CHEMICAL REACTIONS

Lithium-Ion Batteries

The substantial rise in sales of electric vehicles (EVs) due to changing consumer views, new regulations and environmental concerns will drive the continued demand for raw metals, specifically lithium and cobalt. Supply constraints, environmental and human rights concerns over their extraction and new end-of-life policies are making battery recycling an increasingly important material source. Investments into lithium-ion battery recycling are rising rapidly along with a developing network of new alliances between companies in the extractive and recycling industries, battery producers and manufacturers of EVs.

INTRODUCTION

Lithium-ion batteries (LIB) are rechargeable batteries which offer a high energy density, energy efficiency and good high-temperature performance. They were initially created for the consumer electronics sector and first commercialised in 1991 but are now most widely used in electric vehicles (EVs).

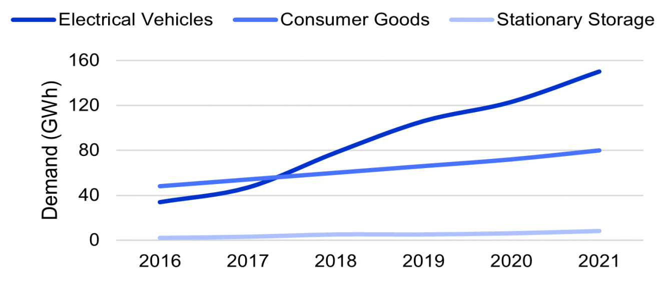
OUTLOOK FOR LITHIUM-ION BATTERIES

By 2027, the global lithium-ion battery market is expected to reach almost $130bn, according to a report from Valuates, with a CAGR of 18% from 2020 to 2027. In the last 10 years, the LIB market has been growing at an extraordinary pace, with this pace expected to increase in the next 10 years. Growth is primarily being driven by the electrification of cars and buses. Despite the COVID-19 pandemic, global sales of electric vehicles have continued to rise rapidly. This expansion has largely been driven by changing consumers' views on EVs. The launch of Tesla's all-electric vehicles into the automotive industry has made EV ownership fashionable and mainstream. Tesla's EV model, the Roadster, was the first legal highway electric car to make use of a LIB. This has led to the development of newer, stylish, high-performance vehicles, which are able to compete with other luxury brands. The Model S has received high praise for its design, performance, engineering excellence, efficiency, value and safety.

With growing acceptance of EVs and increasing legislation, such as the European ban on the sale of petrol and diesel engines by 2035, nearly every Original Equipment Manufacturer (OEM) is expanding manufacturing capacity. It is expected that this expansion will lead to prices of LIB continuing to decline and cement the use of LIBs in the transport industry for years to come.

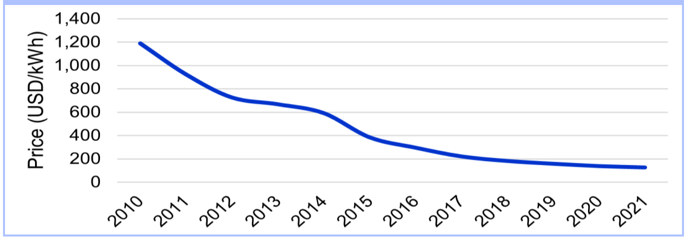
The Solactive Global Lithium Index, which tracks the performance of the largest and most liquid listed companies active in sourcing lithium or the production of lithium batteries, has risen 32% this year. Although production was affected at the height of the COVID-19 lockdowns it has since recovered and strong growth is expected to continue. The key players in the lithium and lithium battery technology industry include **LG Chem** (South Korea), **Samsung** (South Korea), **Varta** (Germany), **Tesla** (US) and **CATL** (China).

Figure 1. *Lithium-ion Battery Demand*



Source: Bloomberg

***Figure 2.** Global Lithium-ion Battery Price*



Source: Bloomberg

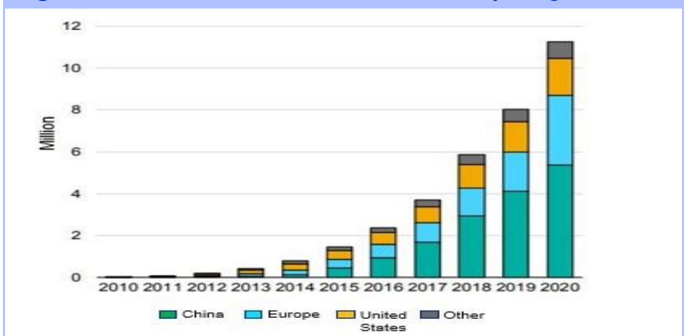
LITHIUM-ION BATTERIES TECHNOLOGY

The cells in a lithium-ion battery are made up of a cathode, an anode, an electrolyte and a membrane. The cathode is generally made of lithium, metal oxides or phosphates, but there are often variations in the chemistry of the cathode, which is key to the amount of energy they can hold: the critical metals used are lithium, cobalt and nickel. Grid storage systems or vehicles travelling short distances, often use lithium, iron and phosphate, a cheaper and less powerful cathode chemistry. The anode is typically made of graphite and the electrolyte of dissolved lithium salt. The membrane is used to separate mechanically the anode and cathode within a cell, while allowing ionic flow between them.

The cathode chemistries commonly used in LIBs in EVs include the more energy dense lithium nickel manganese cobalt (NMC) and lithium nickel cobalt aluminium (NCA). In 2017, Panasonic introduced lithium-ion cells with NCA cathode chemistry for Tesla's Model 3. At over 700 Wh/L, this reportedly offered the highest energy density battery technology to date. NMC is also widely used in EVs by other OEMs such as **BMW**, **Nissan** and **Volkswagen**.

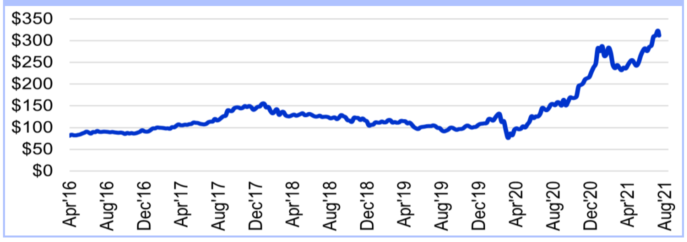
Johnson Matthey has announced that it intends to pursue the sale of all or parts of this business with the ultimate intention of exiting, believing that, whilst demand for battery materials is accelerating, so is competition from alternative technologies and other manufacturers, thereby turning this into a commodity business. Johnson Matthey has already made significant progress in the commercialisation of its

***Figure 3.** Global Electric Vehicle Stock by Region*



Source: IEA

***Figure 4.** The Solactive Global Lithium Index*



Source: Bloomberg

***Table 1.** Examples of common cathode chemistries used commercially*

Cathode Type	Chemistry	Example metal proportions (ex. Li)	Example Use
NMC-111	$LiNiCoMnO_2$	33.3% Nickel 33.3% Manganese 33.3% Cobalt	Tesla Powerwall
NMC-811		80% Nickel 10% Manganese 10% Cobalt	Tesla Model 3 - China BMW iX3
LFP	$LiFePO_4$	100% Iron	Starter batteries
NCA	$LiNiCoAlO_2$	80% Nickel 15% Cobalt 5% Aluminium	Tesla Model S
LMO	$LiMn_2O_4$	100% Manganese	First generation Nissan Leaf
LCO	$LiCoO_2$	100% Cobalt	Portable electronic devices

Source: Bloomberg

eLNO® family of nickel-rich advanced cathode materials, and has entered an agreement with Nano One Materials Corp. (Vancouver, Canada), to co-develop next-generation products and processes for this cathode family. Amongst other strategic partnerships, it has joined with Thomas Swan and Centre for Process Innovation (CPI), an independent UK technology innovation centre to explore the best ways to overcome the limitations of lithium-ion batteries. The project, dubbed the ICE-Batt Project, includes fine tuning the existing cathode formulations and using advanced carbon nanomaterials. These battery businesses will be attractive to the right bidder.

SUPPLY OF RAW MATERIALS

The main critical raw materials for lithium-ion batteries with challenges to supply are lithium and cobalt. Lithium is required for both the cathode and electrolyte and cobalt is required for the majority of cathodes.

As demand for EVs grows, so will the demand for key battery raw materials. Batteries were estimated to account for 71% of the global lithium end-use markets of $5.3bn in 2020, according to the 2021 Mineral

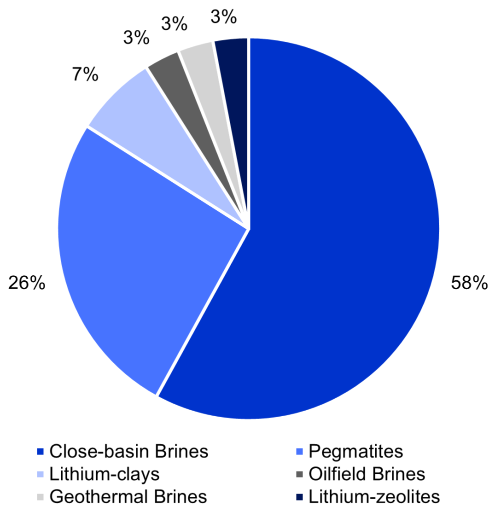
Commodity Summary by the U.S Geological Survey. This is expected to rise to $13.5bn by 2025. With global annual demand for lithium expected to outstrip annual production by 2035, more effective extraction and recycling methods are required.

Over 60% of total recoverable lithium deposits come from brines and much of these are from “China”, Chile, Argentina and Columbia. The other major source being lithium-containing ores. As recoverable lithium-rich ore deposits diminish, the lithium industry is shifting away from these sources and towards brines, with new cost-effective technologies for lithium production emerging.

More than 70% of the world’s lithium supply is controlled by **Ganfeng Lithium** (China), **Albermarle** (US), **SQM** (Chile), **Tianqi Lithium** (China) and **Livent** (US).

Albemarle has recently been scaling up their lithium carbonate and hydroxide capacity via resources in Chile and the U.S, and growing investments in Australia. The company, which acquired Rockwood in 2014, tends to sell lithium in long-term contracts and so developing and expanding mines and securing long-term contracts are crucial to their business. The company has said that it will double capacity for brine

Figure 5. *Lithium Deposit Types*



Source: US Geological Survey

Figure 6. *Lithium Brine*

Figure 7. *World Lithium Resources*

Source: US Geological Survey

extraction at its Nevada site, the only current lithium recovery site in the U.S, by 2025 at a cost of $30m to $50m. According to Eric Norris, president of Albemarle’s lithium business, the future market for the company’s U.S lithium production is expected to be “100% US-based and 100% electric vehicles”.

Livent, which spun out of FMC Corporation in 2018, has operated one of the lowest cost lithium mineral deposits in the world, the Salar del Hombre Muerto in Argentina. The company is currently focusing on the use of lithium hydroxide, with the plan to use a 2-step process to manufacture it from brine-based raw materials, by conversion of lithium carbonate. The extra step will add cost, but it is estimated that the cost will still remain below the global lithium prices. Nickel-rich battery growth, which requires lithium hydroxide, supports their business strategy. The company is a major lithium provider to Tesla and has indicated that they are working to extend their partnership for 2022 and beyond. They also have a 50/50 joint venture with private equity firm, Pallinghurst Resources, to buy Canada’s lithium projects previously managed by Nemaska Lithium. The Canadian location, along with Albemarle’s Nevada mine, may help meet the growing demand of battery grade lithium in North America and Europe.

Over 70% of the global cobalt mine production comes from the Democratic Republic of Congo (DRC). As the demand for lithium-ion batteries grows, so does demand for this controversial battery metal. Artisanal and small-scale mining (ASM) is responsible for a significant proportion of the cobalt mining in the DRC, with human rights organisations such as Amnesty International reporting human rights concerns, calling for urgent attention to the cobalt supply chain and for alternatives to cobalt mining to be found. Other cobalt resources include nickel-bearing laterite deposits in Australia and nearby island countries and Cuba; and nickel-copper sulphide deposits in Australia, Canada, Russia and the United States.

Extraction of critical materials pose both environmental and social challenges. For example, their production often has a higher greenhouse gas emission intensity than bulk metals; the land use for mining can displace communities and have adverse impacts on biodiversity; and mining and processing require large volumes of water and pose contamination risks.

RECYCLING

Given the rising demands and expected supply constraints of lithium and cobalt, the nascent recycling industry is set to become an important source of battery materials as the current electric cars reach their end-of-life and are scrapped. At present, three basic process types are used to recycle batteries: **pyrometallurgy** (melting), **hydrometallurgy** (leaching) and **direct recycling** (physical processes). Components of these processes can be combined in different ways, the choice of which may depend on quantity and characteristics of the material available and the quantity and value of the materials that can be recovered.

Currently, **pyrometallurgy** is the most common method of metal extraction. This uses high temperatures for oxidation and reduction in which transition metals, such as Nickel and Cobalt are reduced from oxides to metals and recovered in a mixed metal alloy. This method requires large amounts of energy and destroys other valuable non-metallic components such as the graphite in the battery anodes. It also fails to separate the lithium, which then has to be separated from compounds in the slag.

Another approach is **hydrometallurgy**, in which acids or other solvents are used to dissolve the metals, including lithium, out of the shredded material. This method is more complex than pyrometallurgy and has the added expense of dealing with the wastewater it generates, to prevent pollution. However, it requires less energy and also recovers non-metals such as graphite. This method is suggested to be the most promising of the future. For retired EV batteries, the full environmental impact of transportation, collection, dismantling, and recycling of batteries must be considered in battery recycling processes.

Over the last few years, governments and industry have invested large amounts into research initiatives. Many different recycling approaches and methods have been proposed but much of the research is still in the "lab- scale" phase. In the US, $15m has been invested into a ReCell Centre to coordinate studies in academia, industry, and at government laboratories. The UK has also invested in the ReLiB project, a multi-institution effort to improve the technology and infrastructure for recycling lithium-ion batteries in large volumes.

Brunp Recycling Technology Co, a subsidiary of the leading Li-ion battery maker **CATL** (China), can reportedly recycle 100,000 metric tons of lithium-ion battery scrap per year at its new plant in China's Hunan province.

Li-Cycle (Canada) the largest lithium-ion battery recycler in North America, has a hydrometallurgical processing plant which has an improved gathering of materials, collecting batteries from multiple uses (not just EVs), from geographically disperse stations. It has been suggested that their approach recycles 95% of a battery's materials and can recover battery-grade cobalt, lithium and nickel.

Umicore (Belgium) recently announced an investment of €25m to upgrade its cobalt refining and recycling plant at Olen, Belgium. They have also recently signed a PPA with Engie (Paris, France) to supply renewable electricity to Umicore's greenfield plant at Nysa, Poland, and have entered a patent cross-licensing agreement for cathode materials with BASF.

Northvolt (Sweden), a company which makes lithium-ion batteries for European carmakers is adding a recycling factory to its factory in Sweden, to process end-of-life batteries. The factory will have an initial capacity of 4GWh, capable of recycling lithium in addition to cobalt, nickel, manganese and other metals. They have also signed a $600m private placement enabling the company to make further investments in expanding its production and battery recycling capacity, as well as R&D activities to support the target of establishing 150GWh of manufacturing capacity in Europe by 2030.

BASF (Germany) has also announced its involvement in the circular economy for batteries by investing in purification to recover battery-grade lithium from "black mass".

CONTACT THE TEAM
Click here

ALASDAIR NISBET
CEO
+44 7767 207 185

LAURA MARSH
Director
+44 7920 473 992

SOPHIE BEADSMOORE
Analyst
+44 7570 723 639

Table 2. Selection of Recent News

Raw Material / Battery Supplier	Significant Entities Supplied to...	Source Type	Notes
Ganfeng	Tesla, Panasonic, LG Chem, Volkswagen, Samsung, BMW	Lithium	The world's largest lithium mining company Announced plans to buy Millennial Lithium, Canada for $353m, buy a $130 stake in a lithium mine in Mali, develop a lithium plant in Jiangxi Province, China Received clearance to build a plant in Argentina
Livent	Tesla, GM, LG Chem	Lithium	Currently focusing on the use of lithium hydroxide 50/50 JV with Pallinhurst Resources to buy projects previously managed by Nemaska Lithium (Canada)
SQM	LG Energy Solution, Tesla, Johnson Matthey	Lithium	8-year supply deal to LG Energy, a division of LG Chem, announced in Dec'20, making them their biggest lithium client
Albemarle	-	Lithium	Capacity for brine extraction at its Nevada site to be doubled by 2025 at a cost of $30m to $50m
Tianqi	Northvolt	Lithium	$1.4bn stake in their Australian lithium mine bought by metals firm IGO Lithium hydroxide supply deal with Northvolt
Northvolt	Volvo Volkswagen BMW	Recycling	Adding a recycling factory to its battery factory in Sweden
Northvolt / Umicore / BMW JV	BMW	Recycling	Pilot plant announced to both produce and recycle batteries, to be used in vehicles from 2025
Redwood Materials	Nissan	Recycling	Currently tripling the size of its operations in Nevada Recipient of Amazon's $2bn Climate Pledge Fund
BASF	Porche	Lithium, Cobalt, Recycling	Production waste from the future Cellforce Group (JV of Porche and Customcells) to be recycled at BASF's prototype plant for battery recycling in Germany
Johnson Matthey	-	Cathode materials	Newly constructed plant in Poland is expected to start producing eLNO cathodes in 2022 Agreement with Finnish Minerals Group to build another plant in Finland with a production capacity of 30,000 tonnes, enough for up to 400,000 cars Agreement to buy nickel from Norilsk Nickel (Russia) and lithium from SQM (Chile) to make its battery materials
Umicore	Audi	Cathode materials	Commercial production at Umicore's greenfield plant at Nysa, Poland expected to begin by the end of the year Entered a non-exclusive patent cross-license agreement with BASF covering a broad range of cathode materials, including chemistries such as NMC and NCA