Lithium also acts a flux, reducing the temperature required for sintering and melting, subsequently reducing energy costs for production. This is useful in the production of ceramics, glass products, aluminium and steel products such as casting steel and iron products.

Other major end-use applications for lithium products include glass, metallurgical powders, polymerisation, air treatment and primary batteries. While comparatively minor in volume, these applications require specific lithium compounds, such as high purity lithium metal in primary batteries, lithium bromide for air treatment and butyllithium in polymerisation applications.

Lithium demand is now driven by the rechargeable batteries industry.

The physical and electrochemical properties of lithium are what make it an ideal material for use in battery cells. The smaller ionic radius and lighter atomic mass of lithium ions (Li^+) compared to other positive ions such as sodium (Na^+) or potassium (K^+) mean it can achieve a higher capacity-to-weight ratio for battery cells. The smaller ionic radius of the Li^+ also allows it to fit into the crystal structure of graphite, allowing less expensive graphite anodes to be used, and combined with its greater diffusion co-efficient also provides greater mobility in the battery electrolyte.

Lithium is utilised within the cathode, anode and electrolyte of batteries, though cathode active materials are the dominant application area.

Lithium is consumed in cathode active material (CAM) as either lithium carbonate or lithium hydroxide. Lithium compounds consumed in cathode materials have very strict specifications, particularly for those used in high-energy density cathode active materials (defined as "battery-grade"). The lithium content of cathode materials is highly dependent upon its chemistry, with high-nickel ternary cathodes (NCM-NCA) containing roughly 7% Li, while lithium-iron-phosphate (LFP) lithium-manganese-iron-phosphate (LMFP) and lithium-manganese-oxide (LMO) cathodes contain 3-4% Li in their structure.

Lithium is also used in anode materials, such as lithium titanate, where the lithium content is around 6%. Lithium metal anodes and prelithiation for silicon-based materials will also consume additional quantities of lithium going forward.

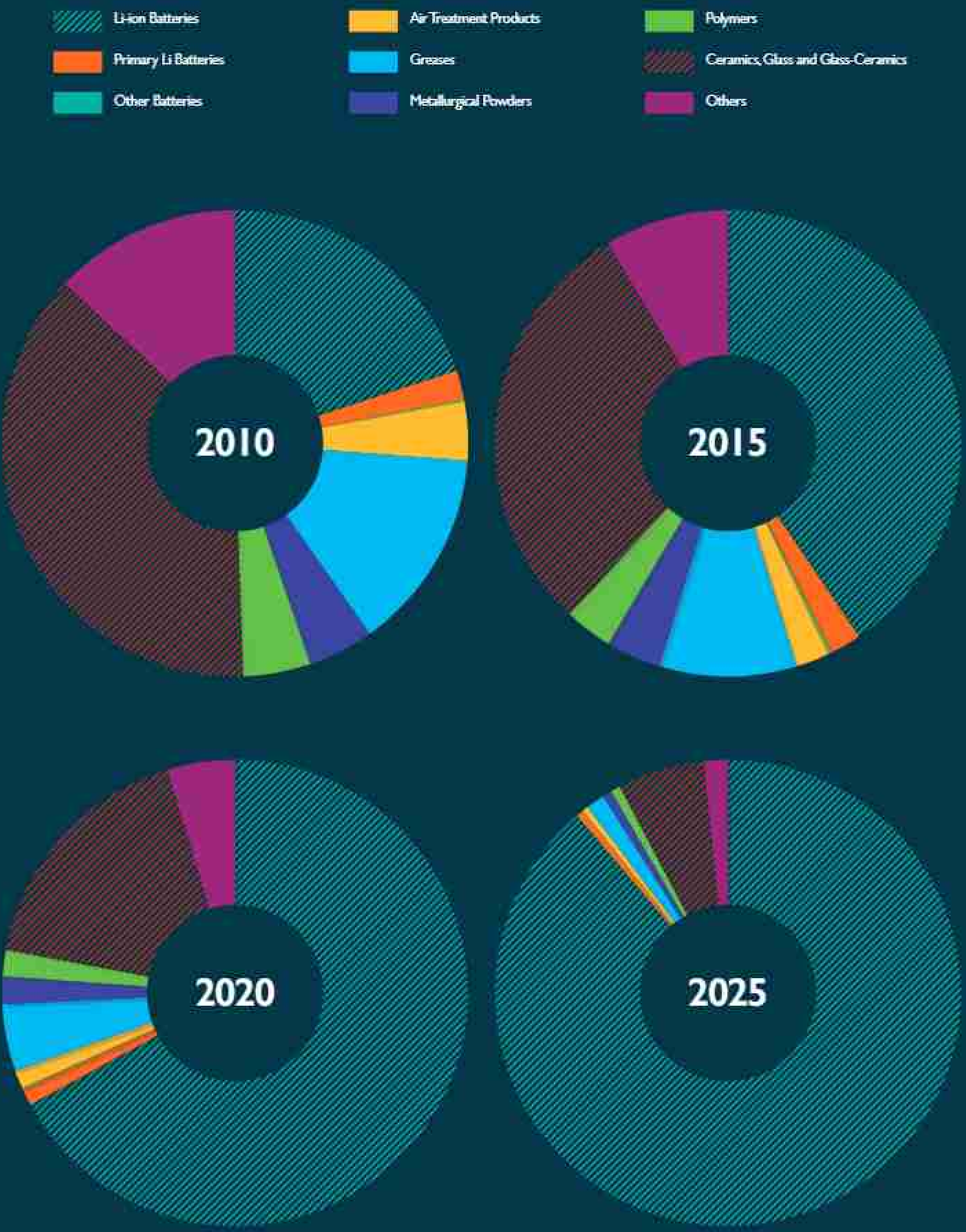
Rechargeable batteries accounted for 89% of total lithium demand in 2024, compared to 40% in 2015. The market share is set to increase further during the 2020s, with the use of Li-ion technologies in high growth applications such as electric vehicles (EVs) and battery energy storage systems (ESS).

Lithium supply and demand is often reported in LCE (lithium carbonate equivalent), as lithium carbonate (Li2CO3) has historically been, and continues to be, the most widely produced and traded lithium compound. Traditionally, lithium hydroxide was produced from carbonate, and it was only in the last decade that increasing volumes of hydroxide were processed directly from spodumene sources. By converting the large number of lithium compounds and grades into LCE, it facilitates comparison for investors, regulators and industry players to make more informed decisions.

Theoretical concentration conversions for lithium compounds

NAME	COMPOUND	Li	Li_2O	Li_2CO_3	$LiOH.H_2O$
Lithium	Li (100% Li)	1.00	2.15	5.32	6.06
Lithium Oxide (Lithia)	Li_2O (46.4% Li)	0.46	1.00	2.47	2.82
Lithium Fluoride	LiF (26.8% Li)	0.27	0.58	1.42	1.62
Lithium Carbonate	Li_2CO_3 (18.8% Li)	0.19	0.40	1.00	1.14
Lithium Hydroxide Monohydrate	$LiOH.H_2O$ (16.5% Li)	0.17	0.36	0.88	1.00
Lithium Hydroxide	LiOH (29% Li)	0.29	0.62	1.54	1.75
Lithium Chloride	LiCl (16.3% Li)	0.16	0.36	0.87	0.99
Lithium Sulfate	Li_2SO_4 (12.55% Li)	0.13	0.27	1.44	1.64
Lithium Hypochlorite	LiOCl (11.89% Li)	0.12	0.26	0.63	0.72
Butyllithium	C_4H_9Li (10.83% Li)	0.11	0.23	0.58	0.66
Lithium Bromide	LiBr (8.0% Li)	0.08	0.17	0.43	0.48
Lithium Phosphate	Li_3PO_4 (18% Li)	0.18	0.39	0.96	1.09

The evolution of lithium demand 2010 - 2025



Source: Project Blue

3. Lithium-ion battery technology

Current state of battery technology

Lithium-ion batteries work by moving lithium ions between the electrodes and the external circuit, which generates power.

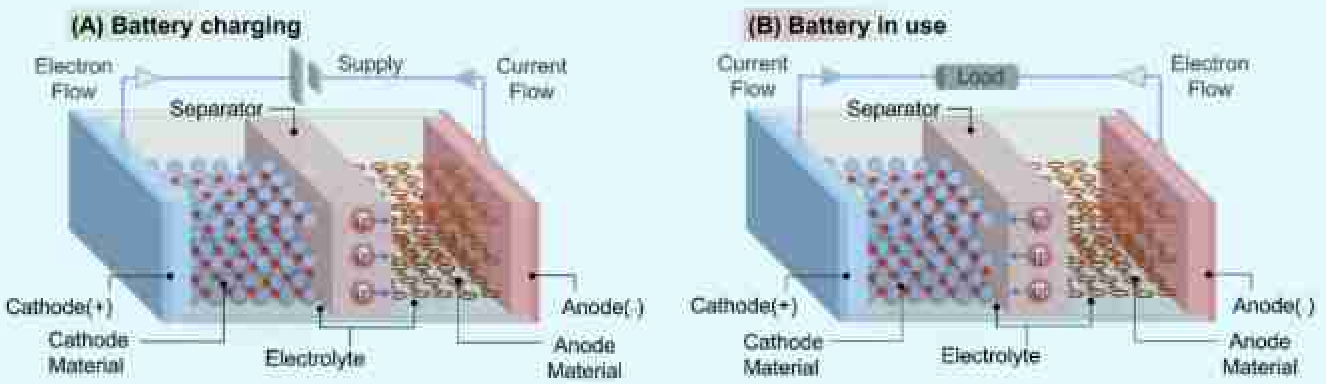
During charging, a lithium ion is liberated from the cathode, migrates through the electrolyte towards the anode, and inserts between the graphite planes at the anode. When the battery is being used (discharged), the lithium ions move from the anode to cathode, then flow through the external circuit to provide electrical energy.

The capacity of the cathode defines the capacity of the battery. Currently, there are a mix of cathode chemistries being used around the world, where the choice mostly depends on cost and performance requirements. These factors have led to the emergence of two critical categories of cathode chemistry: Iron-based and Nickel-based.

Outside of lithium-ion, sodium-ion has received significant attention as an alternative to lower production costs. Due to sodium-ion's intrinsically lower energy density, it will likely be reserved for applications that do not require such performance, such as in ESS and for small, low-range urban EVs.

Hydrogen fuel cell electric vehicles (FCEVs) also receive much attention as an alternative to lithium-ion. Although there are some FCEV models available, sales figures are significantly lower than EVs. As such, FCEVs are not expected to gain significant market share to 2040 and may only ever serve more niche applications.

How a lithium-ion battery works

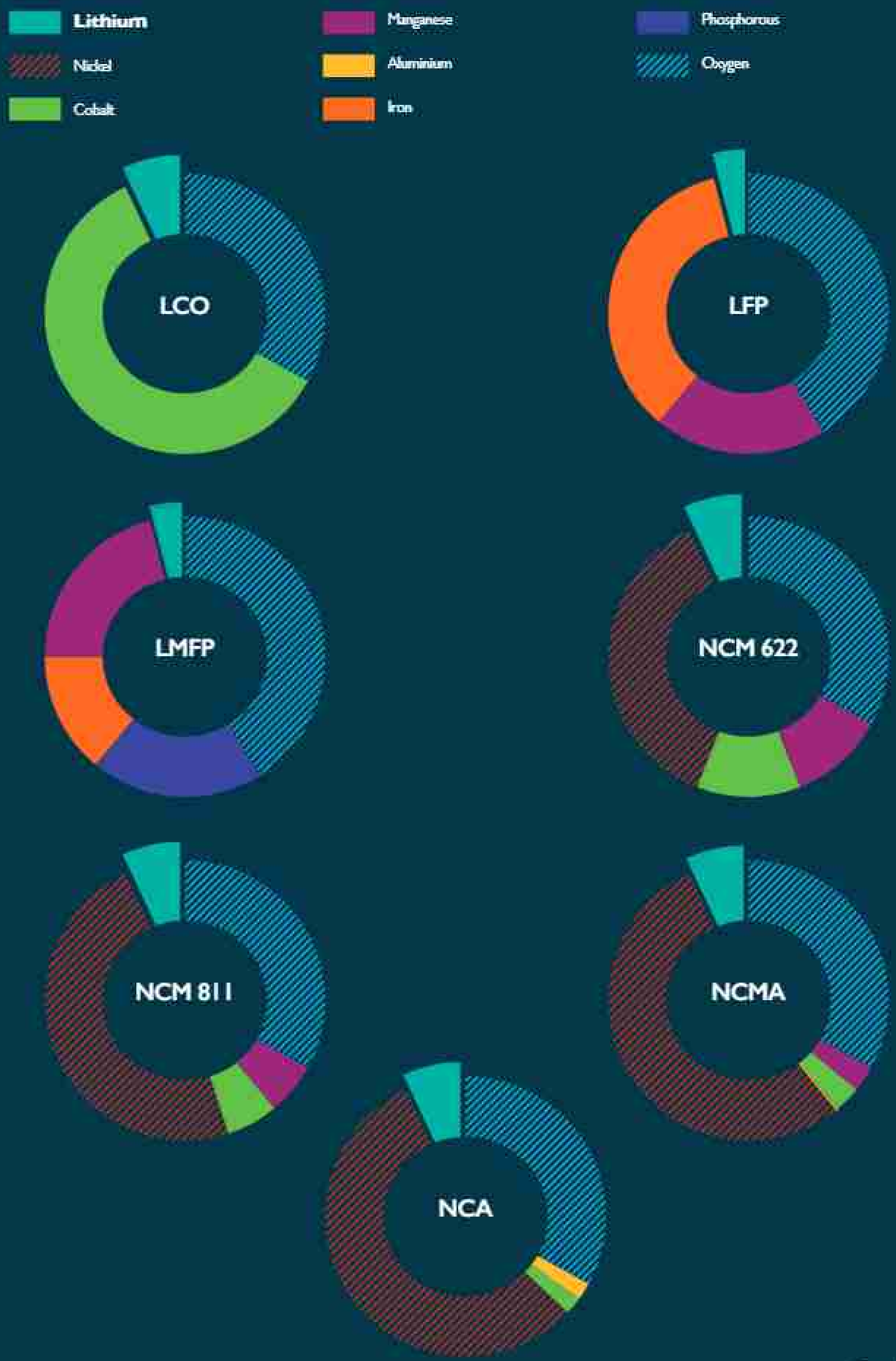


Source: Menye, J. et al. (2025). (10.3390/en18020342)

Iron-based chemistries, such as lithium iron phosphate (LFP), have seen a recent resurgence in adoption due to the drive to reduce production costs and regional build-out in production capacity in China. Although the energy density of an LFP battery is lower than a nickel-based battery, the lower cost of production and long cycle life make it very well suited for entry- to mid-level EVs and battery ESS applications. Considerable work is currently focused on the addition of manganese to LFP to form lithium manganese iron phosphate (LMFP). LMFP cells have a higher energy density than LFP cells and so aim to compete with NCM on performance, whilst maintaining low production costs.

Nickel-based chemistries such as NCM still remain a popular choice for electrification due to the improved performance benefits of higher energy density and a lower volumetric density – which means the same energy packed in a battery with reduced weight and size – resulting in longer driving ranges. To date, increasing the nickel content of NCM CAM has been a strong strategy within the battery industry to boost energy densities for longer range EVs. More recently, mid-nickel variants have received significant attention as a route to enhancing energy densities and lowering cost. By operating the cells at higher voltages, mid-nickel NCM can approach the energy density figures of high-nickel NCM at a reduced cost.

Lithium is a key element required in every cathode active material (CAM) in use today



Source: Project Blue

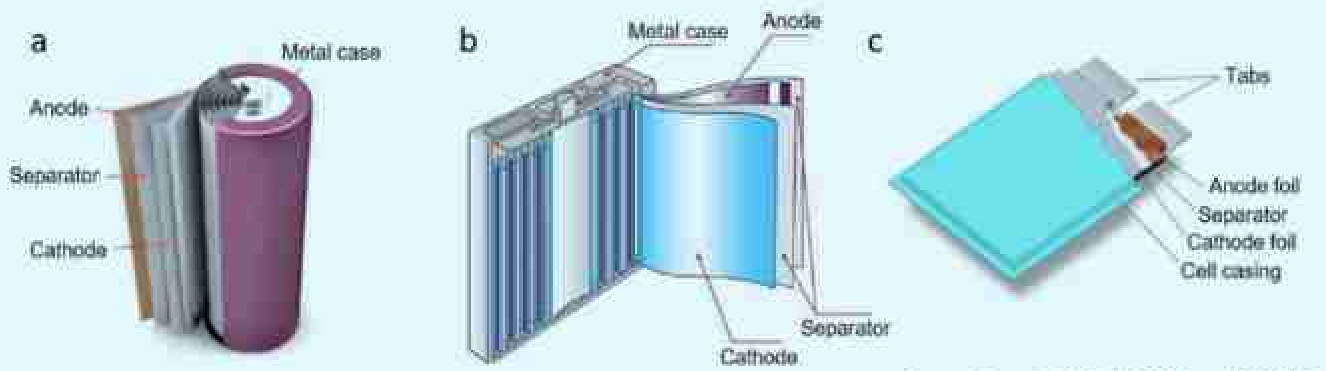
Rechargeable lithium-ion batteries exist in three key formats or shapes: cylindrical, prismatic and pouch.

Each of these formats have benefits and trade-offs that make them more or less suitable for certain applications.

For EVs, the choice of format largely depends on the battery pack platform, vehicle type and OEM strategy. Prismatic cells have been favoured by many OEMs due to the pack-level energy density improvements over cylindrical cells due to packing efficiency, and the safety improvements over pouch cells. Cell-to-pack configurations, where the prismatic cells also contribute to structural integrity and improve on energy density has been a recent trend for many OEMs, particularly in China.

For battery ESS, large-format prismatic cells are often favoured due to favourable energy density, project system simplification and cost reduction. Such cells can reach capacities exceeding 600Ah and contain large quantities of lithium per unit.

Lithium-ion battery form factors: (a) cylindrical, (b) prismatic, (c) pouch



Source: Mun et al. (2021). (10.3390/cryst11091013)

Form factor assessment of key battery characteristics

Characteristic	Cylindrical	Prismatic	Pouch
Energy density	**	**	***
Production cost	***	**	**
Thermal management	**	**	***
Safety	***	**	*
Packing density	*	***	***

Source: Project Blue

Battery evolution to 2040

The desire for greater performance from lithium-ion batteries will lead to lithium being used in new and innovative ways going forward.

Research to develop better-performing batteries have long been underway and will continue. Most impactful for lithium in the short- to medium-term will be the development of CAM to enhance performance and manage production costs.

Higher demand for lithium in the near-term will come from the introduction of lithium-rich layered oxides (LLOs), which offer energy density advantages over current-generation CAM due to excess lithium in the layered structure. Moreover, the use of higher manganese contents within LLOs will allow for lower production costs, hence considerable effort is aimed at commercialisation.

The next major milestone for the battery technology will be the commercialisation of solid-state batteries (SSBs) for use in EVs. Unlike the liquid electrolyte in current lithium-ion batteries, SSBs will make use of a solid electrolyte. This enables the introduction of alternative anode chemistries to achieve even higher energy densities for longer EV ranges. SSBs also have the potential to achieve higher safety ratings than traditional cells due the elimination of the flammable liquid electrolyte.

Commercialisation of SSBs in EV applications is expected to begin towards 2030, with initial offerings utilising silicon-engineered anodes. Silicon experiences large volume fluctuations during lithiation and delithiation, which results in aggravated lithium loss and rapid capacity fade during cycling.

To manage these unwanted side-effects, pre-lithiation strategies will be implemented by embedding lithium in the anode active material (AAM) to replenish lithium consumed by these side reactions during initial cycles. This will inevitably generate incremental lithium demand as silicon anode technologies scale with increasing demand for longer range EVs.

mAh *(milliampere hour) is a unit of electric charge; how much current a material can deliver over time.*

mAh/g *= how much electric charge a material can deliver per gram of its mass.*

Perhaps the most anticipated technological development is the lithium-metal solid state battery, which utilises lithium foil at the anode and will unlock further energy density gains over current-generation batteries.

Lithium metal has an electrical charge storage capacity (3,860 mAh/g) that is more than 10 times that of graphite (372 mAh/g), hence it has received considerable attention.

The addition of lithium foil provides a lithium reservoir to counter lithium loss and provides a substrate for lithium plating and stripping during cycling. The addition of a lithium foil also means there is excess lithium within the system, as this is surplus to requirements given that the cathode is limiting for capacity. Moreover, the introduction of lithium sulfide solid electrolytes to improve ionic conductivity within SSBs will increase lithium consumption further.

The result of lithium metal SSB adoption is that higher quantities of lithium will be required per kWh of cell output, further driving demand for the metal.

New lithium-ion battery technologies are often trialled commercially in portable electronics because these products are replaced more frequently. Moreover, the small size of the batteries keeps total energies low and simplifies production.

As a result, lithium-metal batteries will be utilised in wearable devices and power electronics ahead of EV commercialisation, which is likely to occur in the 2030s.

The circular economy

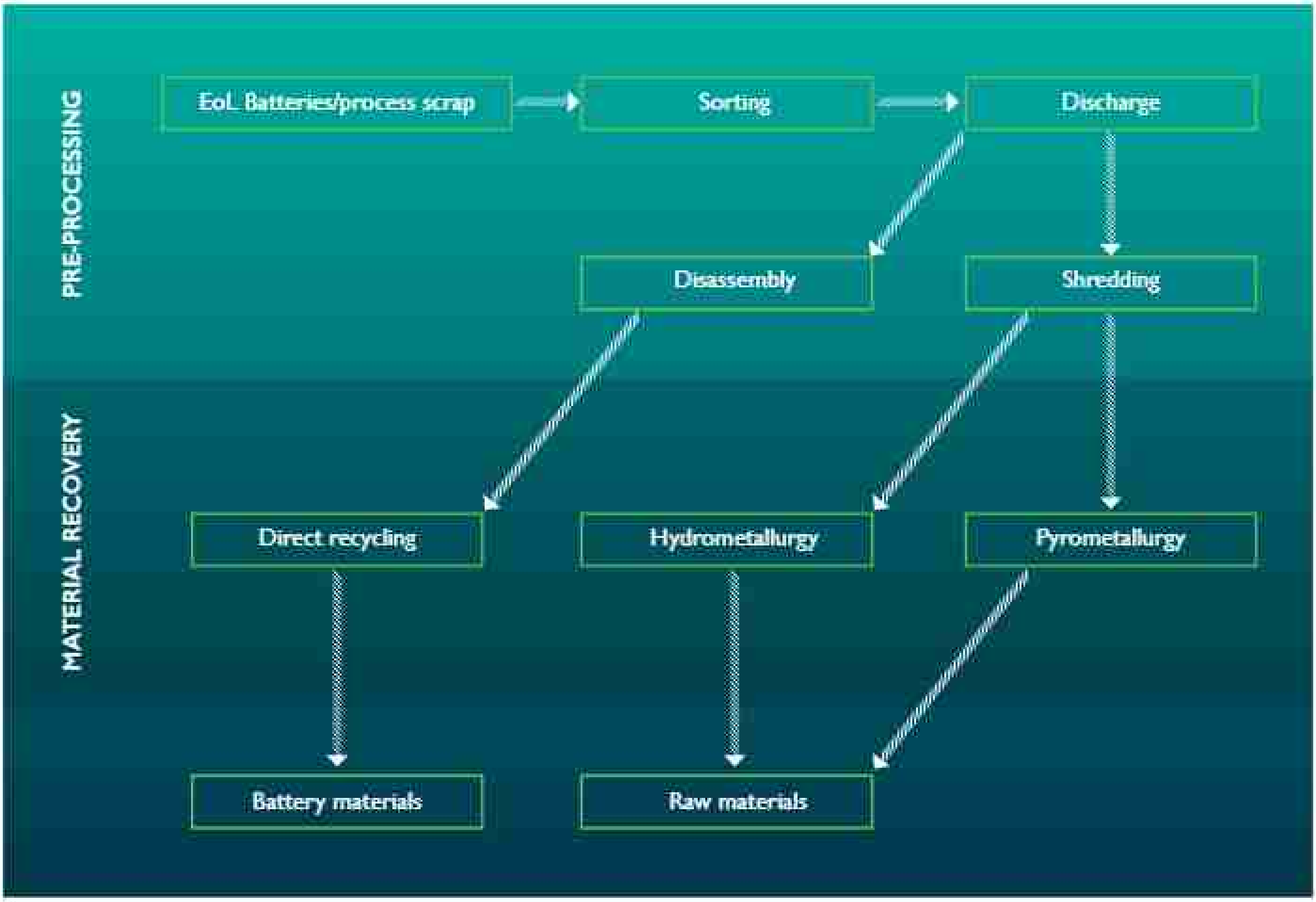
Battery recycling is a critical global strategy to close the loop on the lithium-ion battery value chain by recovering valuable materials from expired cells.

Often, rechargeable batteries can undergo a 'second life' before entering the recycling value chain. This occurs when the battery health has declined to the point where it is no longer suitable for its 'first life' such as in EVs, but still has sufficient capacity for less demanding uses. Some examples are home energy storage or backup power, and low-speed electric vehicles such as forklifts and golf carts.

Eventually, however, recovering metals from end of life (EoL) and process scrap provides alternative sources for battery-grade materials and is fundamental to the success of the energy transition and development of a circular economy.

Recycling lithium becomes even more impactful for regions where there is no, or little, naturally-occurring lithium supply, such as Europe, Japan, South Korea and India. Here, recycling will play a vital role in providing lithium carbonate and lithium hydroxide for use in domestic CAM manufacture.

The recycling process consists broadly of two stages: pre-processing and material recovery. Following the pre-processing stage, the shredded active material powder is known as 'black mass' and is the most valuable part of the processed content due to the lithium, nickel and cobalt contained within. The lithium material recovered can be either a battery-grade material, such as lithium carbonate, or an intermediate product such as lithium sulphate.



Battery health is typically measured by tracking the number of full charge-discharge cycles and measuring the remaining capacity compared to the original design. The general rule of thumb when a battery is no longer practical to use is a State of Health (SoH) of 80%, where SoH = measured capacity (Ah) / initial capacity (Ah) After this point, sudden and rapid capacity fade (or 'rollover') is more likely to happen, and the battery's ability to hold and deliver a full charge declines significantly.