Life Cycle Assessment Method for Direct Recycling of Lithium-Ion Batteries

Comparison of direct recycling and hydrometallurgical recycling

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Abstract

Electric vehicle (EV) batteries contain an increasingly large proportion of critical minerals, with EVs responsible for over 60 % of lithium use in 2022 (IEA, 2023). Efficient recycling methods can recover critical materials, alleviate supply chain pressures, and reduce manufacturing impacts.

Current industrial lithium-ion battery (LIBs) recycling is pyrometallurgical and hydrometallurgical, using melting and chemical extraction respectively. Hydrometallurgical recycling methods are less environmentally burdensome than pyrometallurgy (Kallitsis *et al.,* 2022) and recover a greater number and quantity of elements of a higher quality (Thompson *et al.*, 2021).

Direct recycling recovers the battery cell's constituent components, reducing the processes required to produce a new battery cell. This new recycling method is compared with hydrometallurgical recycling to assess the environmental impact of the two.

This work found that direct recycling results in considerably smaller environmental impacts than hydrometallurgical methods.

Motivation

- In the UK, 339,000 metric tonnes of EV batteries will reach their end of life by 2040 (WMG, 2020). This provides potential for fulfilling the UK's Critical Mineral Strategy by creating a circular battery supply chain in the UK.
- Recycling LIBs reduces the environmental impact of producing new battery cells, making EVs more environmentally friendly.

Methods

- OpenLCA 2.0.0 is used to model the recycling processes and compare the environmental impacts across the 18 categories in ReCiPe Midpoint (H) categorisation.
- The Ecoinvent 3.6 Inventory was used for standard processes and chemicals.
- Electricity production was updated for China in 2022 (Ritchie *et al*., 2022) Fig 1.

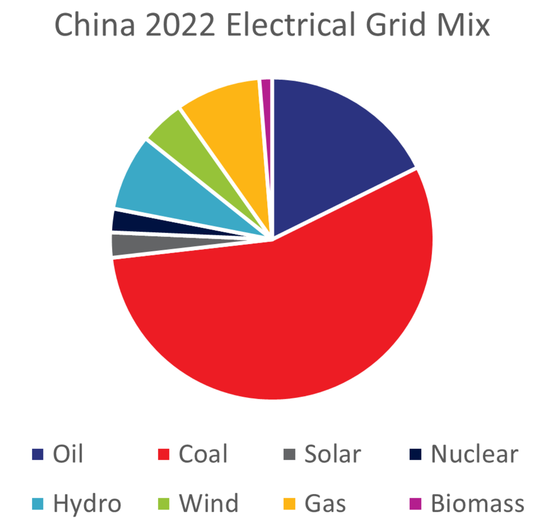

Fig 1. Breakdown of energy sources for China's electricity grid

Inventory

- NMC 811 LIB cell production inventory from (Kallitsis *et al*., 2020).
- Hydrometallurgical recycling process modelled based on data from The Faraday Institution ReLib project and research papers.
- Direct recycling modelled using research papers.
- See further supplementary material explaining all inventories and providing further data.

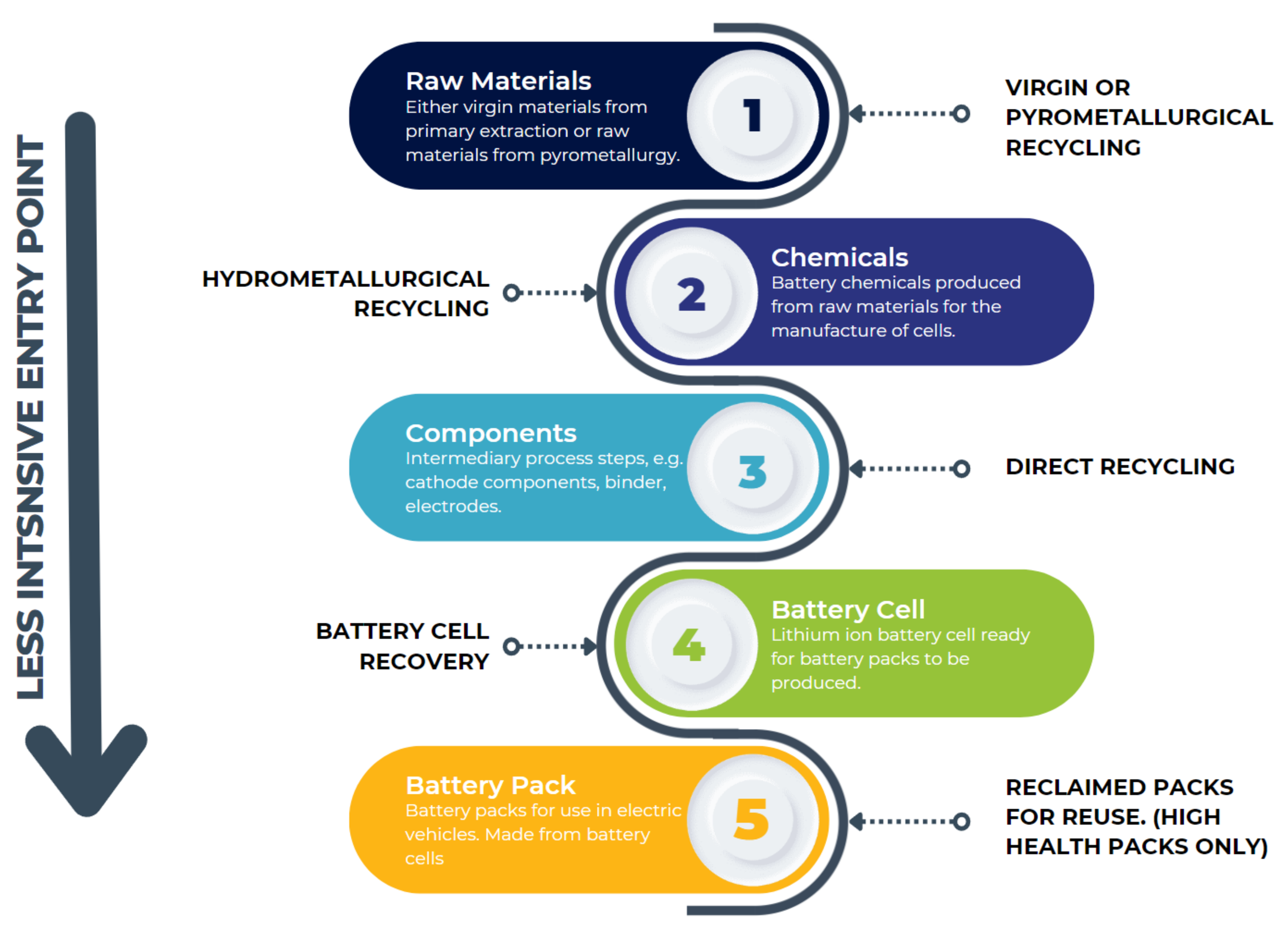

Fig 2. Infographic illustrating benefit to later entry point for battery manufacturing. Direct recycling is better than hydrometallurgical because it can bypass several reprocessing steps.

Results

- Hydrometallurgical recycling has already been shown to reduce the environmental burden of LIB production compared to virgin materials (Kallitsis *et al.*, 2022). The impacts from the hydrometallurgical recycling and direct recycling models are greater than they would be in a scaled-up commercial process since both are modelled from research papers, so they have not been optimised with the reuse and recovery of process chemicals. Fig 3. is representative of this, with hydrometallurgical recycling showing little benefit compared to virgin material production.
- Production of battery cells using recovered and relithiated materials from direct recycling reduces the environmental impact of LIB cell production compared to raw materials and those from hydrometallurgical recycling.
- The use of chemicals (organophosphates, acids and solvents) in both recycling methods are responsible for large proportions of the impacts. Reducing the quantity of these and switching to more ecological alternatives will further reduce the impact from cell production.

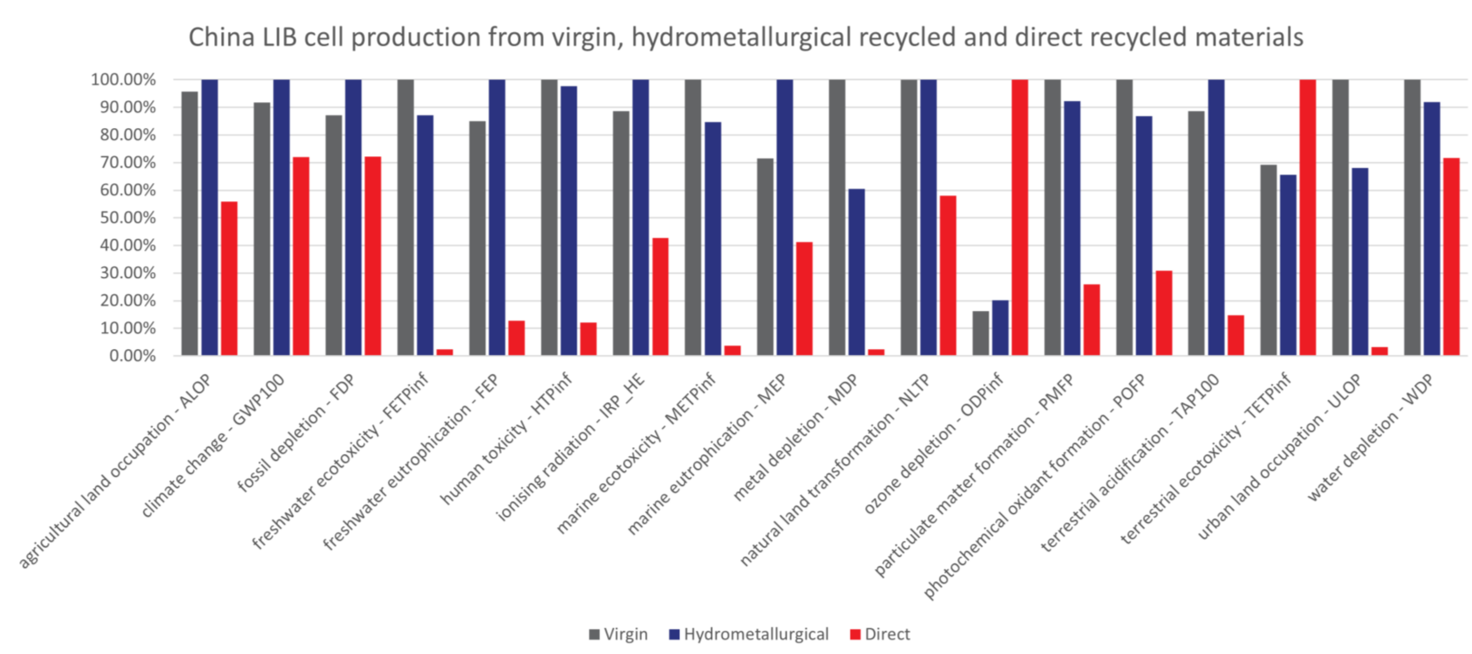

Fig 3. Comparison of environmental impacts from producing NMC 811 cells per kg in China.

Next steps

- Direct recycling methods should be researched further to scale up to recycle batteries industrially.
- Reducing and reusing chemicals in the direct recycling process should be explored. The reason ozone depletion is greater for direct than hydrometallurgical in Fig 3. is due to the high use of solvents in the ultrasound bath. This is based on scaling up worktop lab scale experiments, so it should be possible to reduce.
- LIBs should be designed with recycling in mind. For current pack designs, disassembling the battery pack down to single cells for recycling is very difficult because there is no standardisation of design and terminal connections between car models, even those produced by the same manufacturer.
- Government legislation is required to mandate recycling LIBs, particularly those in EVs, as they contain large quantities of valuable resources.

References

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Intern bio

Joshua is studying Mechanical Engineering with Nuclear Engineering at Imperial College London. He wants to work in the sustainable energy sector and on engineering projects contributing to decarbonisation. Outside his studies he campaigns on environmental policy.

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