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BASF Research Press Conference
on December 10, 2020

Battery recycling: Closing the loop in e-mobility

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

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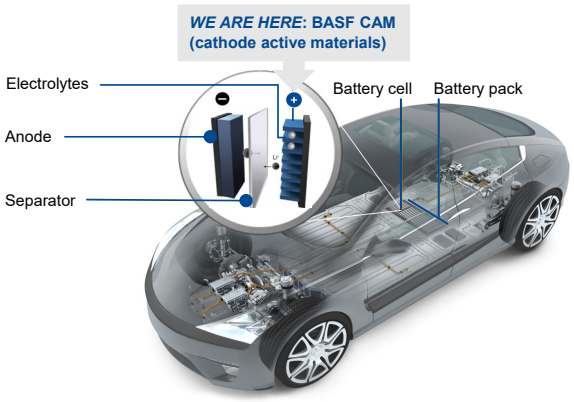
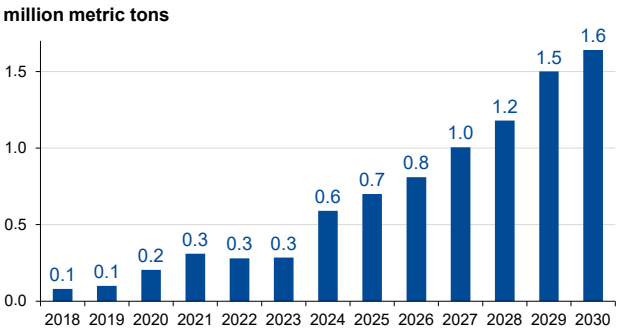
1.6 million metric tons of end-of-life battery packs will be available in 2030



Available used battery packs per year



>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.

Source: BloombergNEF / Bloomberg Businessweek, January 2019, “kt” = thousand metric tons,

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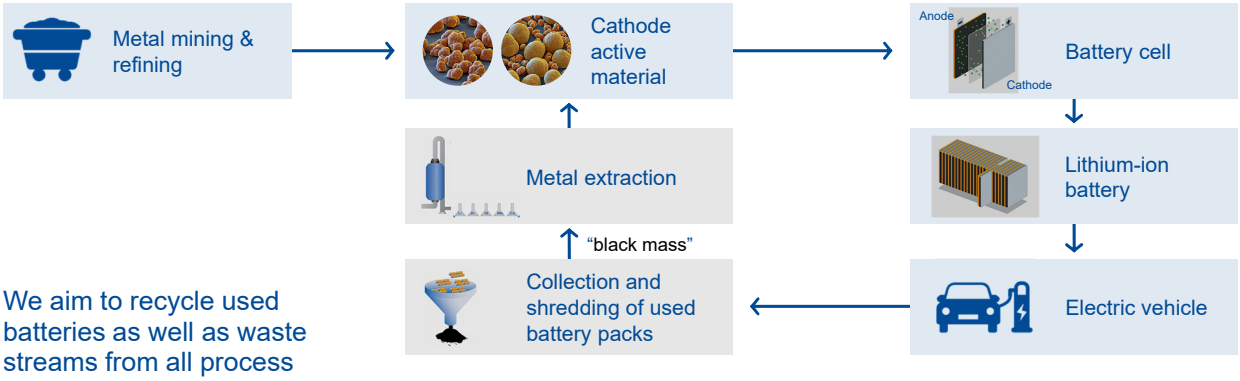
The new value chain for electric vehicles – recycling closes the loop

Creating a circular economy for battery materials

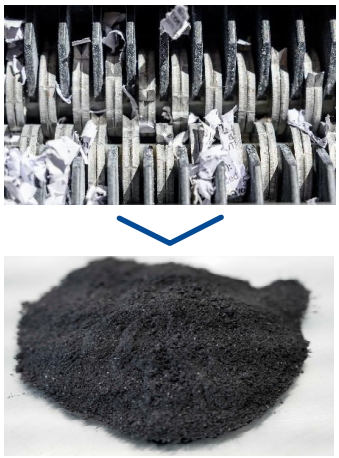


We aim to recycle used batteries as well as waste streams from all process steps and to create a "zero-waste" value chain.

"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.

	Element	Content weight %**
valuable metals	Ni	20
	Co	6
	Mn	6
	Li	3.5
	C	40
	F	3
	P	0.5
	Cu	2
	Al	2
	Fe	1
	Zn	0.1
	Ca	0.1



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

* Black mass = technical term for recycled electrode active materials
** 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 CO_2 footprint
- ✕ Loss of lithium in slag – recovery from slag is expensive

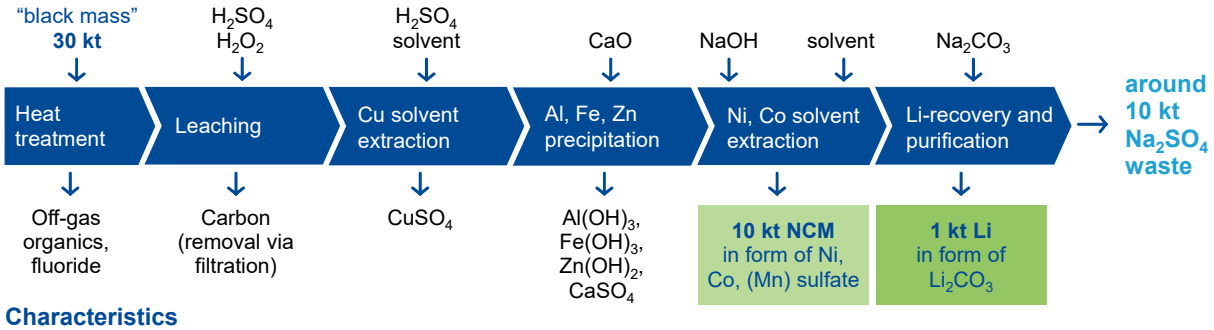
Hydrometallurgy

- ✓ 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



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 CO_2 emissions by -25% vs. CAM* materials based on mining.

*CAM = cathode active materials

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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 CO_2 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.

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New BASF process scheme avoids waste

Step 1: Removal of lithium from "black mass"

"black mass"
30 kt

Smart **lithium release** → **Selective Li-leaching** and purification

1 kt Li in form of $LiOH*H_2O$

Step 2: Extraction of Ni, Co

H_2SO_4 H_2O_2	H_2SO_4 CaO	NaOH	solvent
Leaching	Purification	Ni, Co solvent extraction	
Carbon (removal via filtration)	$CuSO_4$, $Al(OH)_3$, $Fe(OH)_3$, $Zn(OH)_2$, $CuSO_4$	**10 kt NCM** in form of Ni, Co, (Mn) sulfate	

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 CO_2 footprint and is flexible.

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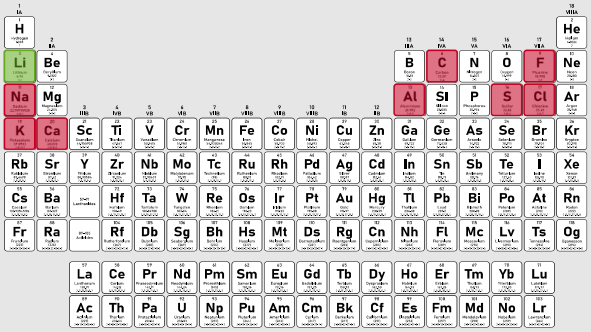
Deep dive lithium purification

"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"

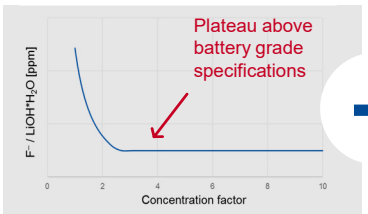
Lithium ex "black mass"

- Cl
- Sulfate
- Ca
- Na
- Al
- K
- F

Off spec.
Not specified

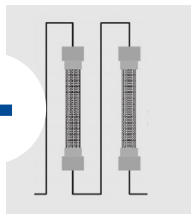
Crystallization

works for most ions,



… but not for fluoride

Ion exchange / adsorption



✓ proof of concept in lab achieved

Purified lithium

- Cl
- Sulfate
- Ca
- Na
- Al
- K
- F

In spec. (=removed)

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

Recycling of battery raw materials

Challenges tackled and status of BASF process development at a glance

Challenges

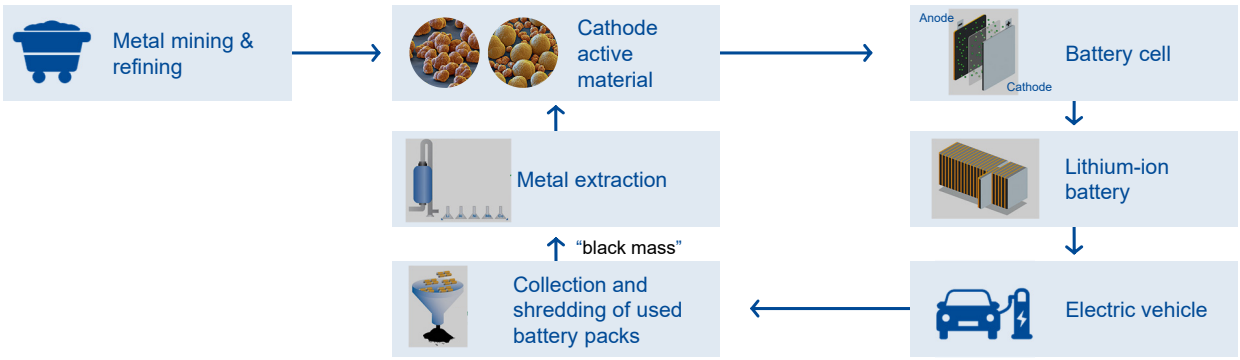
- Efficient and straight forward lithium recycling needed
- Yield insufficient → high variable cost
- Insufficient Li quality → low value

BASF approach

- ✓ Lithium hydroxide first process
- ✓ Proprietary selective leaching additives
- ! Combine complementary purification technologies → upscaling ongoing

BASF innovates to reduce CO_2 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

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages
Förderkennzeichen 16BZF101A/B

LAND BRANDENBURG
Ministerium für Wirtschaft, Arbeit und Energie

eit RawMaterials
Connecting matters

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

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

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