Lithium-Ion Battery Recycling: Combined approach

Advancing Recycling of Heterogeneous Battery Materials: Inductively Heated Reactor Coupled with Biohydrometallurgy

End-of-life batteries arise in a decentralized manner and often reach recyclers as mixed or poorly identified material streams, driving up transport, storage, and safety costs - and complicating process planning and control. Many routes today require near single-stream inputs for economic viability, which does not reflect real-world variability. Addressing heterogeneous, mixed black masses is therefore essential to scale recycling and meet EU recovery targets beyond the traditional focus on Ni/Co/Cu, extending to lithium and phosphorus as well. Compounding this, many batteries lack clear identification of cell chemistry until the battery passport becomes standard, with the unavoidable mixed recycling streams, intensifying feed uncertainty and the need for robust processes tolerant to broad input variability.

A complementary pathway: Pyrometallurgy meets biohydrometallurgy

To manage complexity in mixed feeds, our work emphasizes a complementary approach that couples a high-temperature inductively heated reactor concept with biohydrometallurgical recovery. Biohydrometallurgy is being explored to lower environmental impacts within a closed-loop concept. In parallel, the inductively heated reactor provides precise thermal control using electricity and separation mechanisms that can pre-condition complex black masses for more selective downstream recovery, enabling better routing of mineral versus metal-rich phases.

- While pyrometallurgy can pre-concentrate and separate phases, biohydrometallurgy offers a pathway to recover metallic components from the alloy with potentially low environmental burdens.
- The reactor’s controlled temperature profile and gas-phase removal of reactive species can condition mixed feeds into more uniform, separable outputs. This improves compatibility with subsequent bio-based leaching steps that are otherwise sensitive to feed variability.

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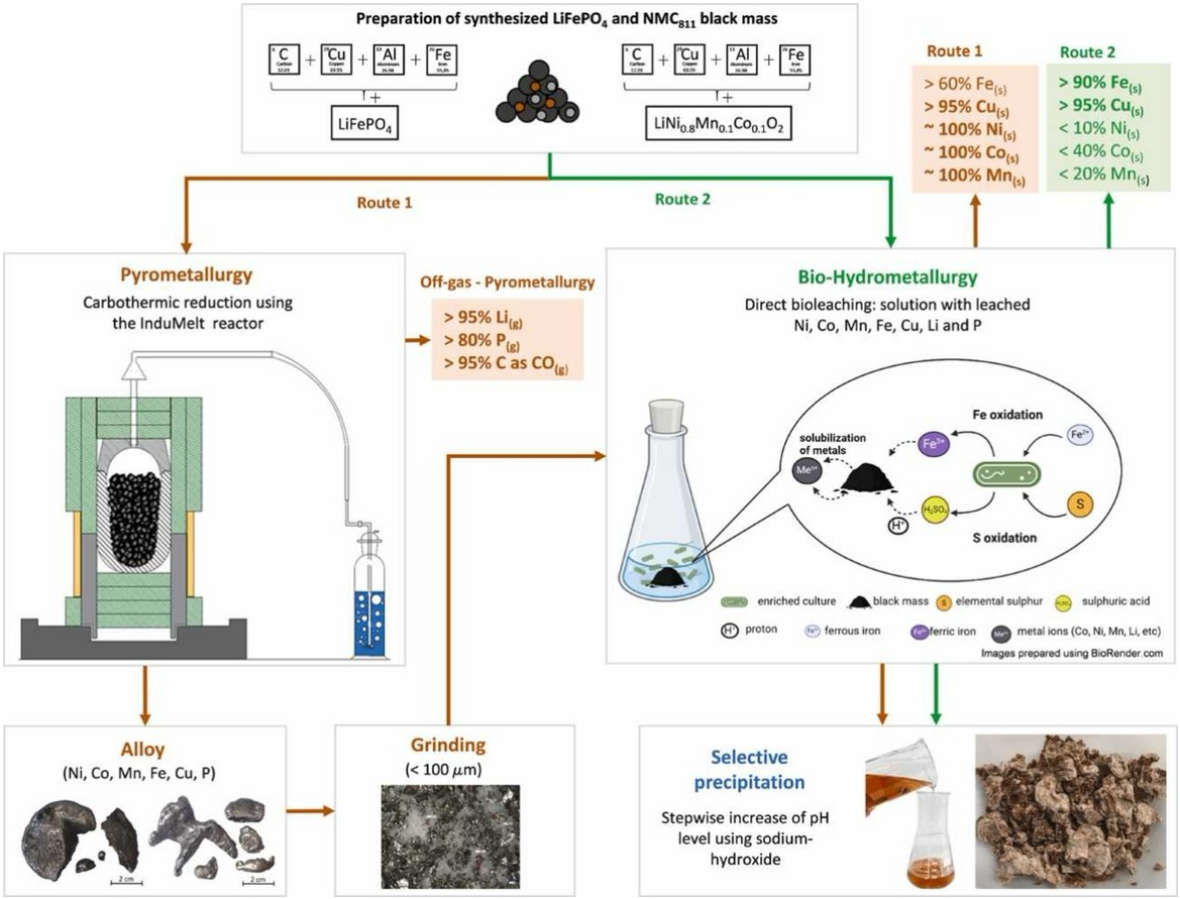

Figure 1: Wiszniewski, L., Lalropuia, L., Spiess, S., Presoly, P., Kremser, K., Doschek-Held, K., Guebitz, G. M., & Raonic, Z. (2025). Integrating pyro- and biohydrometallurgy in a green closed-loop lithium-ion battery recycling approach. Journal of environmental chemical engineering, 13.2025(3).

Integrating carbothermic pyrometallurgy in the InduMelt reactor with targeted bioleaching and selective hydroxide precipitation enables high-efficiency, condition-dependent recovery of critical metals from NMC and LFP black mass achieving high Li transfer into the volatilized phase, strong leaching performance at low pulp density, and high-yield downstream precipitation.

Dissemination

The FuLIBatteR COMET module was presented at the Battery Innovation Days in Graz from 2 – 3 December 2025.

Figure 2: Bettina Rutrecht and Parinaz Seifollahzadeh at the K1-MET research booth.

On 14 April 2026, the 3rd FuLIBatteR Workshop took place in Feldkirchen near Graz and included a side visit to the battery recycling facility of Saubermacher Dienstleistungs AG in Premstaetten.

Figure 3: 3rd FuLIBatteR Workshop at Saubermacher Dienstleistungs AG in Feldkirchen/Graz.

Further selected recent dissemination activities in the FuLIBatteR module were:

- Rutrecht, B., Rosskogler, S., Arnberger, A., Pomberger, R., Nigl, T., Mapping stakeholder perspectives for sustainability transitions: the case of Lithium-Ion Battery recycling, Sustainability 18 (2), paper no. 654
- Baniasadi M., Upvan K., Pourhossein F., Graves J.E., Latyvte E., Farnaud S., Towards a circular economy in lithium ion battery recycling by integrating microbial processes with electrowinning and precipitation for sustainable metal recovery, Journal of Environmental Management 395, paper no. 127891.
- Sieber, A., Kalampaka, A., Matys, S., Lederer, F., Kremser, K., Ribitsch, D., Guebitz, G. M., Phage display screening for highly specific nickel-and cobalt-binding peptides for bio-recovery of metals, Waste Management 208, paper no. 115145.
- Rieger, J., Stuhr, S., Rutrecht, B., Morgenbesser, S., Nigl, T., Arnberger, A., Kunanz, H., Lesiak, S., Graphite separation from LIB black mass by froth flotation and quality evaluation for a reuse as secondary raw material in-cluding non-battery applications, Recycling 10 (2), paper 75.

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- Wiszniewski, L., Juettner, L., Raonic, Z., Arnberger, A., Müller, J., Doschek-Held, K., Raupenstrauch, H., Schmidt, L., Pre-treatment strategies for efficient pyrometallurgical recycling of Lithium-Ion Batteries within the InduRed reactor, BHM Berg- und Huettenmaennische Monatshefte 170 (7), pp. 422 – 427.
- Wiszniewski L., Lalropuia L., Spiess S., Presoly P., Kremser K., Doschek-Held K., Guebitz G.M., Raonic Z., Integrating pyro- and biohydrometallurgy in a green closed-loop lithium-ion battery recycling approach, Journal of Environmental Chemical Engineering 13, paper no. 116811.

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For more information about the FuLIBatteR project and its progress, please visit LinkedIn and the K1-MET-Website.