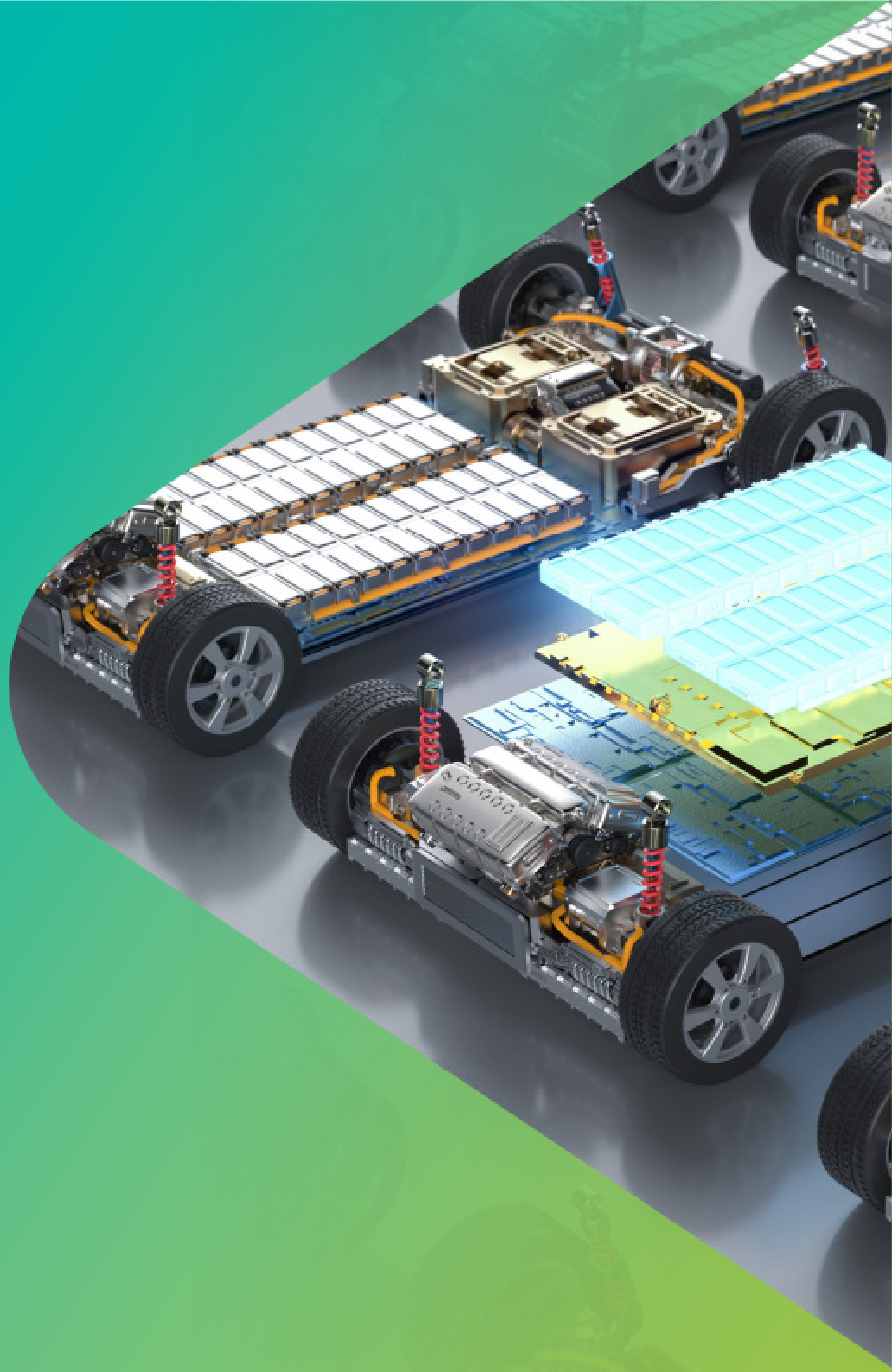
Automotive Battery End-of-Life Value Chain

June 2023



ADVANCED PROPULSION CENTRE UK

Accelerating Progress

Information correct at time of publication

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Document audience

This document is aimed at supporting industry, academia and government in the following ways:

Industry

- Identify strategic strengths within the UK for market growth opportunities
- Understand how each company's technology fits in and its contribution to the supply chain
- Identify gaps within the local supply chain and opportunities for foreign direct investment or local scale-up

Academia

- Guide R&D into next-generation technologies to build a strong UK supply chain
- Promote undergraduate and postgraduate uptake in electronics and electrical engineering to feed the skills gap
- Develop up-skilling and re-skilling programmes to support UK industrial companies train their staff

Government

- Understand where the UK's strengths and gaps lie in the automotive semiconductor supply chain
- Develop policy, strategy and funding to accelerate scale-up in critical parts of the supply chain
- Support foreign direct investment decisions that complement UK strengths and incentivise local production


Autocraft SG

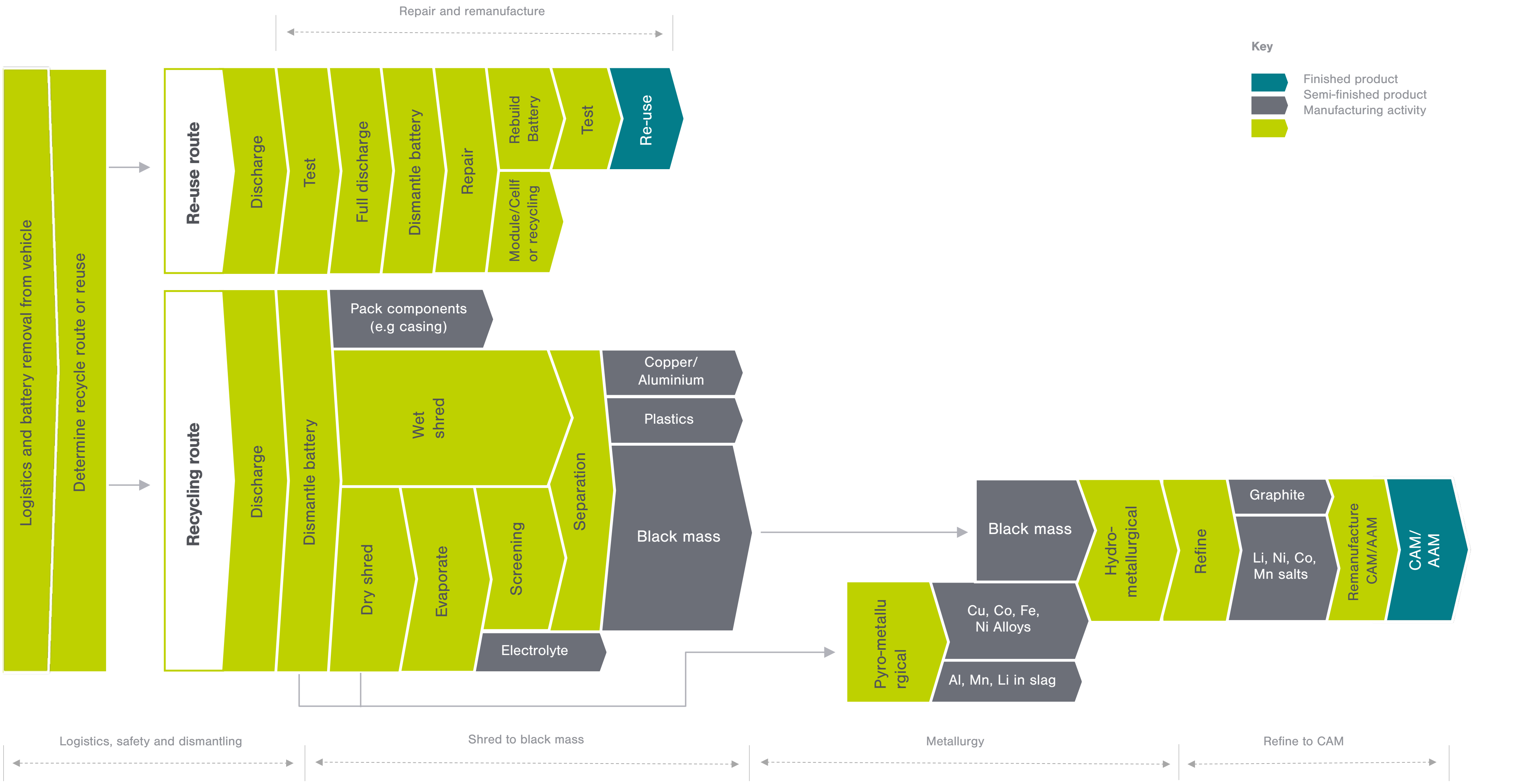
An introduction to the automotive battery end-of-life value chain

With the growing adoption of electric vehicles (EVs) comes a new demand for the critical minerals needed to build new batteries, alongside a potential second-use market. The European Battery Directive provides targets for collection and recycling of EV batteries with minimum targets for recycled content in new EV batteries.

This automotive battery end-of-life value chain map shows the path of the UK's growing re-use and recycling industry.

Developed by the Advanced Propulsion Centre UK (APC), in conjunction with experts from industry and academia, this new value chain details the journey of an automotive battery from the end of vehicle use to second life and recycling, to become cathode active material (CAM) and anode active material (AAM).

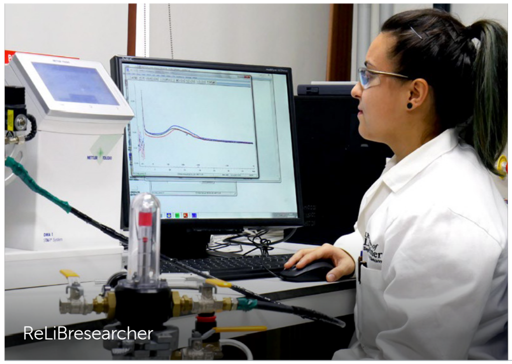
Automotive battery end-of-life value chain



Current UK capacity

The UK currently has some capacity to produce black mass and this capacity is growing with projects like RECOVAS underway. However, this is predominately exported to undergo pyrometallurgical recovery. As it stands, the best prices for black mass are found in Asia, so UK-produced black mass can undertake a considerable journey before being recycled.

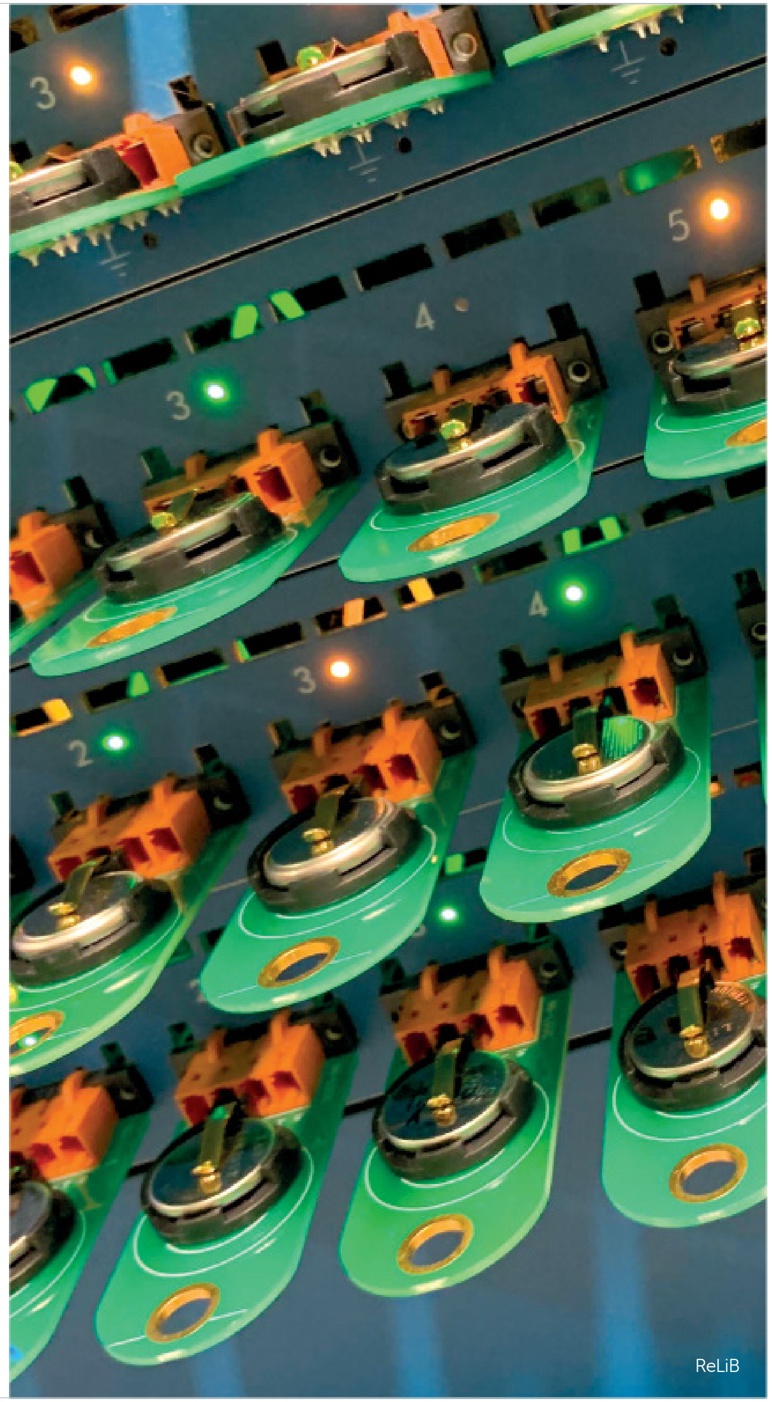
The UK has no hydrometallurgical capacity and no Cathode Active Materials production at time of writing this report. Ideally, the recycling processes would be aligned from hydrometallurgy through to CAM. Going from black mass to CAM, multiplies the value of the material. Investing in hydrometallurgy and CAM facilities in the UK would enable this revenue to stay here, onshoring critical materials for UK battery manufacturing.



ReLiBresearcher

Our nation has an opportunity to create a low carbon circular battery economy over the coming decades if the building blocks are put in place now.

The next few years will be challenging as only a small number of facilities will be commercially viable, with some significant risk in the supply of material to recycle, but this will ramp up over the next 20 years, providing an opportunity that government, OEMs and private investors can take advantage of through supporting R&D and initial plant deployments. Great work is already being done by UK universities and as part of projects like RECOVAS and RELIB.



ReLiB

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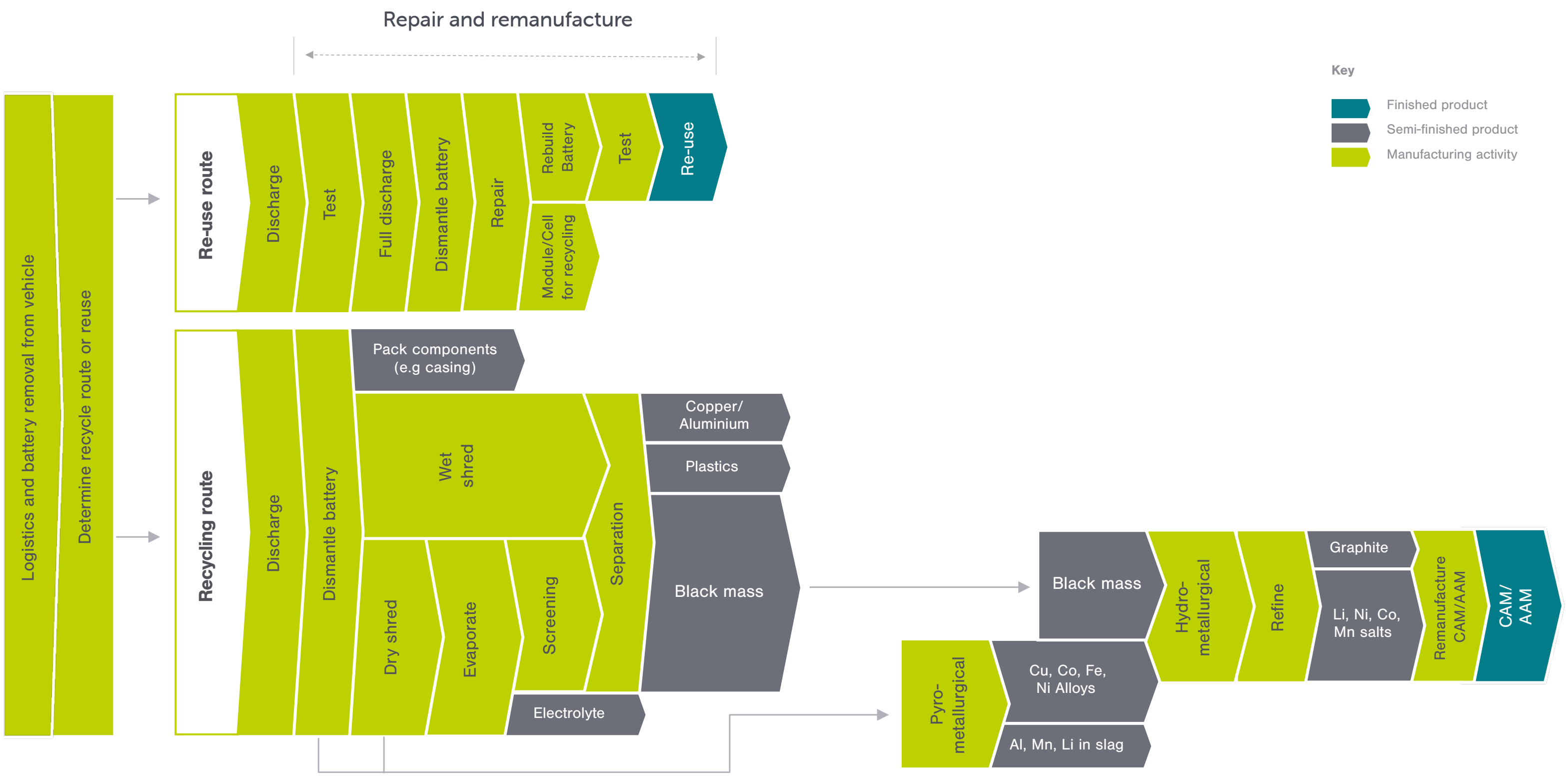
Extending battery life

The life of automotive batteries can be extended beyond the first vehicle, becoming a replacement battery for another vehicle, or applied as stationary energy storage.

This provides an opportunity for ongoing revenue for automotive batteries. An OEM is responsible for the end-of-life management of the battery, including battery repairs, refurbishment, and grading for secondary use.

Companies such as Autocraft Solutions Group offer such a service, where they take an automotive battery, check its health, and make necessary repairs. Consider a battery that has been in a crash, these are typically written off, but may be in perfect condition. These batteries can be checked and reused for stationary energy storage. Other batteries, which may have reduced capacity, could need some cells or modules replacing, but most of the battery can be reused. The replaced cells or modules can be recycled.

Recycling value chain



Log st s, safety and smant ng
Sh ed to b a k mass l
Metal u gy r
Ref ne to CAM

	Logistics, safety, and dismantling	Shred to black mass	Metallurgy	Refine to CAM
CAPEX (per kt capacity)	-	>£1-2 million	>£15-20 million	>£20 million
OPEX (per kt processed)	£1-3 million	£0.5-1 million	£2-3 million	£5-20 million*
Percentage value		8%	26%	66%

Economic viability of recycling

The Nomura Research Institute (NRI) study showed that recycling is not currently profitable in Europe, with high running costs for labour and energy cited as the main issue. In China, labour costs and economies of scale mean recycling is commercially viable.

In the UK, we have world-leading R&D in recycling, that can be leveraged to bring down costs and increase the revenue generated from recycling. We have an ecosystem enabling automotive OEMs, battery manufacturers, recyclers, and CAM manufacturers to be in close proximity, therefore significantly reducing transport costs. The ecosystem needs to grow to build economies of scale, and this is likely to need intervention to support the first players in the market.

Three key challenges:

Regulation and permitting

The initial challenge for setting up new recycling facilities for EV batteries is obtaining the required permits. First, the environmental permits must be in place for a facility. The next step is to apply for Approved Battery Treatment Operator (ABTO) and Approved Battery Exporter (ABE). While the costs are relatively low, the time required to get permits in place can be considerable (in the region of 18-24 months), therefore potentially adding to costs, due to land being unused during this period.

Cost of logistics

The initial cost of transporting a used battery can be high due to health and safety concerns. Recyclers charge an OEM over £5k per battery to recycle, but logistic costs could exceed this owing to packaging and transport requirements for a damaged battery.

Dismantling

Dismantling is conducted by hand and requires trained high voltage technicians. A study by Nomura Research Institute (NRI) estimated dismantling costs at £12 per kWh, meaning a typical 60kWh battery costs around £720 to dismantle. For comparison, labour costs in China reduce this to £145.

With thanks to

Glossary

EOL

End of life. When referring to an automotive battery can refer to end of first life, where the vehicle is retired either due to damage or wear to other components. A battery might be replaced in a vehicle due to warranty repairs. A battery can go on to have further use, either in a vehicle or stationary storage application, before reaching final end of life and going into a recycling pathway.

Logistics

A battery needs to be delivered to site, either as part of the vehicle, or after removal. If the battery is visually damaged, extra precautions are required, which increase cost of logistics.

Re-use

An automotive battery can be repurposed by replacing or repairing damaged cells or modules depending on the design. Batteries are tested to determine the state of health and which cells/modules need replacing. After repair, batteries are tested to determine suitability for onward use in another vehicle or stationary storage application, from domestic to energy infrastructure.

Recycle

Typical automotive batteries, containing nickel and cobalt, are recycled to recover these high-value materials. Increasingly, lithium is being recovered and this is likely to grow, in part due to the value of lithium and in part due to policy and regulation aimed at securing local supply. Although it is possible to recover many materials, other materials of note, such as anode materials, plastics and electrolyte, are often within the waste of the recycling process.

Discharge

Batteries are discharged to reduce the risk of short circuit and self-ignition. This can be done in a number of ways for example via electronic load.

Dismantle

Casing is removed and can be separately recycled, modules or individual cells might be removed depending on process. This is challenging to automate due to variety in battery, module and cell designs and the use of adhesives, which can be used as a structural and thermal management component.

Wet Shred

The shredding of batteries in a solution, e.g. water. Wet shredding can allow the shredding of charged batteries. Wet shredding also eliminates the generation of airborne particulates and fire hazards, making it potentially safer. However, the waste solution will contain hazardous compounds requiring treatment.

Dry Shred

Dry shredding requires no specialist chemicals and is easily scaled up. Dry crushing can be carried out in cryogenic or inert environments to reduce the risk of fire and release of hazardous gases. Dry shredding requires an electrolyte treatment step, for example by combustion or evaporation and condensation. Dry shredding can allow the recovery of electrolyte, whereas in wet shredding it is destroyed.

Separation

Separation of the particles generated by shredding can include a number of steps, including further milling of the particles. The shredded material can be separated into plastic, separator material, steel, nickel and aluminium tabs, aluminium and copper current collectors and black mass. Not every recycler will produce all of these products. Separation can be via sieving based on:

- Particle size
- Magnetic separation to remove steel structures and other ferrous metals
- Electrostatic separation to remove plastics from the metallic components
- Eddy current separation, material conductivity to separate copper, aluminium and plastics
- Density separation, either via vibration, rotating table air or fluid, can separate metal from plastic, as well as the current collectors from the cathode and anode materials

Glossary

Black Mass

Black mass contains the high-value materials from the cathode and anode. It may also contain other materials, such as PVDF, LiPF6, steel, copper and aluminium, depending on shredding and separation processes employed, which means that the percentage of high-value materials can vary.

Pyrometallurgy

Material is put into a high temperature furnace. Plastics, polymers and electrolyte are burned away, leaving a metal alloy of cobalt, copper, iron and nickel and a slag containing aluminium, manganese and lithium. Pyrometallurgy does not require batteries to be sorted or material of a certain size, but, it is advantageous to sort batteries beforehand to reduce impurities which can distort the downstream hydrometallurgical refining. Energy use is high and therefore, so is cost and CO_2 emissions (depending on energy source). The alloy and slag require additional processes to recover the raw materials, and materials such as graphite cannot be recovered.

Hydrometallurgy

Hydrometallurgy can involve a number of steps depending on battery chemistry and required materials. Material is dissolved using corrosive liquids. Once dissolved, organic solvents are used to separate the metals. Pyrometallurgy can be used as a pre-treatment step for hydrometallurgy, potentially improving the recycling efficiency, or hydrometallurgy can be performed on black mass material from shredding.

Refine and Remanufacture

The metallurgy step can produce raw materials which constitute 19% of cell value, however, these materials cannot be used directly in a battery cell. Refined metal compounds, such as nickel and cobalt hydroxide, are used to manufacture CAM material which constitutes approximately 45% of the cost of the cell.

CAM

Cathode Active Material. Constitutes 45% of the value of a cell.

AAM

Anode Active Material. Constitutes 14% of the value of a cell.

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