

UNEARTHED

Black mass: An underused anthropogenic resource

As the electric vehicle revolution gains pace, Theo Harris and Stuart Jones highlight the need to ramp up recycling of lithium-ion batteries

GLOBAL DEMAND for lithium is soaring. Driven by the imperative to mitigate climate change through the green energy transition, lithium-ion batteries (LiBs) are now at the heart of nearly every electric vehicle (EV), and are finding new applications, including electricity storage on the National Grid to balance intermittent renewable energy sources, such as wind and solar. The International Energy Agency (IEA) predicts that compared to 2023, demand for lithium will increase eight-fold by 2040 (IEA, 2024a), largely due to the surging EV market.

Over the past three decades, LiB development has resulted in improved performance and reduced costs, meaning that EVs now compete with internal combustion engine vehicles, offering lower running costs and emissions, and improved performance. Electric car sales are estimated to have reached around 17 million in 2024, accounting for more than one in five cars sold worldwide, with sales expected to grow by 20% annually (IEA, 2024b). Yet, lithium faces challenges around security of supply arising from geopolitical and socio-environmental complexities that can disrupt mineral supply chains, and the long lead times required to bring new mines into

operation. Added to the difficulty of meeting surging demand is a looming waste management issue: the typical lifespan of LiBs used in EVs is estimated at roughly ten years, meaning the rapid uptake of EVs will generate a flood of spent LiBs.

To be clear, without increasing the volumes of primary, mined metals in the supply chain, we cannot meet the spiralling global demands for lithium. However, one currently underutilised option that has the potential to relieve some of the growing gap between supply and demand is the recycling of LiBs. At end-of-life, LiBs are dismantled and shredded. Rich in lithium (and other critical minerals), the shredded material, a granular

“In common with all other critical and strategic raw materials, the lithium supply chain is highly vulnerable to the dynamics of geopolitics”

At end of life, batteries are dismantled and shredded. The granular mix of metals, known as black mass, is an important feedstock for new battery manufacturing

mix of metals known as black mass, is an important feedstock for new battery manufacturing. Once fully established, recycling of LiBs has the potential to contribute to meeting global demands for lithium, while also helping to mitigate a new sustainability crisis around the waste management of spent LiBs. Alongside the development of new, responsibly mined sources of critical minerals, we must focus our efforts on recycling black mass, an underutilised anthropogenic resource in the UK, Europe, and beyond.

Supply chain vulnerabilities

In common with all other critical and strategic raw materials, the lithium supply chain is highly vulnerable to the dynamics of geopolitics, as well as socio-environmental issues. Lithium is predominantly extracted from hard-rock ore (lithium pegmatites) and continental lithium-bearing groundwater (salar or



© Shutterstock

salt lake brine deposits). Currently, over 90% of all lithium is extracted via mining operations in just four countries – Australia, Chile, China, and Argentina – while China dominates lithium processing and the midstream and downstream stages of the LiB supply chain (IEA, 2024a).

In Europe, policies are increasingly aimed at securing and diversifying the supply chains for critical raw materials (e.g. Rietveld et al., 2022; EU, 2024). Various lithium mining and processing projects are being developed to aid self-sufficiency, but achieving self-sufficiency will take time – the complexities of geological exploration, feasibility studies, environmental permitting procedures, and consultation processes with local stakeholders (such as indigenous communities), mean that mining operations typically take 16.5 years from discovery to first production (IEA, 2021a).

Protests and lawsuits against existing lithium mining are also growing, as environmental concerns surrounding some mining practices are brought to light. For example, Vera and colleagues (2023) highlight numerous issues with water pollution, water depletion in an already arid region, biodiversity loss, and even carbon emissions in the lithium fields of the Salar de Atacama salt flats, Chile, the world's largest brine-based lithium mine.

New, improved mining technologies are already facilitating more responsible and sustainable lithium extraction. For example, across Europe, Direct Lithium Extraction – a low-impact, low-carbon, and low-water usage method, often carried out using renewable energy sources – is being employed to explore lithium extraction from geothermal brines in the Upper Rhine Graben, Germany, the Permian Cornish granites, and the North Pennines Devonian granite, Weardale, UK.

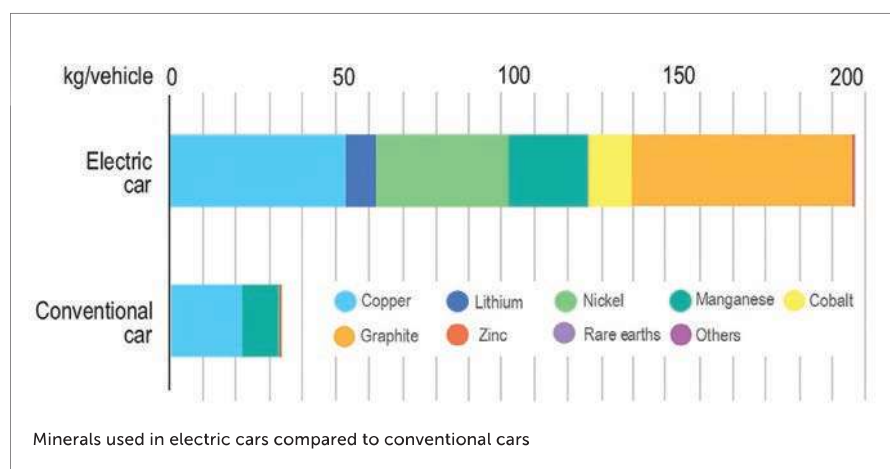
Even with such improved technologies, it remains paramount to develop any mining project in a way that involves local communities from an early stage (see, for example, imerysbritishlithium.com/community-engagement and responsiblerawmaterials.com).

Anthropogenic feedstock

A recent UN Development Programme report estimates that the global volume of end-of-life LiBs will be ~900,000 tons in 2025, and may reach 20.5 million tons by 2040 (UNDP, 2025). Given that a typical EV battery can contain up to 200 kg of critical minerals and elements (including lithium, graphite, cobalt, manganese, and nickel; IEA, 2021b), this potentially huge volume of black mass offers an important feedstock for new battery manufacturing.

While the LiB recycling market is growing, black mass extraction is complicated and currently faces challenges around efficiency, scalability and cost. After shredding and separating the battery into different components (including the most precious parts of LiBs, the cathode and anode), the material is further processed using pyrometallurgy (high-temperature smelting), hydrometallurgy (acid dissolution), or a mechanochemical approach (i.e. mechanical force) to create black mass. This end product can be compositionally diverse, consisting of an array of components each with different energy requirements for extraction and efficiencies in metal recovery, as well as differing levels of pollution and market values. The current market value of black mass is roughly £3,500 per tonne (Recyclus, 2023), but profits vary depending on which processing technique is used.

Despite the challenges, the pressing role for recycling has already been recognised, and both investment and recycling capabilities are growing globally. For example, both Contemporary Amperex Technology Co. Limited (CATL), the world's largest battery company, based in China, and Redwood Materials, based in the US, have recently announced →



© IEA. Licence: CC BY 4.0

billions of dollars of investment to establish new LiB recycling facilities. The EU has also fast-tracked the approval of battery recycling projects and is using regulation to encourage recycling: from 2030, batteries in EVs sold in the EU will be required to contain a share of recycled materials (for example, at least 4% recycled lithium, rising to 10% recycled lithium by 2035).

The UK's first industrial-scale LiB recycling facility opened in Wolverhampton in 2023. Operated by Recyclus Group LTD, the plant processed ~8,300 tonnes of LiBs in its first year, but once fully operational is licenced to process 22,000 tonnes annually (equivalent to 48,000 EV batteries). Recyclus aims to increase capacity to ~50,000 tonnes per year spread across five processing facilities in the UK (Hebden, 2023). Currently, much of the black mass produced in the UK is exported abroad for processing. However, the clean technology company Altilium, which is at the planning stage for their own LiB recycling facility in northeast England, also aims to invest in UK-based black mass processing.

Typical battery manufacturing plants can take around five years from planning to become operational. Certainly, many more recycling facilities will be needed before 2035, when an estimated 150,000 tonnes of LiBs are expected to reach end-of-life annually in the UK (UKRI, 2023). In the interim, second-life batteries – those that have reached the end of their automotive EV life but still have a

ENVIRONMENTAL NECESSITY

As demand for EVs accelerates and the surge in spent LiBs looms closer, increasing the capacity for efficient recycling of black mass will offer a sustainable way to help ease pressure on lithium supply chains and provide an avenue for profit through waste management. The successful and economical recycling of large volumes of black mass in the UK and Europe will require improved government regulation and incentives, alongside significantly more research and development into the generation and processing of anthropogenic critical minerals. Despite the challenges, increased capacity for LiB recycling (alongside growth of EV production) must be treated as an urgent environmental necessity for the UK.

residual capacity of ~70–80% – can be used in stationary systems, such as the electricity network, in combination with renewable energy systems. Extending the life of EV batteries converts some immediate waste disposal costs into residual value, while also reducing the carbon footprint of each battery. But improved regulation and incentives to reuse are needed as the price of new LiBs continues to fall.

Additionally, innovations in battery chemistry are helping to identify alternatives for standard LiBs. For example, the cathode used in LiBs is typically composed of lithium, nickel, manganese, and cobalt. A cheaper alternative cathode composed of lithium, iron, and phosphate is now being adopted by some EV manufacturers. Likewise, anodes are typically made of graphite, but a graphite-silicon blend is emerging as a potentially cheaper substitute. Furthermore, solid-state batteries, rather than typical liquid electrolyte batteries, offer the possibility of packing more energy into a smaller space, thereby requiring fewer critical minerals and improving the range of EVs. Finally, one particularly exciting development is the possibility of sodium-ion and magnesium-ion batteries that rely on more commonly found (and thus cheaper) ingredients rather than lithium. **G**

THEO HARRIS

Intern at Durham Energy Institute & master's student at Durham University, UK

STUART J. JONES

Co-director of Durham Energy Institute & Associate Professor of Sedimentology, Durham University, UK

FURTHER READING

A full list of further reading is available at [geoscientist.online](https://www.geoscientist.online).

- EU (2024) European Critical Raw Materials Act; commission.europa.eu
- Hebden, K. (2023) UK's first industrial scale lithium-ion battery recycling plant to open. The Chemical Engineer; thechemicalengineer.com
- IEA (2021a) The Role of Critical Minerals in Clean Energy Transitions. IEA, Paris; [iea.org](https://www.iea.org)
- IEA (2021b) Minerals used in electric cars compared to conventional cars, IEA, Paris; [iea.org](https://www.iea.org)
- IEA (2024a) Lithium. IEA, Paris; [iea.org](https://www.iea.org)
- IEA (2024b) Global EV Outlook 2024. IEA, Paris; [iea.org](https://www.iea.org)
- Vera, M.L. et al. (2023) Nat Rev Earth Environ 4, 149–165
- Rietveld, E. et al. (2022) Strengthening the security of supply of products containing Critical Raw Materials for the green transition and decarbonisation. Publication ITRE, European Parliament, Luxembourg; europarl.europa.eu
- Recyclus (2023) Recyclus achieves up to 45% recycling rate for black mass; recyclusgroup.com
- UKRI (2023) The 2035 UK Battery Recycling Industry Vision. UKRI; iuk-business-connect.org.uk
- UNDP (2025) Analysis of EV Battery End-of-Life. Mini Report. United Nations Development Programme; undp.org