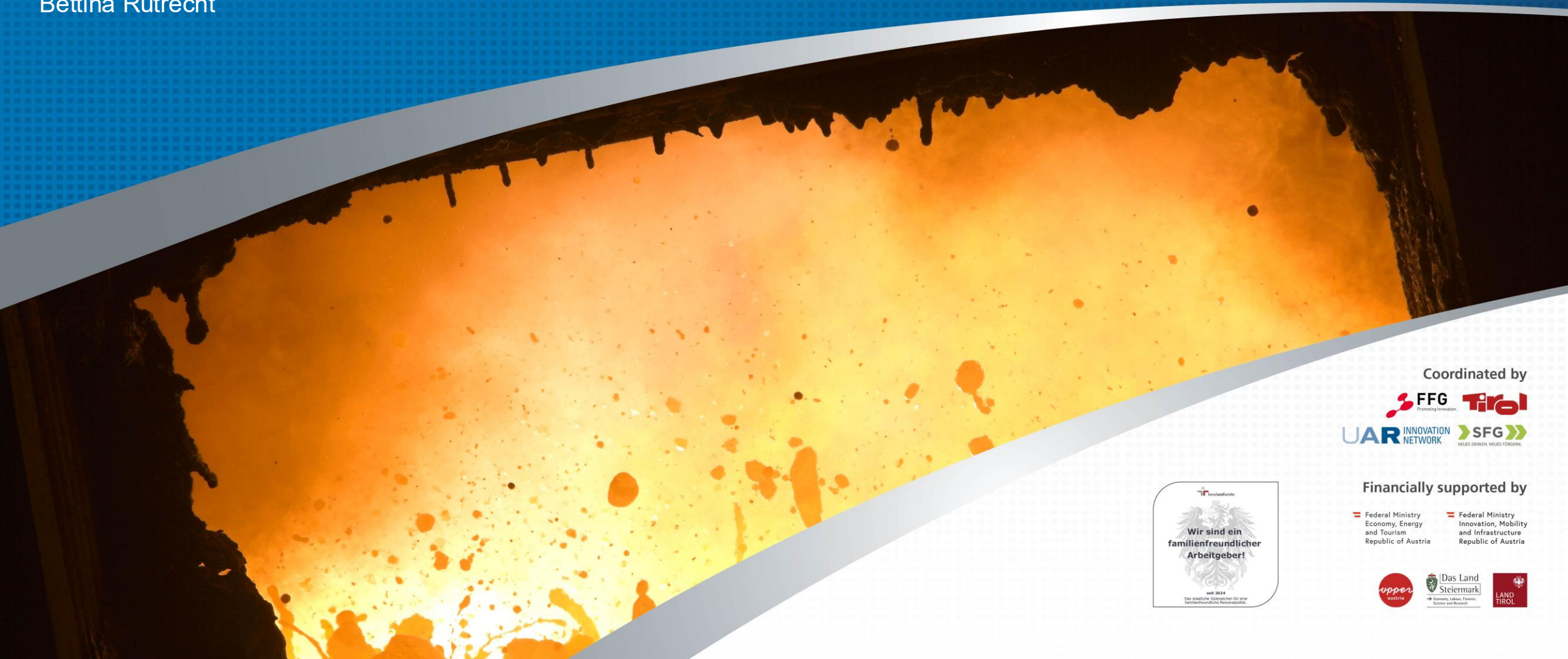
From Recycling to Sustainable Battery Design

Insights from COMET Module FuLIBatteR and Move-it

Vienna, 13th of November 2026

Bettina Rutrecht



metallurgical competence center

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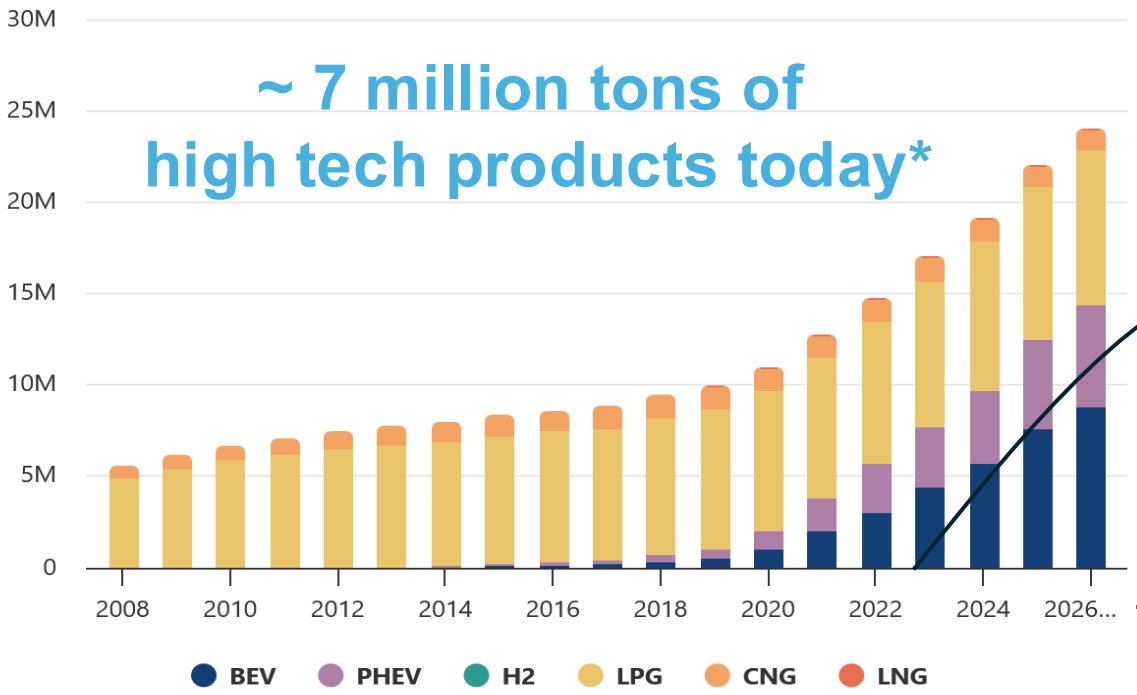
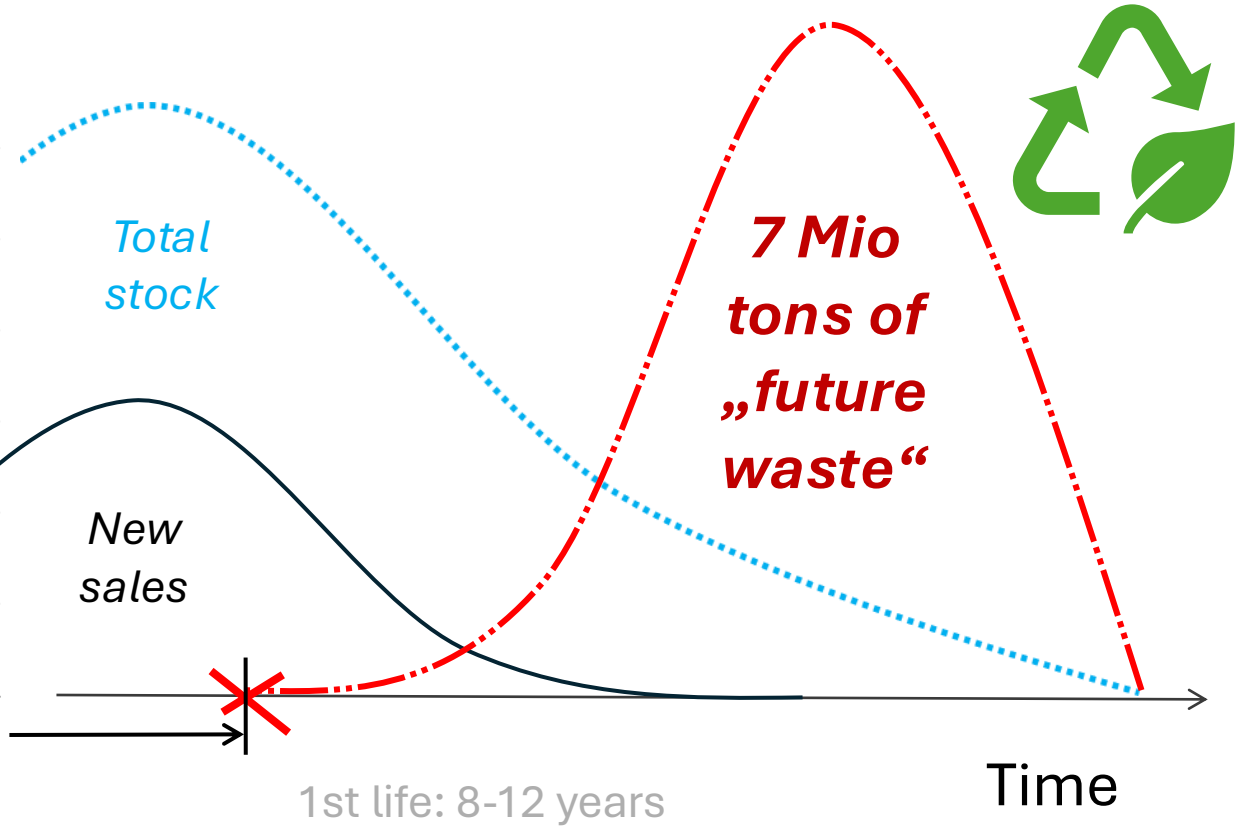
upper austria Das Land Steiermark LAND TIROL

Inofficial „First law of waste management“ – „Everything turns into waste…at some point.“

- Total number of **(PH)EV** passenger cars in the **EU** (EU, Aug. 2026) and LIB recycling



~ 7 million tons of high tech products today*



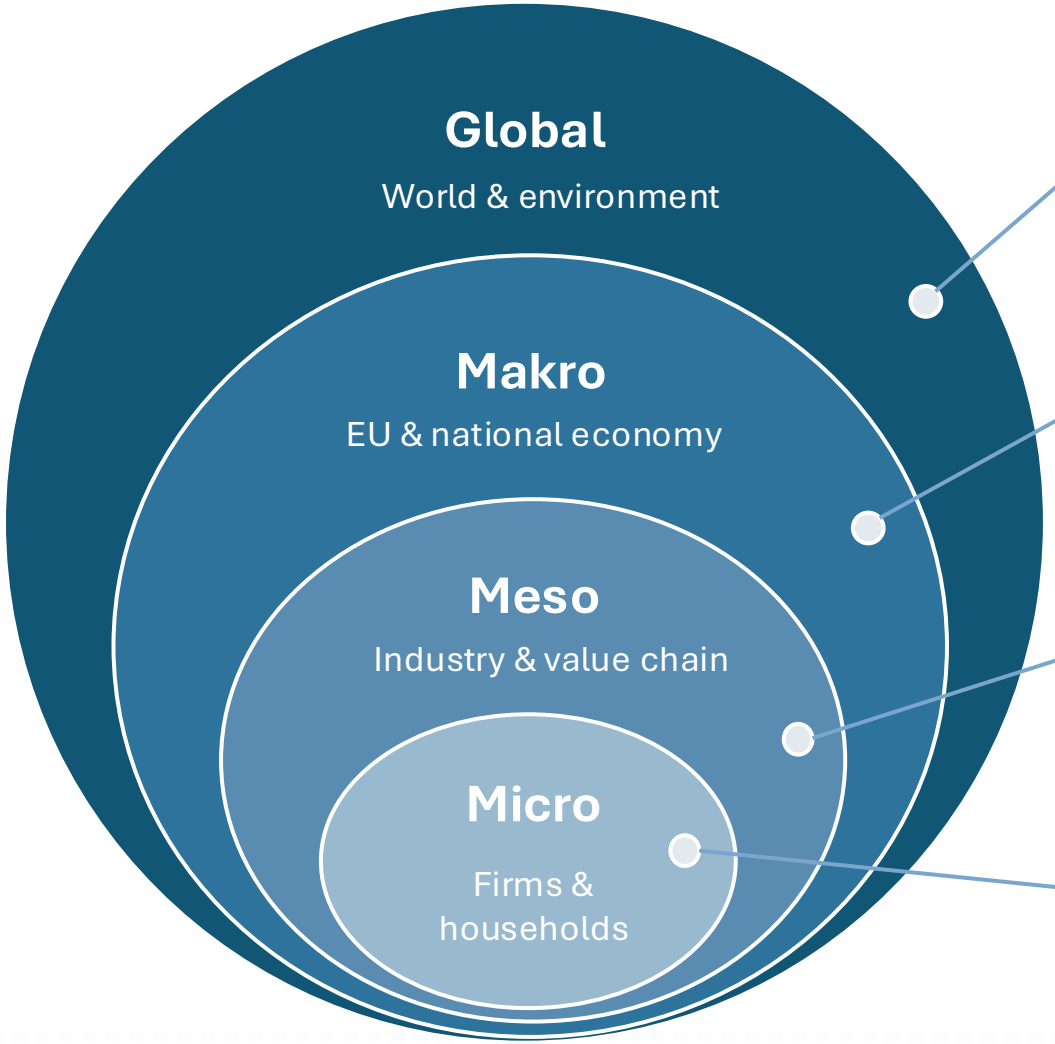
1st life: 8-12 years

2nd life: 15+ years

* Average weight BESS ~ 500 kg

https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/european-union-eu27/vehicles-and-fleet

Reasons for lithium-ion battery (LIB) recycling



Global

- Natural environment
- Climate protection
- Primary raw material
- Human health

Makro

- Critical raw materials
- Import independence
- Jobs & value creation
- EU refining capacity

Meso

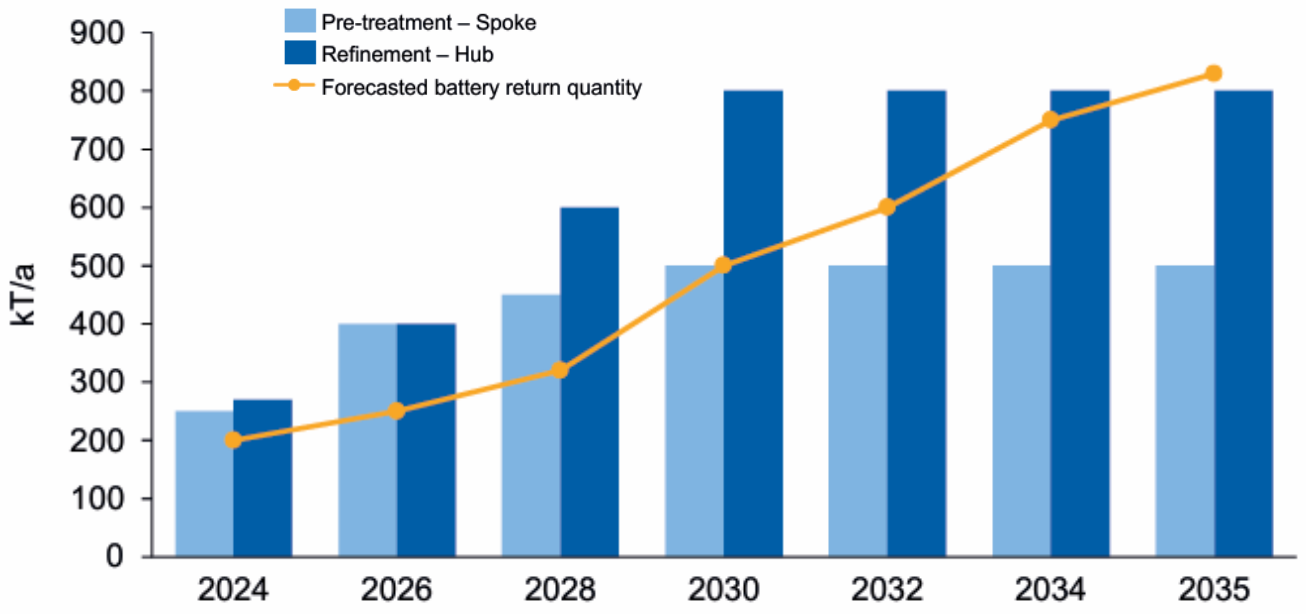
- Closed material loops
- Competitive advantage
- Safe waste collection

Makro

- Compliance
- Material revenues
- Residual value
- Fire safety at home

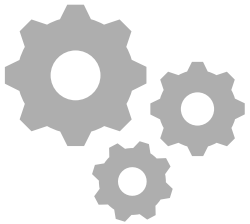
EU LIB recycling capacity in perspective

- Current volume vs. EU recycling capacity



200 kT (<3%) of potentially 7 Mio tons

Pretreatment: Mechanical treatment to gain „blackmass“



M

Refinement: Large scale industrial metal refining facilities



Pyro



Hydro

Heimes et al. (2026) Battery atlas 2026 - Mapping the EU LIB industry, available online at www.battery-atlas.eu

Battery Recycling Projects as of January 2026

Published by BATTERY-NEWS.com

Authors: Natalia Soldan, Ali Bajaber, Heiner Heimes
(PEM of RWTH Aachen University)

LUXEMBOURG

R3 Robotics	Mondercange				

NETHERLANDS

SK tes	Rotterdam	10,000	M		

GREAT BRITAIN

altilium	Teesside		M, H	50,000	2026
altilium	Devon	100	M, H	8,000	2026
CELLCYCLE	Manchester	6,000	M, H		
ecobat	Darlaston	20,000	M		
RECOVER	Newport				
RECYCLUS GROUP	Wolverhampton	22,000			20XX
VEOLIA	Minworth	5,000	M, H		

BELGIUM

ABEE	Dour	20,000	D		
Aurubis	Olen		H	100,000	2027
umicore	Hoboken	7,000	P		

FRANCE

battri	Saint-Laurent-Blangy	15,000	M		
Hydrovolt	Hordain		M		
GLENCORE	Harnes	10,000	M		
SNAM	Saint Quentin	1,000	H, P	5,000	20XX
SK tes	Grenoble	600	M		
VEOLIA	Dieuze	4,000	M		
VEOLIA	Amneville	7,000	H		

SPAIN

CNLi	Alicante		M, H	45,000	20XX
endesa	Cubillos del Sil			8,000	20XX
IBERCHEM	Erandio				
SungEel HiTech	Navarra		M, H	10,000	20XX
BOTRES eff	Valladolid			6,000	2027

NORWAY

Hydrovolt	Fredrikstad	12,000	M		
GLENCORE MORROW ecopro	Moss	10,000	M		
NIKKELVERK A GLENCORE COMPANY	Kristiansand		P		

FINLAND

	Nivala	800	M	3,000	20XX
fortum	Harjavalta	1,000	H	30,000	20XX
fortum	Ikaalinen	5,000	M		

ITALY

GLENCORE	Portovesme		H	50,000	20XX
	Seval	15,000	M		
riplastic Hitech Recycling	Riplastic	15,000	M		

SWITZERLAND

BATREC	Wimmis	4,000	M		
KYBURZ	Freienstein	200	D		
librec	Biberist	9,000	M		

TÜRKİYE

EXITCOM recycling for future	Kocaeli	10,000			

SWEDEN

STENA	Halmstad	10,000	M	20,000	2029

GERMANY

ACCUREC	Krefeld	4,500	M, H	20,000	2027
Aurubis	Hamburg		M, H		
BASF	Schwarzheide		M, H	15,000	20XX
CellCycle	Randersacker		D	25,000	20XX
cylib	Aachen	120	M, H	10,000	2027
cylib	Dormagen		M, H		2027
Duesenfeld	Wendeburg	3,000	M, D	5,000	2026
ecobat	Hettstedt	20,000	M		
ERLOS	Zwickau	3,500	M		
fortum	Kirchardt	3,000	M		
H.C.Starck	Goslar		H	20,000	2029
Ionidrive	Aachen		H	3,000	2029
GLENCORE	Magdeburg	10,000	M	30,000	20XX
NICKELHÜTTE AUE	Aue	10,000	M, H, P		
northvolt	Heide				
PURE BATTERY	Hagen	2,500	H	15,000	20XX
REDUX	Bremerhaven	10,000	M		
prezero RE.LI.ON.BAT.	Meppen	30,000	M		
tozero	Munich	500	H	30,000	20XX
WALCH	Baudenbach	5,000			
ENCORY	Salching		D		

POLAND

elemental	Zawiercie			12,000	2026
ROYAL BEES	Legnica	3,600	M		
SungEel HiTech	Bukowice	7,000	M, H		
WASTES SERVICE	Wszemirów				
BTS&BAKER	Wroclawskie				
eneris	Żarki				
elemental	Zawiercie				

BULGARIA

altilium	Medet	8,000			
ABEE	Stara Zagora		D	50,000	2028
BM	Burgas		M	14,000	2026

M – Mechanical recycling
H – Hydrometallurgy
P – Pyrometallurgy
D – Direct recycling

All data based on official announcements. All values in tons per year. No claim to completeness and accuracy.

Many LIB recycling options – which is best?

- The refinement…
- The goal and scope…
  - Economically?
  - Environmentally?
  - Resource recovery?
- The input…
- …and pretreatment.

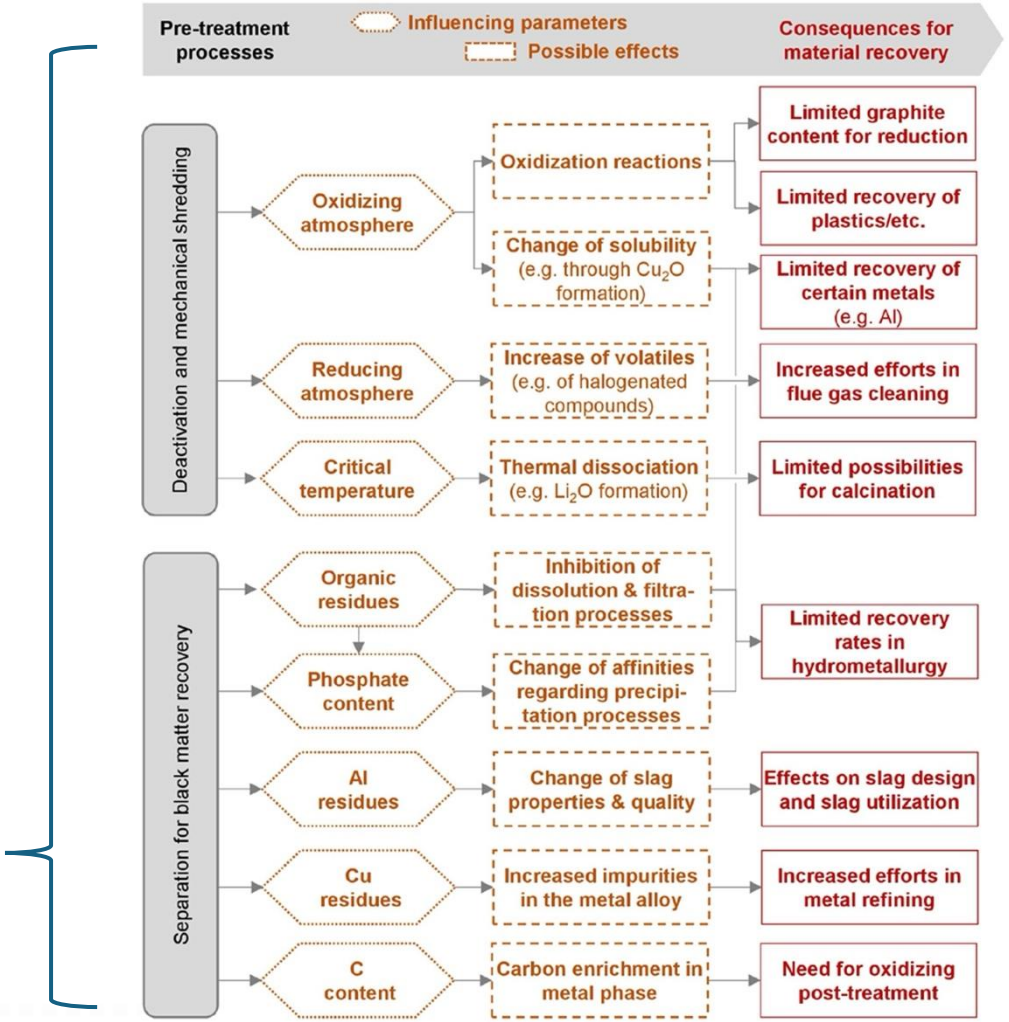


Figure: Windisch-Kern et al. (2022)

- **Reduced recovery**
  - Li, Co, Mn, Ni, Al, Cu, C,…
- **Higher efforts**
  - Gas cleaning, refining, post-treatment
- **Lower quality**
  - Limited valorization options

Highlights COMET Module FuLIBatteR P1

COMET Module FuLIBatteR – P1

Future Lithium-Ion-Battery Recycling for Recovery of CRMs

UK

Coventry University

Germany

VERFAHRENSTECHNIK FÜR ROHSTOFFE

B·R·A·I·N



Duration 2022 -06/**2026**
Budget **3.75 Mio €**

Austria

EBNER®

K1 MET metallurgical competence center

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VTU

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TÜV SÜD Landesgesellschaft Österreich

Saubermacher

Sub-projects

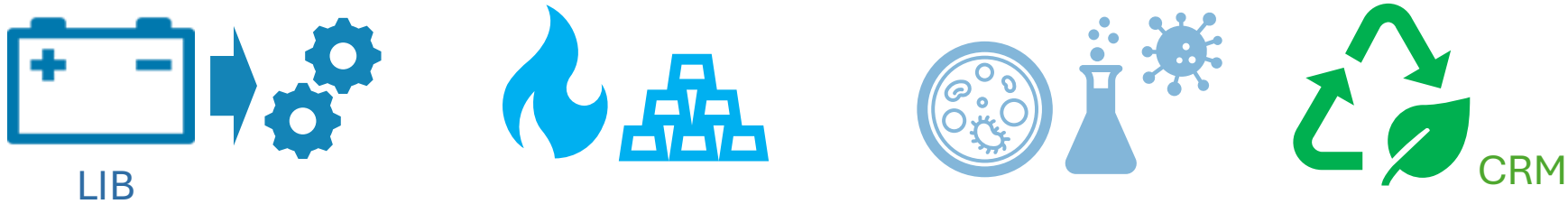
FuLIBatteR …… 2026

P1 Waste Management and Waste Technological Approaches for LIB Recycling

P2 Pyrometallurgical Process of LIBs and Black Matter

P3 Bio-Hydrometallurgical Treatment of LIB Residues

Project Goals



From battery to resources,… …to selective recovery of materials… …to close material loops.

LCA of European LIB pretreatment for recycling

14 facilities

11 companies

76,000 t a^{-1} nominal capacity

48 % of active EU capacity

#	Name
1	Accurec Recycling
2	Akkuser
3	Duesenfeld
4	Ecobat
5	Ecobat
6	Fortum Waste Solutions
7	Fortum Waste Solutions
8	Hydrovolt
9	Librec
10	Primobius
11	Redux
12	TES Recupyl
13	TES SBS
14	Veolia/EDI
Total	

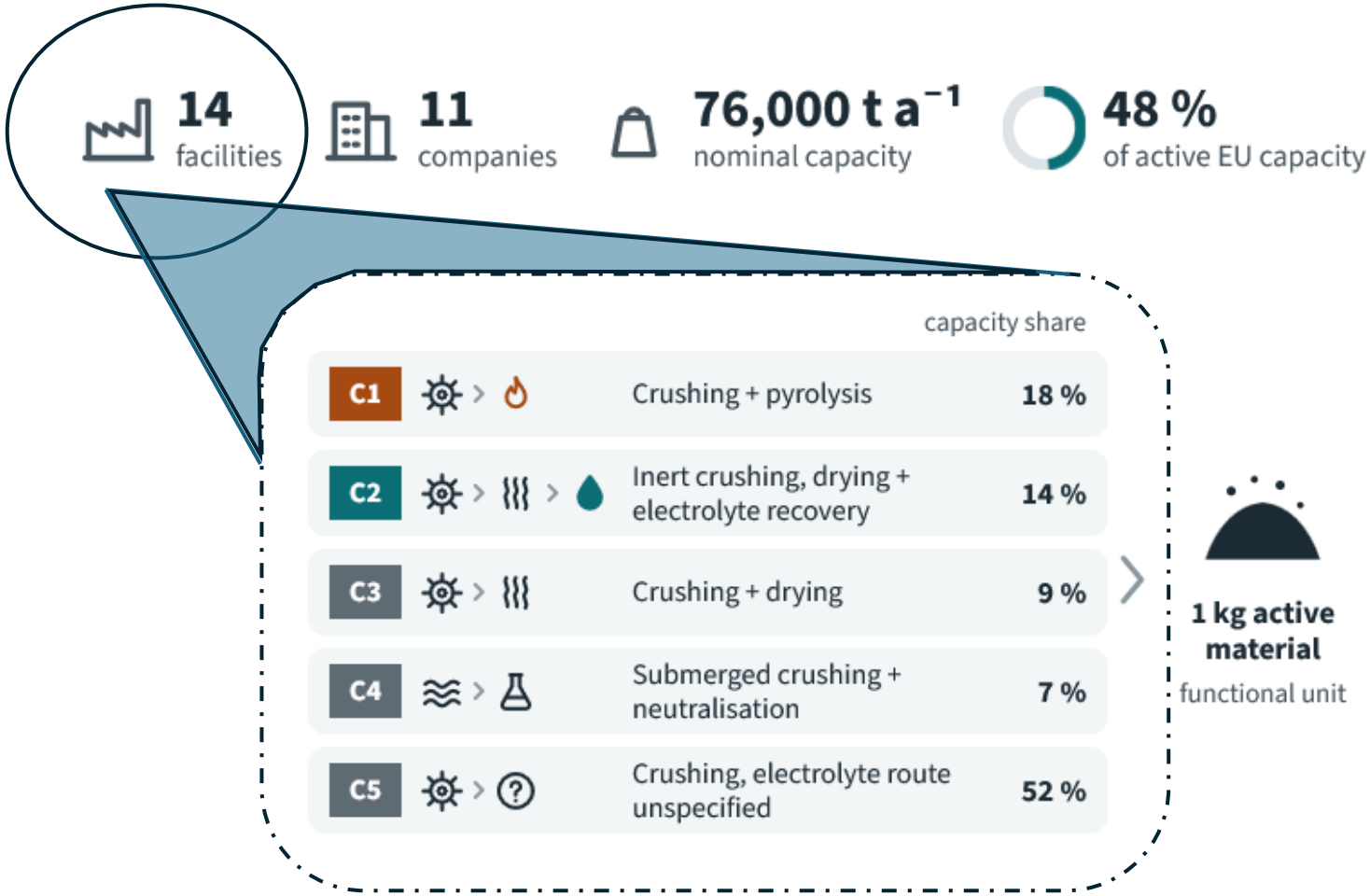


Methodological background info

- **Goal:** Assessment of environmental impacts
- **Hypothesis**: Overlooked significant impacts of LIB recycling
- **System boundary:** Gate-to-gate LCA study
- **Modelling approach**: Attributional LCA, ecoinvent 3.11 (cut-off); ISO 14044 and ILCD Handbook
- **Impact assessment:** Environmental Footprint (EF3.1), 16 midpoint categories
- **Sample:** June 2025

Source: Rutrecht et al., unpublished research results, manuscript in preparation.

LCA of European LIB pretreatment for recycling



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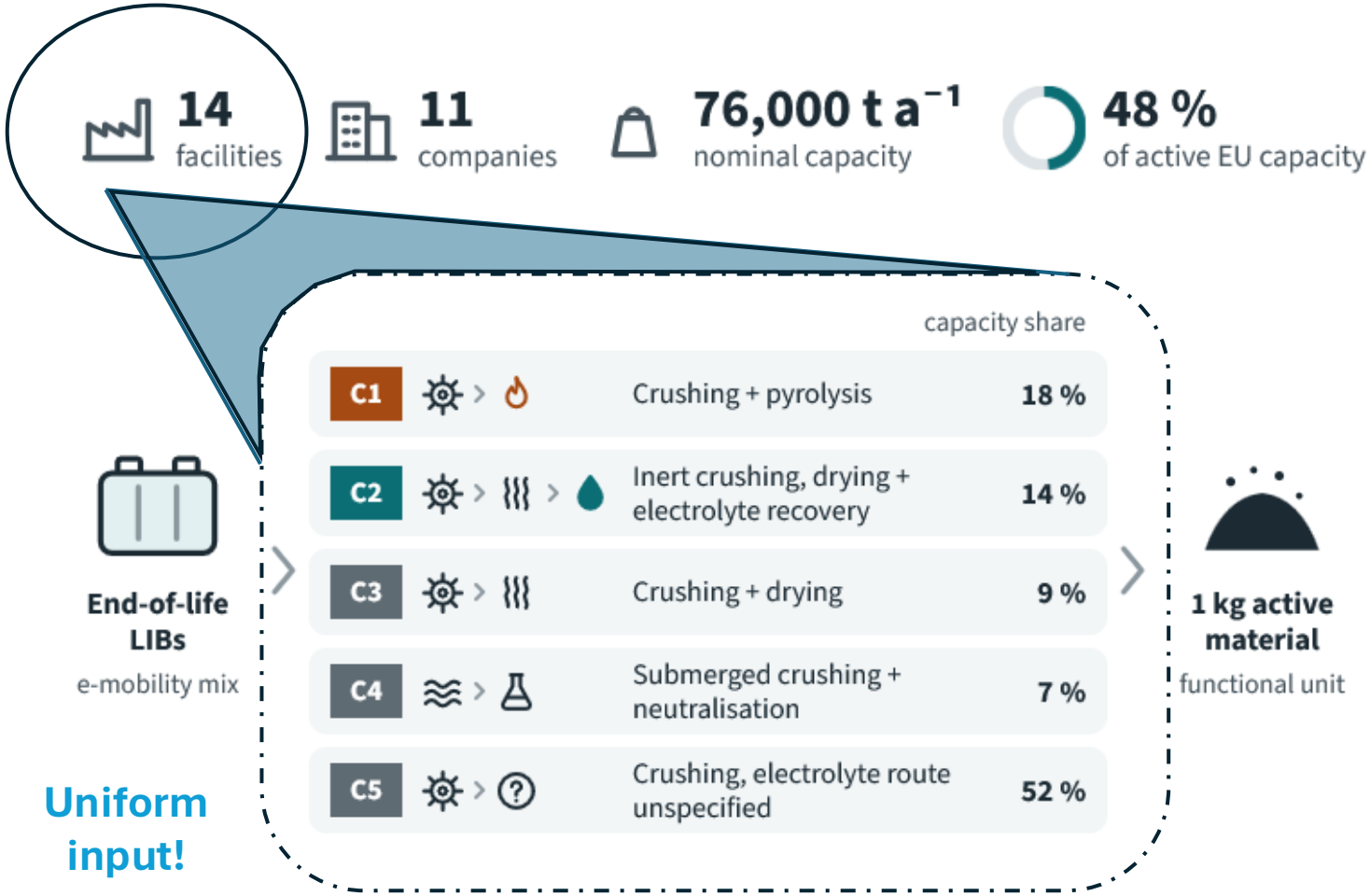

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Uniform LIB input model to allow comparison

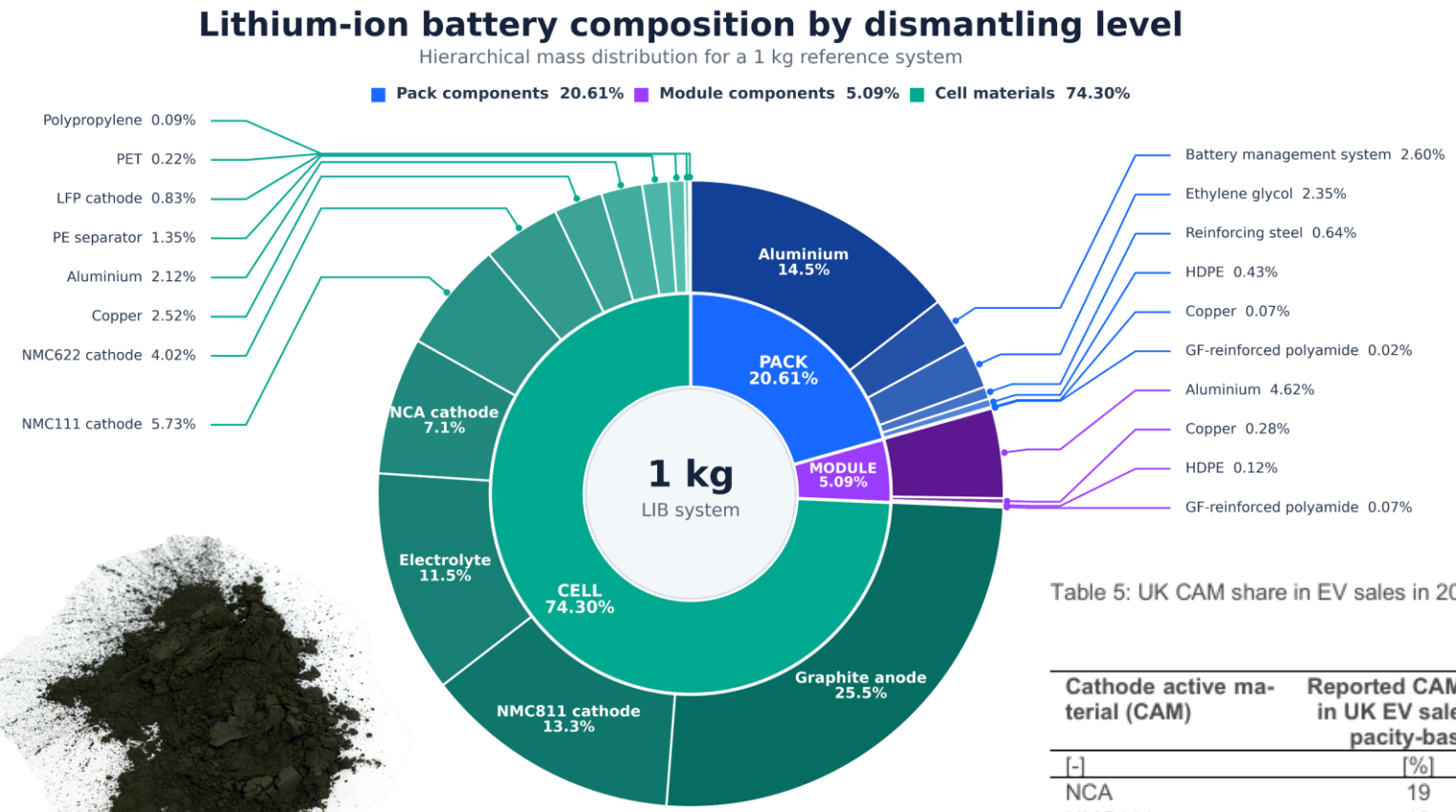




Table 5: UK CAM share in EV sales in 2020 based on capacity and recalculated to mass-based market shares (Gifford, 2022).

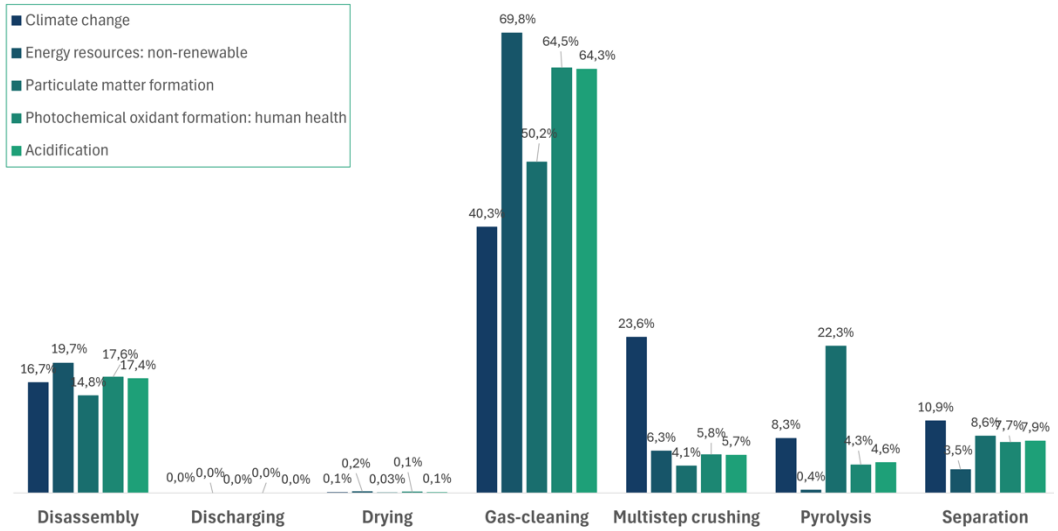
Cathode active material (CAM)	Reported CAM share in UK EV sales, capacity-based	Specific energy from ecoinvent v3.11	Relative battery mass corresponding to capacity share	Calculated mass-based market share for 1 kg LIB pack sold
[-]	[%]	[kWh/kg]	[kg]	[%]
NCA	19	0.159	1.195	18.50
NMC111	12	0.143	0.839	13.00
NMC622, NMC433 and NMC532	43	0.155	2.774	42.96
NMC811	22	0.149	1.477	22.87
NMC 9.5.5	2	n.a.	n.a.	n.a.
LFP	2	0.116	0.173	2.68

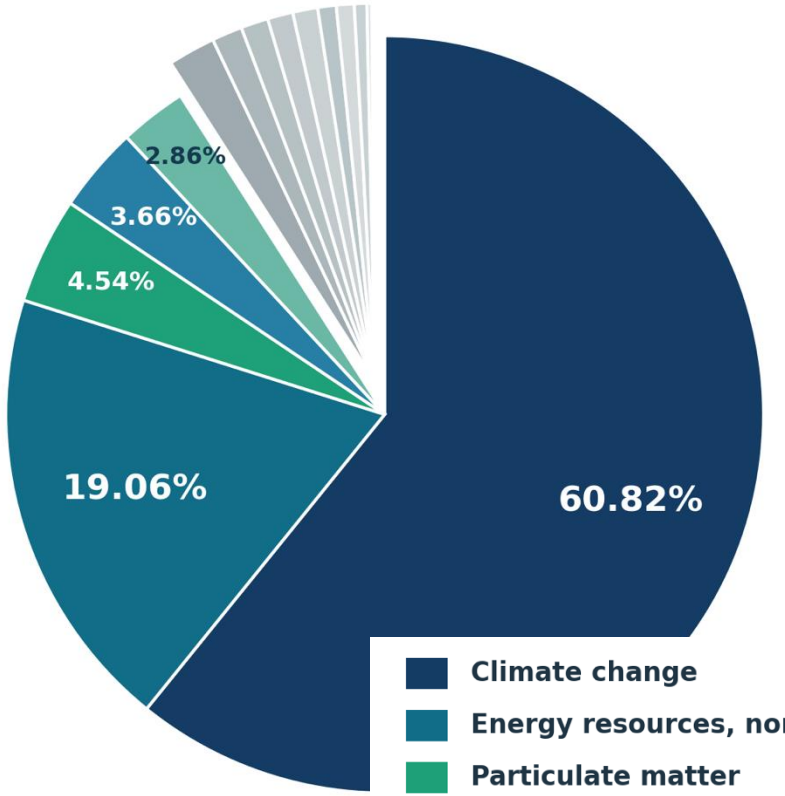
Source: Rutrecht et al., unpublished research results, manuscript in preparation.

Environmental impact of European LIB pretreatment

0.832
kg $CO_{2\text{-eq}}$/ kg AM

5.68 MJ
non-renewable energy / kg AM



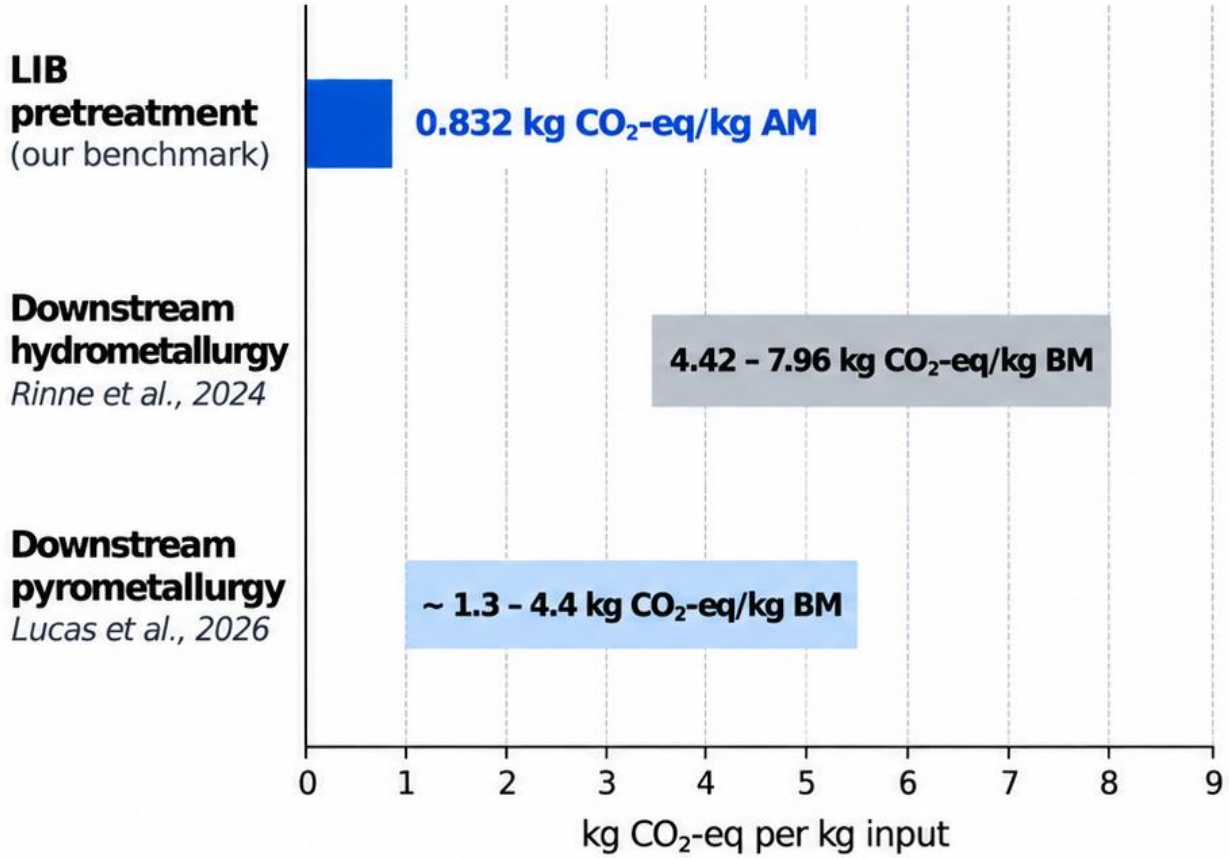


Top 5 = 90,9 % of total EF3.1 Single Score

Climate change	60.82%
Energy resources, non-renewable	19.06%
Particulate matter	4.54%
Photochemical ozone formation, human health	3.66%
Acidification	2.86%
Others (11)	8 %

Source: Rutrecht et al., unpublished research results, manuscript in preparation.

Environmental impact of European LIB pretreatment



Pretreatment share of total impact

~ 10 – 20 %

- Major impact lies in downstream recycling.
- Nonetheless, pretreatment significantly influences downstream impacts.

Order of magnitude in perspective

Battery production	~ 60 – 100 kg CO_2-eq/kWh
Primary steel (BF-BOF)	~ 1.8 – 2.3 kg CO_2-eq/kg
Primary aluminium	~ 11 – 17 kg CO_2-eq/kg
Primary copper	~ 3.5 – 6.0 kg CO_2-eq/kg

Indicative comparison: literature values with different system boundaries and input definitions (AM = active material, BM = black mass).

Environmental impact of European LIB pretreatment

40-70% of top-5 impacts



Gas cleaning

Residue treatment

Direct emissions

< 5 % effect



Electricity

Heat

Emission and residue management, not „mechanical“ vs. „thermal“, decides the environmental footprint.

= f [technology, efficiency, **battery design**]

Source: Rutrecht et al., unpublished research results, manuscript in preparation.

And then a pretreatment challenge becomes also a design challenge

Design decisions influence processing effort, cost and material quality at end of life.

Pretreatment requirement	Question for battery design
Safe opening and disassembly	How accessible are joints, cells and service fluids?
Electrolyte and residue management	How do material choices affect emissions and treatment demand?
Separation and feed quality	Can components and materials be separated into useful fractions?

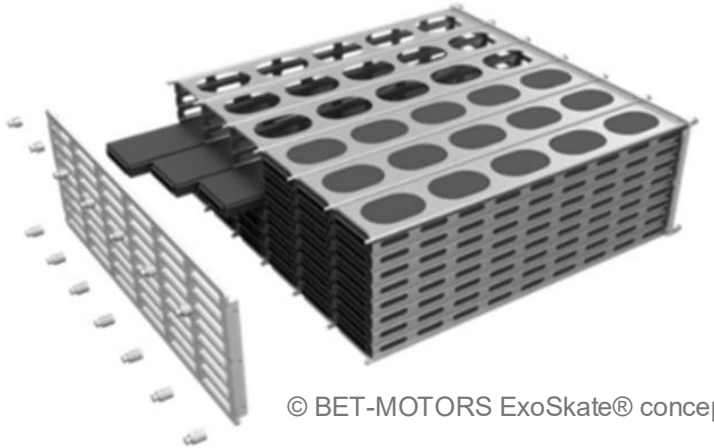
Interpretation of the pretreatment findings; Windisch-Kern et al. (2022); Lander et al. (2023)



Highlights of FFG project Move-it

Introduction to FFG project Move-it

Modular optimized BESS for innovative transport vehicles



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- **Project aim:** A simulation and assessment framework for modular heavy-duty truck battery design
- **Simulation and assessment:** Compare design variants for thermal, mechanical and electrochemical performance, safety and cost
- **K1-MET contribution (WP6)**
  - Screening LCA and material flow analysis
  - Assessment model of repairability and recyclability indicators and engineering trade-offs

Challenges of design for recycling

- Safety, compliance and required performance are prerequisites

Engineering needs		Circularity needs
Low mass, compact packaging Structural integration, fewer parts	Architecture ⟷	**Access and selective replacement** Serviceable modules and components
Low cost, rapid assembly Short cycles and reproducible quality	Production ⟷	**Economical disassembly** Accessible steps, low handling effort
Durable joints and reliable seals Structural stability and load transfer	Joining ⟷	**Controlled separability** Deliberate release at end of life
Stable electrode interfaces Binder adhesion and cycling durability	Electrodes ⟷	**Clean material recovery** Separate coatings from current collectors

OEM priorities and recycling benefits

- **OEMs decisions:** Shape value beyond the production gate

Illustrative OEM priorities

1. Weight
2. Cost
3. Material properties
4. Processing
5. Sustainability

Whole-life value

Potential stakeholder benefits

Micro: firms and users
Retained value and compliance

Meso: industry and value chain
Reliable feedstocks and material loops

Macro: EU and national economy
Supply resilience and regional value

Global: environment and health
Resource conservation and lower impacts

Sustainability is shaped by every design choice.

Benefits depend on lifetime, recovery quality, displaced primary production and treatment burdens.

Closing the circle – how to enable circularity?

01 Idealism and commitment
Keep circularity among the design priorities.

02 Subsidies and tax incentives
Give demonstrably sustainable options a competitive edge.

03 Early recycler partnerships
Include treatment expertise while design choices are still open.

04 Live tests and feedback
Use practical treatment findings to improve the design.

05 Think big
Coordinate decisions across the battery value chain.

From Recycling to Sustainable Battery Design

Vienna, 13th of November 2026

Bettina Rutrecht

K1-MET

Move-it

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