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The battery value-chain

How batteries and lithium are powering the energy transition

Key risks
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Contents

Introduction

Batteries have a critical role to play in the transition to net zero and the development of a decarbonised global economy. While the range of applications is wide, one of the most dynamic and rapidly evolving segments is the market for electric vehicles (EVs):

Transport accounted for more than **20% of global CO2 emissions** in 2022[1]

20%
of global CO2 emissions in 2022

The push to electrify continues, and 2022 was a landmark year for EVs: **YoY sales grew by 55%**, reaching a record high of more than 10 million[2]

YoY EV sales grew by
55%

Among the metals required to power the growth in battery performance and production, lithium is a key input. **Demand could rise 40 times** from 2020 to 2040 in a scenario in which the global economy is on track to meet the Paris Agreement target[3]

From 2020 to 2040, lithium demand could rise
40 times

This whitepaper will navigate the entire battery value-chain to provide insights into this vital area of technology, highlighting expectations for future demand growth, exploring the current battery technology landscape, analysing the market for the critical metals needed for batteries, and looking ahead to consider how the value-chain may evolve along with key innovations in the space.

[1] https://www.iea.org/data-and-statistics/charts/global-co2-emissions-by-sector-2019-2022
[2] https://www.iea.org/reports/global-ev-outlook-2023/trends-in-electric-light-duty-vehicles [3] https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary

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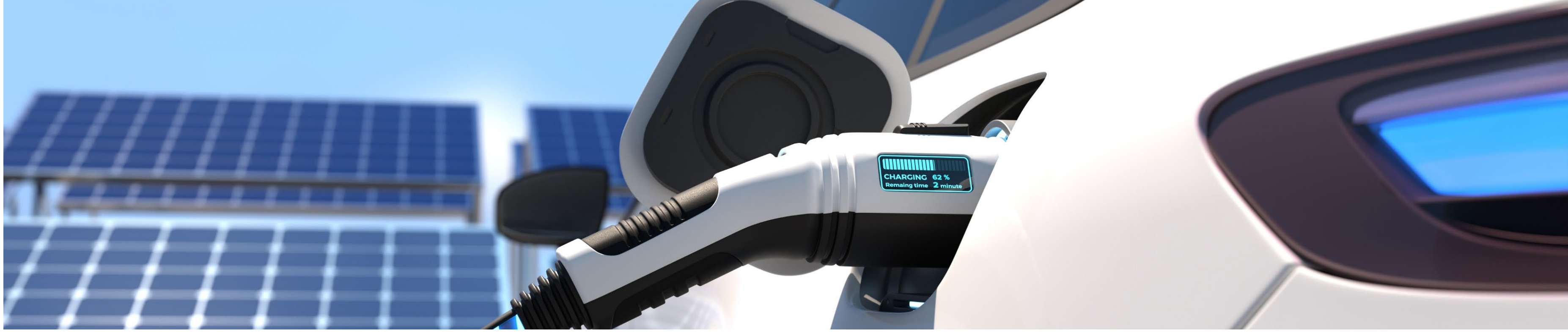


Executive summary

A new decade of growth in battery demand

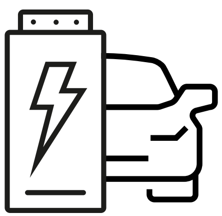
Batteries are a key component of the energy system because of the role they play in electrification and grid storage. Transport electrification is a significant area of development that is driving our decarbonisation journey. A strong increase in demand and competitiveness in the market is already under way, with profound implications for the entire value-chain, including the raw materials needed to produce batteries at scale. The total addressable battery market is expected to grow by more than six times by 2030.[4]

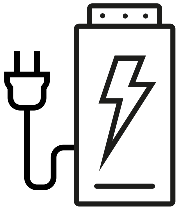
Fundamentals of the battery value-chain

While various combinations of materials can be used in batteries, lithium's unique properties mean it remains a critical metal across a number of battery chemistries. Battery-grade lithium miners benefit from an attractive market environment in which demand continues to rise while high technical and logistical hurdles to increasing production have created high barriers to entry.

The future of battery technology

Batteries are expected to continue to play a fundamental role in the energy transition, alongside other energy storage technologies. Lithium remains a core component of present and future battery technologies.





[4] Goldman Sachs Research, November 2022. Goldman Sachs Research - Marquee (gs.com)

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A new decade of growth in battery demand

EVs to drive battery demand today and tomorrow

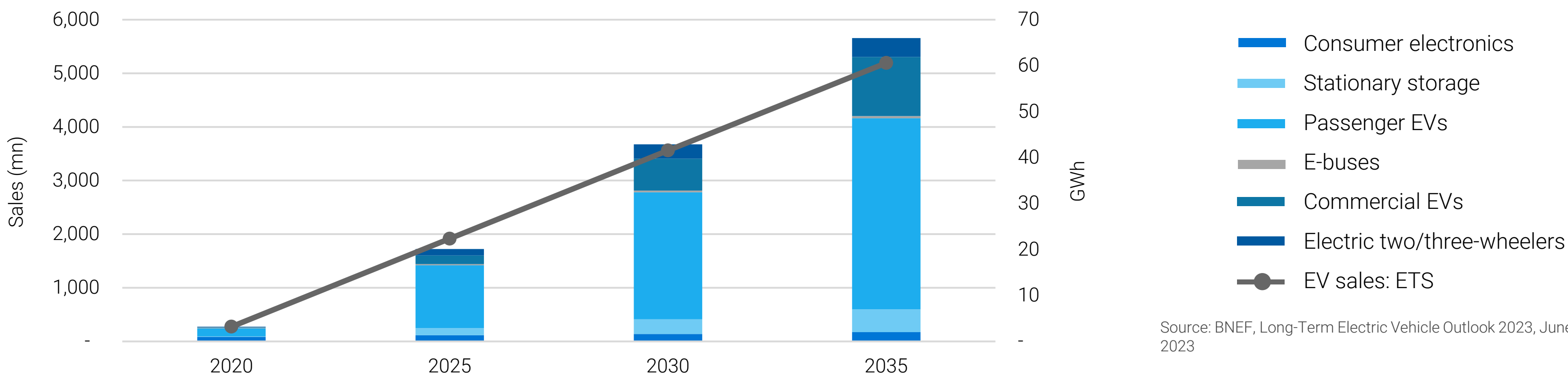
The EV market has grown rapidly since the start of the decade, in part due to growing recognition of the need to tackle climate change. In 2022, transport accounted for more than 20% of global CO2 emissions,[5] and EVs are considered to be a key component of the energy system on the path to net zero.

The European Commission aims to end the sale of CO2-emitting cars by 2035, the UK has vowed to ban petrol cars sales by 2030 and the US plans to achieve 50% EV auto sales by 2030. These policies are expected to support continued growth in EV sales, in turn driving ongoing battery demand. The total addressable battery market is expected to grow by more than six times to reach 3.1 terawatt hours (TWh) by 2030.[6]

Electric mobility – mainly though passenger EVs – is expected to remain the main driver of battery demand, although consumer applications and stationary energy storage systems also represent a growing opportunity for batteries to contribute to the power systems transformation.

According to Bloomberg New Energy Finance (BNEF), the total amount of battery storage for EVs by cumulative sales was over 13 times greater than sales for stationary storage in 2022. It is expected that in 2030 it will still be more than 10 times greater. See the chart below for more detail and source. Within mobility, passenger car sales dominate the landscape, but other vehicles, such as electric buses and electric bikes, are also contributing to growth.

Passenger EV sales and lithium-ion battery demand (GWh) in Bloomberg's Economic Transition Scenario (ETS)



Source: BNEF, Long-Term Electric Vehicle Outlook 2023, June 2023

[5] Executive summary – The Role of Critical Minerals in Clean Energy Transitions – Analysis - IEA, [6] Goldman Sachs Research, November 2022. Goldman Sachs Research - Marquee (gs.com)

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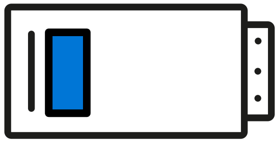
Insight: EV categories explained

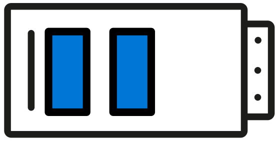
Batteries power hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and full battery electric vehicles (BEVs).

HEV



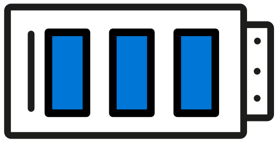
Vehicles with a standard internal combustion engine (ICE) that also include a battery to store energy generated during braking and when cruising. This energy is used to drive a motor to supplement propulsion from the ICE.

PHEV



The battery in a PHEV can be charged via mains power, is larger than that found in an HEV, and can allow the vehicle to run solely on battery for a typical range of 20-50 km.

BEV



The most technically demanding of the three types, the battery in a BEV powers one or more electric motors and is charged by plugging into grid energy sources or specialised chargers.

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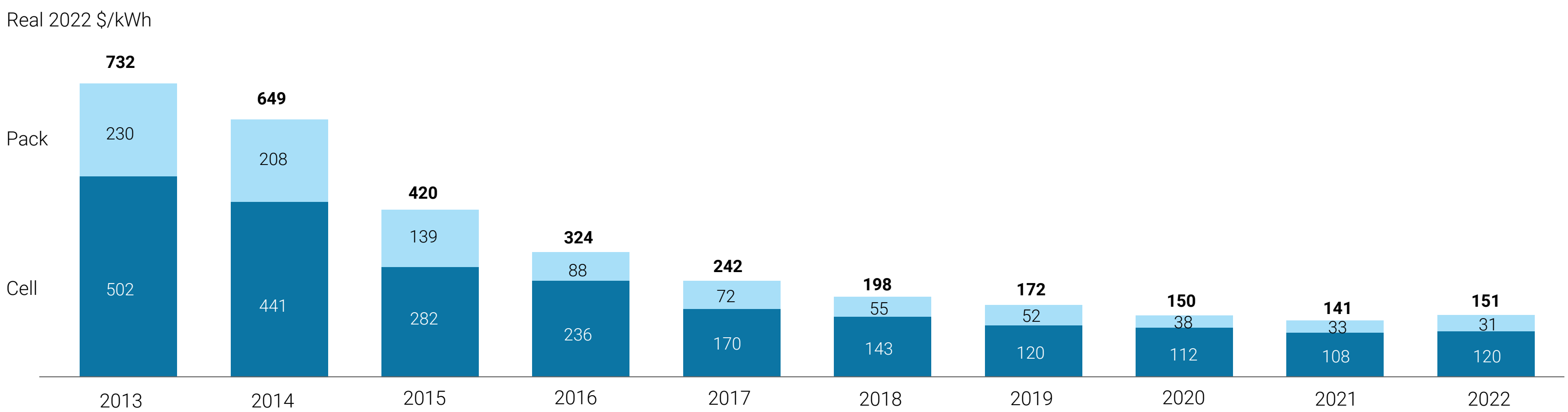
Demand for EVs growing as critical inflection point for battery prices approaches fast

BNEF predicts that by 2026 average battery pack prices should be below $100/kWh, an important inflection point where the cost and margin of mass-producing EVs and internal combustion vehicles (ICVs) will be equal.

Raw material price inflation and supply-chain bottlenecks have caused this trend of price declines to reverse recently. However, financing from governments and the private sector and R&D investment are key elements that should lead to improvements in battery technology and further cost reductions. Many automakers have already published roadmaps to reach a price below $100/kWh.[7]

Volume-weighted average lithium-ion battery pack and cell price split, 2013-2022



Source: BloombergNEF. All values in real 2022 dollars. Weighted average survey value includes 178 data points from passenger cars, buses, commercial vehicles and stationary storage.

[7] https://about.bnef.com/blog/battery-pack-prices-fall-to-an-average-of-132-kwh-but-rising-commodity-prices-start-to-bite/

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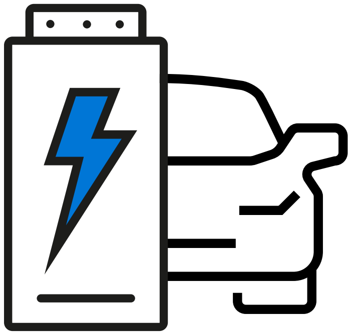
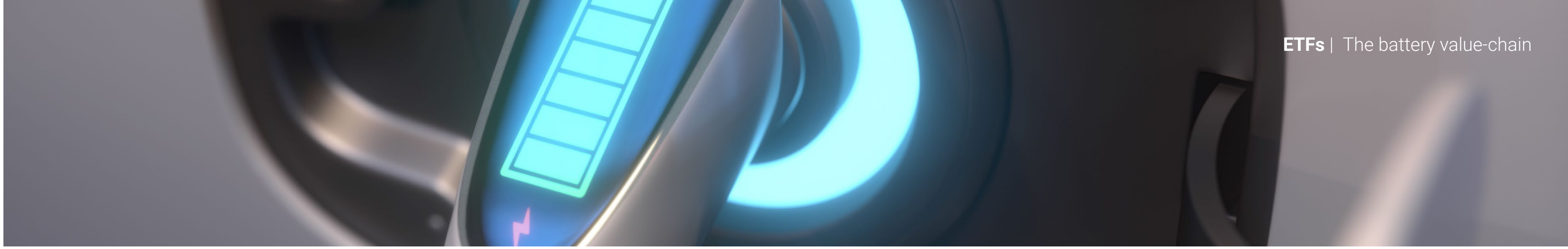
Key takeaway

Rising battery demand has profound implications for underlying raw materials

Increasing demand for batteries within the context of the energy transition is putting pressure on global supply chains for key components. As such, it's important to understand not only the battery technology landscape but also the underlying building blocks of a battery, and the implications of rising demand for the underlying raw materials.



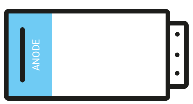
Fundamentals of battery value-chain



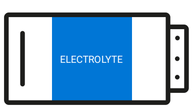
All batteries have three fundamental components

Although researching different battery chemistries and materials can lead one down a rabbit hole of acronyms and unfamiliar vocabulary, the key building blocks of batteries are consistent and straightforward. The batteries we use day-to-day in laptops, mobiles and increasingly stationary energy storage systems and EVs all comprise three parts:

Cathode (key for energy density, reliability) – the choice of material used to construct the cathode is critical as this dictates the capacity and power of a battery. Cathodes are often a mix of metals with high energy density and stability, such as **lithium** and **nickel**, mixed with metals for safety and reliability such as **cobalt** and **manganese**.



Anode (key for stability of performance, lifespan) – the choice of material for the anode in high-performing batteries has long been **graphite**, used for its ability to hold charge and remain stable for long periods of time. Recent developments may see additional use of **silicon** or **lithium** in the anode, with the additional benefits of increased overall capacity.

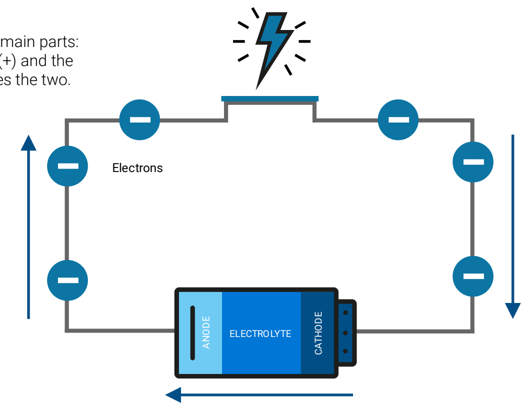


Electrolyte (facilitates the reaction) – materials which are highly conductive, often in a gel or semi-liquid state (although solid state electrolytes are starting to get deployed), are chosen for the electrolyte, which facilitates the overall chemical reaction within the battery.

How batteries work

A battery cell has three main parts: an **anode** (-), a **cathode** (+) and the **electrolyte** that separates the two.

Flows of elections around the circuit



When a battery is connected to a circuit, a chemical reaction occurs that causes electrons (negative charge) to flow around the circuit. The movement of **electric charge** creates an electrical current through the circuit.

These three elements form a battery cell. When many cells are stacked together, they form a battery pack.

Given its high electrochemical potential and low weight, **lithium** is a highly preferable metal in battery compounds and specifically for EV batteries under the lithium-ion chemistry. Understanding the market for lithium is therefore critical given the increase in demand expected over the coming years.

Other key metals used in batteries include **copper** and **aluminium** for their conductivity and light weight, respectively.

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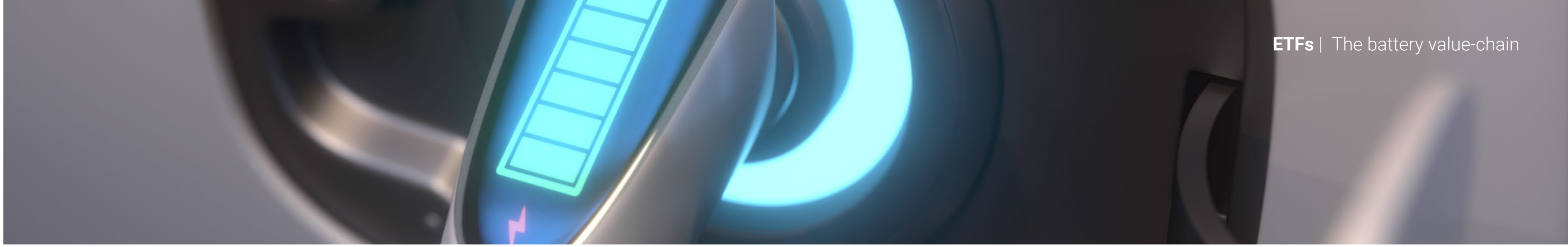


Lithium is important for high-performance, lightweight batteries, but is all lithium the same?

Lithium is the lightest of all the metals, with only half the density of water, and is highly reactive. These characteristics explain why lithium plays such an important role in the battery market, as manufacturers seek ever-lighter and more energy-dense batteries. But not all lithium is battery-grade. While lithium can be extracted from a variety of materials such as underground rocks, brines, or clay deposits, the lithium that is obtained is not directly in a usable state for battery cathodes. To achieve the level of stability and purity needed for battery compounds, lithium must be refined into either:

- **Lithium hydroxide:** For high-performance lithium-ion batteries, lithium hydroxide has a very high energy density to weight ratio, making this the top grade of lithium used in commercial batteries.
- **Lithium carbonate:** A lower-cost solution than lithium hydroxide, for use when energy density of a battery is not critical. Lithium carbonate does not require the same level of refinement as lithium hydroxide but can be converted into lithium hydroxide at an additional cost.

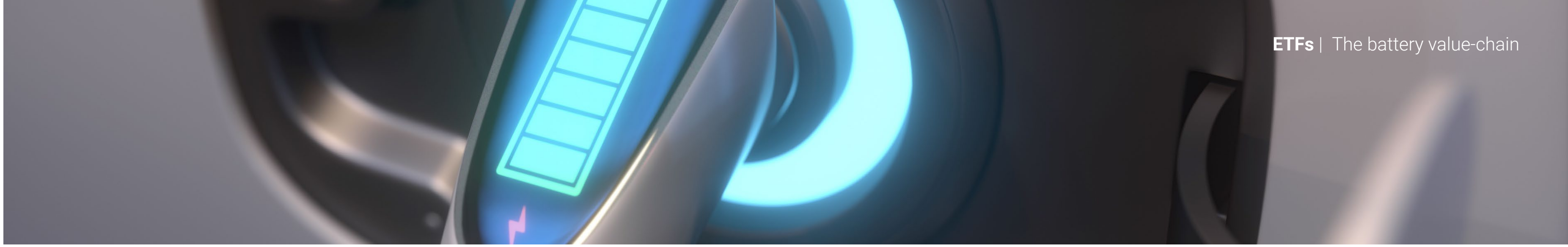
Lithium is highly sought after, but extraction is dominated by just a handful of countries

All major lithium flows come from six countries: Argentina, Australia, Brazil, Chile, China and the US, although others have started to focus more on lithium production in recent years given the metal's importance in meeting net-zero targets and relevance for energy security.

Given the concentrated nature of lithium production and processing, supply security has become a top priority for technology companies in Asia, Europe and North America. Strategic alliances and joint ventures among technology companies and exploration companies are being established to ensure a reliable, diversified supply of lithium for battery suppliers and vehicle manufacturers.

Regardless of how and where lithium is extracted, processing raw lithium into a useable state is critical. China is home to over half of the world's processing capabilities and is on track to continue to dominate this area of the market through to the end of the decade.

Source: FastMarkets, April 2023



World resources (deposits): Owing to continuing exploration, identified lithium resources have increased substantially worldwide and total about **98 million tons.** Identified lithium resources are distributed as follows:

Source (all resources): FastMarkets, April 2023.

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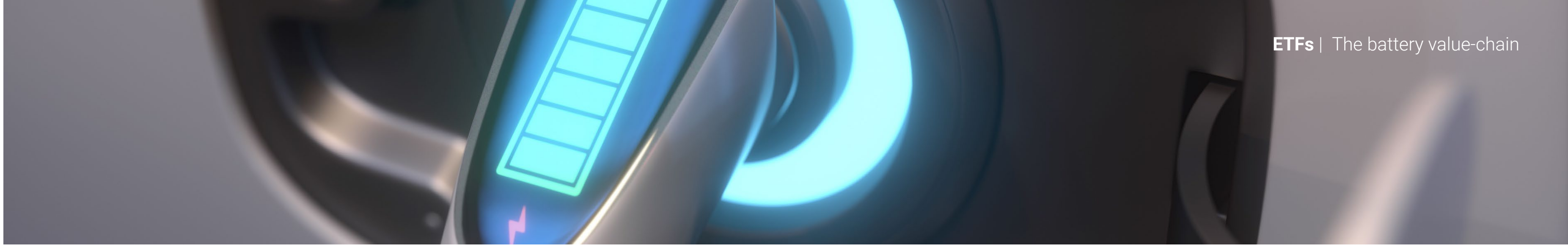
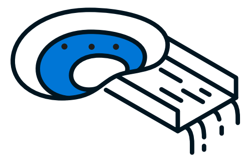


Lithium extraction is a complex process that takes years to develop

There are two primary sources from which lithium is extracted: brines and hard rock.

Extraction from underground brines typically starts by drilling a hole and pumping brine to the surface in salt flats called salars. These are located mainly in South America (Argentina, Bolivia, Chile) and China. The brine moves from one evaporation pond to the other, where mixes of manganese, potassium, borax and salts are created while water evaporates. Brines are then processed in a chemical plant from which the lithium carbonate concentrate, typically with a standard grade of 0.03%[8], can be sold directly or converted into hydroxide. This process takes roughly eight months to three years and requires specific environmental conditions.

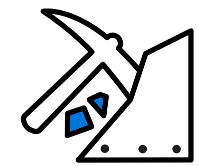


Did you know?

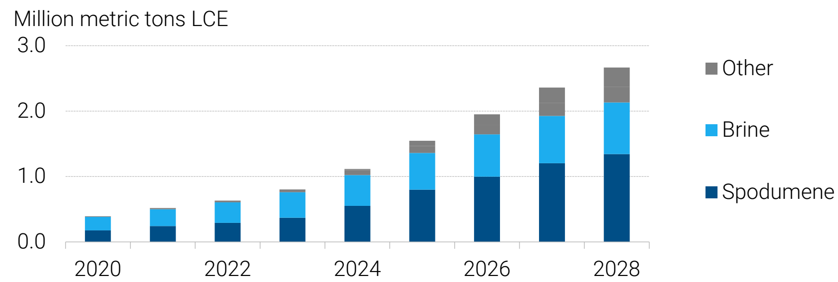
Argentina, Bolivia and Chile form the lithium triangle, which accounts for more than half of global extracted reserves.[9] Brine-based lithium sources here are in various stages of development or exploration.

[8] FastMarkets, April 2023. [9] https://www.iadb.org/en/improvinglives/lithium-white-gold-regions-development#:~:text=Argentina%2C%20Bolivia%20and%20Chile%20make,to%20the%20U.S.%20Geological%20Survey.
[10] https://stockhead.com.au/resources/so-you-think-you-can-drill-how-do-i-know-if-my-lithium-stock-is-onto-a-winner/ [11] https://source.benchmarkminerals.com/article/hard-rock-vs-brine-how-do-their-carbon-curves-compare

Extraction from hard rock is carried out using conventional mining, crushing, concentration and separation methods. Lithium is found in spodumene-bearing pegmatites, intrusive rocks that are formed during the last phases of the crystallisation of magma in countries such as Australia and Brazil.
As magma cools, water and minerals become concentrated.
The standard grade of spodumene concentrate is ~6%, although the benchmark for drilling is considered 1-1.5%.[10] Once extracted, it can be sold and shipped as hydroxide or carbonate.
The exploration phase of a lithium mine can take up to six years and development approximately four years.



Lithium resources supply by type



Source: Bloomberg NEF, June 2023

Lithium from brines tends to be on average approximately 200 times less concentrated than hard rock. However, the lower concentration is offset by lower operating cost and greater ease of extraction compared with hard rock. Looking forward, the development of Direct Lithium Extraction (DLE) could increase the Lithium yield from brines significantly and potentially gain over 16% of the total mined lithium market share over the next decade.[11]
Despite being abundant, because lithium is found in low concentrations, extracting it is not only technically challenging but also costly.

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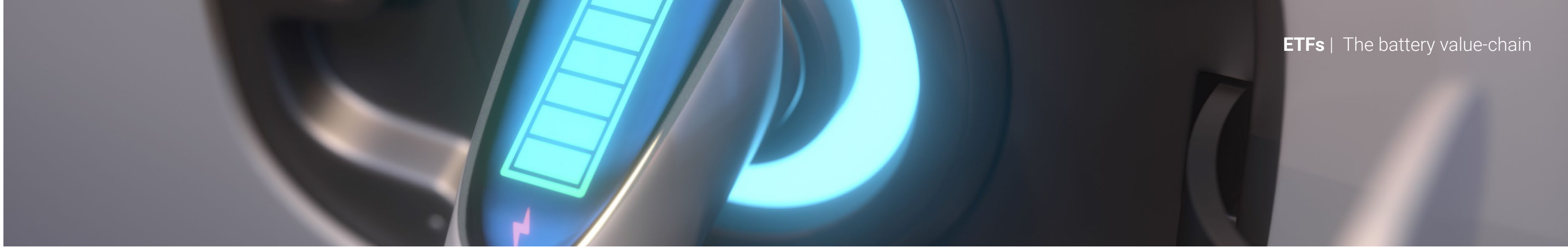
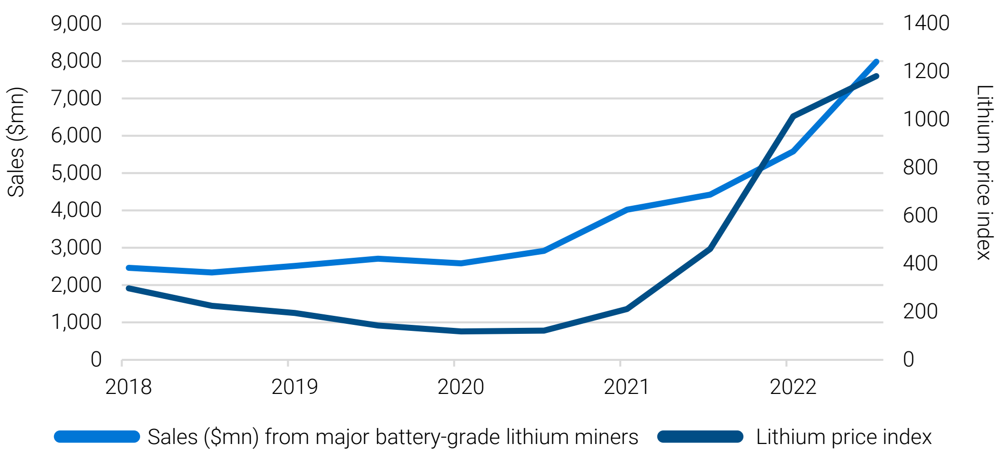


In addition to technical challenges, lithium mining can be logistically difficult, creating high barriers to entry

Lithium projects can take eight to 15 years to come online.[12] Both main extraction processes require up to four years of project evaluation and feasibility studies. Permitting, specifically for greenfield projects and those located in highly populated areas, can take over a year. All projects require mapping, surveying, drilling and testing, before production can be scaled up and stabilised. The extracted ore needs to be performance-tested and go through a quality assurance and packaging/storing process before it can be shipped. This long production cycle, coupled with complex logistics, creates significant barriers to entry in the lithium market.

Lithium revenues proxy lithium prices



Source: LGIM, Bloomberg, as of December 2022, all values in USD
[12] FastMarkets, April 2023

Portfolio perspective

Combining battery-grade lithium miners with battery technology providers gives exposure to the entire battery value-chain.

Investors who only have exposure to battery technology producers may be exposed to the cost of raw inputs to battery production. Lithium miners may hedge a battery portfolio against lithium price volatility because their revenues closely track the price of lithium. Therefore, having exposure to both upstream and downstream players increases the level of diversification, potentially limiting raw material pricing risks.

Battery producers have historically fixed the quantity and price of lithium on long-term (five to 10 years) negotiated fixed-price contracts. Today, however, the market is changing, with a fifth of participants adopting floating spot prices assessed by price reporting agencies such as Fastmarkets and fixed quantities.[12] This is benefitting producers at times when lithium prices are subject to high volatility. Ultimately, prices depend on lithium content, impurities and negotiations.

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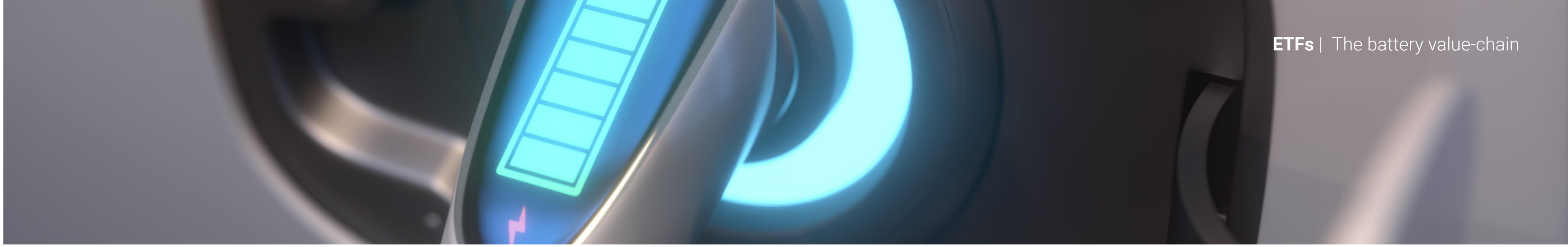

Strong growth in lithium demand is creating a significant imbalance between supply and demand

The IEA estimates that lithium demand from 2020 to 2040 could rise 40 times if the global economy were on track to meet the Paris Agreement goal. This would imply using 60% of known global reserves by 2030. [13]

Given the rapid shift to EVs and the lengthy extraction time for lithium, the potential for a significant scarcity risk and an imbalance between supply and demand is being created.

Owing to continuing exploration, identification of potential lithium resources has increased substantially worldwide and, together with currently operational lithium reserves, now total approximately 138 million tonnes. Taking the expected level of demand in 2030 to be three million tonnes per annum, current analysis shows that overall extractable lithium reserves are plentiful and would last over 40 years at 2030 levels of demand. Elevated lithium prices make the majority of these deposits economical to extract.[14]

So, the problem is not that the world doesn't have enough lithium, but instead getting the metal out the ground quickly enough to keep up with demand and ensuring the refining capacity to turn it into a battery-grade product that can be inserted into the battery value-chain.

[13] BofA - Thematic Investing (baml.com) [14] FastMarkets, April 2023

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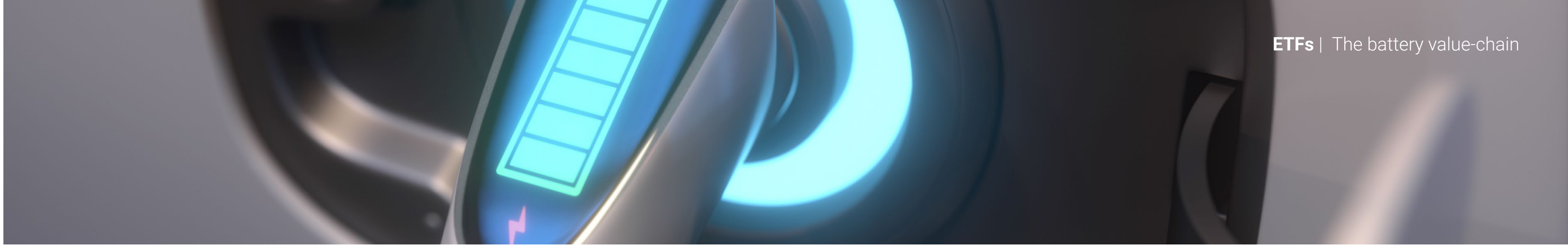
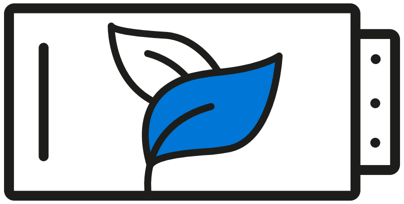
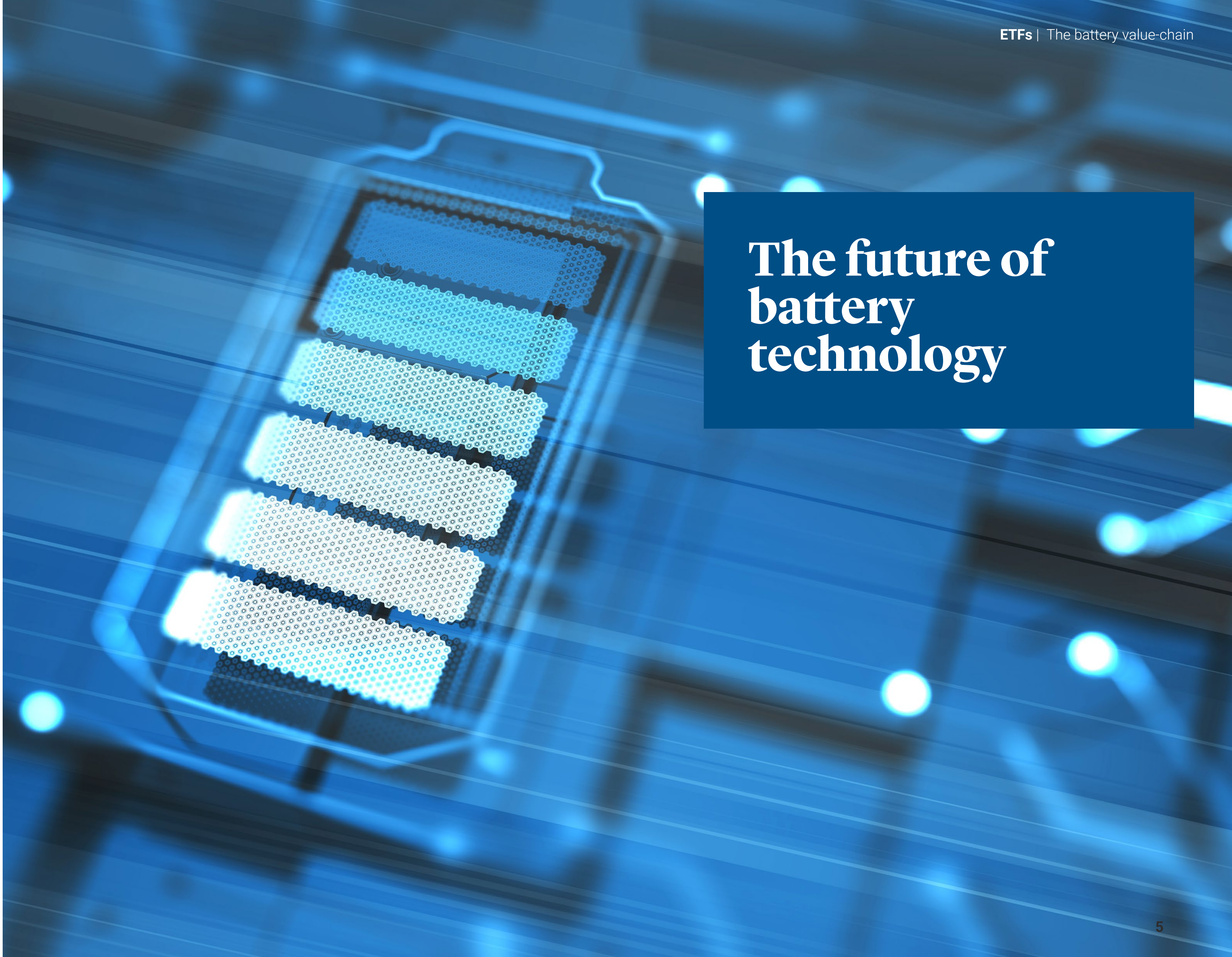


Key takeaway

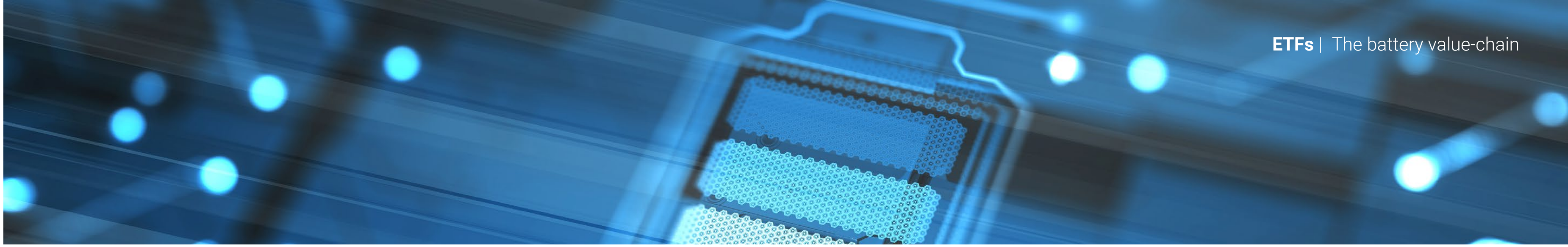
Lithium extraction can be difficult, but is fundamental

Lithium's unique properties make it a fundamental input in the battery value-chain. While demand is rapidly increasing, there are high technical and logistical hurdles to increasing production that could create an attractive environment for
battery-grade lithium miners.





The future of battery technology



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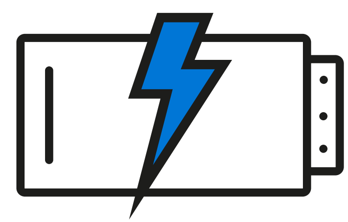
Lithium is a critical metal in many battery chemistries

Lithium has come to dominate the high-performance battery market due to its unique and attractive properties, but lithium-ion batteries are not all the same and there are a number of different types, or ‘chemistries’, common in the market today.

For high-performance combined with low-weight, lithium-nickel-manganese-cobalt (NMC) and lithium-nickel-cobalt-aluminium (NCA) are two of the most relevant chemistries today, especially for the high-end electric vehicle market, due to their very high levels of energy density resulting in long range. Lithium-iron-phosphate (LFP) chemistries are more regularly seen in entry-level electric vehicles, as they are cheaper to produce and have longer lifecycles, enabling them to be recharged up to twice as many times as NMC or NCA batteries.

Although most innovations in the battery market refer to the metals that make up the cathode, manufacturers are also looking to enhance the anode to extend overall battery performance. Replacing graphite with silicon is one such concept that may find its way to electric vehicles batteries in the years to come.



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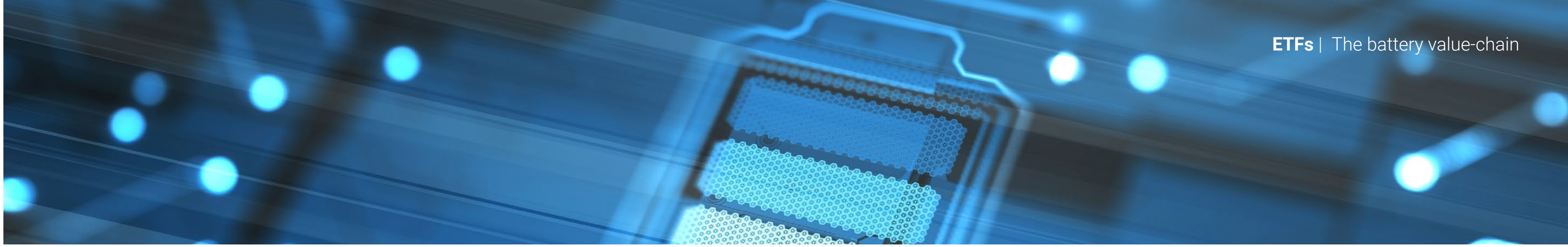
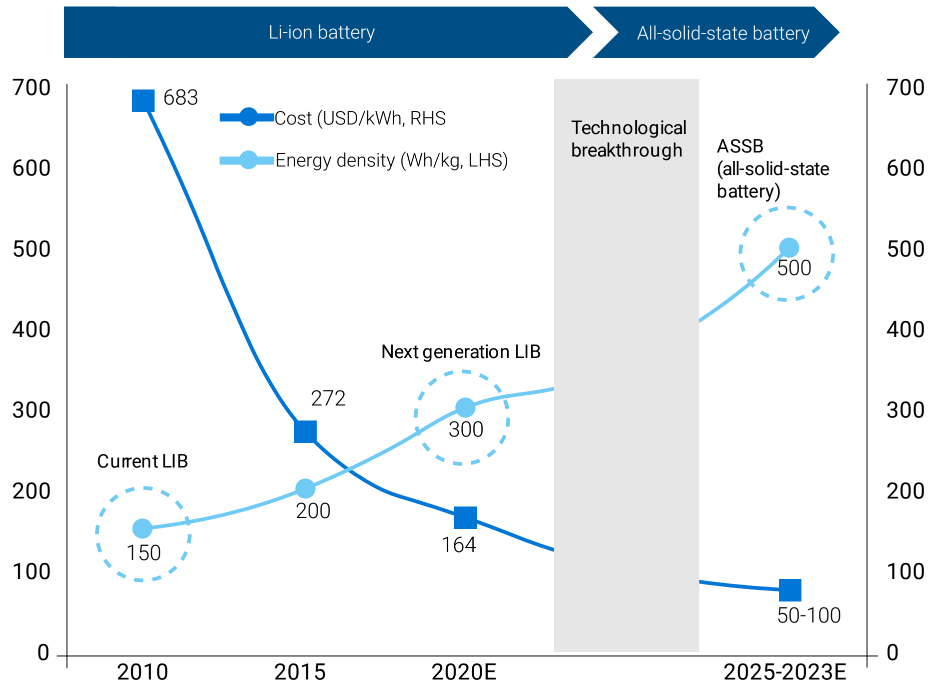


Innovation continues, but lithium is still set to play a central role…

Markets are pushing for innovation to increase the lifecycle of batteries, make them more energy dense, lighter, longer-lasting, quicker to recharge, cheaper, and perhaps most importantly, safer. All-solid-state batteries (ASSBs) are leading the charge to become the main contender in the next five to 10 years, and this is why many lithium-ion battery manufacturers are investing in R&D to become key players in this innovative space.

Similar to lithium-ion batteries, ASSBs have a cathode, an anode and an electrolyte. Importantly for lithium miners, they are lithium-intense as their cells tend to share the same chemistry as lithium-ion cells. Critically, an ASSB cell could require up to 130% more lithium than a traditional Lithium-ion battery cell.[14] The main difference concerns the electrolyte, which is not liquid but made up of ceramics or other solid materials. Additionally, they can store more lithium (density improvement from 300 Wh/kg with Lithium-ion to 400-500 Wh/kg with ASSBs), can achieve a longer range (~80% improvement) and recharge faster (~30% improvement).

New chemistries for next-generation batteries such as sodium-ion might become more popular, especially due to the need to reduce overreliance on lithium. However, even with a rapid sodium-ion adoption, according to BNEF, lithium carbonate demand could still reach 2.4 million metric tons by mid 2030s, which represents a fivefold increase from 2022.[14] We expect lithium to remain the most critical metal in batteries for years to come.



[14] BloombergNEF. June 2023. https://marquee.gs.com/content/research/en/reports/2021/02/19/6ff3b911-d7a5-4788-98fc-0bcb5eb3a81c.html

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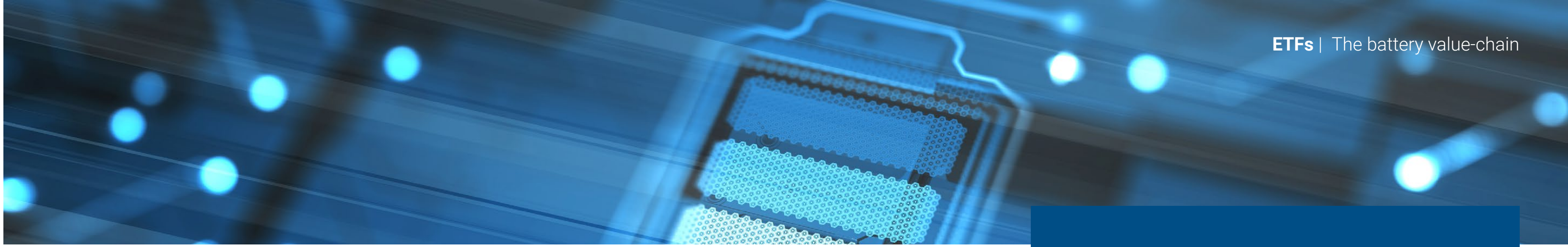

… and batteries remain essential in the path to decarbonisation, despite the emergence of other energy storage technologies

We believe battery demand is only going to increase with the spread of light mobility applications, thanks to their efficiency and affordability. Battery manufacturers are expanding their capacity as a result and global cumulative lithium-ion battery capacity could rise over fivefold to 5,500GWh between 2021 and 2030.[15]

Alongside more high-performance battery chemistries, an emerging energy-storage technology is green hydrogen. Although hydrogen has certain advantages over batteries in an energy-storage context – it is lighter, it has a much faster recharge/refuel time, it can be transported in gas or liquid form – it is better suited to certain use cases in which batteries are impractical. These include applications that demand long ranges, heavier mobility or stationary applications in industries that are hard to electrify. While we strongly believe hydrogen is one of the key tools for the global economy to achieve net zero, we see it playing a complementary role with batteries and other clean energy technologies.

We believe batteries will remain a critical energy-storage technology, and the raw materials that constitute them will continue to shape global supply chains and mineral exploration activities for years to come.

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[15] https://www.woodmac.com/press-releases/global-lithium-ion-battery-capacity-to-rise-five-fold-by-2030/

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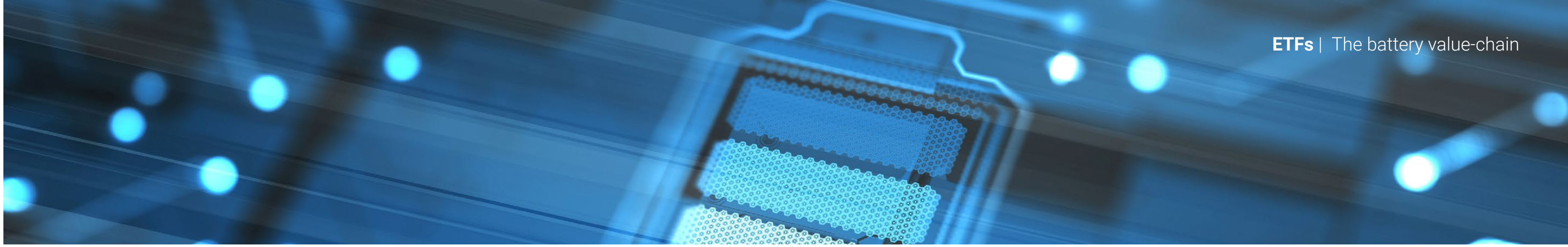
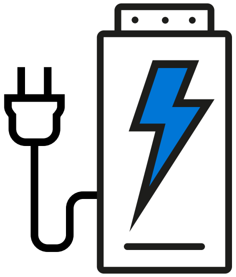


Key takeaway

Lithium is the metal enabling batteries to drive progress on the path to net zero

Lithium is the key metal used in a number of battery chemistries, including the most advanced ones. In our view batteries remain a vital solution to store energy in a way that contributes towards global decarbonisation targets.



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Contact us

For any questions on this report, please contact your usual LGIM representative or email **fundsales@lgim.com**. All calls are recorded. Call charges will vary.

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