Rückgewinnung kritischer Rohstoffe aus verschiedenen LIB-Anwendungen

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Coordinated by

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Federal Ministry
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Republic of Austria
Climate Action, Environment,
Energy, Mobility,
Innovation and Technology

Agenda

(1) Project partners and general overview

(2) Objectives of the research work and current status (3 Sub-Projects)

- Waste management and waste technological approaches for recycling of Lithium-Ion Batteries (LIB)
- Pyrometallurgical processing of LIBs and black mass
- Bio-hydrometallurgical treatment of LIB residues

Project „FuLIBatteR“ (2022-2026)

Future Lithium-Ion Battery Recycling for Recovery of Critical Raw Materials

Module Consortium

AUDI AG

BRAIN Biotech AG

Ebner Industrieofenbau GmbH

RHI Magnesita GmbH

Saubermacher Dienstleistungs AG

TÜV SÜD Landesgesellschaft Österreich mbH

voestalpine High Performance Metals GmbH

VTU Engineering GmbH

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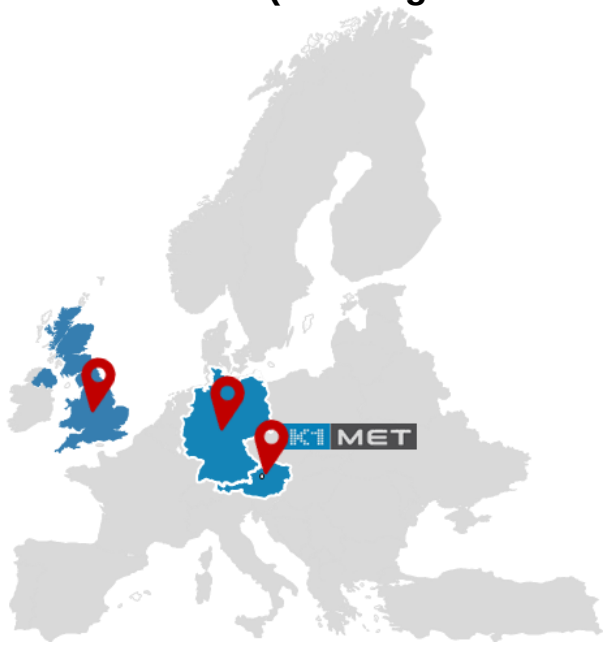
ACIB GmbH

BOKU University

Coventry University

K1-MET (Coord.)

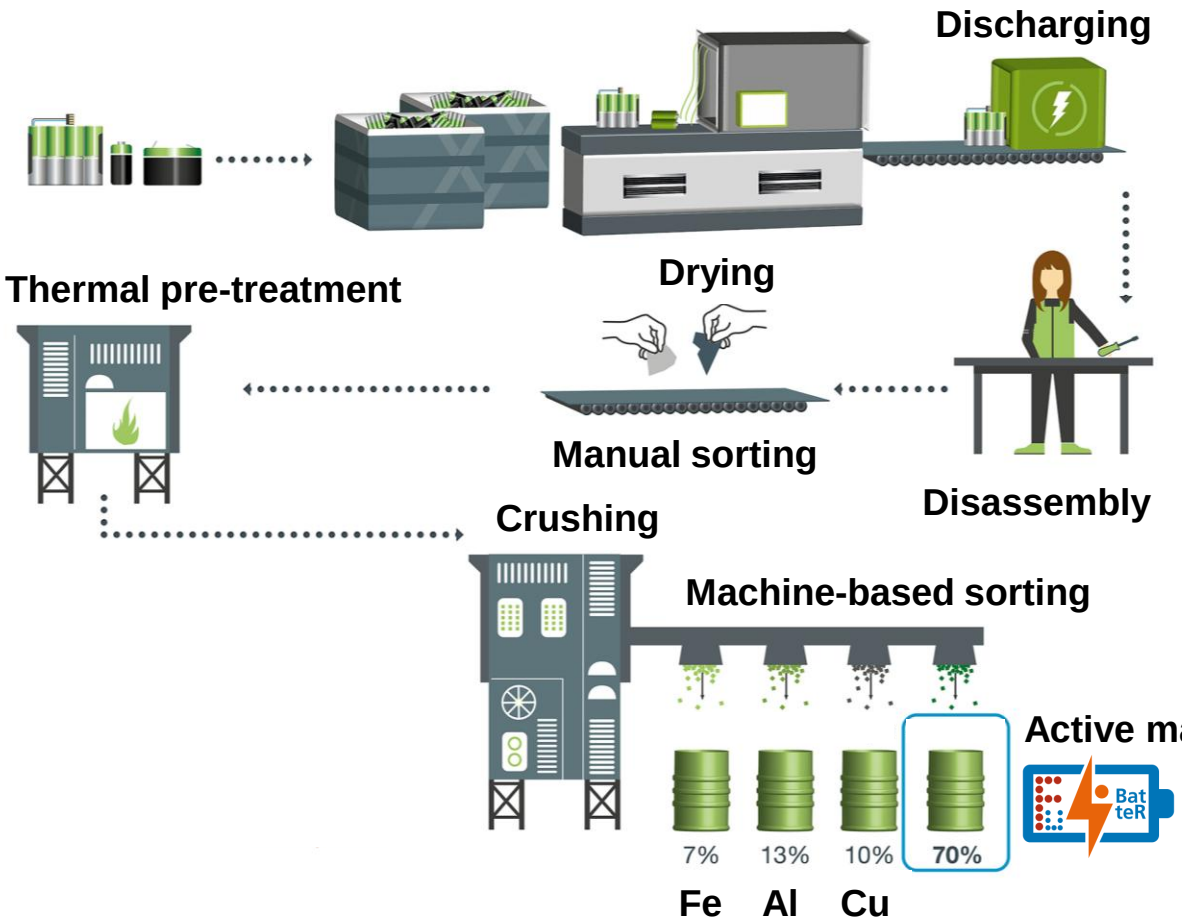


Montanuniversitaet Leoben (MUL, 3 Chairs)
- Waste Processing Technology & Waste Management
- Thermal Processing Technology
- Process Technology & Industrial Environmental Protection

UVR-FIA

REDUX LIB recycling process

Active material (black mass) as starting point of FuLIBatteR



- Black mass accounts for ~70% of the total battery weight with up to 40 wt.-% C (graphite), Li, Co, Mn, and P
  - No large-scale industrial processes yet available for a selective recovery of valuable materials

Source: https://www.redux-recycling.com/en/media/

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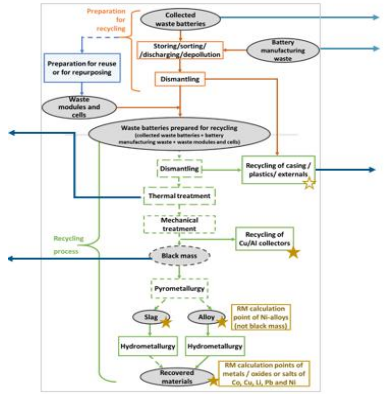
Sub-Project 1
Waste management and waste technological approaches for LIB recycling

Physico-chemical treatment and waste management related aspects

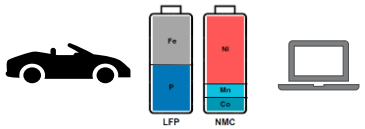
Flotation, magnetic separation, ion-exchangers

Active material

Graphite-rich foam product



Material Flow Analysis
Life Cycle Assessment
Recycling efficiencies



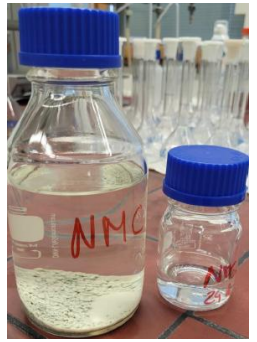
Spent
Lithium-ion batteries

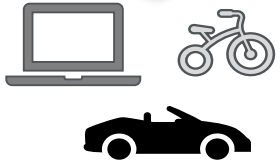
Froth flotation

Separation of graphite from the active material

Lithium removal and recovery from flotation process water

Use of zeolites





Reuse including open-loop scenarios (reuse outside battery applications)

Sub-Project 1

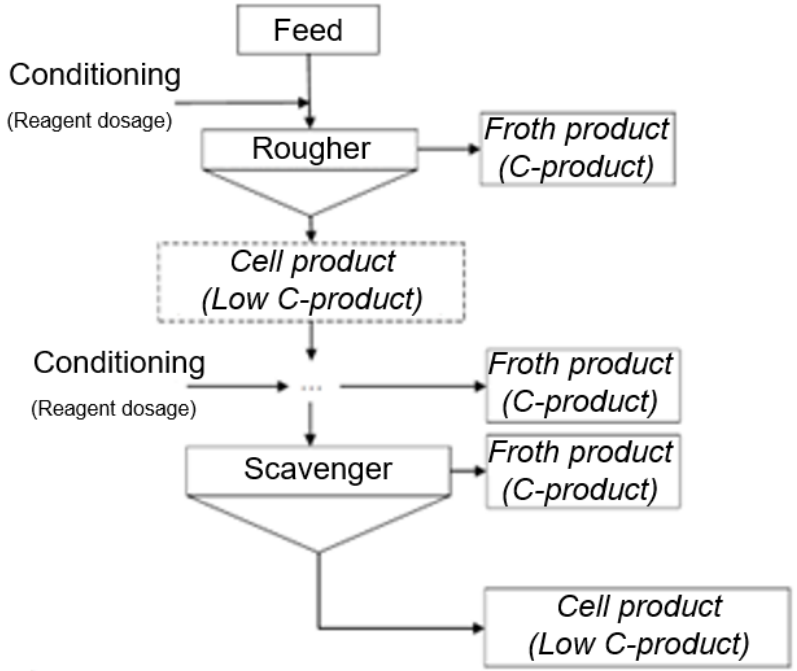
Froth flotation and accompanied flotation liquid treatment

Graphite separation and quantitative/qualitative verification

- Froth flotation process to separate graphite (see Fig. on the right)
- ~90% carbon recovery maximum reached for NMC[1)], LCO[2)], LFP[3)]
- Strong impact of input active material (NMC, LCO, LFP) on selectivity
- Flotation graphite successfully tested as secondary carbon source in a refractory brick (Magnesia-carbon brick, MgO-C) with no negative impact on thermo-mechanical properties (example for open-loop recycling)

Processing of liquid flotation fraction to recover lithium

- Use of zeolites (natural and artificial)
- First trials done to quantify lithium removal



Scheme of froth flotation process (© UVR-FIA)

1) Lithium-Nickel-Mangan-Cobalt-Oxide
2) Lithium-Cobalt-Oxide
3) Lithium-Iron-Phosphate

Sub-Project 1

Waste management aspects and LIB recycling efficiency

Materials characterisation life cycle assessment

- Characterisation of the REDUX process outputs (see Fig. right)
- Derive a comprehensive Material Flow Analysis (MFA)
- Life Cycle Assessment modelling based on MFA results

Outputs from the REDUX LIB treatment process
(© Montanuniversitaet Leoben, Saubermacher Dienstleistungs AG, K1-MET)
NFe…Nonferrous metals, Fe…Iron

Opportunities and challenges for LIB recycling

- Consider currently ongoing plannings on EU level regarding the calculation of recycling efficiencies (work in progress by the Joint Research Centre (JRC) of the European Commission)
- Overall rate for the recycling efficiency of wastes from battery recycling (is already known in EU documents/communications)
- **NEW:** Rates for material recovery on elemental level (Co, Ni, Li)
- This situation also affects the analyses of all intermediate and final products from LIB recycling processes (quantify product qualities as exact as possible)

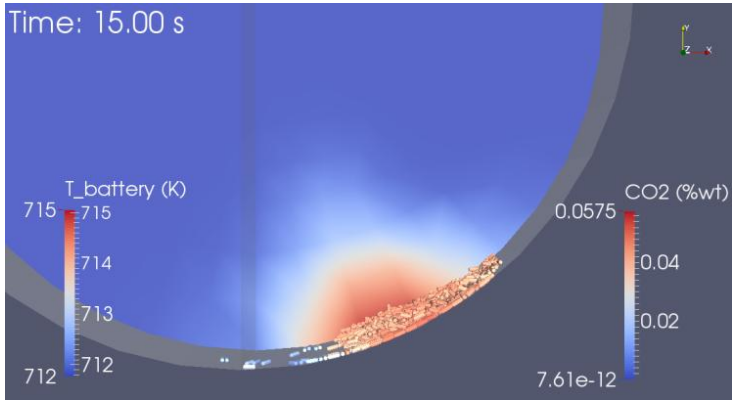
Sub-Project 2 Pyrometallurgical processing of LIBs and black matter

Sub-Project 2

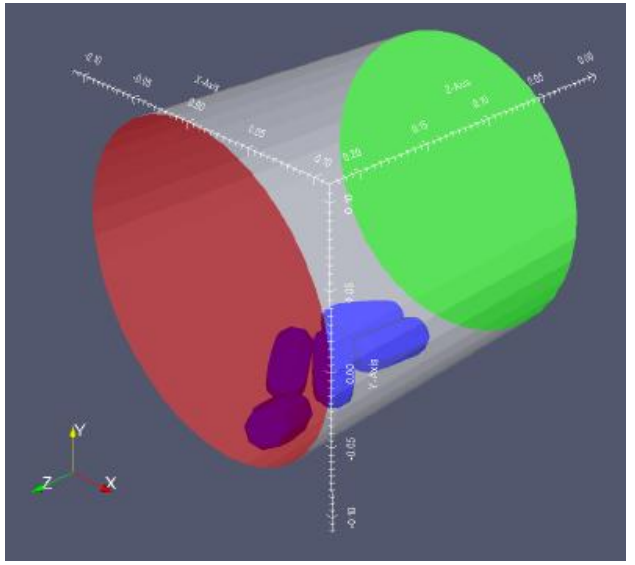
Simulation of the thermal pre-treatment of a LIB

Simulation and development of optimised thermal deactivation step in REDUX process

- Experimental 'box test' to evaluate a mathematical model for thermal events (gas release and explosions)
- Developing the CFDEM[1)] numeric model to evaluate the model based on the experiments
- Numerical model is in sufficient agreement with the experiments
  - Modelling thermal deactivation in larger scale as one major next step
  - Rotary drum (see Fig. right) as one possible furnace type



Simulated CO_2 mass fraction of thermal LIB deactivation in a drum furnace (© Montanuniversitaet Leoben, K1-MET)



Simplified drum case geometry for the thermal LIB deactivation step (© Montanuniversitaet Leoben, K1-MET)

1) Computational Fluid Dynamics / Discrete Element Method model

Sub-Project 2

Experimental pyrometallurgical LIB treatment

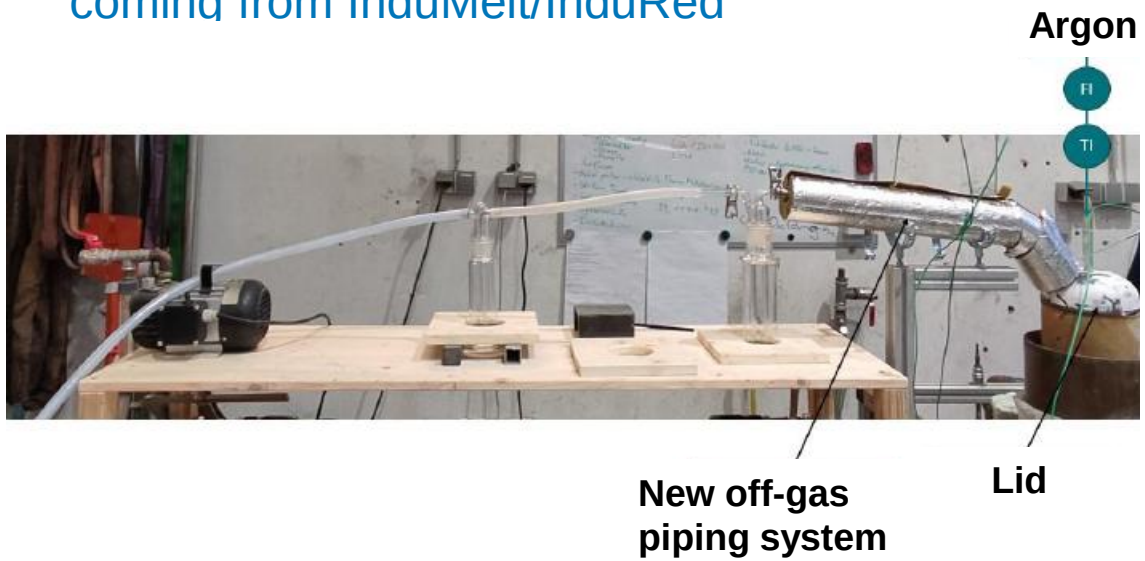
High-temperature experiments in inductively heated packed bed reactor (InduMelt/InduRed, see Fig. right)

- Investigating the effect of refractory materials during carbothermal reduction on corrosion and thermal stress
- Adapted off-gas system to recover Li and P (see Fig. below)

InduMelt plant
(© Montanuniversitaet Leoben)

Post-treatment of pyrometallurgical recycling output

- Determining metallurgical post-treatment methods for the metal-rich fractions coming from InduMelt/InduRed



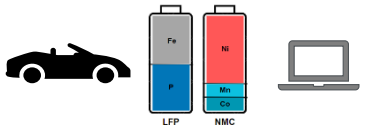
Adapted InduMelt off-gas system to recover Li and P
(© Montanuniversitaet Leoben)

Sub-Project 3
Biohydrometallurgical treatment of LIB residues

Developing a biohydrometallurgical route for LIB recycling

Active material

Metal enriched leachate



Spent
Lithium-ion batteries

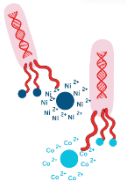
Bioleaching

Solubilisation of metals from solid materials utilising microorganisms

Metal recovery methods

Selective precipitation

(Bio)electrochemistry



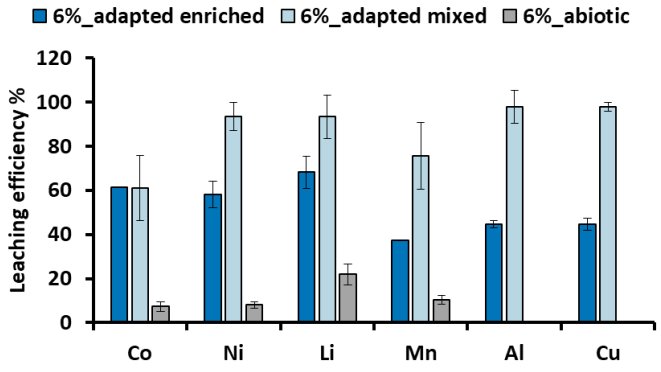
Metal binding peptides

Reuse

Sub-Project 3

Bioleaching batch tests and process scale-up advances

- Direct bioleaching trials of active material of 1% up to 6% pulp density with pure and mixed cultures were performed and already published*
  - >3% pulp density is too high for a direct bioleaching approach due to bacterial inhibition (except for black mass from LFP batteries
  - Leaching trials of pyrometallurgical product (from Project 2) also performed to show, how different approaches can be combined with each other to increase the recovery efficiency of valuable materials from black mass
- Indirect bioleaching trials with biogenic sulfuric acid
  - High leaching efficiency of Co, Li, and Mn achieved even at 10% pulp density
  - Stepwise leaching trials of graphite-poor flotation product (from Project 1)
  - Quantification of the leaching efficiency of organic acids (citric acid, oxalic acid) for LFP and NMC leaching



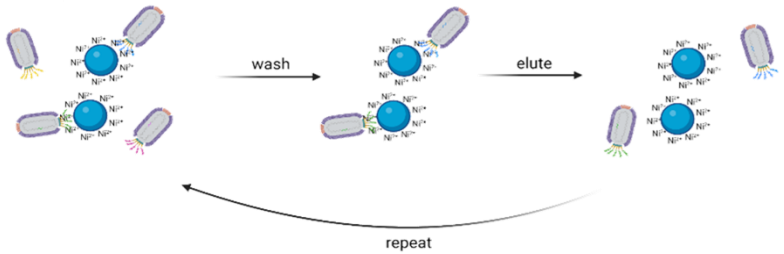
(© BOKU, K1-MET)

*https://www.frontiersin.org/journals/microbiology/articles/10.3389/fmicb.2024.1347072/full

Sub-Project 3

Metal recovery from leaching product

- Metal binding peptides
  - Ni and Co binding peptide(s) have been identified and characterisation of binding events
  - Usage of brewery's yeast as a biosorbent for metal recovery, publication

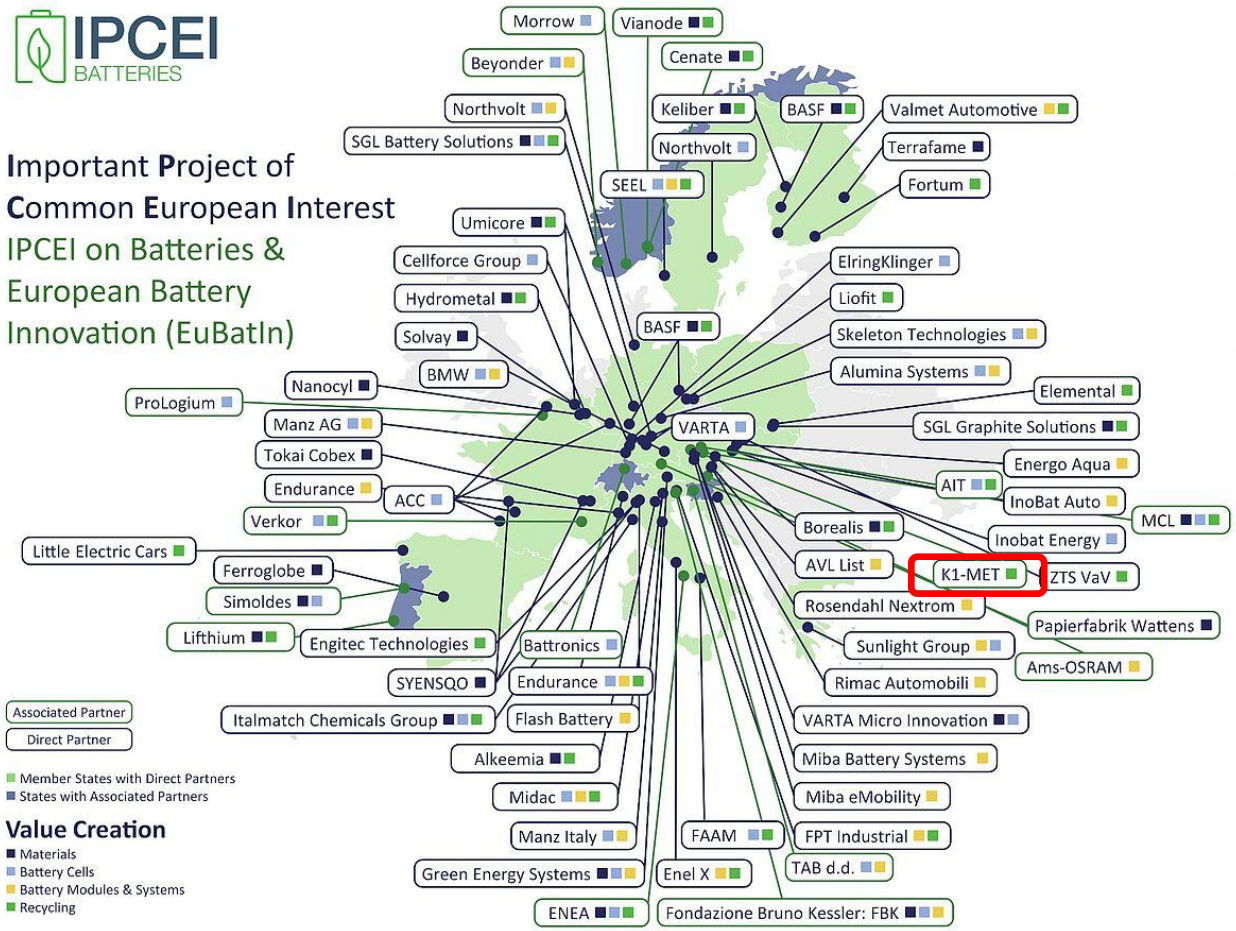


- Electrowinning of Co, Ni and Mn and bioelectrochemical Co and Ni recovery
  - Testing of different cathode materials (stainless steel, nickel foil, nickel foam, carbon felt) and parameters
- Selective precipitation of metals from NMC and LFP leachates
  - Fe at lower pH precipitated followed by Al and Co (co-precipitation with Ni) at increasing pH values, Mn and Li precipitation afterwards

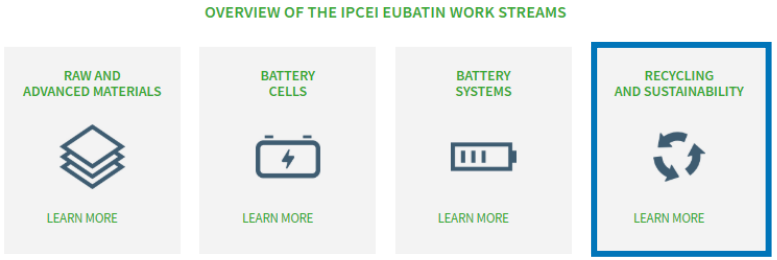
(© BOKU, K1-MET)

International visibility of FuLIBatter

Important Projects of Common European Interest (IPCEI)



- K1-MET became associated partner of IPCEI EuBatIn (European Battery Innovation) in Workstream 4 “Recycling and Sustainability”
- Further participation in national battery working groups
  - Solution Group Battery Recycling (Styria)
  - Future Mobility Region (Upper Austria)
- Sponsorship for Battery Innovation Days 2025 (Graz, 02.-03.12.2025)



Source: https://www.ipcei-batteries.eu/

Thank you! Questions?

Wien, 18.03.2025

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