Can we ensure a sustainable energy transition using current battery technologies and do Sodium batteries have a role to play in the transition?

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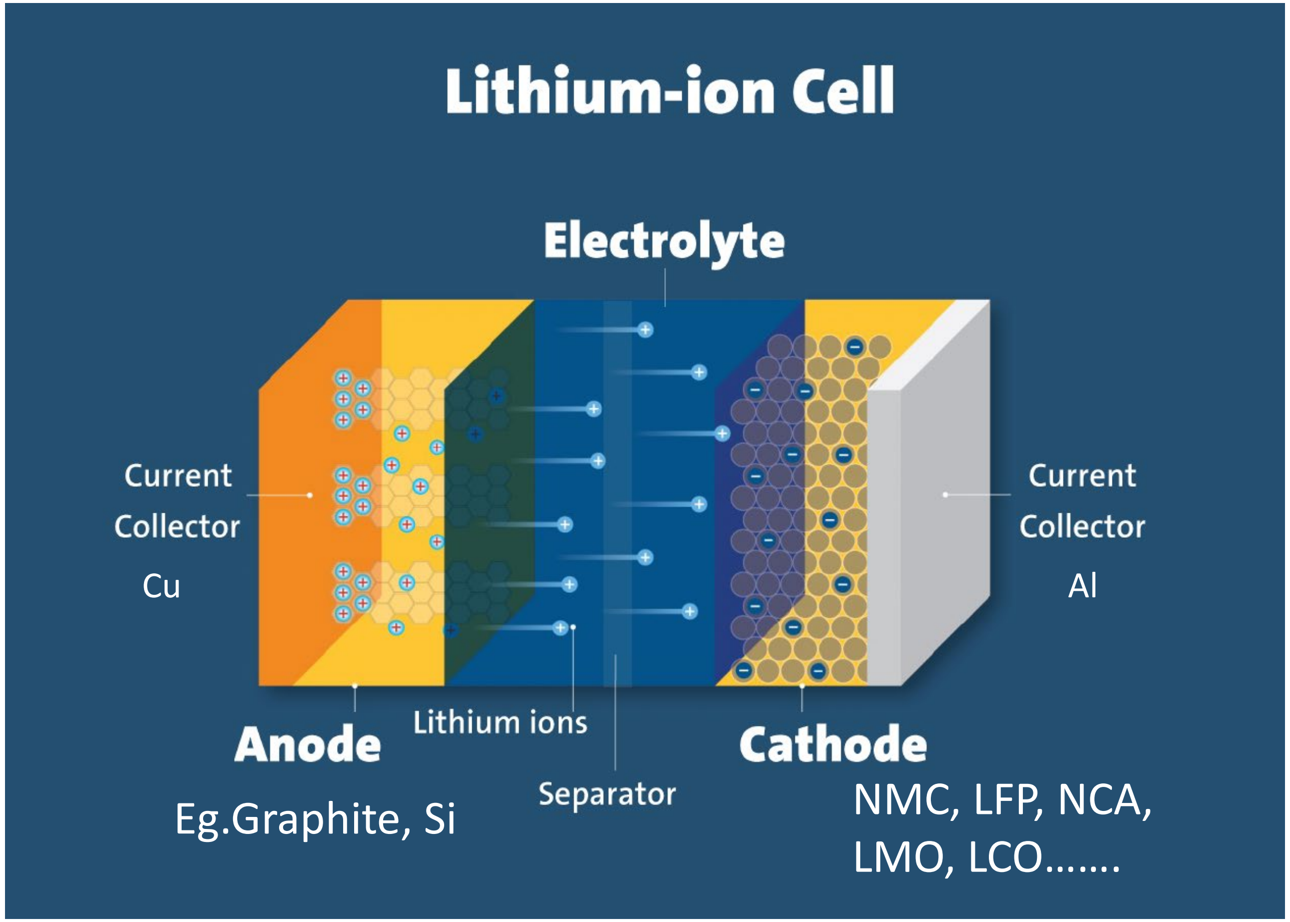
Lithium ion batteries (LIBs)…currently the most widespread battery type - multiple battery chemistries available.

Critical minerals/metals
- Lithium
- Copper
- Graphite
- Cobalt
- Nickel

Other important elements
- Aluminium
- Manganese
- Iron
- Phosphorous
- Silicon

Organic components
- PVDF binder
- carbonates
- ……..



Cell manufacturing (after mining and beneficiation)

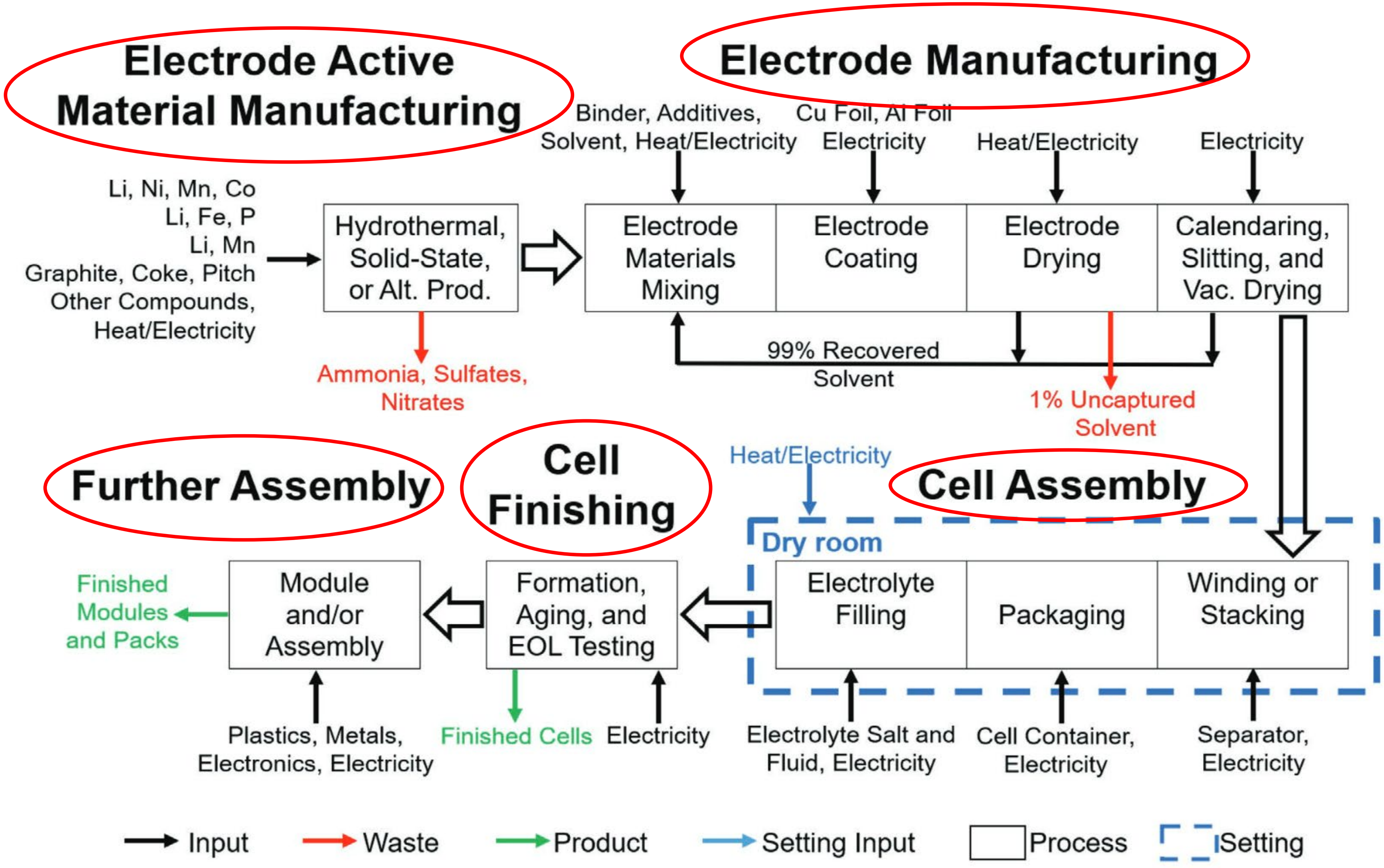
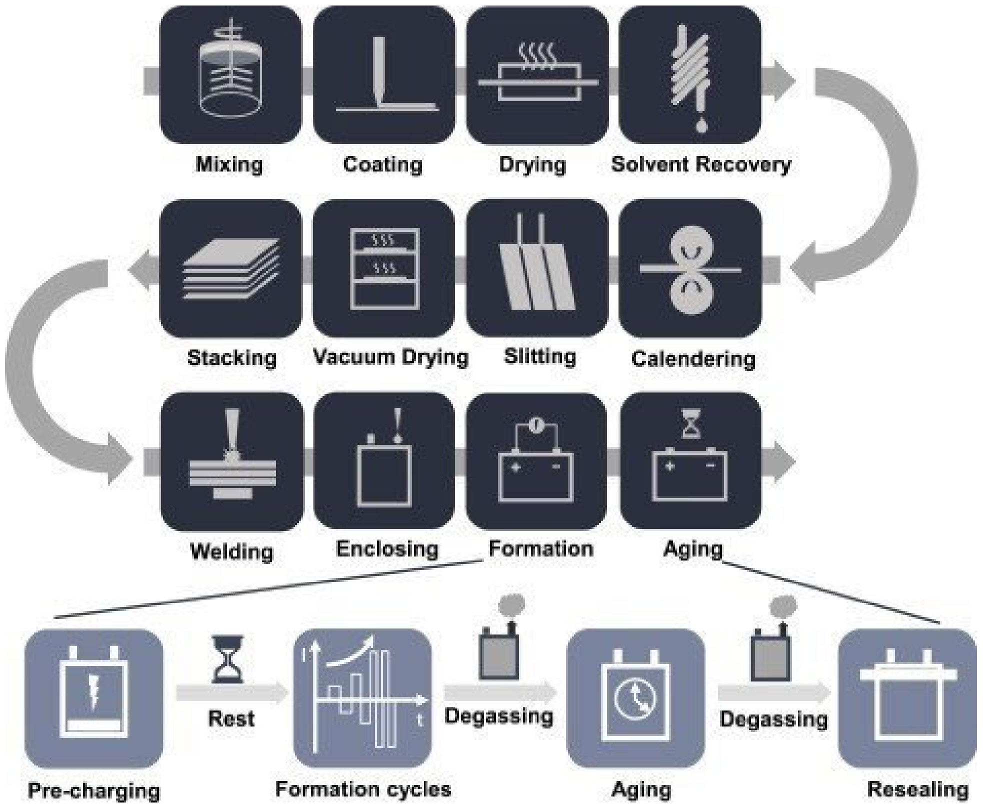


Figure 2. Li-ion battery production process flow diagram.[26,82,90,92,93]

Adv. Energy materials **2021**,11 p2100771

Breakdown of Cell Manufacturing steps and their GHG emissions (kg CO_2/kWh cell)



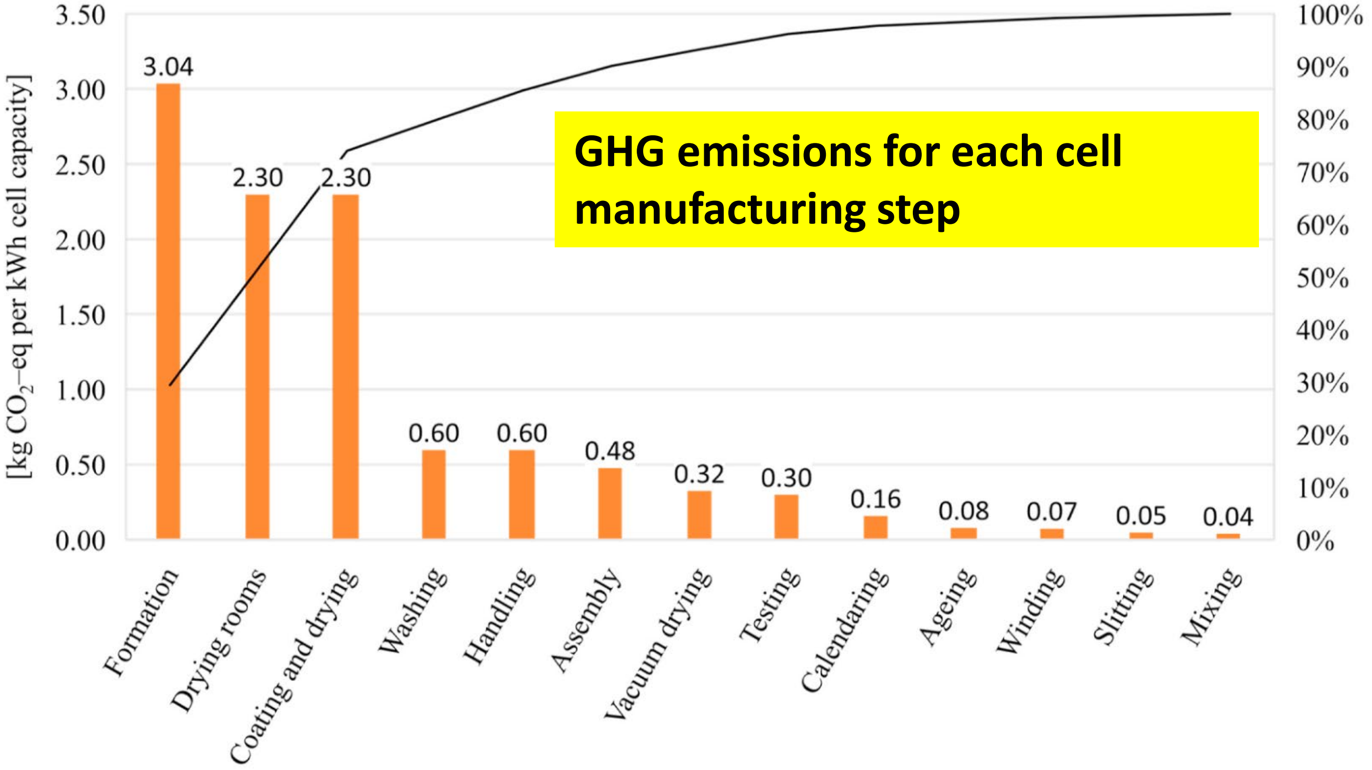
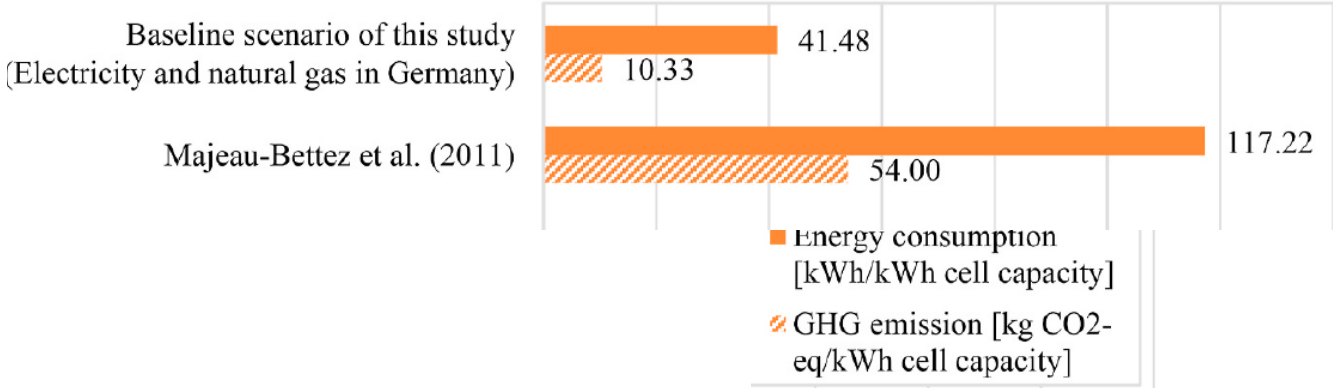


Fig. 4. Baseline GHG emissions for the FFB in Germany. The line represents the cumulative share of the production steps.



Energy required:- >40 kWh/1kWh cell capacity

Journal of Cleaner Production **2022**, 330, 129798

https://etn.news/energy-storage/li-ion-cell-manufacturing

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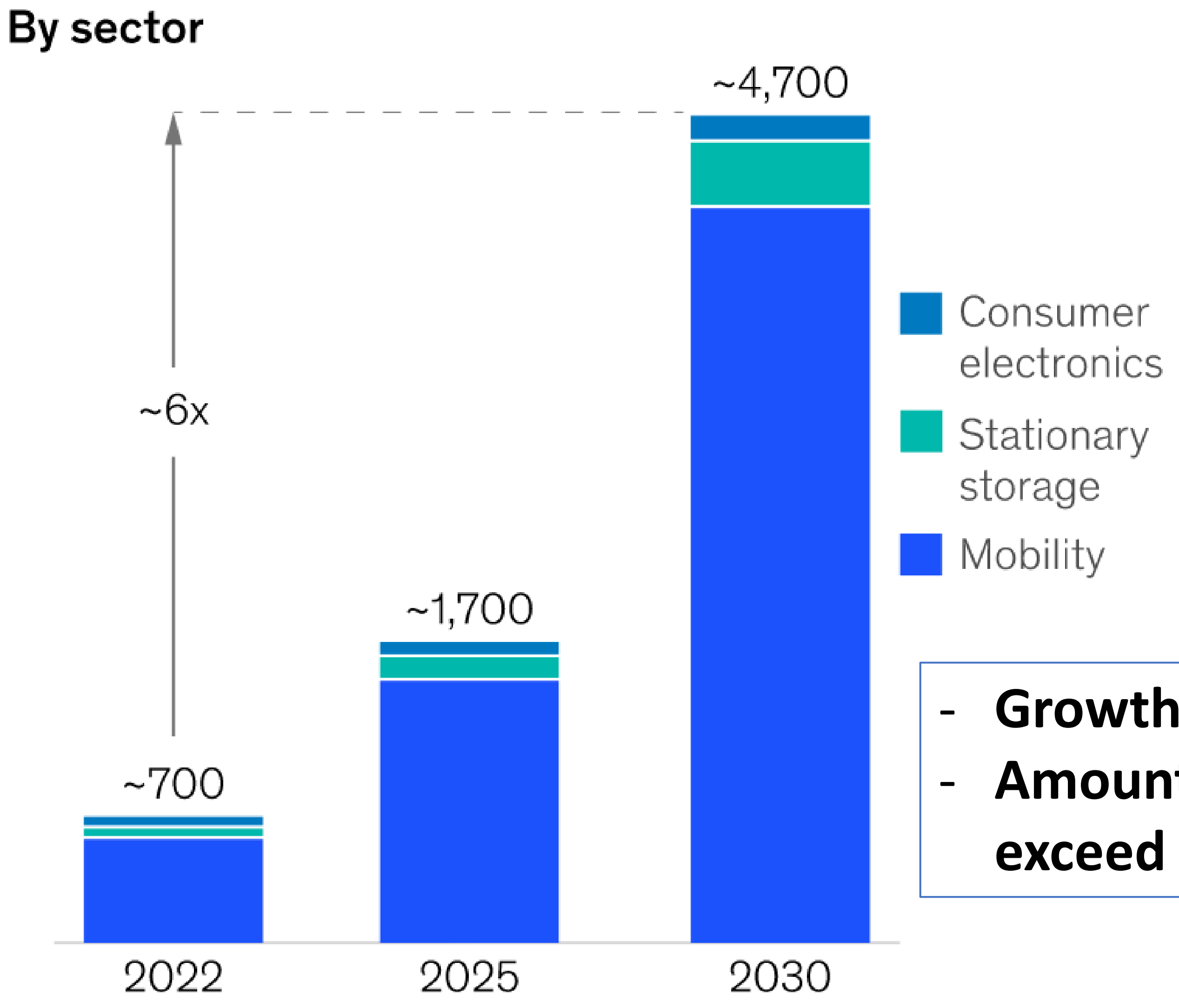
Li-ion battery demand expected to grow almost 30% annually reaching 4,700 GWh by 2030



Source : McKInsey Battery Insights Demand Model

- **Growth in demand across all applications.**
- **Amount of Li required for EVs alone projected to exceed known *currently accessible* Li reserves**

- A typical EV has at least 8kg of Lithium ; 30-60kg of Cu; and for NMC chemistry, up to 14kg Co and up to 40kg Ni
- LFP cathode chemistry is seen as having better ESG as it avoids Ni/Co as well as overall safer and longer cyclability

- Recycling must be implemented for true sustainability of battery technologies

EU has regulated re sustainable battery technologies

- **Minimum levels of materials recovered** from waste batteries: lithium - 50% by 2027 and 80% by 2031; cobalt, copper, lead and nickel - 90% by 2027 and 95% by 2031;
- **Minimum levels of recycled content** from manufacturing and consumer waste **for use in new batteries**: eight years after the entry into force of the regulation - 16% for cobalt, 85% for lead, 6% for lithium and 6% for nickel; 13 years after the entry into force: 26% for cobalt, 85% for lead, 12% for lithium and 15% for nickel.

https://www.europarl.europa.eu/news/en/press-room/20230609IPR96210/making-batteries-more-sustainable-more-durable-and-better-performing

Currently three processes for recycling LIBs – Direct Recycling, Pyrometallurgy and Hydrometallurgy

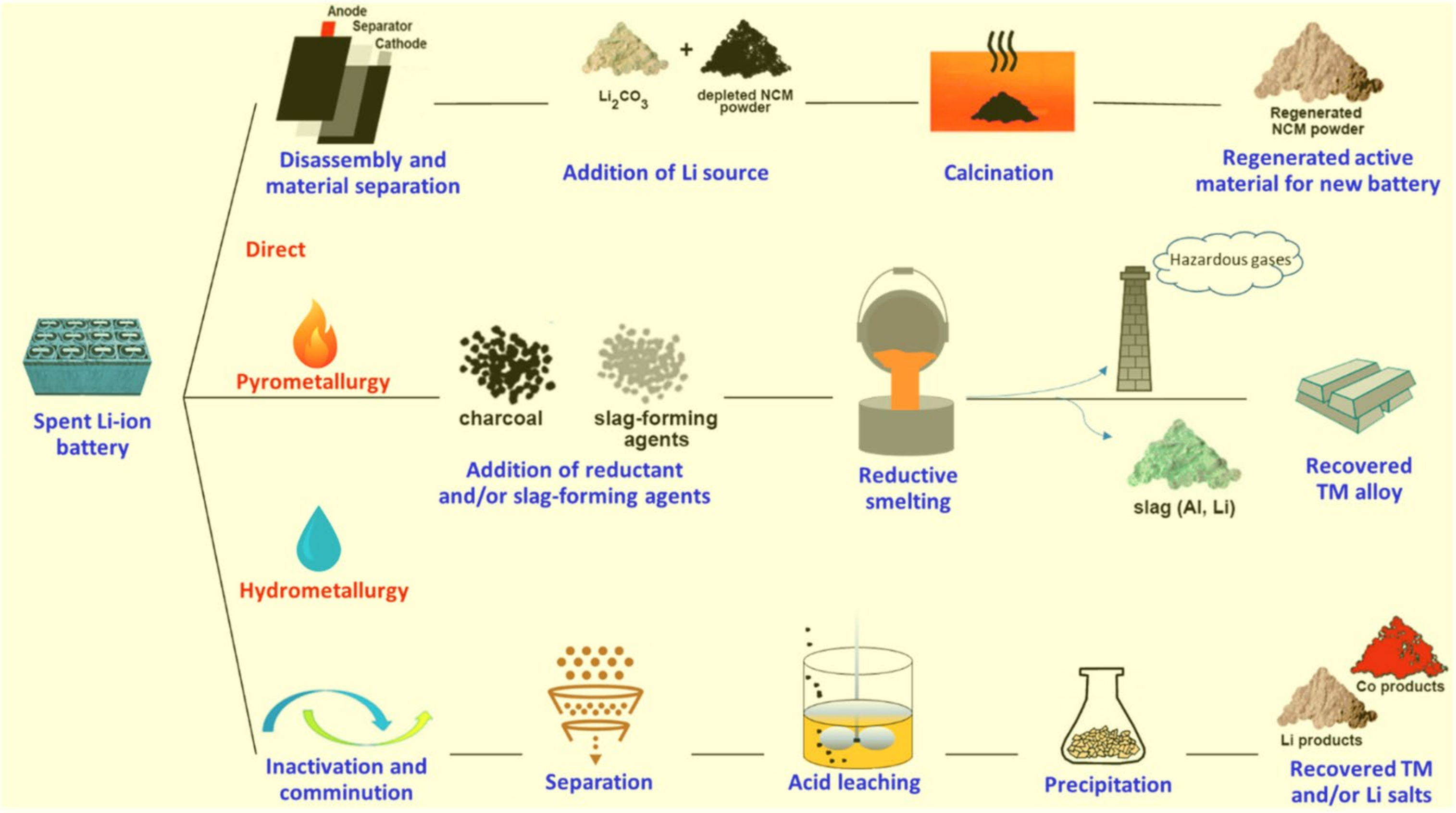


Figure 2. Typical direct, pyrometallurgical, and hydrometallurgical recycling methods for recovery of Li-ion battery active materials. From top to bottom, these techniques are used by OnTo,[15] Umicore,[20] and Recupyl[21] in their recycling processes (some steps have been omitted for brevity).

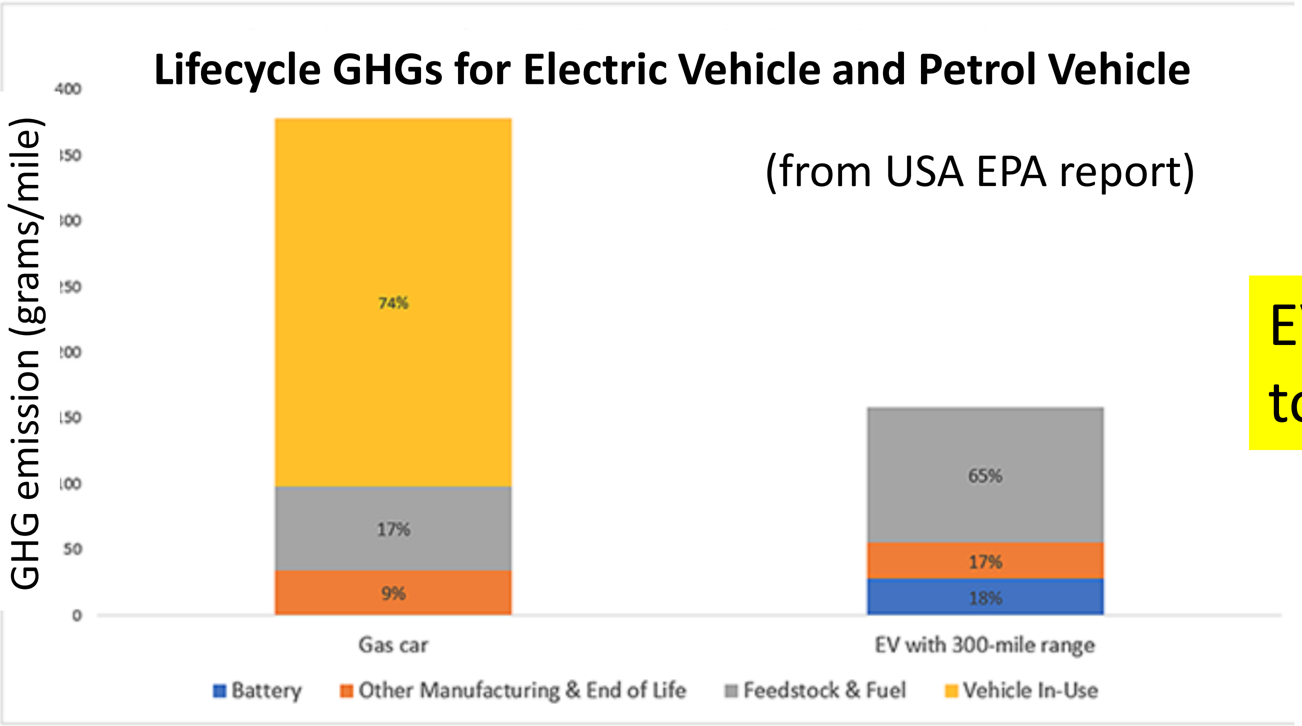
Zachary J. Baum et.al. *ACS Energy Lett.* 2022, 7, 2, 712–719

→→ Time consuming/costly but environmentally friendlier

→→ ‘quick and easy’ but GHG emissions high and waste slag generation not useful, Li not recovered

→→ currently most efficient butstill has environmental implications so significant room to improve technology
- Envirostream Australia uses this approach

“The greatest challenge remains logistics – collecting enough batteries to support a viable enterprise.”



Estimates shown[2] from GREET 2 2021 are intended to be illustrative only. Estimates represent model year 2020. Emissions will vary based on assumptions about the specific vehicles being compared, EV battery size and chemistry, vehicle lifetimes, and the electricity grid used to recharge the EV, among other factors.

EVs are **still** cleaner with respect to GHGs than petrol/diesel cars

https://www.epa.gov/greenvehicles/electric-vehicle-myths; https://greet.es.anl.gov/

However, we need to keep improving mining, extraction, manufacturing and RECYCLING processes and implement manufacturing with renewable electricity

Beyond current Li-ion battery technologies

Sodium-ion battery

(Faradion, UK)

Solid State Lithium(based on Li metal anode)

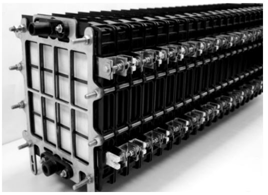
Lithium-metal polymer

Blue Car *(Bollore group, France)*

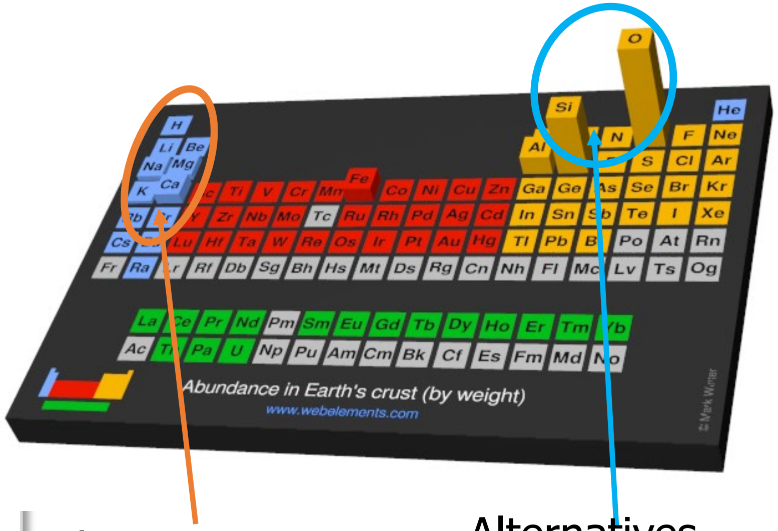
Lithium-sulfur battery

(LiS Energy and Gelion, Australia)

Metal-air battery



Aluminium metal-air EV *(Phinergy, Israel)*



Alternatives to Lithium anode: Sodium, Potassium, Magnesium, Aluminium

Alternatives high energy electrodes: anode: Silicon. cathode: S, O_2 (air).

Flow cell

Zinc-bromide flow battery *(Redflow, Australia), vanadium flow (redT), Iron flow (Lockheed Martin amongst others)*

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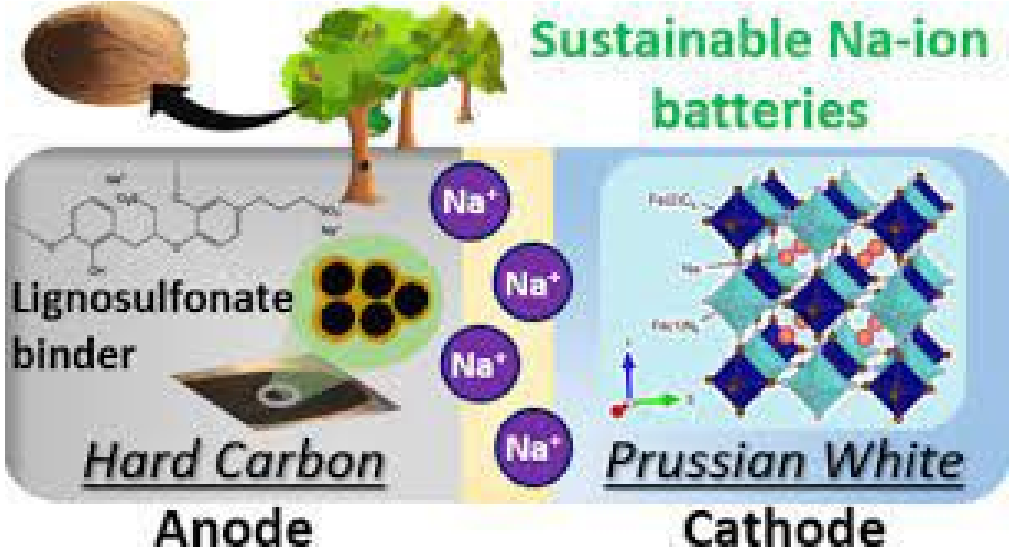
Na ion battery more sustainable in terms of resources

Sodium more abundant and more readily accessible



$Na_2Fe[Fe(CN)_6]$

HC anode derived from waste biomass

Current work also assessing feasibility of

- Waste textiles; food and organic waste collections
- biochar from water treatment

Cathodes

More abundant e.g.- Iron, Phosphate, Vanadium, Nickel

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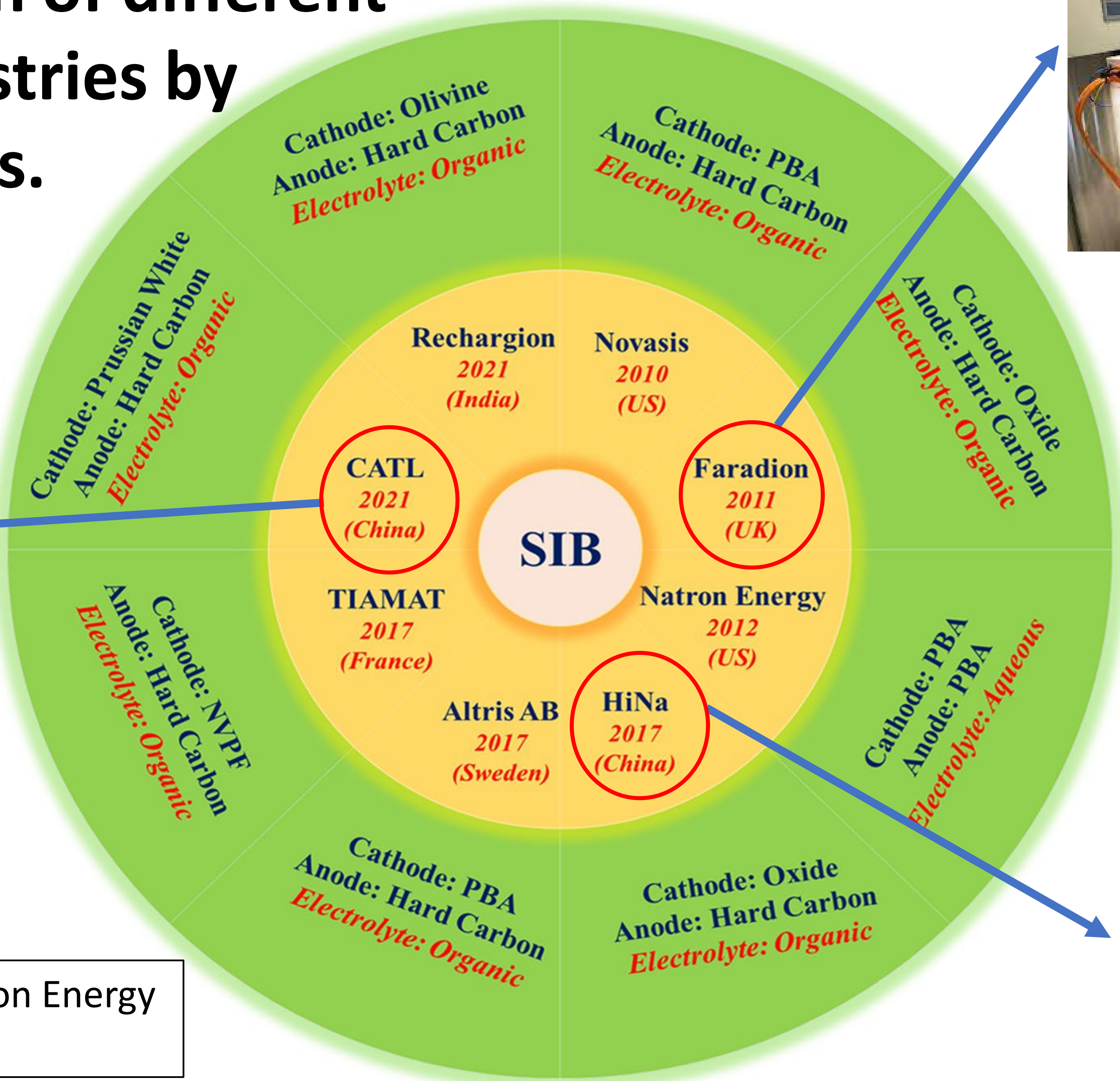
Commercialization of different Na battery chemistries by various companies.

CATL reported to supply SIBs for Chery's 'New Energy Vehicle' by end 2023



-First Faradion stationary storage battery installed in NSW Australia by Nation Energie Dec 2022
- Reliance (India) acquired Faradion 2022

HiNa releases first Na battery EV Feb 2023

All technologies apart from Natron Energy use **Hard Carbon** as the ANODE.

OXF OPEN MATER SCI, VOLUME 3, ISSUE 1, 2023, ITAC019, HTTPS://DOI.ORG/10.1093/OXFMAT/ITAC019

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Benefits of Na batteries

- Cheaper and abundant resources, use Al current collector instead of Cu
- Current NIBs have similar energy density to existing LFP LIBs (160Wh kg^{-1}) – and still opportunity to improve
- Much wider range of operating temperatures
- Safer and can be shipped charged (where LIBs cannot)

Opportunity for Na batteries

- Na batteries can be manufactured on same line as LIBs so reduced energy costs need to be considered as with LIBs
- Design Na batteries with recyclability in mind and with longer life
- Target specific applications don't compete with LIB (eg lower range EVs, home storage, telecommunications, power tools, light vehicles ….)
- Commercialisation still in it's infancy so opportunities to innovate; safer electrolytes; novel hard carbons; sustainable manufacturing

Summary

- Lithium ion battery here for the long haul and in particular for transportation
- GHG and electricity requirements for LIB manufacturing needs to be considered and advanced, more sustainable methods researched and implemented
- Recycling will be critical for sustainability and in the materials supply chain
- Promising emerging technologies (already in the commercialization phase) include Sodium Ion and Lithium Sulfur batteries; these will be in addition to LIBs not instead of.