17th – 18th May 2022 Valencia (Spain)

Electromobility Technology Workshop:

Driving a Greener Value Chain by i-HeCoBatt

Finland-based Circular Ecosystem of Battery Metals BATCircle 2.0

TITLE: Dr.

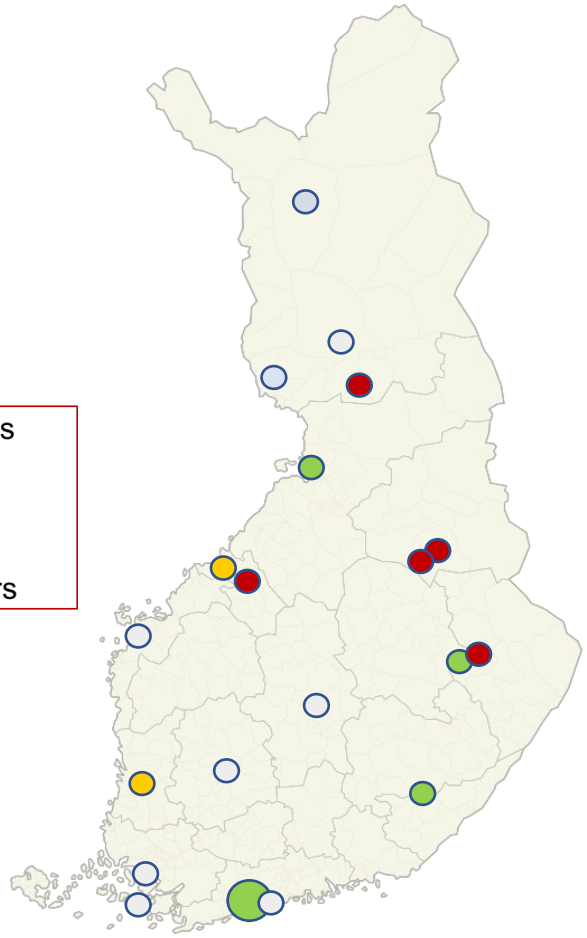
SPEAKER: Ben Wilson

i-HeCoBatt

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824300

hosted by LOMARTOV [Applied Innovation Engineering]

Finnish Battery Ecosystem



- One of the largest Li deposits in EU
- Rich in primary raw materials
- Biggest in Europe in Co and Ni mining
- Significant natural graphite deposits
- > 10% of global Co refining, 4% of Ni refining
- Base for major industrial players
- Nornickel, Freeport Cobalt, Boliden, Metso Outotec, Umicore, Terrafame, BASF, Fortum, Valmet Automotive
- World class minerals processing & metallurgical know-how
- Low CO_2 in electricity production (80% produced from nuclear, wind, solar, hydro and biomass)

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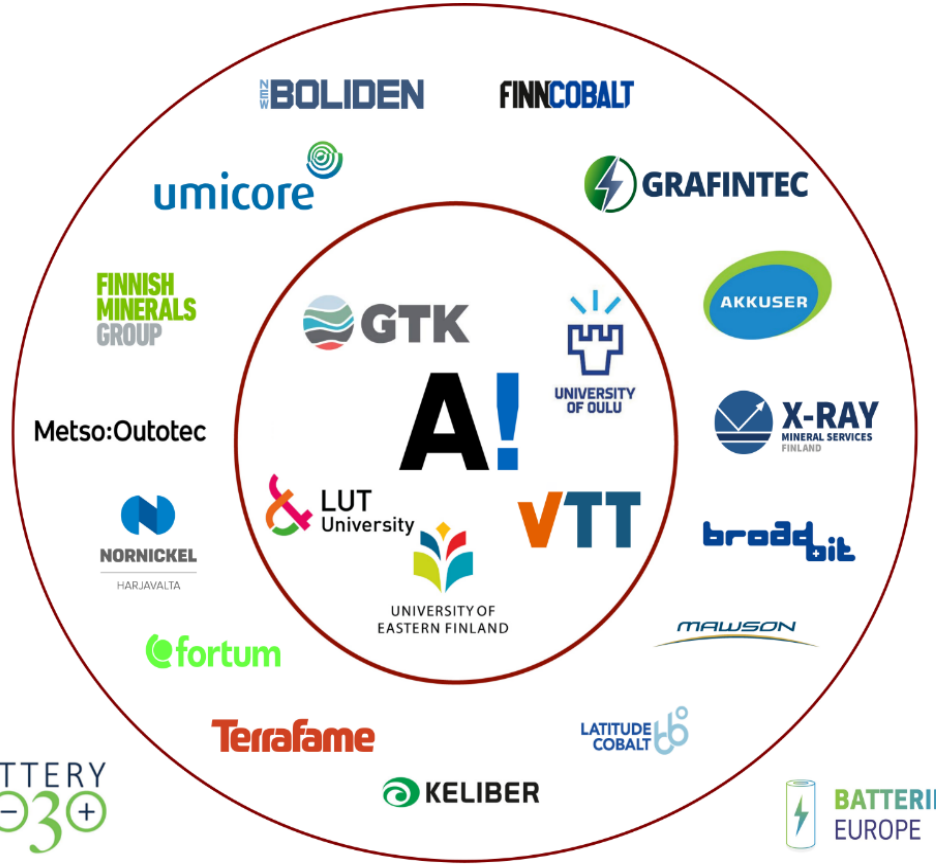
BATCircle2.0 consortium

Joint industry-academia project (2021-2024):

- 2nd phase after the 1st BATCircle phase (2019-2021)
- Coordinated by Aalto University
- Total budget of 19 M€

1. Open research
- Performed by 6 research organizations (ROs)
  - 4 universities and 2 research centers
    - Aalto University, LUT University, University of Eastern Finland, University of Oulu, GTK and VTT

2. Confidential R&D research
- Performed by 15 companies



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https://batcircle.aalto.fi/en

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Goals

- Improving the manufacturing processes of mining industry, metals and battery chemicals industries
- Increasing the recycling of lithium-ion batteries
- Strengthening the cooperation between companies and ROs in Finland

Advisory Board

- The Advisory Board members are part of an extended network of stakeholders who are interested in the Finnish battery value chain

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BATCircle2.0 Open Research

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EnhanceBatteryRecycling

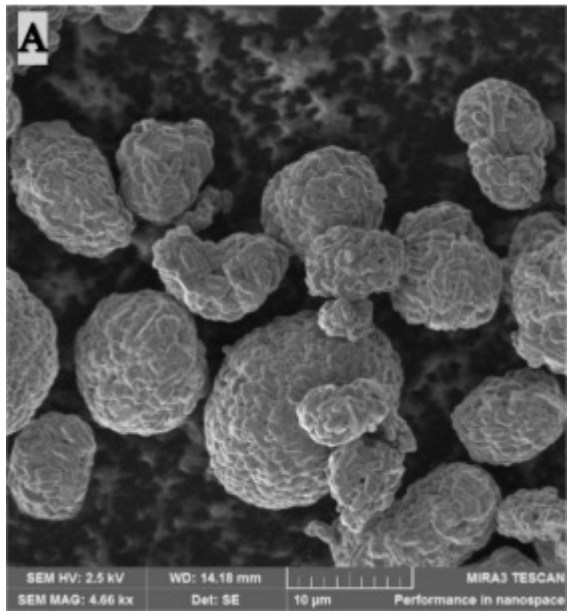

Fig. 1. (A) SEM micrograph of synthetic active material

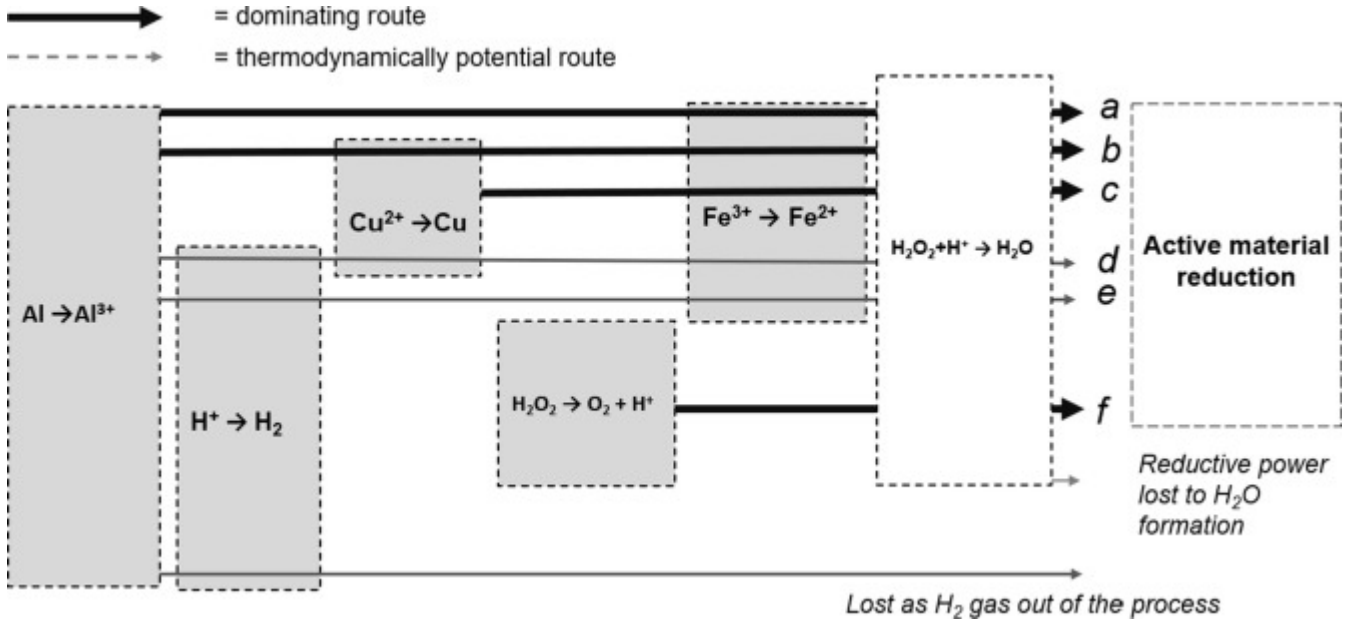

Fig. 8. Schematic of the potential interaction reaction routes of the studied reductants (H_2O_2, Cu, Fe, Al) in the leaching of active materials. Reactions providing reductant described on gray and oxidizing reactions by white.

Chernyaev, A., Yanmin, Z., Wilson, B.P., Lundström, *(2021), The interference of copper, iron and aluminum with hydrogen peroxide and its effects on reductive leaching of $LiNi_{1/3}Mn_{1/3}Co_{1/3}O_2$, Separation and Purification Technology (2021), 119903. doi.org/10.1016/j.seppur.2021.119903*

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Advanced Minerals and Metals Processing

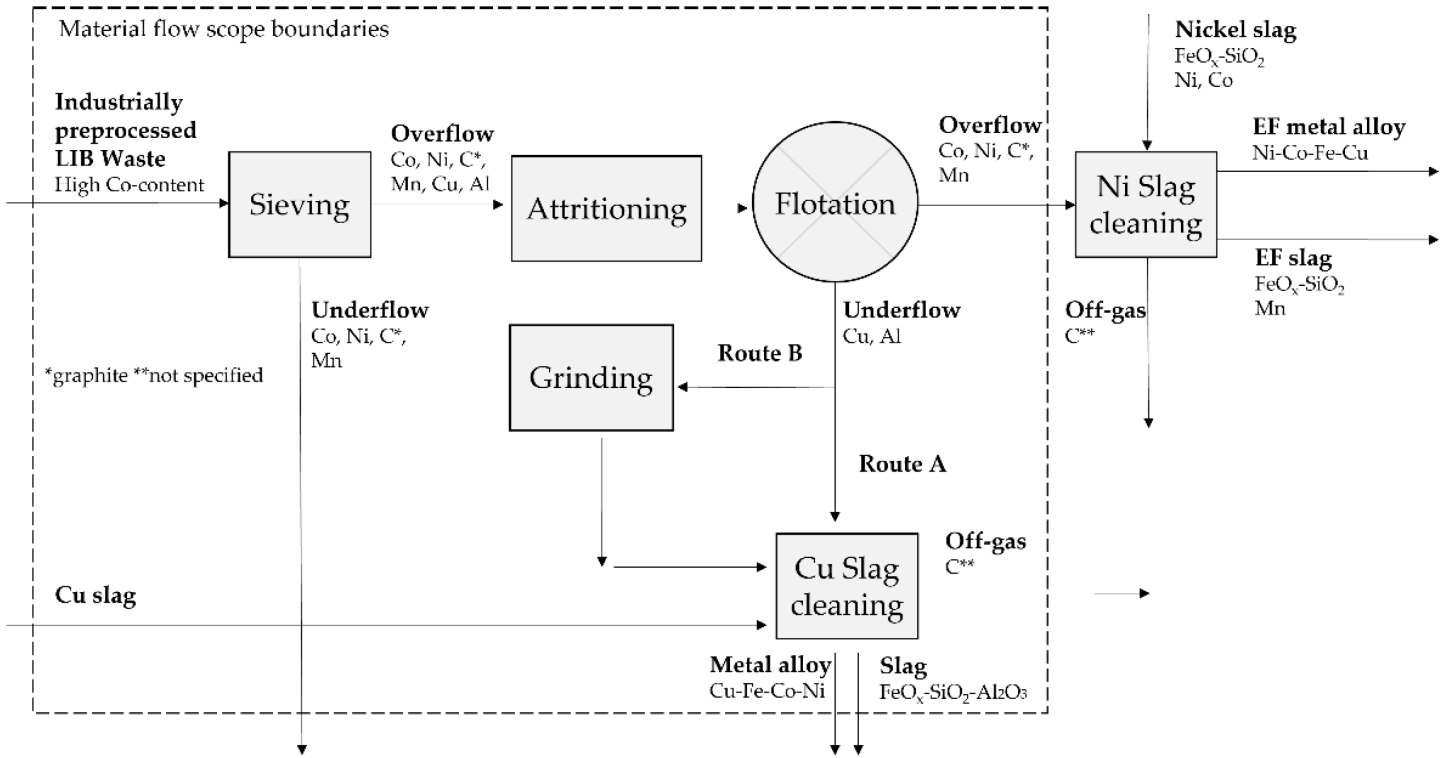

Figure 1. Flowchart of the combined waste LIB enrichment and refining processes investigated in the present and previous studies [21,22].

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metals

Rinne, T., Klemettinen, A., Klemettinen, L., Ruismäki, R., O'Brien, H., Jokilaakso, A. & Serna-Guerrero, R., 2022, "Recovering value from end-of-life batteries by integrating froth flotation and pyrometallurgical copper-slag cleaning", Metals 12 (1), 15, doi.org/10.3390/met12010015

State-of-art Battery Material Processes

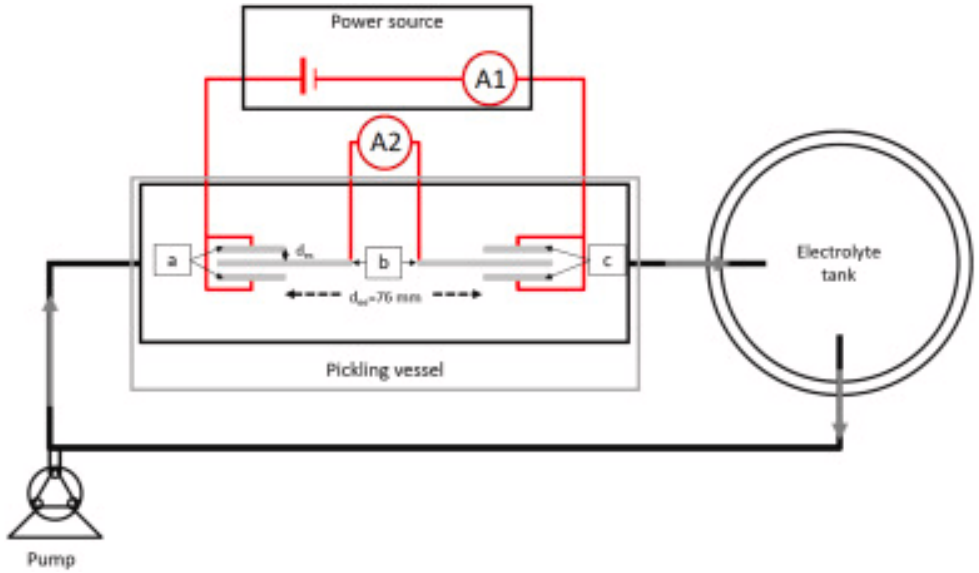

Fig. 1. Measurement system for bipolar pickling. The electrolyte is pumped from the tank to the pickling vessel, and the flow is marked with gray arrows.

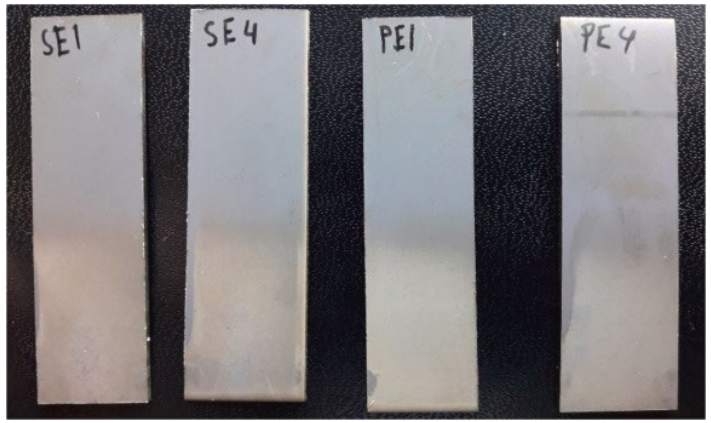

Fig. 2. An example of the localization of the scale dissolution at the sample. Dissolution at the total current of 1A and sample current density of 75 mA cm^{-2}. SE1 and PE1 pickled twice, with total current of 0.6 A and with 0.7 A. SE4 and PE4 pickled with total current of 0.7 A.

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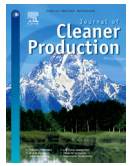


Tuovinen, T., Vielma, T., Tynjälä, P. & Lassi, U., 2021, "Utilization of waste sodium sulfate from battery chemical production in neutral electrolytic pickling", Journal of Cleaner Production 324, 129237, doi.org/10.1016/j.jclepro.2021.129237

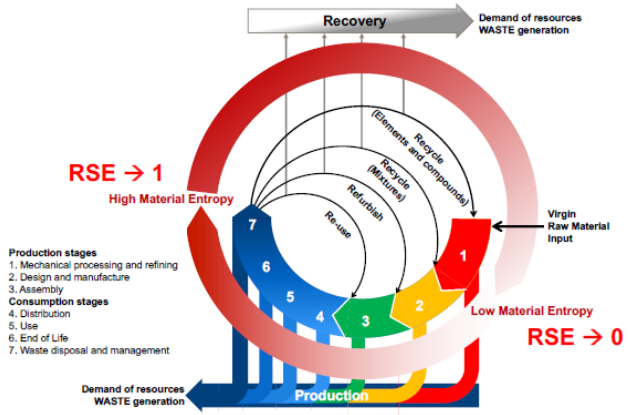
Circular Battery Materials Value System

Aalto University
School of Chemical Engineering

Statistical Entropy Analysis: an Engineering Tool for the Circular Economy

Prof. Rodrigo Serna
rodrigo.serna@aalto.fi
Department of Chemical and Metallurgical Engineering
International Process Metallurgy Symposium, 2021

Circular model based on Statistical Entropy

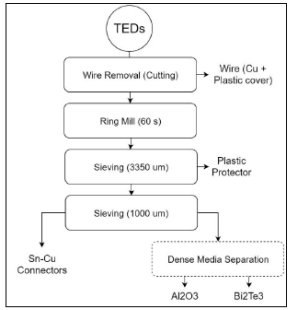


Velazquez-Martinez et al., J. Cleaner Production 212 (

Aalto University
School of Chemical Engineering

Case study: Process Design for Recycling of Thermoelectric Devices

- **Choice of recycling process based on RSE**
  - Requires adequate characterization of physical and chemical properties
  - Provides clear guidelines for decision-making
  - Analyzes the process from a systemic perspective, including all side-streams
  - Identifies points for optimization and future development



Velazquez-Martinez et al., Res. Conserv. Recycl. 159 (2020) 1048431

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Publications iBATCircle2.0 batcircle.aalto.fi/en/home/publications

- Chernyaev, A., Zou, Y., Wilson, B.P. & Lundström, M., 2022, "The interference of copper, iron and aluminum with hydrogen peroxide and its effects on reductive leaching of $LiNi_{1/3}Mn_{1/3}Co_{1/3}O_2$", *Separation and Purification Technology* 281, 119903, doi.org/10.1016/j.seppur.2021.119903
- Chernyaev, A., Wilson B.P. & Lundström, M., 2021, "Study on valuable metal incorporation in the Fe-Al precipitate during neutralization of LIB leach solution", *Nature Scientific Reports* 11, 23283, doi.org/10.1038/s41598-021-02019-2
- Hietaniemi, M., Hu, T., Välikangas, J., Niittykoski, J., Lassi, U., 2021. Effect of precursor particle size and morphology on lithiation on $Ni_{0.6}Mn_{0.2}Co_{0.2}(OH)_2$. *Journal of Applied Electrochemistry,* 51, 1545−1557. doi.org/10.1007/s10800-021-01596-4
- Partinen, J., Halli, P., Helin, S., Wilson B.P. & Lundström, M., 2021, "Utilizing Cu^+ as catalyst in reductive leaching of lithium-ion battery cathode materials in H_2SO_4–NaCl solutions", *Hydrometallurgy,* 208, 105808, doi.org/10.1016/j.hydromet.2021.105808
- Rinne, T., Klemettinen, A., Klemettinen, L., Ruismäki, R., O'Brien, H., Jokilaakso, A. & Serna-Guerrero, R., 2022, "Recovering value from end-of-life batteries by integrating froth flotation and pyrometallurgical copper-slag cleaning", *Metals,* 12 (1), 15, doi.org/10.3390/met12010015
- Tuovinen, T., Vielma, T., Tynjälä, P. & Lassi, U., 2021, "Utilization of waste sodium sulfate from battery chemical production in neutral electrolytic pickling", *Journal of Cleaner Production* 324, 129237, doi.org/10.1016/j.jclepro.2021.129237

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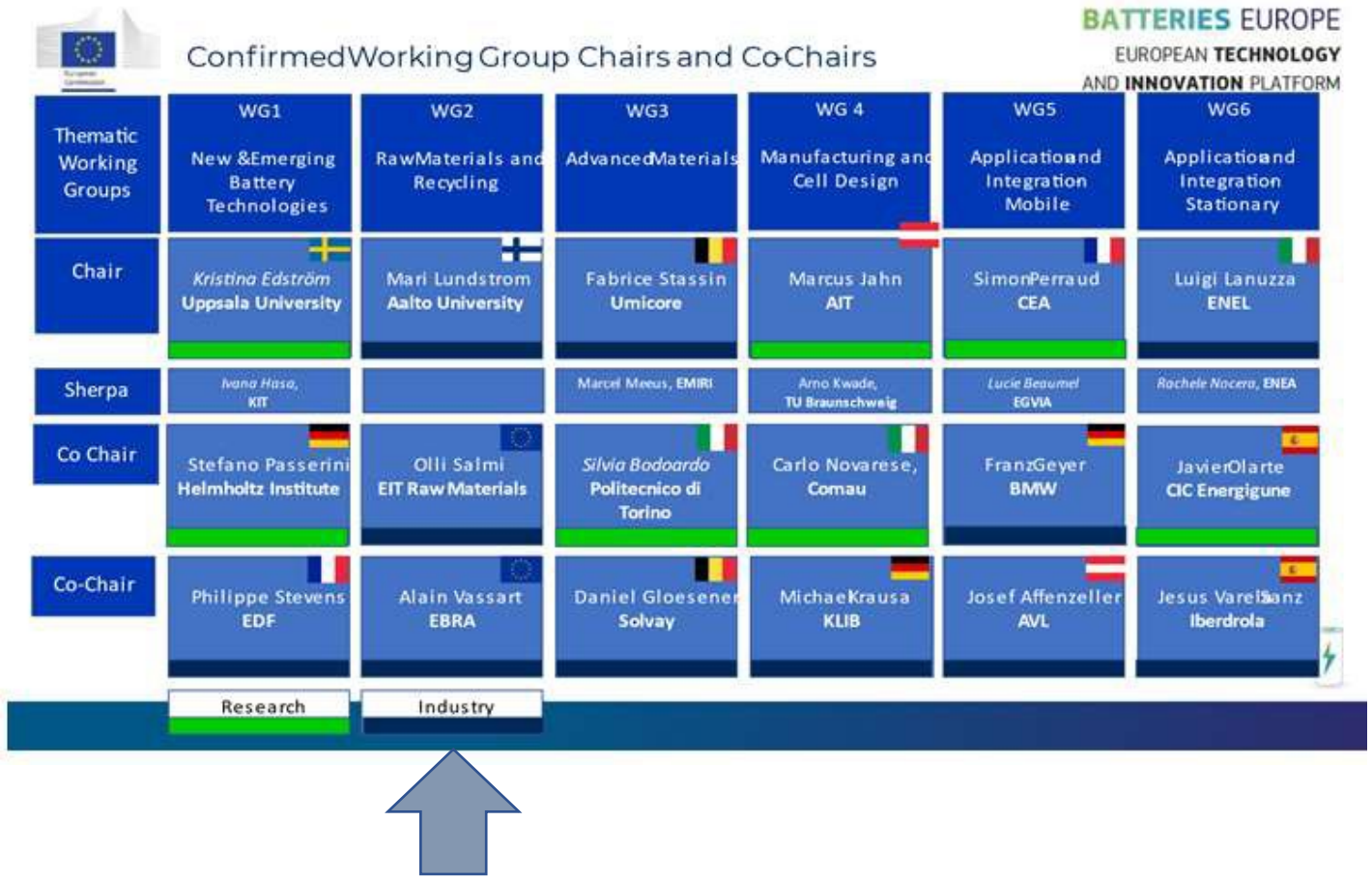
Batteries Europe



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Roadmaps 2020 and 2021 published

https://ec.europa.eu/energy/topics/technology-and-innovation/batteries-europe/news-articles-and-publications/batteries-europe-raw-materials-and-recycling-roadmap

https://ec.europa.eu/energy/sites/default/files/documents/vol-2-009.pdf

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Research and Innovation Priorities

- Harmonizing EU battery raw material resource estimation methods
- Certified materials traceability solutions within the value chain
- Develop (semi-)automated processes for energy recovery and dismantling of EV and industrial battery packs and modules
- Standard SoC/SoH evaluation methods for EoL batteries and quality criteria for reuse/repurposing vs. waste recycling
- Improve recycling processes to meet Battery Regulation targets.
- Decrease the carbon footprint of the recycling processes
- Valorization of anode materials from EoL batteries

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Research and Innovation Priorities

- Create reliable open access LCA/LCI data for primary and secondary materials, battery chemicals and active materials
- LCSA of the battery materials value chain (inc. LCA, LCC, S-LCA)
- Use of LCA forecasting in design of new materials and manufacturing processes
- A common standard for sourcing of materials and components within and outside the EU
- Integrated digital tools for data sharing throughout the value chain (e.g., Battery Passport)

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More information

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Mari Lundström,
Hydrometallurgy and Corrosion

Rodrigo Serna
Mineral Processing and Recycling

Daniel Lindberg
Metallurgical Thermo-dynamics and Modelling

Ari Jokilaakso
Metallurgy

Tanja Kallio
Electrochemical Energy Conversion

Jussi Leveinen
Engineering Geology

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