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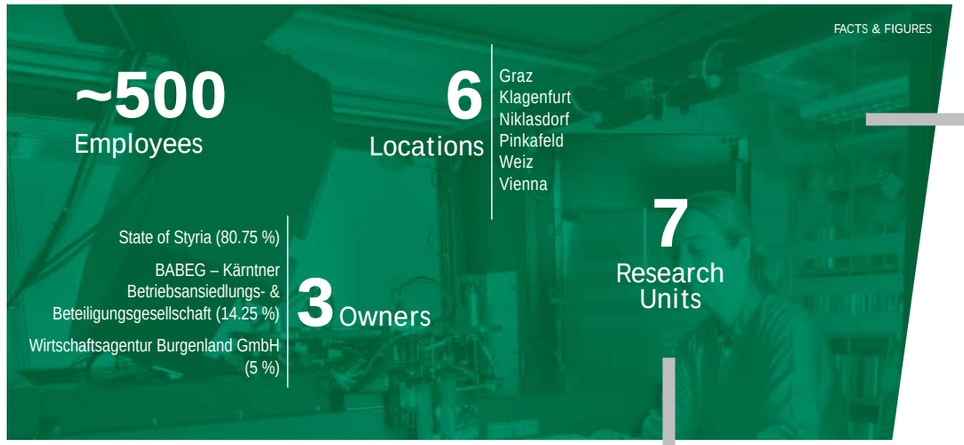
IEA TCP HEV Task 40

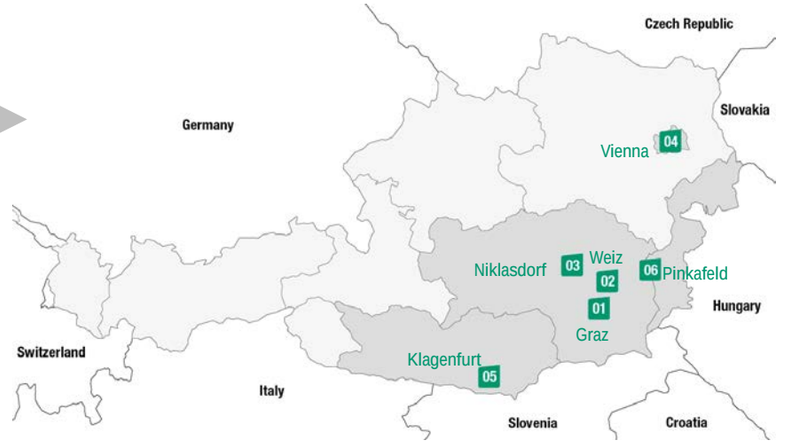
Critical Raw Materials for Electric Vehicles

IEA JRC Workshop Petten

Martin Beermann
12.12.2023

JOANNEUM RESEARCH / non-university RTO in Austria





Information- and production technologies

DIGITAL – Institute for Digital Technologies

MATERIALS – Institute for Sensors, Photonics and Manufacturing Technologies

ROBOTICS – Institut for Robotics and Flexible Production



Human technologies and medicine

COREMED – Centre for Regenerative and Precision Medicine

HEALTH – Institute for Biomedical Research and Technologies



Society and sustainability

LIFE – Institute for Climate, Energy Systems and Society

POLICIES – Institute for Economic, Social and Innovation Research



LIFE supports R&D projects and companies with:

- **Science-based system assessments of energy and production systems** (LCA, micro + macro economics, social)
- Development of **company roadmaps towards net-zero GHG emissions**,
- „Best technology choice“: assess the potential and the **impacts of emerging technologies** in early development stages

IEA TCP HEV Task 40

CRM4EV
Critical Raw Materials Electric Vehicles

Objective and added value of Task 40:

Integrated view of future supply of critical raw materials for electric vehicles, including

- **battery technology** developments,
- scenarios of global **electric vehicle fleets**
- primary **raw material supply**,
- development of **recycling technologies**,
- **Material demand - supply bottlenecks** until 2030
- **LCA of material and battery production**



- **Task period**: Oct 2018 – Dec 2022
- **Operating agent**: Bert Witkamp / Valuad, The Netherlands
- Participation of JOANNEUM RESEARCH **financed in Energieforschungsprogramm 5. AS** by:

klima+ energie fonds

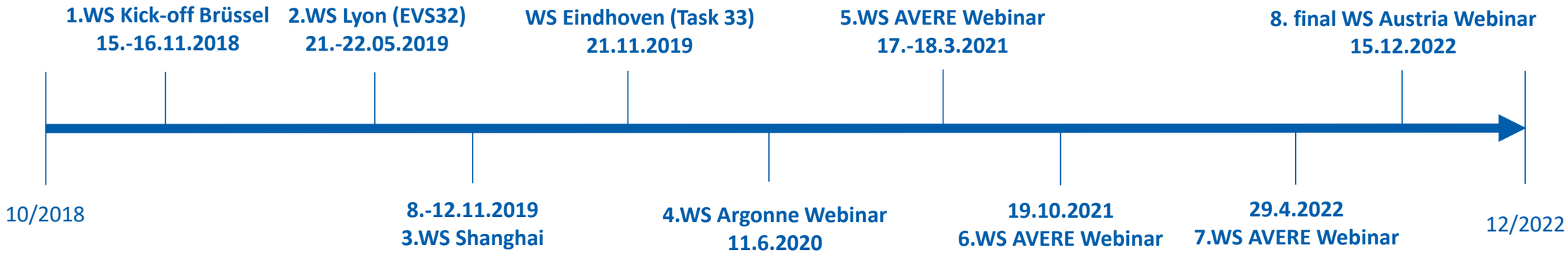
Bundesministerium Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie

FFG Forschung wirkt.

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Approach in Task 40

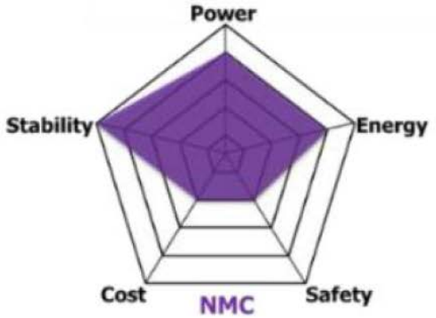
- Critical materials in Scope: **Nickel, Cobalt, Lithium, Graphite, (Copper), Rare Earths, Phosphate**
- Internal papers and meta-studies on battery technologies (development of chemistries and markets) and on external EV and raw material forecasts
- Internal working groups on battery recycling and Life Cycle Assessment
- 8 international Task workshops with invited external experts (5 workshops online due to COVID-19)



- International Task 40 report available on https://ieahev.org/tasks/40/
- National Task 40 report by Joanneum Research to be published early 2024 on https://nachhaltigwirtschaften.at/en/publications/

Dominant EV battery cathode chemistries 2022

Nickel-Manganese-Cobalt



\+ High (mass) energy density

\- High cost
CRM Ni, Mn, Co

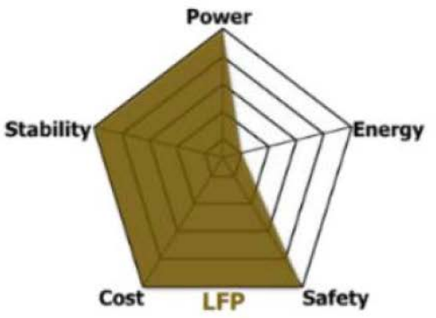
Nickel-Cobalt-Aluminium



\+ High power and energy density

\- High cost
CRM Ni, Co

Lithium-Iron-Phosphate

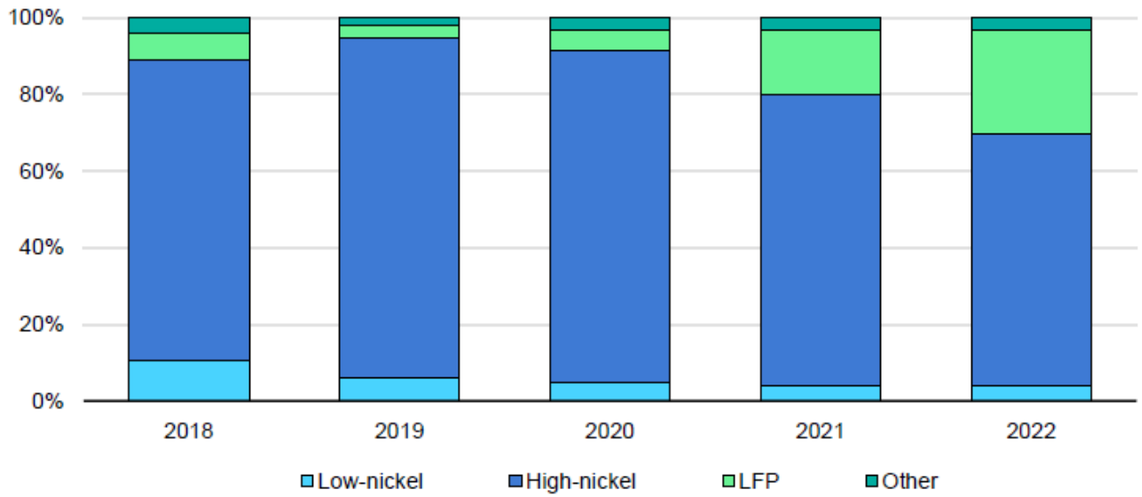


\+ High power density
Low cost (high cycle life)

\- Low (mass) energy density
CRM Phosphate

Source: Houache 2022

High-Nickel-NMC dominating global markets, with increasing share of LFP (in China > 60%)



IEA. CC BY 4.0.

Source: IEA Global EV Outlook 2023

Battery technology developments – outlook 2030

NMC: **High shares of Nickel** / lower shares of Manganese and Cobalt (e.g. NMC532, NMC622, NMC721, NMC811) leave a wide space of design options to find the **optimum between battery performance, lifetime and costs**. **NMC likely to remain dominant in EU**

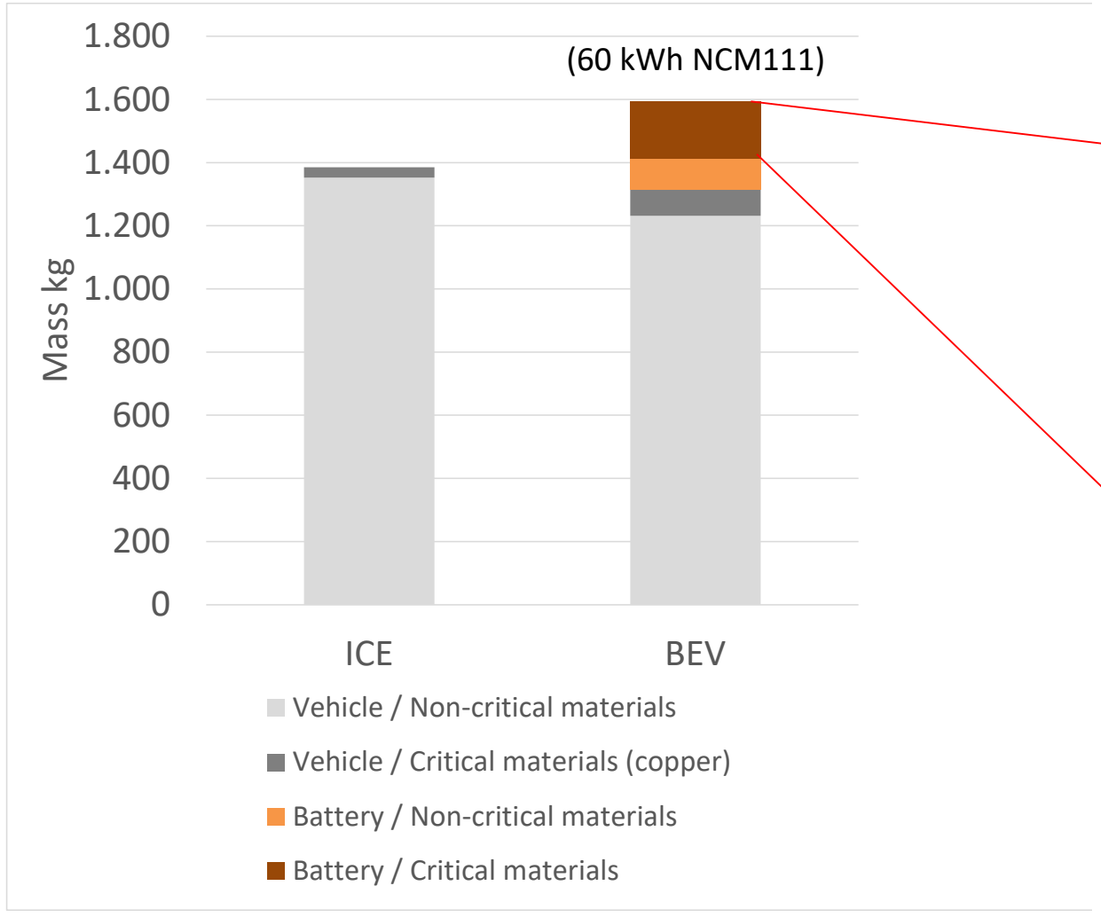
LFP: dominant technology in China where the 2022 market share of LFP was 61% (Witkamp 2023). Currently there **is no production of LFP-cells in the EU**, but announced by several OEMs.

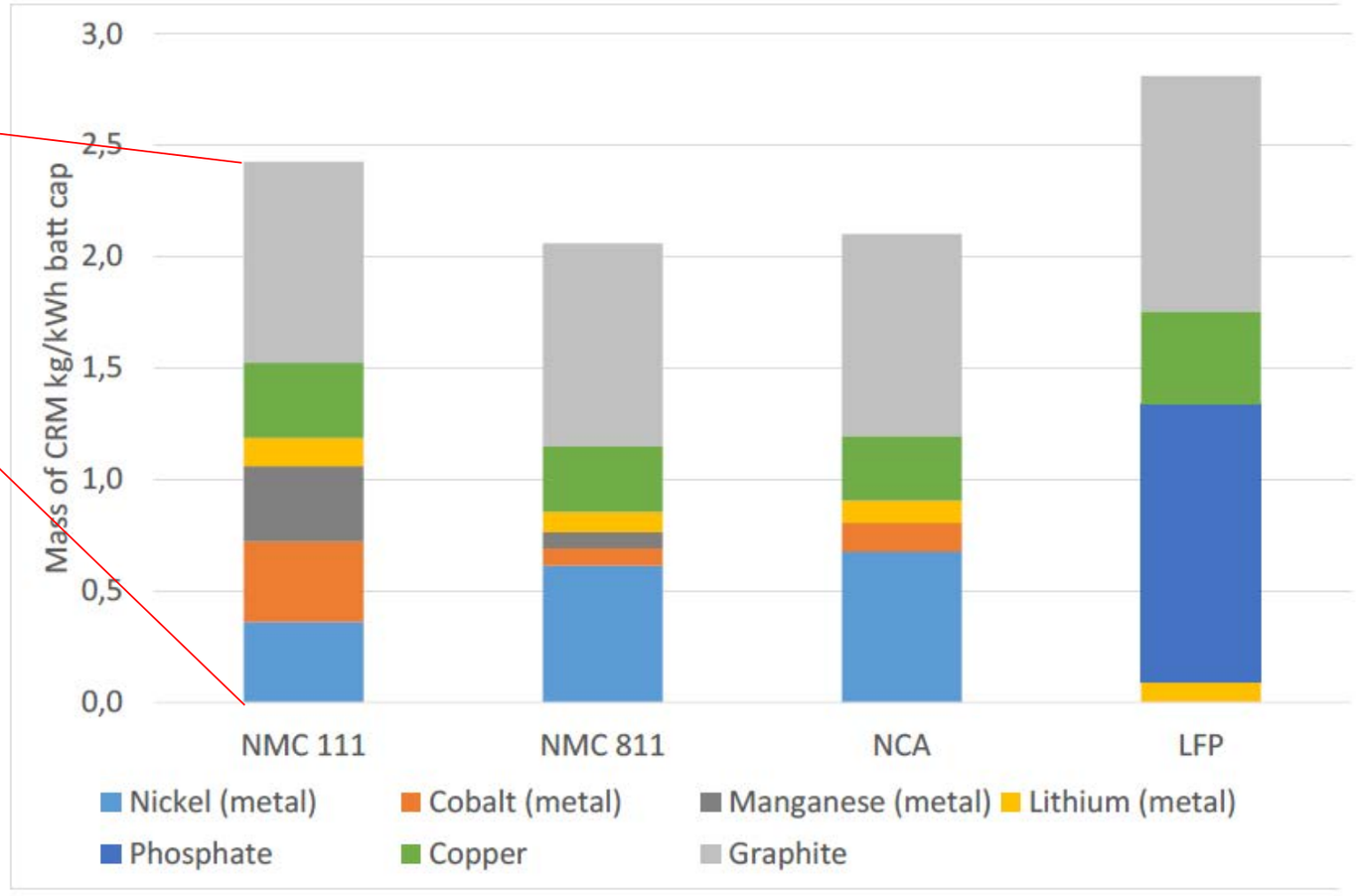
Na-ion: **only post-Lithium-ion** battery technology already being **commercialized today**. Energy density will be slightly lower than that of LFP-chemistries, mainly suitable for storage applications where energy density is not critical. **2030 expected global market share of max 5%** (IEA 2022).

All-solid-state: this development is an enabler also of Lithium metal anodes (which cannot be used with liquid electrolytes) which can result in significant increases in battery energy density compared to current Li-ion batteries with Graphite anodes. Upscaling of production as a challenge. **Not expected to have a significant impact on battery markets before 2030** (IEA 2022).

Critical raw materials for EV batteries

~2.1-2.8 kg CRM per kWh battery capacity

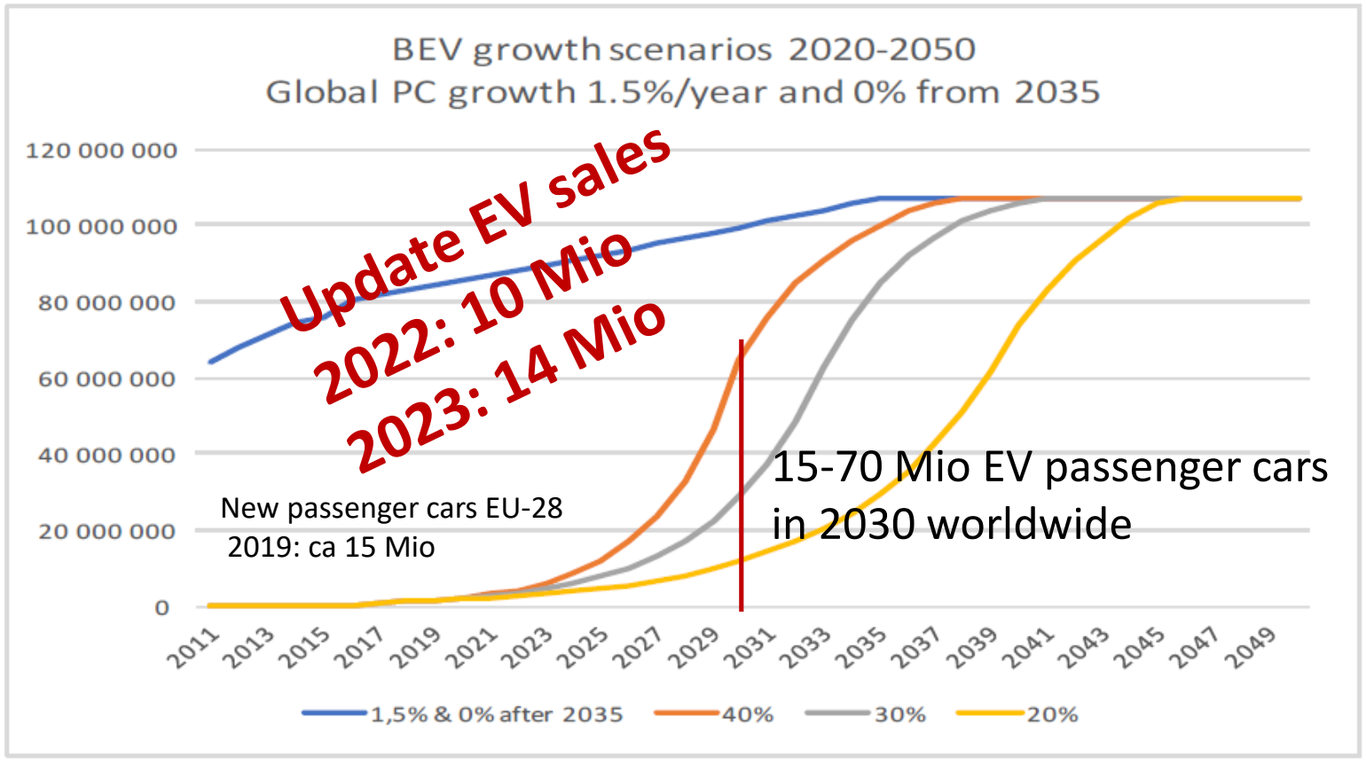




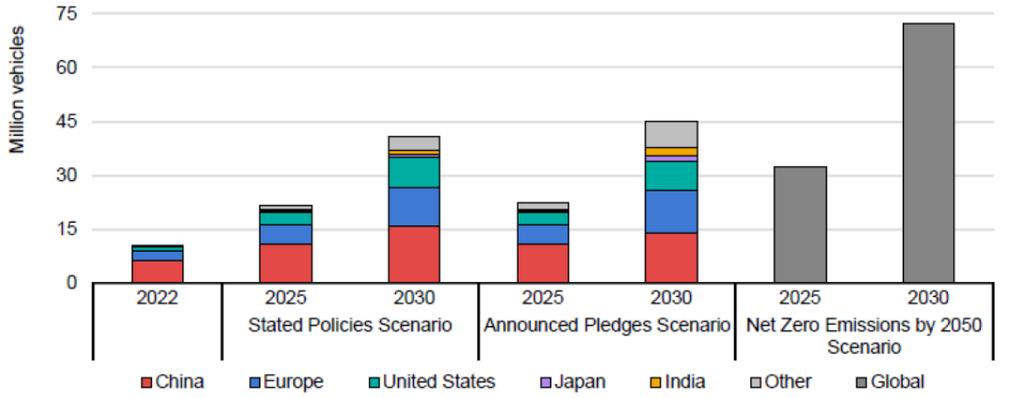
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Global BEV and battery demand scenarios

Task 40: global EV sales 2030



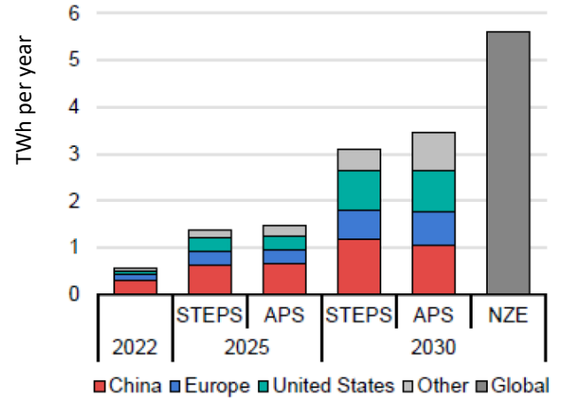
IEA scenarios: global EV sales 2030



Source: IEA Global EV Outlook 2023

IEA. CC BY 4.0.

IEA scenarios: global battery demand 2030



Source: IEA Global EV Outlook 2023

IEA. CC BY 4.0.

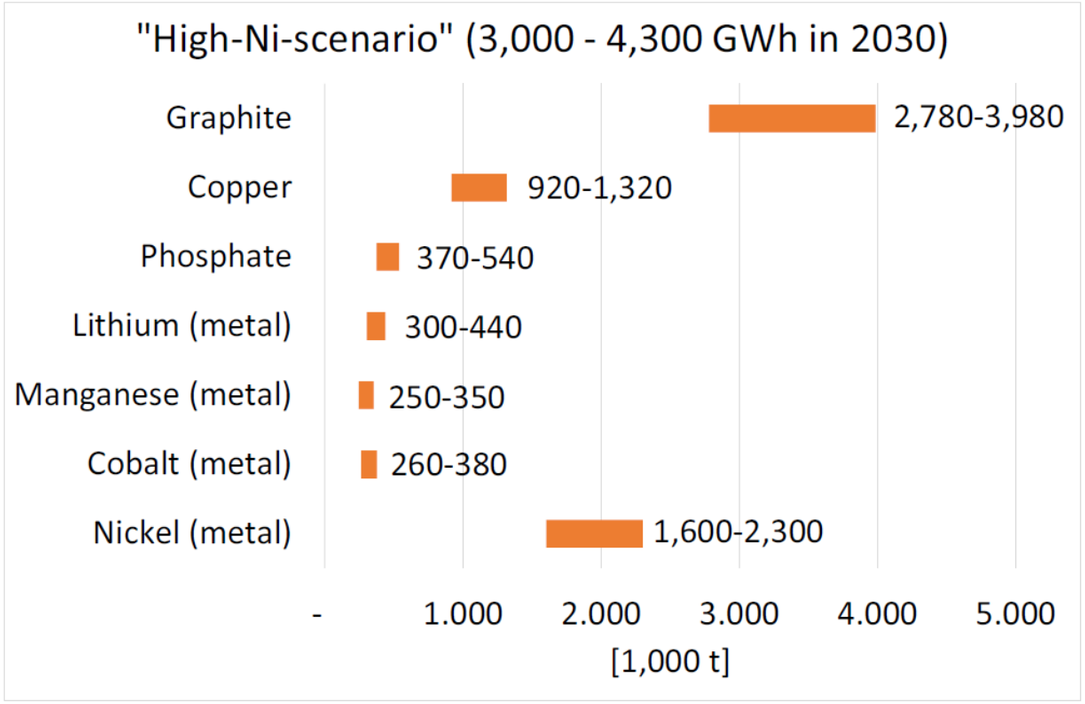
“Middle of the road” scenario:
50 million EV sales
3 - 4.3 TWh battery demand

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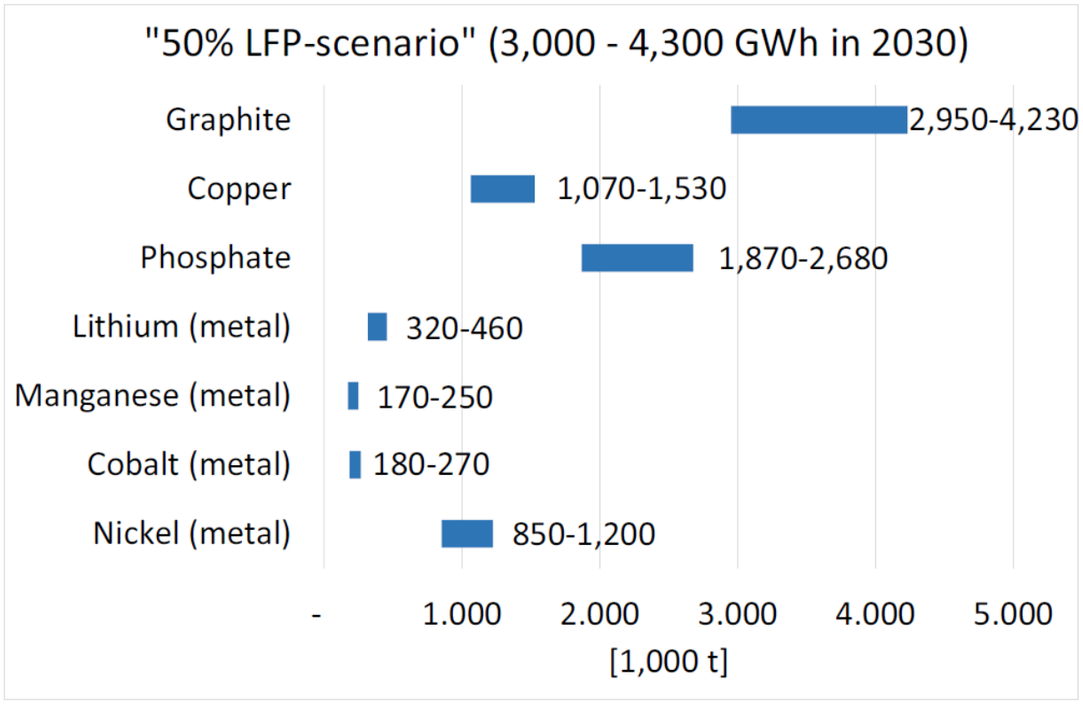
Task 40 CRM demand scenarios

“Middle of the road” scenario:
50 million EV sales
3 - 4.3 TWh battery demand

“High-Nickel” scenario: 90% NMC, 10% LFP



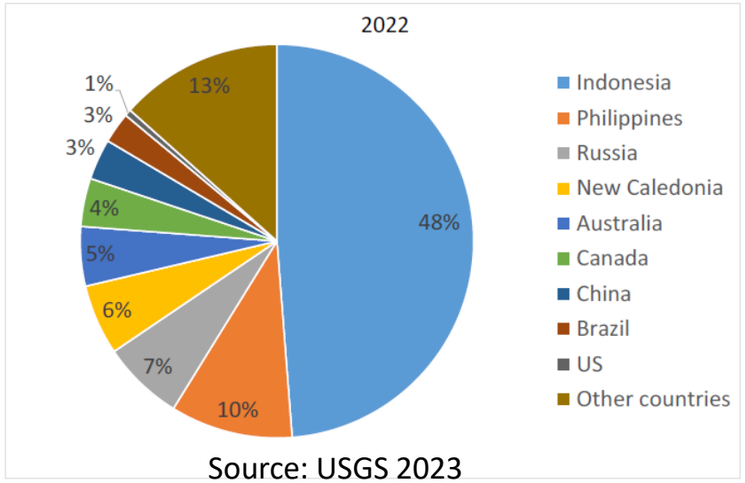
“50% LFP” scenario: 50% NMC, 50% LFP



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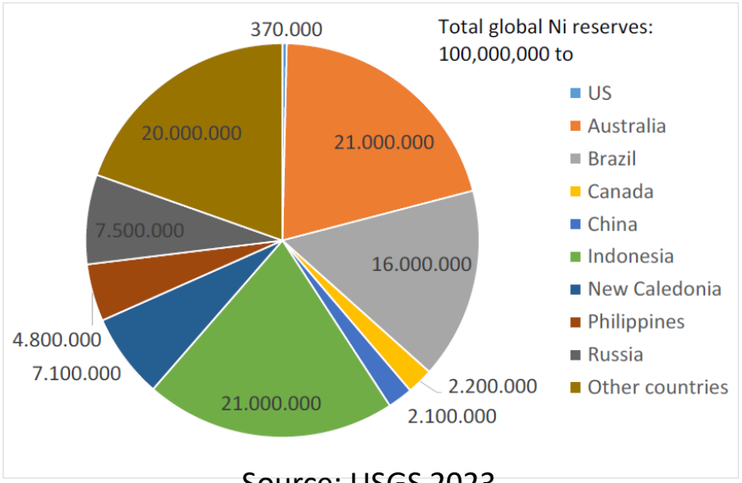
Global CRM supply scenarios (example Nickel)

Global Ni mining 2022
2.5 Mio tons



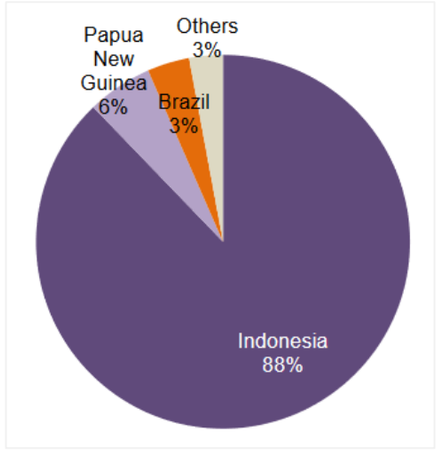
Source: USGS 2023

Global Ni reserves (resources)
100 (600) Mio tons



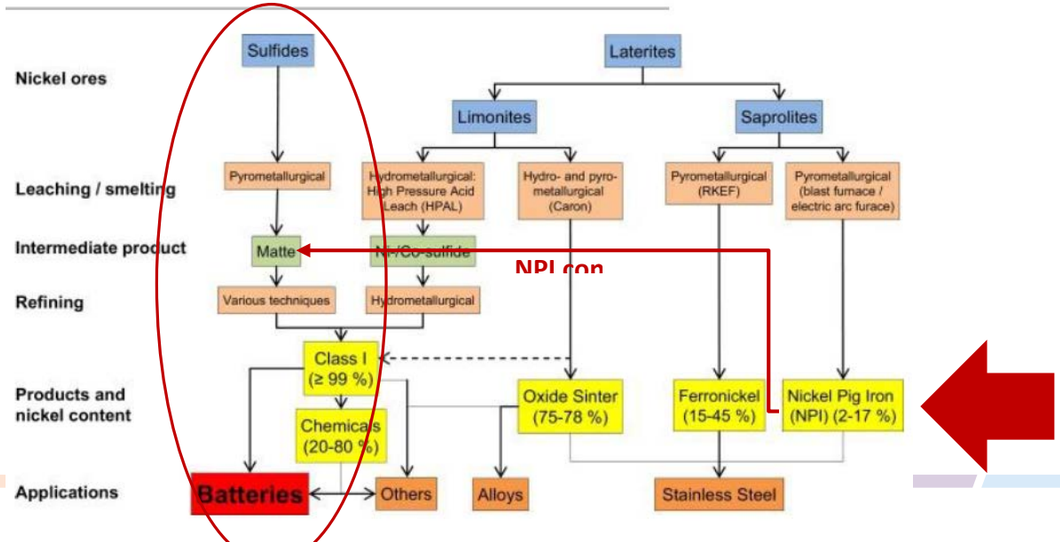
Source: USGS 2023

Planned Ni refining projects
2023-2030



Source: IEA 2023

Nickel production routes



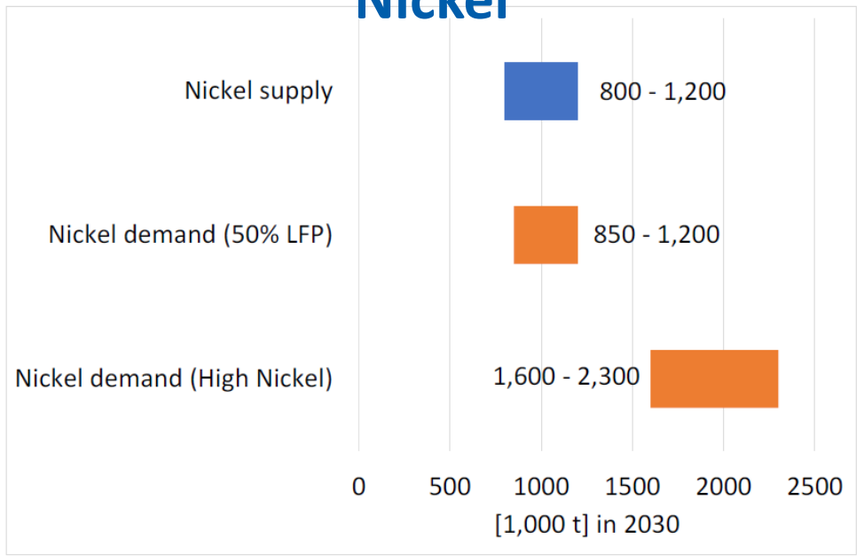
Main **driver** of Ni (NPI) production is **Chinese steel production**, investments into Ni class I (battery-grade) production still low.

Conversion of NPI to battery grade Nickel comes along with High potential local environmental and social impacts!

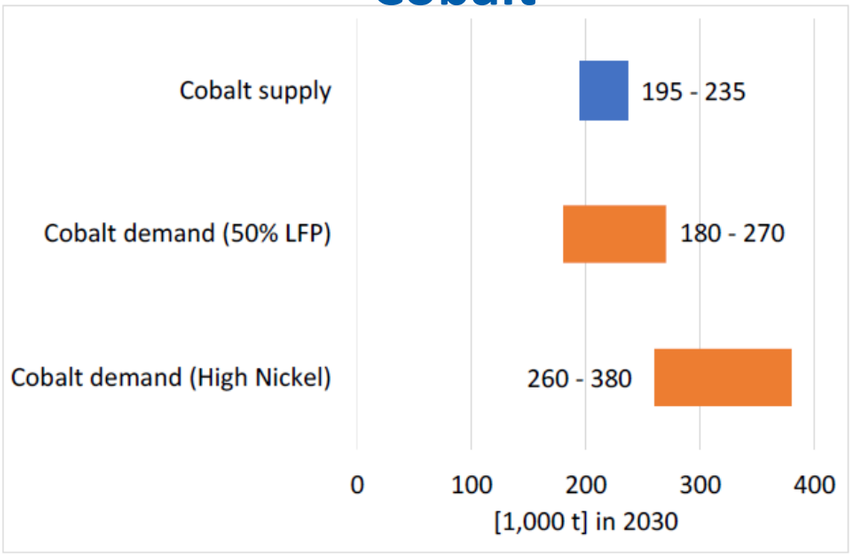
(due to surface mines in SE-Asian virgin rainforests)
+ coal-related GHG emissions in SE-Asia (+33% 2022)

Task 40 global CRM supply and demand scenarios

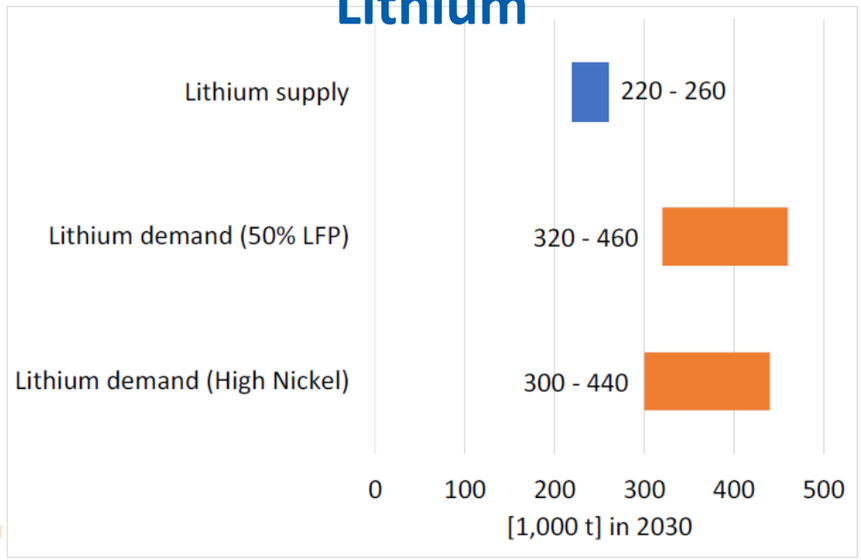
Nickel



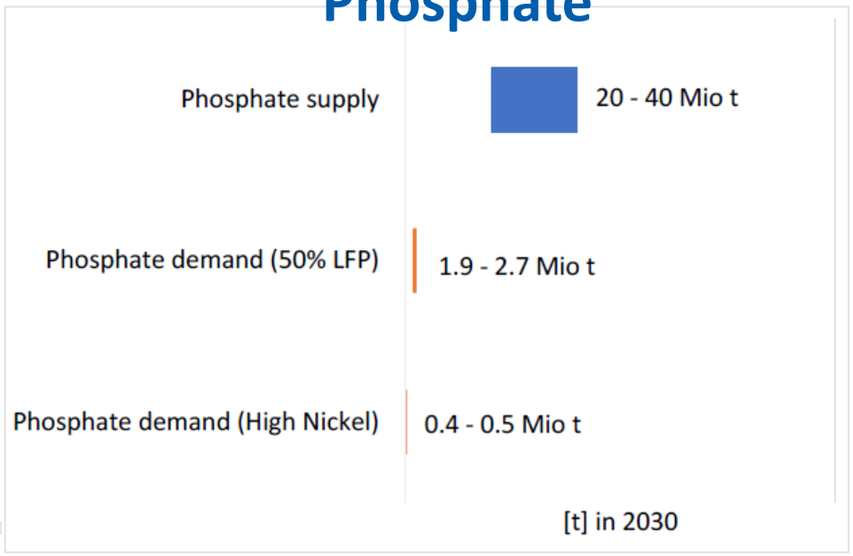
Cobalt



Lithium



Phosphate

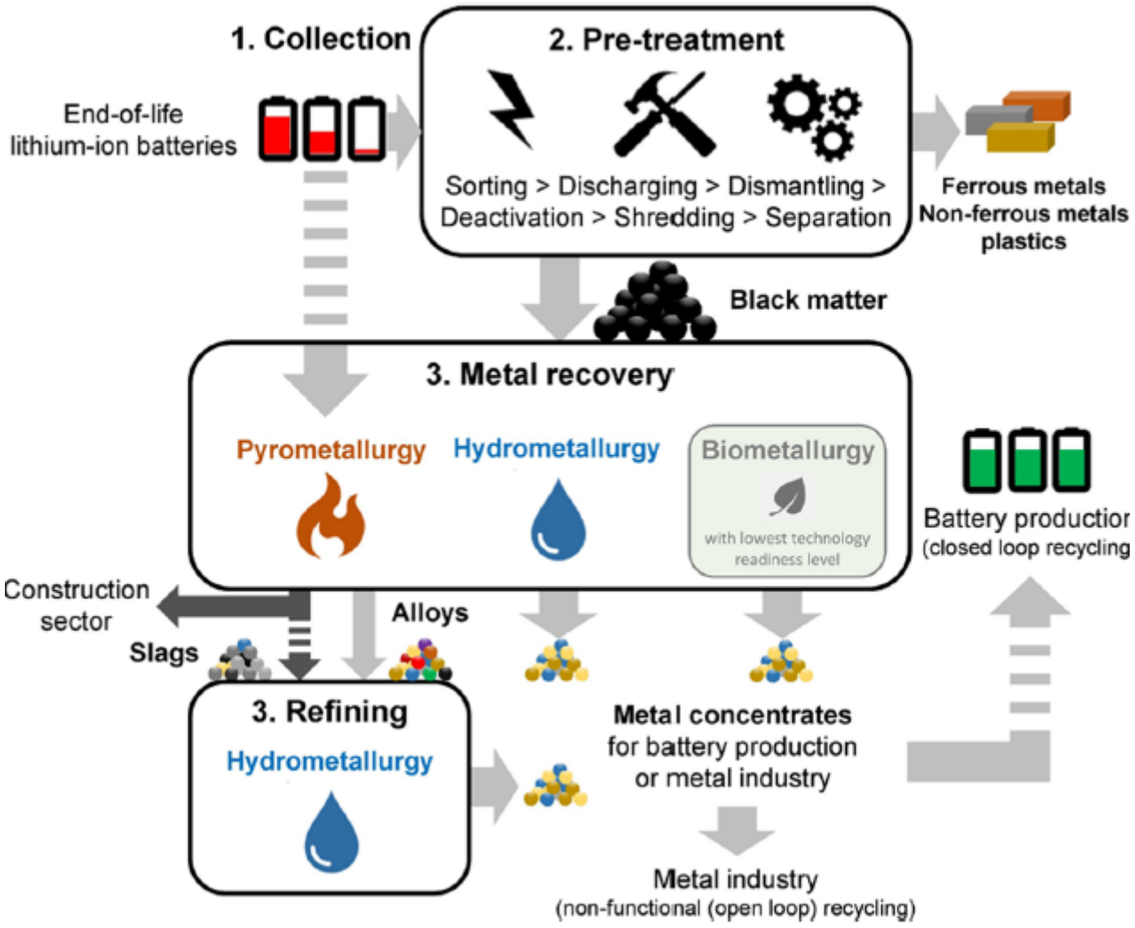


Task 40 global CRM supply and demand scenarios

- **Nickel**: availability for EV batteries by 2030 could be (as a max) 1.2 million ton per year (analyst view), **shift to ZERO nickel chemistries required**
- **Cobalt:** does not seem to be a big issue, large potential from (new nickel) Indonesian sources and scale-up potential DRC, **shift to ZERO Ni/Co chemistries required**
- **Lithium:** very large resources available which will be further extended, but **possible short term supply shortages**, R&D has demonstrated effective and low-cost lithium recovery from sea water
- **Graphite:** large potential for additional mining, **synthetic graphite available for gaps**, with silicon-graphite anodes the graphite content will be reduced, solid state battery anodes do not use graphite
- **Phosphate**: **Deficits on the global supply side are unlikely**. Based on additional Phosphate production driven by fertilizer production, the share of future demand for batteries might be ~ 10%.
- **REE**: for EVs **alternative motor solutions** will be implemented, due to the challenges related to establishing additional REE supply production. The most notable non-permanent magnet motor being used is the induction motor, announced to be used in some Tesla models in 2024

Battery recycling

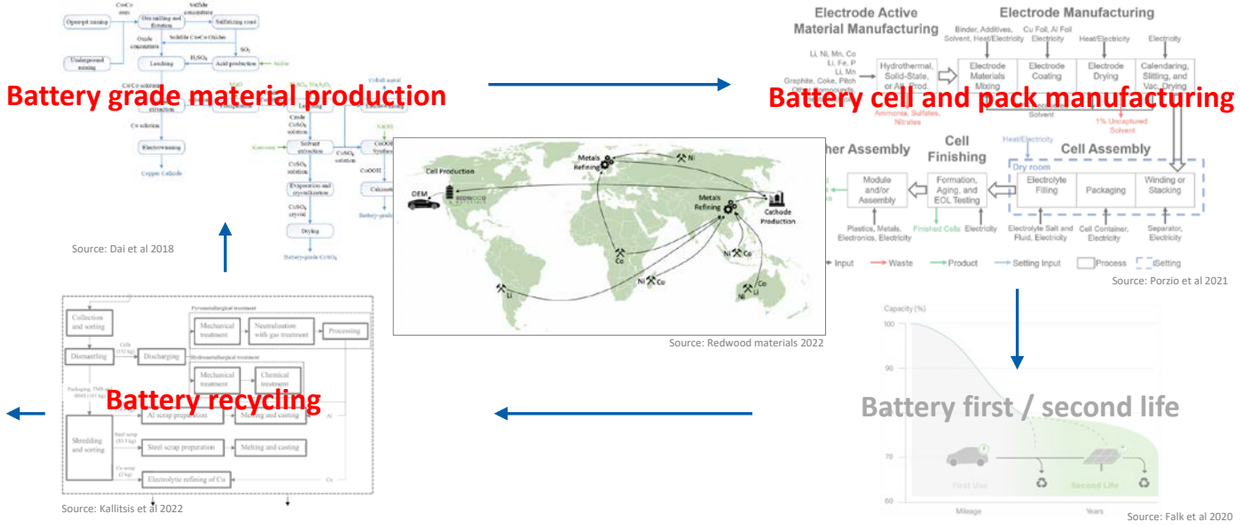
- **Hydrometallurgy as most likely technology in medium term,** since all metals can be recovered separatly which supports the main purpose of recycling of enabling circular economy to reach EU recycling targets
- Large-scale **NMC-recycling** can be **expected to be in place in 2030** (likely cost-efficient due to critical metals recovered)
- Large-scale **LFP-recycling** can be expected **to be in place later than 2030** (**less cost-efficient** since lithium and copper are the only electrode-metals to be recovered); BUT: new EU-battery directive will require recovery rates for Lithium (50% in 2027, 80% in 2031)
- **Sequence and interplay of processes** depending of input quality and chemistry, required quality of output material as **biggest technical challenge** to reach EU recycling targets



Source: Nigl 2021

Life Cycle Assessment / Carbon Footprint of battery



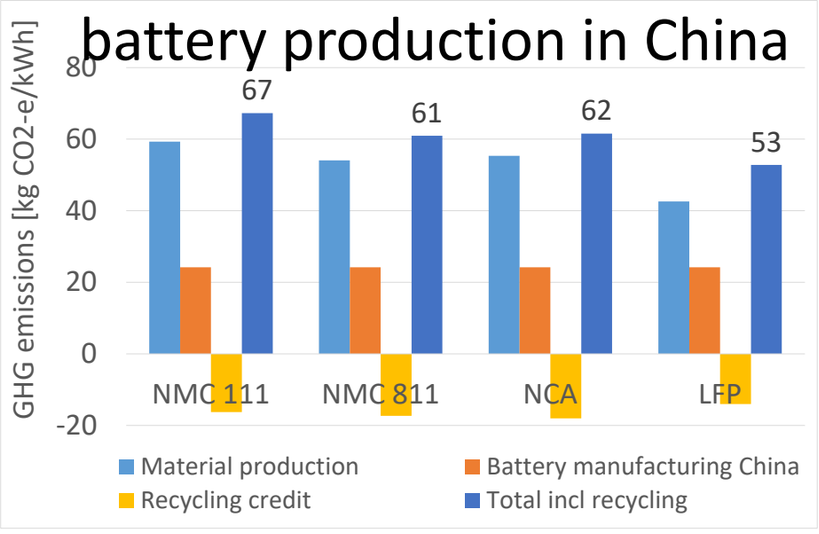


Relevant parameters depend on choice of:

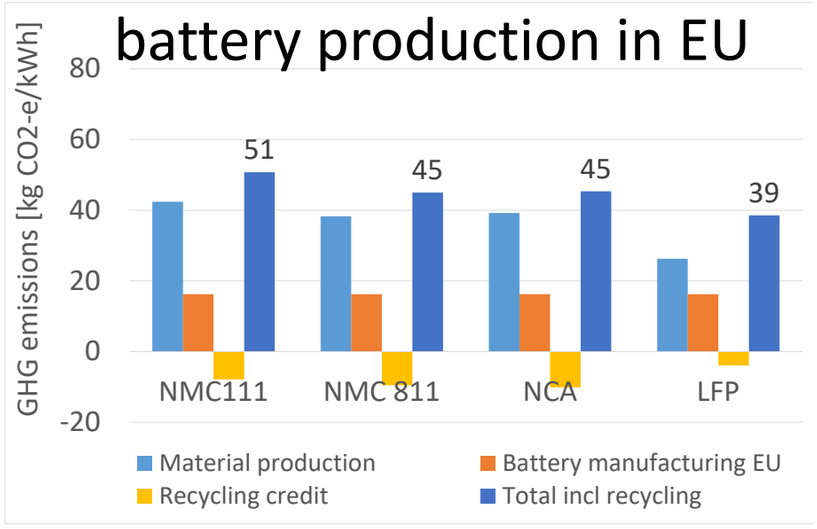
- Battery technology
- Upstream material source and process technologies
- Regional energy mix for material sourcing and battery production

Data collected in cooperation with Task LCA partners

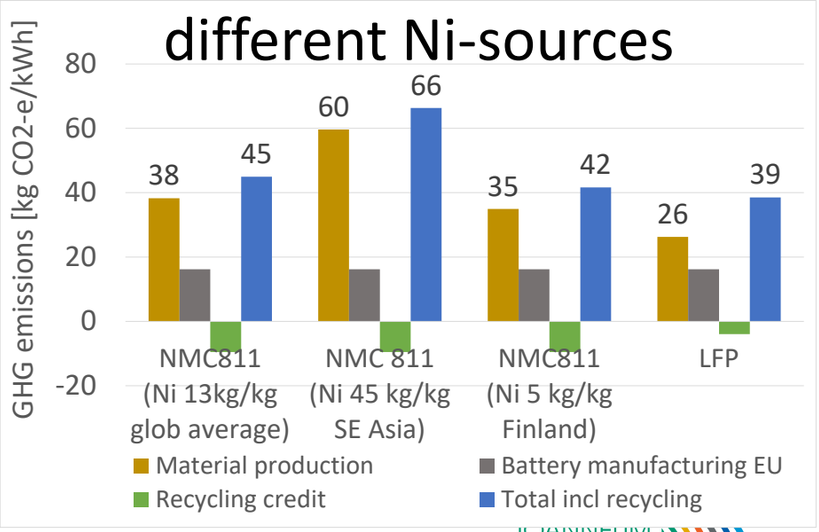
Most materials and battery production in China



Some materials from EU and battery production in EU



NMC811 production in EU + different Ni-sources



Concept of Environmental Criticality (complementing LCA)

- Mining & processing of minerals often have far-reaching consequences for local, regional environments which also may affect downstream users
  - corporate reputation risk for downstream manufacturing industries, opposition against mining, increasing mid-and long-term supply risks (e.g. closure of existing mines, no granting of new concessions)
- Concept of environmental criticality developed by Umweltbundesamt Germany in project ÖKORESS II
  - 11 indicators + qualitative assessment (low-high-medium) of Environmental Hazard Potential (EHP)
    - Geology (e.g. deposit has elevated heavy metal concentrations)
    - Technology (e.g. mining method – underground, open pit, auxiliary materials)
    - Natural Environment (e.g. accident hazards due to landslides, water stress index)
    - Value Chain (size of global material flow, energy demand)
    - Governance (environmental performance index of countries)

Concept of Environmental Criticality (complementing LCA)

EHP Indicators								GSMEF		Raw materials	(Aggregated)Results		
1.	2.	3.	4.	5.	6.	7.	8.	SMF	SEF		aEHP	EGov	GSMEF
l	l	l	l	m	m	m	m	l	l	Graphite	l	h	l
l	l	m	h		h	m	l	l	l	Lithium	m	l	l
l	m		m	l	l	m	h	m	h	Manganese	m	h	m
l	m	h	m	h	h	m	l	m	m	LREE	h	m	m
l	m	h	m	h	h	l	l	m	m	HREE	m-h	h	m
h	h	m	m	m	m	l	h	h	h	Nickel	h	l	m
l	m	h	h	h	m	m	m	h	h	Phosphate rock	h	m	h
h	h	h	m	h	l	l	m	m	m	Cobalt	h	h	m

1. Pre-conditions for acid mine drainage (AMD)
2. Paragenesis with heavy metals
3. Paragenesis with radioactive substances
4. Mine type
5. Use of auxiliary substances
6. Accident hazards due to floods, earthquakes, storms, landslides
7. Water Stress Index (WSI) and desert areas
8. Designated protected areas and Alliance for Zero Extinction (AZE) sites

SMF Size of material flow
SEF Size of energy flow
EHP Environmental hazard potential
aEHP Aggregated environmental hazard potential
EGov Environmental governance

ASM Artisanal and small-scale mining
AR Share of mining sites in the arctic region
HREE Heavy rare earth elements
LREE Light rare earth elements

h High EHP
m-h Medium to high EHP
m Medium EHP
l-m Low to medium EHP
l Low EHP

Umweltbundesamt Germany, ÖKORESS II (Dehoust 2020)

Conclusions for research & development

- **Battery recycling**: development of hydrometallurgical technologies combined with battery pretreatment.
  - Only but complex technology besides direct recycling, to support the development of a closed loop use of battery critical raw materials.
  - Austria has research institutions as well as industries with a profound expertise in metallurgical processes. Austria has a strong position in plant engineering both in the metal industry and the waste recycling branch.
- **Battery research**: development of sodium-ion technology and other technologies with reduced demand in critical raw materials
  - Reduced risk of supply deficits and geopolitical dependencies
  - Due to chemical and physical material properties, Na-ion comes along with reduced energy capacities compared to “close-to-ideal” materials. Research focus on new combinations of cathode / anode / electrolyte materials
- **Development of system assessment methods:** prospective LCA modeling, circularity assessment
  - Model the dynamics of the transition of global economics towards climate neutral transport and production systems within the short timeframe of 20 to 30 years.
  - A second research area is to further develop the LCA method to integrate the assessment of circularity to better assess the circularity potential of products and services.

Thank you for your attention!

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Forschungsgesellschaft mbH

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EU Critical Raw Materials



- The production capacities for battery cells in Europe (EU-27, UK, Norway) will increase from around 35 GWh/a in 2020 to 900 to 1,300 GWh/a in 2030. This corresponds to an increase by a factor of up to 30 (Bechberger 2022).
- The only Nickel mining countries within the EU in 2022 are Finland and Greece. Finland produced about 45,000 t and Greece about 10.000 t in 2021, which is 1.5% of global production. Lateritic ores are mostly located in tropical and subtropical climate zones in Brazil and SE-Asia (in Europe in Greece and Albania), sulfidic ore resources are mostly located in Canada, Russia, China, South Africa and Australia (in the EU in Finland
- The EU share of the global mined Cobalt was 1.1 % or 1,700 tons from Finland. In the EU the main Cobalt provinces are the Fennoscandian shield (Norway, Sweden, and Finland
- Primary Manganese supply in Europe comes from Bulgaria, Hungary and Romania, although jointly this accounts for less than 1% of total global supply.
- The EU share of the global Lithium production was 0.4 % or 600 tons (2022), all of that is from Portugal
- The EU share of the global Phosphate production was 0.5 % or 1 million tons (2022), all of that is from Finland.