Battery recycling: Closing the loop in e-mobility

Dr. Kerstin Schierle-Arndt  
Vice President Research Inorganic Materials and Synthesis

1.6 million metric tons of end-of-life battery packs will be available in 2030

>160 kt nickel, cobalt, manganese and lithium can be "mined" from used battery packs in 2030. By 2025 significant amounts of off-spec cells and CAM will be available.

The new value chain for electric vehicles – recycling closes the loop

Creating a circular economy for battery materials

We aim to recycle used batteries as well as waste streams from all process steps and to create a “zero-waste” value chain.

“Black mass*” – a new resource

- Recycling of lithium-ion batteries (LIB) starts with mechanical operations (e.g., dismantling, shredding, sorting).
- This yields “black mass”.
- It mainly consists of the electrode active material.
- Black mass contains valuable Co, Ni, Mn, Li, but also carbon and many contaminants.

Chemical treatments are needed to extract the valuable metals from “black mass”.

<table>
<thead>
<tr>
<th>Element</th>
<th>Content weight %**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni</td>
<td>20</td>
</tr>
<tr>
<td>Co</td>
<td>6</td>
</tr>
<tr>
<td>Mn</td>
<td>6</td>
</tr>
<tr>
<td>Li</td>
<td>3.5</td>
</tr>
<tr>
<td>C</td>
<td>40</td>
</tr>
<tr>
<td>F</td>
<td>3</td>
</tr>
<tr>
<td>P</td>
<td>0.5</td>
</tr>
<tr>
<td>Cu</td>
<td>2</td>
</tr>
<tr>
<td>Al</td>
<td>2</td>
</tr>
<tr>
<td>Fe</td>
<td>1</td>
</tr>
<tr>
<td>Zn</td>
<td>0.1</td>
</tr>
<tr>
<td>Ca</td>
<td>0.1</td>
</tr>
</tbody>
</table>

* Black mass = technical term for recycled electrode active material
** Illustrative values, composition can strongly vary
Processing “black mass”
Comparison of main technologies

**Pyrometallurgy**
- ✓ High recovery rates for nickel, cobalt and copper
- ✓ Graphite and solvents burned, providing much of the process energy
- ✓ Mature technology
- √ High energy intensity (around 1,500°C) and CO₂ footprint
- √ Loss of lithium in slag – recovery from slag is expensive

**Hydrometallurgy**
- ✓ High recovery rates for cobalt, nickel and copper
- ✓ Lithium is recycled
- ✓ Option for manganese and graphite recycling
- ✓ Moderate temperature range
- √ High investment required
- √ Inflexible process
- √ High amounts of by-products, waste

Both technologies call for improvements towards lithium yield, by-products or investment cost.

---

**Deep dive hydrometallurgy**
Illustrative process

<table>
<thead>
<tr>
<th>“black mass”</th>
<th>H₂SO₄</th>
<th>H₂O₂</th>
<th>CaO</th>
<th>NaOH</th>
<th>Na₂CO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 kt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat treatment</td>
<td>Leaching</td>
<td>Cu solvent extraction</td>
<td>Al, Fe, Zn precipitation</td>
<td>Ni, Co solvent extraction</td>
<td>Li-recovery and purification</td>
</tr>
<tr>
<td>Off-gas organics, fluoride</td>
<td>Carbon (removal via filtration)</td>
<td>CuSO₄</td>
<td>Al(OH)₃, Fe(OH)₃, Zn(OH)₂, CaSO₄</td>
<td>10 kt NCM in form of Ni₃Co₃(Mn) sulfate</td>
<td>1 kt Li in form of Li₂CO₃</td>
</tr>
</tbody>
</table>

Waste:
- around 10 kt Na₂SO₄

**Characteristics**
- ✓ Well established processes in mining industry up to nickel and cobalt recovery to build on
- √ Inflexible process – lithium is always recycled at the end and comes as lithium carbonate only
- √ Significant amounts of sodium sulfate waste by-product

The process cuts CO₂ emissions by -25% vs. CAM* materials based on mining.

*CAM = cathode active materials
Deep dive lithium salts

- State of the art lithium recycling produces lithium carbonate along with significant amounts of sodium sulfate waste.
- However, today’s CAM material syntheses require lithium hydroxide and not lithium carbonate.
- Lithium carbonate can be transformed into lithium hydroxide – but this increases CO₂ footprint.

Our approach
- Avoiding process steps and waste – direct lithium hydroxide process
- Flexibilize the value chain – lithium hydroxide first

Lithium recovery holds the biggest innovation potential in the value chain.

New BASF process scheme avoids waste

**Step 1: Removal of lithium from “black mass”**

“black mass”

- Smart lithium release
- Selective Li-leaching and purification

**Step 2: Extraction of Ni, Co**

H₂SO₄, H₂O₂

- Leaching
- Purification
- Ni, Co solvent extraction

- Carbon (removal via filtration)
- CuSO₄, Al(OH)₃, Fe(OH)₃, Zn(OH)₂, CuSO₄

**Benefits of LiOH first:**
- avoids sodium sulfate by-product
- allows direct access to lithium hydroxide
- cuts investment cost in the value chain

The new BASF process scheme reduces CO₂ footprint and is flexible.
Deep dive lithium purification

“black mass”
30 kt

Smart lithium release
Li-recovery and purification

Impurities that need to be removed

New BASF purification scheme
Recovering battery-grade lithium from “black mass”

Lithium ex “black mass”
Crystallization

Ion exchange / adsorption

Purified lithium

Smart combination of purification technologies needed to extract battery-grade lithium from “black mass”.

Plateau above battery grade specifications

proof of concept in lab achieved

works for most ions, ... but not for fluoride
Recycling of battery raw materials
Challenges tackled and status of BASF process development at a glance

**Challenges**
- Efficient and straightforward lithium recycling needed
- Yield insufficient → high variable cost
- Insufficient Li quality → low value

**BASF approach**
- Lithium hydroxide first process
- Proprietary selective leaching additives
- Combine complementary purification technologies → upscaling ongoing

BASF innovates to reduce CO2 footprint of lithium recycling to close the loop for battery materials.

Creating a circular battery value chain in Europe

Key to success are partnerships and innovative recycling technologies.
Closing the loop in e-mobility
Next steps

2020
- Pilot trials
- Flowsheet development

2021
- Start of pilot plant construction
- Process fine tuning

2022
- Start up pilot plant
- First battery-grade LiOH from pilot plant

BASF innovations will enable a new circular value chain in Europe.