of EU climate legislation designed to directly contest the IRA. They both tackle separate areas of the green technology industry and include ambitious goals the EU hopes to reach, and a range of subsidies designed to help Europe reach these targets, establishing the bloc as a dominant player in the industry. Both Acts are still in the pipeline but have reached the advanced stages of the draft process.

THE NATIONALISATION OF CHILE'S LITHIUM PRODUCTION

In April of this year, Chile's President, Gabriel Boric shocked the world by unveiling plans to nationalize Chile's lithium reserves, the largest in the world. Boric believes this is the "best chance [Chile has] at transitioning to a sustainable and developed economy." (25) His new policy falls short of full-scale nationalization; however, critics have been quick to label it as such. Under the new measures, the state will take a controlling stake in lithium operations considered strategically significant (specifically the exploration and production of lithium deposits). The end goal of this strategy is to revive the nation's struggling economy and make the lithium production process more sustainable. Boric also intends to promote the development of value-added lithium products within the country, giving Chile a competitive advantage over other Latin American producers. The plan involves the establishment of a new national lithium company. The country's two main lithium extractors, SQM and Albemarle, currently have state contracts expiring in 2030 and 2043, respectively. (26) They face the decision between relinquishing 51% ownership to the state in return for contract extensions and expansions, or rejecting the proposed takeover bid and having their operations terminated once their contracts expire.

Boric's plans have prompted fierce debate amongst the international community as well as on home soil. Many argue that historical data has shown that private-sector natural resource mining is more economically efficient than a state-controlled approach and the more viable option is to explore fiscal policy measures. Competition within the global lithium production market has never been rifer. Once a global market leader, Chile now faces fierce competition from Australia and Africa to neighboring Argentina; it simply cannot afford to get this new approach wrong. Chile's share of the world lithium market is forecasted to slide to just 10% by 2030, from 28% now, according to JPMorgan. (27) It is expected that this policy change will divert investment in lithium production from Chile to more politically stable nations such as Australia; investors are often unreceptive to the idea of investing in inefficient state agency projects. There is also fear amongst the international community that this could be the foundation for an OPEC equivalent Latin American natural resource cartel, further threatening the global supply of this key battery material. However, progress in these discussions has repeatedly stalled. Boric's policy highlights the fragility of the global lithium supply chain and gives Western countries a fresh incentive to accelerate their domestic lithium production efforts and funnel investment into more stable producer nations.

Outlook

DIRECT LITHIUM EXTRACTION (DLE)

The current lithium extraction process is inefficient. It is a 12- to 18-month-long process, has an average yield of just 40%, is reliant on climate, and has damaging environmental impacts. DLE promises to solve these problems. DLE has a far smaller environmental footprint, takes days as opposed to months, can offer yields of over 90%, and does not rely on areas containing lithium to have hot climates to evaporate the brine. (28) Additionally, most of the water used in the process is recycled. This is crucial as it can alleviate concerns that lithium mining is eroding the water supply of the surrounding communities.

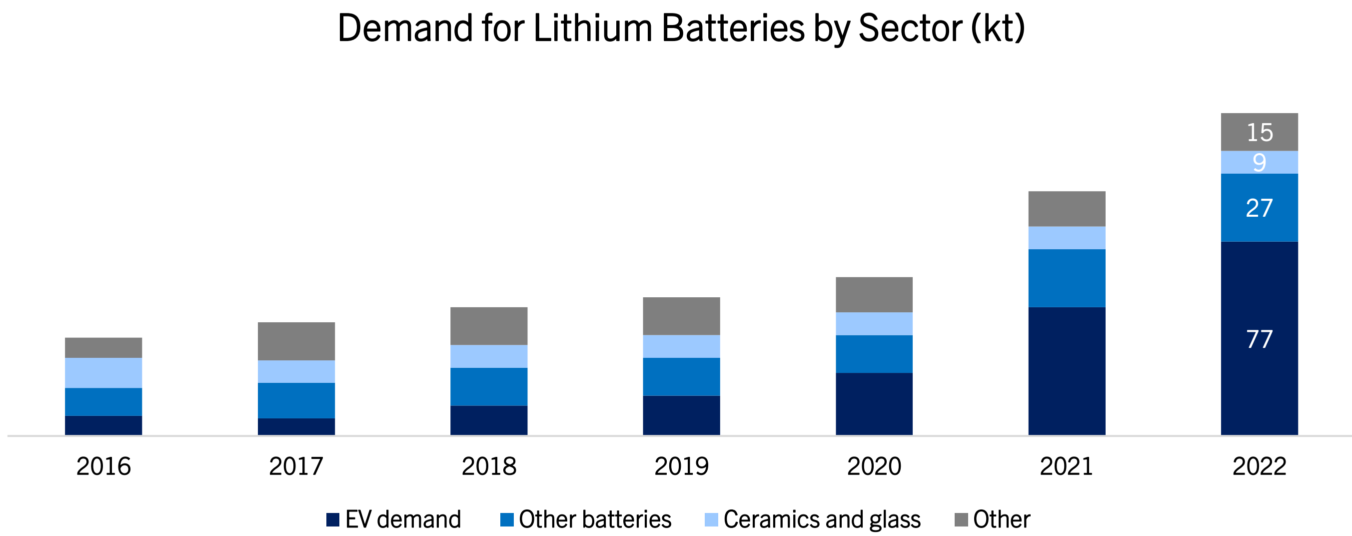
Currently, no commercial DLE technology has reached production without the use of a large brine pool, but Goldman Sachs estimates that DLE could be implemented by 2025-2030. (29)During their Q2 earnings call, Albemarle announced that it is building a facility in Arkansas to test its version of direct lithium extraction. Jerry Kent, CEO of Albemarle stated that if this is successful, DLE will be implemented to extract lithium from existing bromine operations. (30)

DLE is also of huge interest to oil and gas companies. Rising Lithium prices and global efforts to cut down on oil and gas have caused some oil companies to investigate the viability of lithium extraction as Brine is a by-product of oil and natural gas extraction. Many oil and gas companies have shown interest in making a move into lithium extraction, however, this potential move hinges on the commercial development of DLE technology.

FUTURE OF LITHIUM-ION BATTERY DEMAND

Lithium-ion batteries have been at the forefront of the world's efforts to reduce reliance on fossil fuels and reach the ambitious net zero emissions targets required to mitigate the catastrophic impacts of global warming. They have powered an electric revolution in the automobile industry and helped decarbonize electric grids. These two areas are forecasted to account for most of the future lithium-ion battery demand.

In 2022 electric vehicle batteries accounted for 60% of total demand for Li-ion batteries. To date, sales have increased at a fast pace. This is due to several factors, including falling EV prices, increased choice of electric vehicles, improved battery capacity, and government incentives. While demand has been robust, there are still a few factors that will slow the uptake of EVs. The first factor is the large upfront cost. As of February 2023, the average cost of an electric vehicle is $65,202 compared to $56,962 for internal combustion engine (ICE) vehicles. Insurance is also more expensive, the average insurance premium for an EV is $6,824 which is much more expensive than the $5,707 average for ICEs. (31) Countries must also improve EV charging infrastructure. According to a survey carried out by EY in the UK, 54% of consumers interviewed said that lack of infrastructure would deter them from purchasing an electric vehicle in the future. (32)



More recently, macroeconomic conditions have impacted EV sales. Elon Musk admitted in a recent earnings call that Tesla EV sales were suffering due to high-interest rates. Despite these concerns, the forecasted demand for electric vehicles and lithium-ion batteries is extremely positive. Despite total car sales falling by 3% in 2022, EV sales were up 55% in the same year. (33) As governments around the world continue to set ambitious goals to eliminate ICEs, there is no doubt that demand for electric vehicles is set to rise over the next decade.

Another driver of lithium-ion battery demand is battery energy storage. Lithium-ion is the dominant technology in this space and the BESS market is forecast to double in size by 2030. (34) The primary driver of this growth is the continued transition towards renewable energy sources as BESS will play a huge role in the emergence of renewable energy instead of fossil fuels over the coming years. Several key challenges could result in other alternatives being favored over Li-ion. One of the primary objectives of BESS is to provide cost savings which will be very hard to achieve at scale considering the high cost of Li-ion batteries. Safety and the relatively short life span of Li-ion batteries are also a cause for concern. As safer and cheaper batteries, with a longer life cycle come to market, we could see Li-ion lose its position as the dominant player in BESS.

THE THREAT OF SODIUM-ION BATTERIES

The significant technological advancements that the lithium-ion battery's chemistry brings to rechargeable batteries have made the battery technology the new industry standard. The sodium-ion battery (SIB), however, poses perhaps the greatest threat of all the rechargeable battery alternatives to lithium's dominance. China is gearing up to be the frontrunner in the race to replace lithium with sodium. There are currently 20 sodium battery factories planned or already under construction across the globe, 16 of which are in China. (35) China is expected to have nearly 95 percent of the world's capacity to produce sodium batteries within the next two years. (36) The predominant use case for SIBs is currently large-scale energy storage systems. These stationary storage applications can be realized at acceptable prices, due to the low cost and sustainability of sodium-ion batteries. SIBs have the potential to play a critical role in decarbonizing electric grids, by facilitating the storage of renewable energy and providing a constant supply of green energy. Early generations of sodium-ion battery technology have yet to disrupt LIBs' dominant position in the EV market, due to their smaller energy density. Battery size is a crucial factor manufacturers consider when deciding on a battery type, due to the limited space of cars, in contrast with electric grids, where size is far less of a concern. There have, however, been some applications of SIBs in lower-range EVs. As their battery chemistry develops, SIBs could become a viable alternative to LIBs in the production of EVs. Mixed battery packs are one solution being adopted by the largest EV battery manufacturer in the world, CATL. The Chinese giant has developed a battery which uses a combination of sodium and lithium to compensate for the first-generation weaknesses of SIBs and to take advantage of the low cost and weather resistance of sodium cells with the extended range of lithium cells.

To truly overtake LIBs as the predominant rechargeable battery choice, further advancements must be made to increase the energy density of SIBs. There is also the risk that lithium prices continue to fall, having dropped two-thirds in recent months. Furthermore, concerns remain regarding the durability of SIBs and whether they can perform outdoors for an extended period. Although China is leading in the adoption of SIBs, over 90% of the world's readily mined reserves for soda ash (the main industrial source of sodium) are found in the US. (37) China relies on synthetic soda ash produced in chemical plants powered by fossil fuels. The synthetic soda ash industry is plagued with environmental controversy, yet the superpower remains unwilling to rely on imports of natural soda ash from the US.

GROWING ADOPTION OF LFP BATTERY TECHNOLOGY

As global demand for lithium continues to soar and lithium-ion battery pack prices remain high, automakers are increasingly turning to lithium iron phosphate (LFP) technology to reduce production costs. There are also geopolitical advantages to making the transition to this new battery technology for American automakers, as both iron and phosphate can be readily sourced in new battery technology for American automakers, as both iron and phosphate can be readily sourced in the US, meaning lower transportation costs and a more secure supply chain. Cobalt and nickel are mined in the Congo and Russia, respectively. Human rights violations, the ongoing conflict in Congo, and a reluctance to rely on Russian exports have caused the industry to seek alternatives. Many US auto manufacturers are heavily investing in LFP cell manufacturing plants, with Ford Motor recently announcing a $3.5 billion plant in Michigan and Our Next Energy building a $1.6 billion battery manufacturing complex in Michigan too (38). The market is growing at such a rate that both the LFP and LIBs are necessary, and LFP batteries are certainly not going to dethrone LIBs overnight, however, as automakers seek to stabilize their supply chains and reduce production costs, demand for LFP batteries shows no sign of slowing down.

THE SOLID-STATE BATTERY RACE

The race to develop a cost-effective solid-state battery solution that can deliver on the promises of 10-minute charging times, increased energy density, and enhanced safety is well underway, and there appears to be one clear leader. Toyota has led the charge in solid-state R&D, pledging over $35bn worth of investment in EV R&D by 2030. (39) They appear to be reaping the rewards of their commitment; their market capitalization has surged $26bn since the beginning of a series of announcements in June detailing their research progress and technical breakthroughs. (40) The automaker has laid out a three-phase plan to commercialize solid-state batteries by 2027/2028. Further research and development are required to ensure the promised benefits of solid-state batteries can be guaranteed, but experts agree the obstacles are not insurmountable. The cost at which automakers will be able to mass produce solid-state batteries is one of the most significant challenges they face. They are currently far more expensive than lithium-ion batteries, which are already considered too costly by many. Smaller battery packs with increased density are the solution many solid-state advocates are hoping for, but it remains to be seen if this can be achieved within the coming years.

Moreover, there is a real risk that whilst the development of solid-state batteries lags, advancements in other battery technology could result in a situation whereby their competitive advantages dwarf those of solid-state batteries. In an industry which is currently dominated by China, the geopolitical impacts of competitive solid-state technology in the hands of Japan would be dramatic. China's CATL boasted a battery manufacturing market share of 37% as of 2022, leading many to believe solid-state is the only chance to squash the superpower's competitive lead. (41) Toyota is just one of the many automakers exploring the route of solid-state batteries; other auto manufacturers adopting the technology include Nissan, Honda, BMW and Volkswagen to name a few. Although huge progress has been made, we are still a few years away from a solid-state battery-powered EV that is fit for the market; it remains to be seen if Toyota's leap of faith will pay off, and if solid-state technology will have the disruptive effect that it is poised to have.

BATTERY PASSPORT

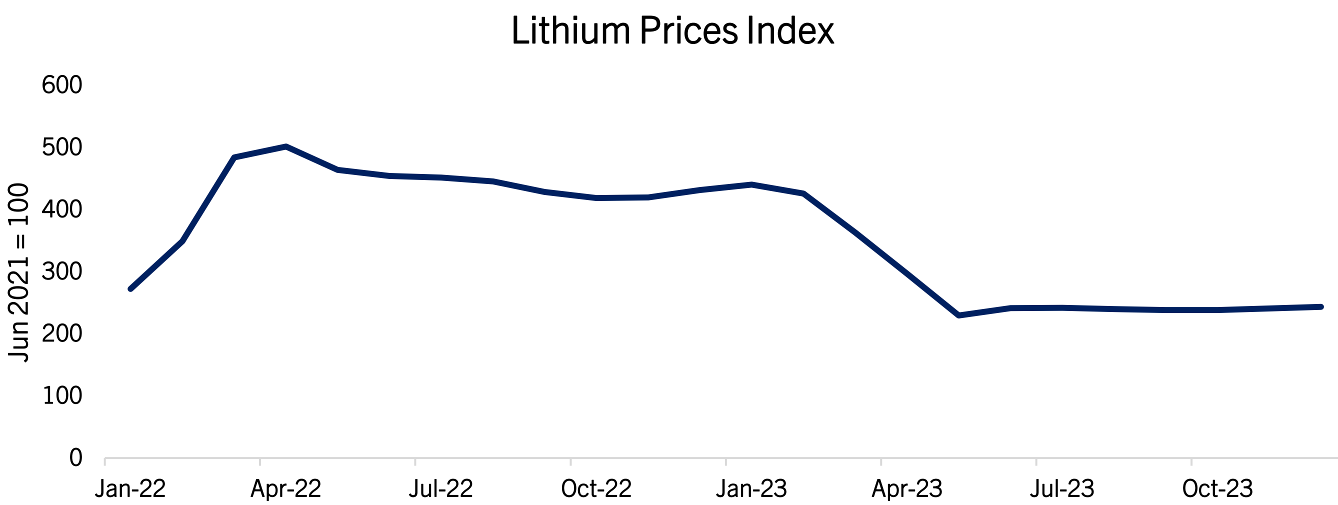
With the lithium-ion battery industry expected to experience annual growth of over 30% between 2022 and 2030, the introduction of battery passports represents a response to environmental and social concerns. Human rights issues are especially prominent within cobalt supply chains in the Democratic Republic of the Congo. These digital tools aim to enhance transparency by providing information on sustainability, the source of material, manufacturing history, and the overall lifecycle performance of batteries. Following the Battery Regulation update, any industrial or electric vehicle (EV) battery available on the EU market, featuring a capacity exceeding 2 kWh, will require a battery passport featuring a unique QR code as of February 2027. (42)

M&A OUTLOOK

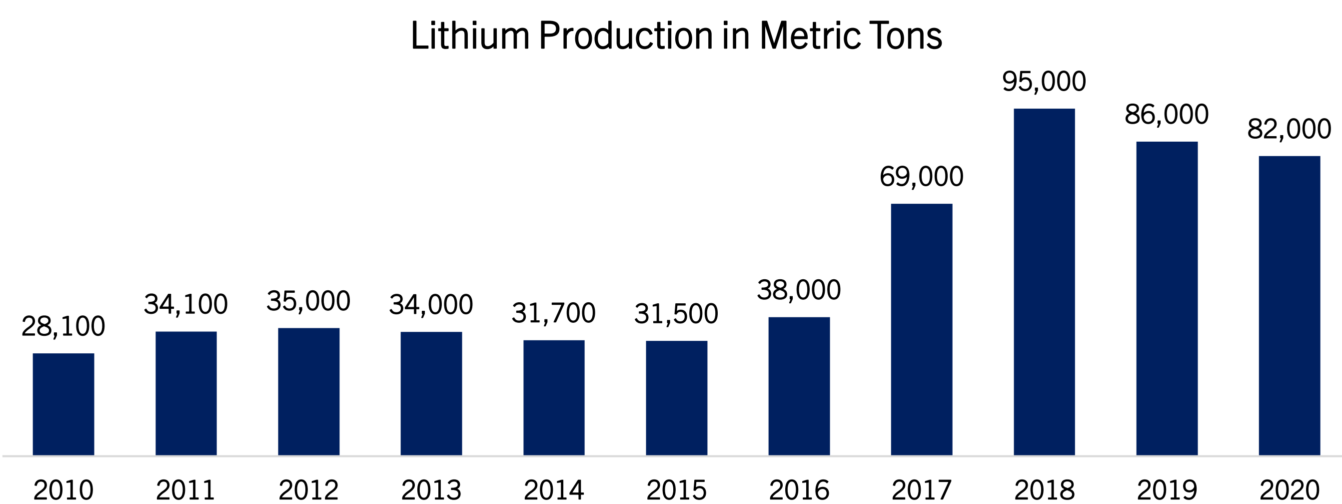
The IEA expects lithium demand to grow by 26 times before 2050. (43) While this is far lower than previously forecasted, lithium supply will need to increase if the ambitious net zero targets are to be met. Experts have called for consolidation in the industry to support the scaling of lithium supply. 2023 has seen an increased level of M&A activity in the market. The most notable is the merger of Livent and Allkem, which combines Livent's impressive processing capability and Allkem's broad range of mines including both brine and hard rock mining facilities to create one of the biggest players in the Lithium market. Geopolitical tensions have also affected the M&A landscape. Earlier this year, Australia blocked the Chinese-backed takeover of Alita resources. This was on the back of advice from the Foreign Investment Review board.

For years Gina Rinehart has been at the forefront of the M&A landscape in the lithium industry. Her strategy has involved acquiring stakes in various companies large enough to prevent takeover bids, but just below the 20% threshold that would trigger a formal takeover offer in Australia. In 2019 Rinehart foiled Wesfarmers' takeover attempt of Kidman Resources by purchasing a 19.9% stake in the company. In October 2023, Rinehart also increased her stake in Lionsdale to 19.9%, preventing Albemarle's takeover attempt. Despite this, there is still potential for consolidation within the industry. Falling lithium prices have resulted in lower valuations. This combined with the consensus that lithium prices will rise again due to supply shortages has resulted in companies seeking growth opportunities through M&A.

IMPACT OF FALLING LITHIUM PRICES ON FUTURE SUPPLY



Lithium has followed the general trend of falling commodity prices throughout 2023. The decline can be attributed to weaker demand for electric vehicles in China and a rapid increase in the supply of lithium. Head of commodities research at Société Générale believes that the fall is a reversal of the 'irrational exuberance' that led to the rapid increase in the price of lithium in 2021. Lower lithium prices may seem like an optimal outcome for OEM and EV manufacturers, allowing them to pass on these cost reductions to end consumers and hence increasing EV sales. However, lithium is a scarce resource, and while its supply is currently relatively healthy, as previously mentioned lithium demand is projected to grow 26 times by 2050, according to the IEA.(43) Lower lithium prices risk deterring



investment in junior mining projects and thus risk impacting the sustainable supply of lithium in the future. Analysts emphasize the need for lithium purchasers to send clear signals about long-term demand, to ensure that lithium supply and demand can be balanced adequately.

RECYCLING

It is estimated that 100 million vehicle batteries will reach their end of life in the next decade. Recycling will play a huge role in the battery revolution as it will help alleviate the issues of supply shortages while allowing countries to become less reliant on the Chinese-dominated rare metals supply chain. On top of this, battery recycling will help countries move towards a circular economy and achieve net zero targets. It is estimated that recycled materials have around 4 times lower emissions than virgin materials. (44)

The current recycling technology in the Li-ion battery market is simply not feasible at scale. The batteries that are currently reaching their end of life will be very difficult to recycle. They contain toxic chemicals that are used to bind the metals to electrodes, making it much more difficult to separate the metals for recycling purposes. A combination of both regulatory pressure and incentives has been introduced to encourage innovation and investment to improve recycling technology. Under the EU battery directive, minimum levels of recovered cobalt (16%), lead (85%), lithium (6%), and nickel (6%) from manufacturing and consumer waste must be reused in new batteries. (45) The IRA incentivizes the use of recycled battery materials through lucrative tax breaks. A McKinsey report highlights the future role of battery recycling in the transition away from ICEs. “As such, the growth and profitability of the EV battery recycling sector has the potential to make or break the pace of the vital transition from an internal-combustion world to an electric one.” (45)

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Miguel is a third-year Global Business student and is the Head of Research and an Investment Officer in the Trinity Student Managed Fund for the 2023/24 session. Last year, he was the Industrials Sector Manager and began in the fund as a Junior Analyst in the Real Estate sector. After a successful summer, Miguel will be returning to DigitalBridge as a Private Equity Summer Analyst. Additionally, he has also held internships at Charlesbank Capital Partners, Glasswing Ventures, and built an app to combat food waste. His hobbies include surfing, playing poker, and listening to podcasts.

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