The 2035 UK Battery Recycling Industry Vision

Sustainable thinking for the future

Nikoleta Piperidou, Knowledge Transfer Manager - Infrastructure & Energy
Sheena Hindocha, Knowledge Transfer Manager - Materials Chemistry

1. The opportunity

Governments across the world are increasingly moving towards the electrification of road transport, with the aim to reach their Net Zero and decarbonisation commitments. In November 2020, the UK Government announced a ban on the sales of new petrol and diesel engine passenger vehicles by 2030. This has led to an acceleration in the pace of electrification.

At the end of December 2022 there were more than 660,000 battery-electric cars registered in the UK. More than 265,000 battery-electric cars were registered in 2022, a growth of 40% on 2021[1].

By 2040, it is predicted that the UK will produce nearly 1.6 million EVs per annum[2] , requiring somewhere in the region of 450,000 tonnes of cell production capability. Plans for gigafactories have already been drawn up to satisfy the cell demand but as the electric revolution gathers pace, there is a once in a lifetime opportunity to develop the end of life infrastructure allowing for the safe treatment and reintroduction of the material into the circular economy.
To put the scale of the opportunity into perspective; automotive lithium ion batteries differ in chemistries but the cells generally contain around £7/kg in material value if they contain nickel or cobalt.

By 2035, 150,000 tonnes of batteries are estimated to reach end of life annually and by 2040, up to 45,000 tonnes of manufacturing waste will be produced per year. According to a recent report by Market Research Future[3], the battery recycling market globally could be worth £27 billion by 2030. How the different waste streams evolve over the coming decades is still unknown, and will depend on the volume and type of EV EoL batteries, and the volume and type of manufacturing scrap. These two waste streams are likely to have significant variations within them that then also change over time. For the UK to address this challenge, the battery recycling sector and the related infrastructure will need to have routes to mitigate this risk.

The development of a circular economy whereby battery materials are separated, recycled, then re-manufactured into new batteries all within the UK would allow for significantly more of a battery's economic value to be kept within the UK's economy while also reducing the UK's dependency on other countries for critical minerals.

[1] SMMT, December 2022

[2] https://faraday.ac.uk/wp-content/uploads/2020/03/2040_Gigafactory_Report_FINAL.pdf

[3] https://www.marketresearchfuture.com/reports/battery-recycling-market-10020

In July 2022 the UK Government highlighted the importance of critical minerals with the launch of the UK's Critical Minerals Strategy[4]. With both Cobalt and Lithium class as minerals with high criticality to the UK. The Strategy details the UK's approach to secure a resilient long term supply of Critical Minerals. To support the Strategy the UK Government established the Critical Minerals Intelligence Centre (CMIC)[5], which aims to produce data, intelligence and reports to support the critical minerals and manufacturing industries in mitigating the criticality of the minerals they depend upon.

The main approach for managing waste from LIBs should follow the 4R's - Reduce, Reuse, Recycle and Recover. While it is expected that manufacturers will aim to minimise the amount of waste in the future, the ambition to meet the UK's Net Zero targets will increase the demand of LIBs over the coming decades. As such, there is a need to focus on the Reuse, Recycle and Recover.

Recycling of batteries is an attractive proposition for most LIBs. The primary recycling technologies are pyrometallurgy and mechanical shredding, both of which produce products for hydrometallurgical refining.

Other technologies are under development, for example direct recycling which aims to separate components and reuse them without having to change the composition, this approach may be more appropriate for use on waste streams from manufacturing i.e. slurry or electrode scrap. There is also ongoing research into green solvents like ionic liquids which could be developed for use in battery recycling however these have not yet reached commercialisation.

The current LIB recycling capacity in the UK is currently very limited, with a few projects underway aimed to start developing the recycling industry.

Re-using batteries for second life is another option. This involves repurposing LIBs to be used in secondary applications for example stationary storage. A recent study[6] commissioned by the Office for Product Safety and Standards from Newcastle University explores the utilisation of LIBs in second life applications reviewing the market, hazards, safety regulations and standards. Whilst there are challenges associated with using LIBs for second life applications there are also opportunities for innovation which could support this market.

[4] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1097298/resilience_for_the_future_the_uks_critical_minerals_strategy.pdf

[5] https://ukcmic.org/

[6] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1133213/safety-of-second-life-batteries-in-bess.pdf

There are several ongoing activities which will enable the development of a battery recycling industry in the UK. In particular, the Government through the Faraday Battery Challenge and the Advanced Propulsion Centre has funded a range of projects such as RELiB[7] , CALIBRE and RECOVAS trying to commercialise and scale-up the emerging technologies and establish a UK supply chain.

Facilities for battery recycling tend to focus on processing either waste batteries to black mass (a shredded and dried material) or black mass to metal salts, which can then be utilised as precursor cathode active materials and be put back into the battery materials supply chain. Over the past couple of years there have been a few announcements from the industry on plans to develop battery recycling facilities in the UK, such as the new planned facility[8] by Veolia and Technology Minerals in the Midlands which will dismantle batteries into cells and modules before they are transported to Europe for further processing. Currently there is no large-scale capacity for battery recycling in the UK, and the majority of lithium-ion EV batteries are dismantled and shipped to Europe.

In terms of the regulatory environment, this is rapidly changing to accommodate the changing landscape. The Department for Environment, Food & Rural Affairs (Defra) is expected to launch a consultation on improvements to batteries regulations in 2023; this is likely to cover issues surrounding portable batteries, the changes in industrial and automotive batteries and EU regulation. At an EU-level the European Parliament and the Council have reached a provisional political agreement[9] to make all batteries on the EU market more sustainable, circular and safe. This builds on the Commission's proposal[10] from December 2020. Expected to be introduced from 2024, and fully operational from 2028, the agreement will gradually introduce requirements on the carbon footprint of a battery and recycled content placing sustainability alongside performance and durability.

In an international context, the Global Battery Alliance has just launched the world's first battery passport proof of concept[11]. The prototype, available on the Global Battery Alliance website, includes data on material provenance, sustainability performance indicators and technical specifications from across the value chain. In Germany, the Federal Ministry for Economic Affairs and Climate Action (BMWK) announced its "Battery Pass" project. This is a three-year, government-funded R&D global project with 11 consortium members. The aim of the project is to develop the technical standards and content for a "Battery Pass," as well as demonstrate the integration of such data into a shared data space to provide transparency .

This Vision Paper highlights the opportunity for the UK to become a leading country in battery recycling by 2035.

[7] https://relib1.relib.org.uk/

[8] https://www.veolia.co.uk/insights/insight/recycling-electric-car-batteries-ecological-issue-circular-solution

[9] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_7588

[10] https://ec.europa.eu/commission/presscorner/detail/en/ip_20_2312

[11] https://www.globalbattery.org/press-releases/global-battery-alliance-launches-world%E2%80%99s-first-battery-passport-proof-of-concept/

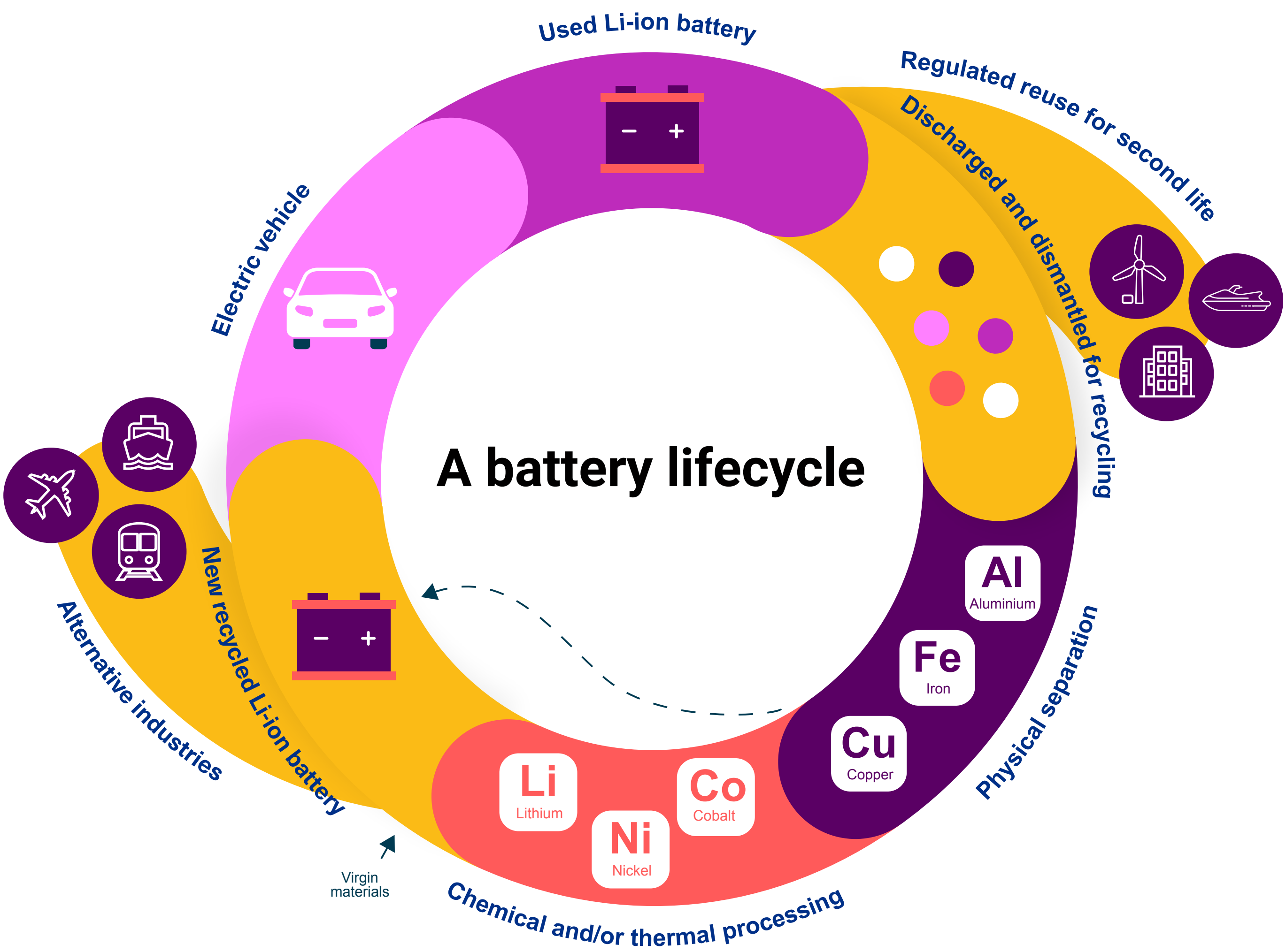
2. The Vision

2.1 Research and Innovation

Sustainable Battery Recycling Processes

It is imperative for battery recycling processes to be sustainable and have low environmental impacts, the different processes a battery will go through in order to be recycled can be seen in the lifecycle of a battery diagram.

As such, there is an opportunity to increase research and development into this area i.e. the physical and chemical separation, for example green solvents can be utilised in the chemical separation of black mass into metal salts, which can be used in battery production. This would enable the battery recycling industry to produce products with low embodied carbon and environmental impacts. These products can then be directed back into the battery materials supply chain to produce new batteries with recycled materials.



[12] https://thebatterypass.eu/

[13] Funding secured for EV repair and insurance pain point research - Thatcham

Rapid and safe discharging of end of life packs

There is no industry standard for discharging EV batteries. It is important for such a standard to be developed in order to develop a safe process minimising the fire or explosion hazard, as well as a rapid process ensuring that discharging does not become a bottleneck in recycling processes. In addition, innovation around automation of the discharge process would be beneficial to provide safe and efficient means of discharging.

Easy and safe transportation and storage of end of life battery packs

Storage and transportation costs are amongst the highest involved in battery recycling. Alongside the high costs, further clarity is required as to how to transport damaged packs and vehicles in the safest way required. A best practice guide for transportation mechanisms would be helpful for the nascent industry, there is already work ongoing to identify challenges and opportunities in electric vehicle repair, vehicle insurance and activity aimed at providing guidelines on battery storage across the whole life cycle[13].

New recycling processes for other chemistries such as LFP and LMO

There is a move towards using cheaper battery chemistries like LFP, as Tesla has shown recently. However, LFP cells have very low material value and therefore it is not economically viable to recycle them using current recycling processes. Future research should be also focused on the development of new recycling processes that can recycle LFP cells with a view to retain the LFP structure and utilise other components to develop high value by-products.

[12] https://thebatterypass.eu/

[13] Funding secured for EV repair and insurance pain point research - Thatcham

Integration of State of Health systems into battery management systems

The State of Health (SoH) system defines whether a battery needs to be recycled, reused or can be repurposed for another application. This is somewhat difficult to determine on the module or pack level, as there are tens if not hundreds of cells, adding to this, SoH can also vary widely over a pack or module. Once again, research is being undertaken into more accurate SoH testing, but one potential solution to this problem would be to integrate a system that monitors SoH over time into the battery management system of a pack. It is of note that there is not yet an agreed definition of SoH, as such any advances in this area need to remain aligned to international activities.

Another potentially helpful option to increase the efficiency of testing could be to introduce some form of standardised connection point to the battery. This would have multiple benefits, for example if automation of testing is developed, it would also enable battery management systems to be more accessible, allowing for EV maintenance and repair of EVs. Development of a standardised set of commands for onboard diagnostic systems which can control or assess the battery for second life would increase efficiency and enable the decision making process when handling a used battery. There is currently ongoing work in this area to identify barriers and opportunities.

2.2 Policy and Regulation

New end of life and second life regulations for batteries

The regulatory environment surrounding batteries is rapidly changing to accommodate the evolving landscape. The Department for Environment, Food & Rural Affairs (Defra) is expected to launch a consultation on improvements to batteries regulations in 2023; this is likely to cover issues surrounding portable batteries, changes in industrial and automotive batteries and incoming EU regulation.

Consultation topics are likely to include separating electric vehicle (EV) batteries from industrial batteries in their own category and considering individual producer responsibility obligations for EV batteries. The consultation will also look to revise treatment standards and introduce separate material recycling requirements alongside recognising battery reuse and repurposing.

The introduction of regulations which support the handling, dismantling, repair, repurposing and recycling of batteries at the end of their first life will support a UK battery recycling sector. As previously mentioned the study[14] commissioned by the Office for Product Safety and Standards from Newcastle University reviews this area from a regulations and standards perspective providing an overview of the current status of the nascent second-life market.

High use of recycled materials in new battery manufacture

One of the primary issues facing the development of the recycling industry is the fact that recycled material is currently not cost competitive with raw materials. This will not change until there is either sufficient economies of scale for recycled materials or until the supplies of critical minerals shorten to the point that the prices increase to match recycled materials.

There is work ongoing in the EU to develop a regulatory framework[15] for batteries; the most recent briefing note proposes minimum target levels on recycled content on specific metals which would apply to certain sectors. There is a need to keep connected to this approach in order for UK products to be viable for an EU market.

A global battery passport and materials tracking system

The implementation of a Battery Passport system that is capable of tracking batteries and their components is essential and some work is already underway to develop this. However, further international collaboration is required. There are ongoing activities in this space and ensuring alignment will be important, for example the Global Battery Alliance action partnership on a battery passport which has recently published a Battery Passport prototype[16]. Other sectors including composites and permanent magnets are also looking to implement similar systems so ensuring knowledge is shared across sectors will be critical.

[14] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1133213/safety-of-second-life-batteries-in-bess.pdf

[15] https://ec.europa.eu/commission/presscorner/detail/en/ip_22_7588

[16] https://www.globalbattery.org/press-releases/global-battery-alliance-launches-world%E2%80%99s-first-battery-passport-proof-of-concept/

2.3 Infrastructure and Skills

Access and support to demonstrate innovation

Currently there are insufficient volumes of batteries to sustain large scale battery recycling; however, the number of End of Life batteries in need of recycling is going to exponentially increase. For the UK to handle the waste it generates in a responsible manner there is a need to develop the required infrastructure to process EoL EV LIBs and manufacturing waste produced within the UK. If recycling facilities are not developed within the UK there is a risk that the volume of waste will overwhelm the UK's current recycling infrastructure, both in processing batteries to black mass and onwards to metal salts, leading to international shipping of UK EV waste.

For the UK to address this growing need to process its own waste there is a requirement to support organisations to pilot and demonstrate their technologies at a scale which would unlock further investment. Support for SMEs to achieve this could be delivered in multiple ways for example access to pilot or scale-up facilities located within the UK i.e CATAPULTs and Universities. Identifying where appropriate open access facilities are located, establishing a network through these organisations and disseminating this to SMEs could be beneficial. In addition, there is added value in establishing a network of this nature, focussed on recycling, which can provide companies with data for techno-economic assessments, understanding of health and safety and environmental compliance alongside supporting skills and training development.

Investment to establish the battery recycling industry

In terms of the economies of scale, it is predicted that the breakeven point for pyrometallurgical processes is 17,000 tonnes per year, for hydrometallurgical processes it is 7000 tonnes per year and for direct recycling it is 3000 tonnes per year, although there is some uncertainty due to a lack of data. However, this is based on cell chemistries that contain cobalt and the current trend in battery manufacturing is to move away from cobalt containing batteries. For batteries with no cobalt content, the breakeven points increase dramatically to over 50,000 tonnes per year for pyrometallurgy and to around 17,000 tonnes per year for hydrometallurgy. In order to establish a UK battery recycling industry there will be a requirement to develop, demonstrate and deploy technologies, like hydrometallurgical processing, at the scale required to have an impact.

To support investment there is a need to understand the capital cost estimation, estimation of operating costs, wastes produced, suitable locations and calculations into the availability of supply of feed and demand for refined metals over time. The location of recycling facilities will also be critical and considering the proximity to battery manufacturing locations, where the metal salt products can be utilised in new battery material production, would be beneficial.

Regional collection and pack processing facilities.

As mentioned previously, transport makes up a significant portion of the costs of the recycling process, potentially contributing up to 29% of the costs for the UK. Regional collection points, which process packs into material for hydrometallurgical refining, would be beneficial. Current UK capacity for this is low, although it is starting to increase with the new planned facility by Veolia and Technology Minerals in the Midlands which will dismantle batteries into cells and modules before they are transported to Europe for further processing. Studies to explore the best locations for recycling plants, in order to reduce transport costs and reduce the risk posed by transporting End of Life batteries, are required. In addition, this concentration of battery packs will require increased throughput of the facilities as such there is an opportunity to automate aspects of processing to ensure the expected volumes can be managed.

Trained, skilled and diverse workforce for handling end of life packs

As electric vehicles become ubiquitous there is a need to ensure that there is appropriate training for all those who will be expected to handle end of life batteries. Development of a training programme which ensures the holder can handle end of life batteries in a safe way is required. Different levels of training will be required based on the point at which the battery is received and how it needs to be managed prior to further processing, for example from vehicle garages to processing facilities.

[17] https://www.veolia.co.uk/insights/insight/recycling-electric-car-batteries-ecological-issue-circular-solution

3. Battery Recycling Library

This is a non-exhaustive list of further reading which you can use to explore the topic of battery recycling further.

Automotive Lithium ion Battery Recycling in the UK
https://warwick.ac.uk/fac/sci/wmg/business/transportelec/22350m_wmg_battery_recy cling_report_v7.pdf

Battery EV uptake doubles, but new car market remains well adrift of pre-pandemic levels
https://www.smmt.co.uk/2021/12/battery-ev-uptake-doubles-but-new-car-market-rem ains-well-adrift-of-pre-pandemic-levels/

UK electric vehicle and battery production potential to 2040
https://faraday.ac.uk/wp-content/uploads/2020/03/2040_Gigafactory_Report_FINAL.pdf

Research Study on Reuse and Recycling of Batteries Employed in Electric Vehicles
https://www.api.org/~/media/Files/Oil-and-Natural-Gas/Fuels/Kelleher%20Final%20E V%20Battery%20Reuse%20and%20Recycling%20Report%20to%20API%2018Sept 2019%20edits%2018Dec2019.pdf

End of Life strategies for electric vehicle lithium ion batteries
https://hssmi.org/explore-the-ways-of-recovering-and-maximising-battery-value-in-our-latest-report/

It's time to get serious about recycling lithium-ion batteries
https://cen.acs.org/materials/energy-storage/time-serious-recycling-lithium/97/i28

Recycling lithium-ion batteries from electric vehicles
https://www.nature.com/articles/s41586-019-1682-5

The Role of Sub and Supercritical Co2 as "Processing Solvent" for the Recycling and Sample Preparation of Lithium Ion Battery Electrolytes
https://www.researchgate.net/publication/314243271_The_Role_of_Sub-_and_Super critical_CO2_as_Processing_Solvent_for_the_Recycling_and_Sample_Preparation_of_Lithium_Ion_Battery_Electrolytes

Regulation of the EU concerning batteries and waste batteries
https://ec.europa.eu/environment/pdf/waste/batteries/Proposal_for_a_Regulation_on _batteries_and_waste_batteries.pdf

A Critical Review of Lithium-Ion Battery Recycling Processes from a Circular Economy Perspective
https://www.mdpi.com/2313-0105/5/4/68/htm

Key Challenges and Opportunities for Recycling Electric Vehicle Battery Materials
https://www.mdpi.com/2071-1050/12/14/5837/htm

Alternative Recycling Process for Lithium-ion Batteries: Molten Salt Approach
https://www.technology.matthey.com/article/64/1/16-18/

World's largest' giga-scale lithium-ion battery recycling facility gets backing
https://www.circularonline.co.uk/news/worlds-largest-giga-scale-lithium-ion-battery-re cycling-facility-gets-backing/

Business critical:Understanding thematerial life cycle_
https://www.apcuk.co.uk/wp-content/uploads/2023/04/APC-Business-critical_Understanding-the-material-life-cycle-report.pdf

UK Battery Strategy goes flat: Net-zero target at risk
https://committees.parliament.uk/publications/6975/documents/72817/default/

The importance of coherent regulatory and policy strategies for the recycling of EV batteries
https://faraday.ac.uk/wp-content/uploads/2020/09/Faraday_Insights_9_FINAL.pdf

State-of-the-art in reuse and recycling of lithium-ion batteries - A research review
http://www.energimyndigheten.se/globalassets/forskning--innovation/overgripande/st ate-of-the-art-in-reuse-and-recycling-of-lithium-ion-batteries-2019.pdf

Lithium Battery Reusing and recycling: A circular economy insight
https://www.sciencedirect.com/science/article/pii/S2405844019347012

A qualitative assessment of lithium ion battery recycling processes
https://www.sciencedirect.com/science/article/pii/S0921344920305358

Recycling lithium cobalt oxide from its spent batteries: An electrochemical approach combining extraction and synthesis
https://www.sciencedirect.com/science/article/pii/S0304389420322019

Selective extraction and separation of Li, Co and Mn from leach liquor of discarded lithium ion batteries
https://www.sciencedirect.com/science/article/pii/S0956053X20305638

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Selective extraction and separation of Li, Co and Mn from leach liquor of discarded lithium ion batteries
https://www.sciencedirect.com/science/article/pii/S0956053X20305638

Ultrasonic renovation mechanism of spent LCO batteries: A mild condition for cathode materials recycling
https://www.sciencedirect.com/science/article/pii/S0921344920303360

Financial viability of electric vehicle lithium-ion battery recycling
https://www.sciencedirect.com/science/article/pii/S2589004221007550

To shred or not to shred - a comparative techno-economic assessment of lithium ion battery hydrometallurgical recycling retaining value and improving circularity in LIB supply chains
https://www.sciencedirect.com/science/article/pii/S0921344921003505

A novel pulsated pneumatic separation with variable-diameter structure and its application in the recycling spent lithium-ion batteries.
https://www.sciencedirect.com/science/article/pii/S0956053X21003123

Recycling-oriented cathode materials design for lithium-ion batteries: Elegant structures versus complicated compositions
https://www.sciencedirect.com/science/article/pii/S2405829721002828

Pyrometallurgical options for recycling spent lithium-ions batteries - a comprehensive review
https://www.sciencedirect.com/science/article/pii/S0378775321001671

Electric field driven de-lithiation - a strategy towards comprehensive and efficient recycling of electrode materials from spent lithium ion batteries
https://www.sciencedirect.com/science/article/pii/S0926337320310493

Heavy liquids for rapid separation of cathode and anode active materials from recycled lithium-ion batteries
https://www.sciencedirect.com/science/article/pii/S092134492100358X

A review on the recycling of spent lithium-ion batteries by the bioleaching approach
https://www.sciencedirect.com/science/article/pii/S0045653521014168

Pursuing green and efficient process towards recycling of different metals from spent lithium-ion batteries through Ferro-chemistry
https://www.sciencedirect.com/science/article/pii/S1385894721032186

Recycling of mixed lithium-ion battery cathode materials with spent lead-acid battery electrolyte with the assistance of thermodynamic simulations
https://www.sciencedirect.com/science/article/pii/S0959652620318746

Reaction mechanism of antibiotic bacteria residues as a green reductant for highly efficient recycling of spent lithium-ion batteries
https://www.sciencedirect.com/science/article/pii/S0304389421009961

A review of recycling spent lithium-ion battery cathode materials using hydrometallurgical treatments
https://www.sciencedirect.com/science/article/pii/S2352152X20320405

Beyond the EVent horizon: Battery waste, recycling and sustainability in the United Kingdom electric vehicle transition
https://www.sciencedirect.com/science/article/pii/S2214629620301572

Global Implications of the EU Battery Regulation
https://www.science.org/doi/10.1126/science.abh1416

This is an independent paper reflecting the views of the membership of the Cross Sector Battery Systems Innovation Network - an open and collaborative cross-sectoral community for innovators in battery manufacturing (including next-generation batteries), the related supply chain and end users.

Authored in April 2023 by:

Nikoleta Piperidou,
Knowledge Transfer Manager - Infrastructure & Energy

Sheena Hindocha,
Knowledge Transfer Manager - Materials Chemistry

Contact Details

To discuss UK battery recycling further, please contact the Innovate UK KTN Cross-Sector Battery Systems Innovation Network team at **batterysystems@iuk.ktn-uk.org**

Telephone: 03333 403251
Email: enquiries@iuk.ktn-uk.org
Website: iuk.ktn-uk.org