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ADVANCED
BATTERY RECYCLING

EverBatt: Cost and Environmental Impacts of Battery Recycling

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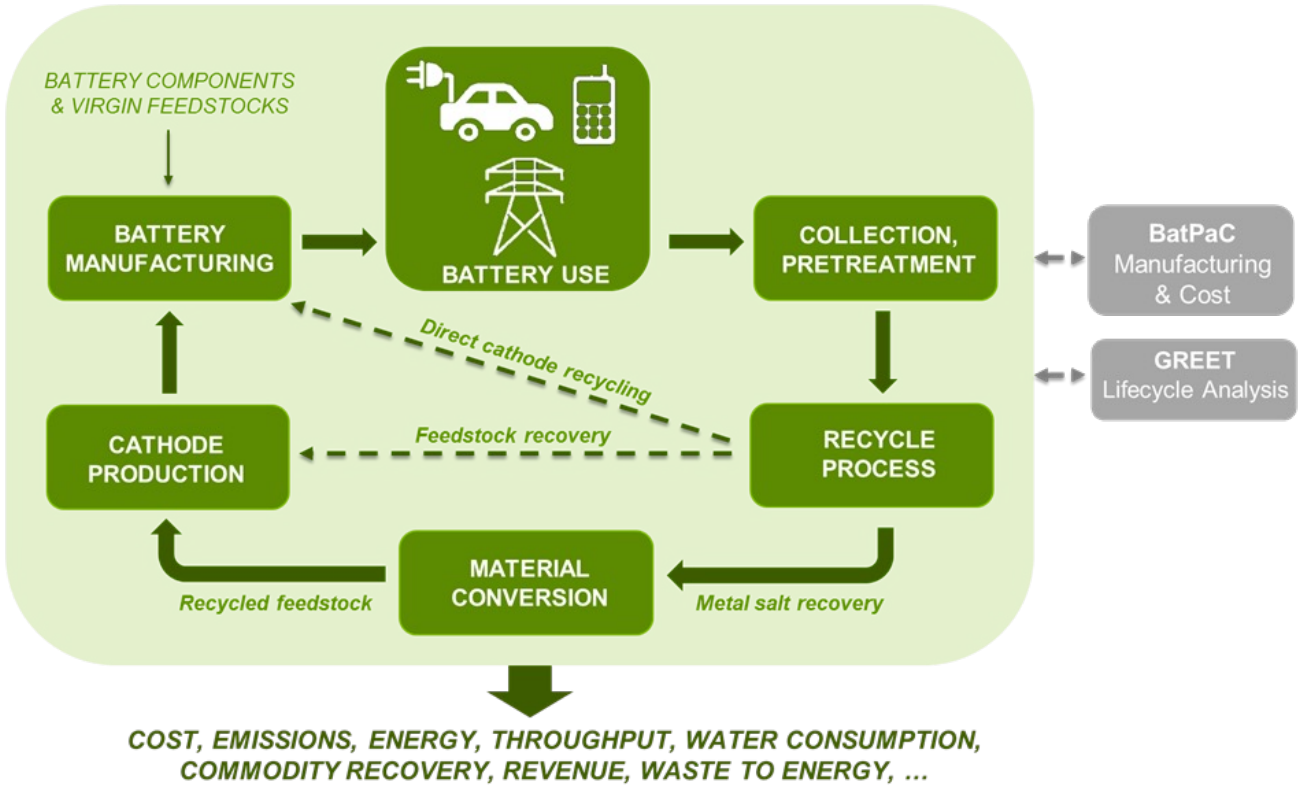
EverBatt: A Battery Recycling Process and Supply Chain Model

The model is a tool that helps compare cost and environmental impacts within, and among, each of the life-cycle stages of a battery and can be used to inform decision making

Example functions:

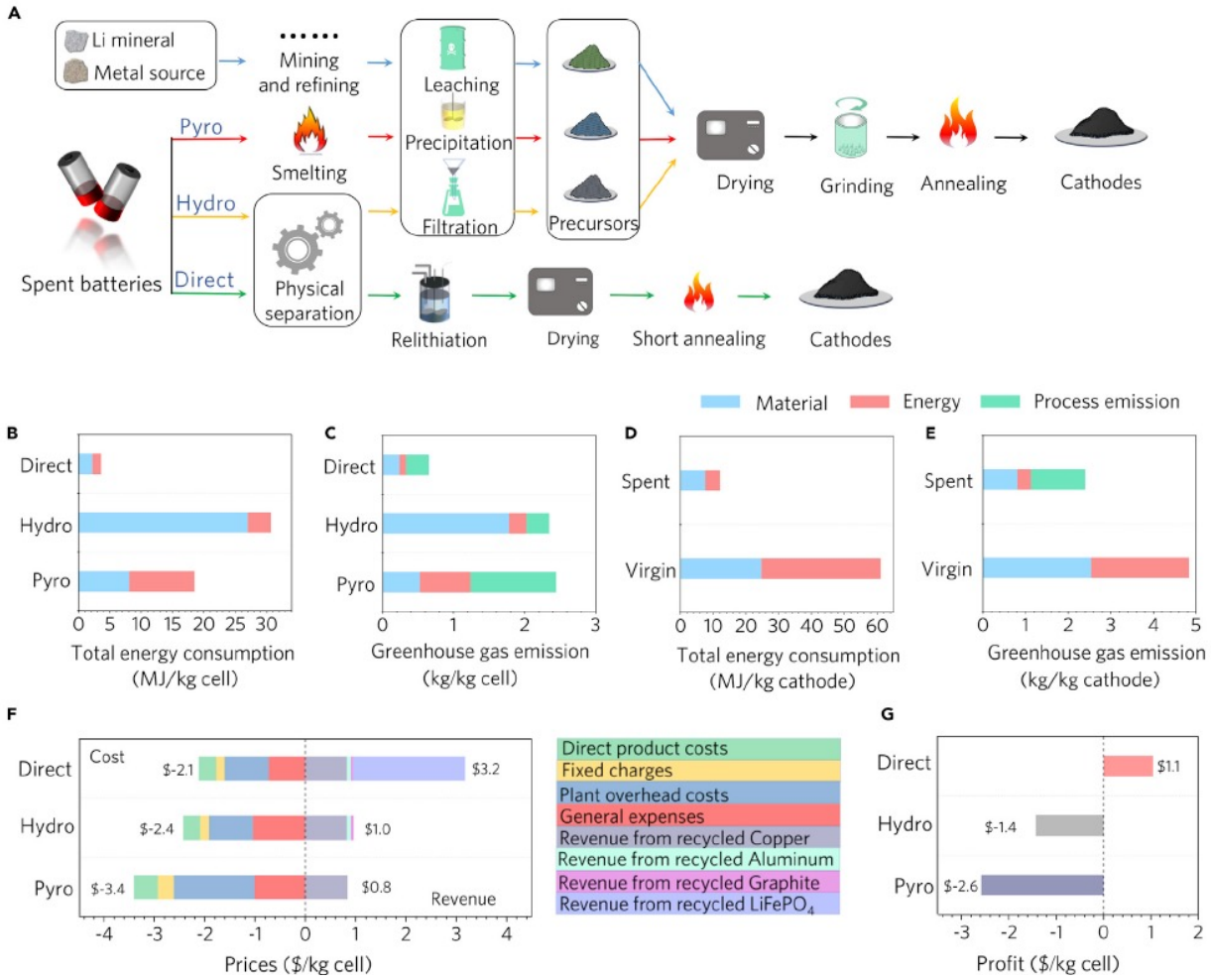
- Process flow optimization
- Pinpoint process and supply chain hotspots
- Identify opportunities for improvement
- Identify barriers to commercialization
- Provide a holistic picture of battery sustainability over its life cycle



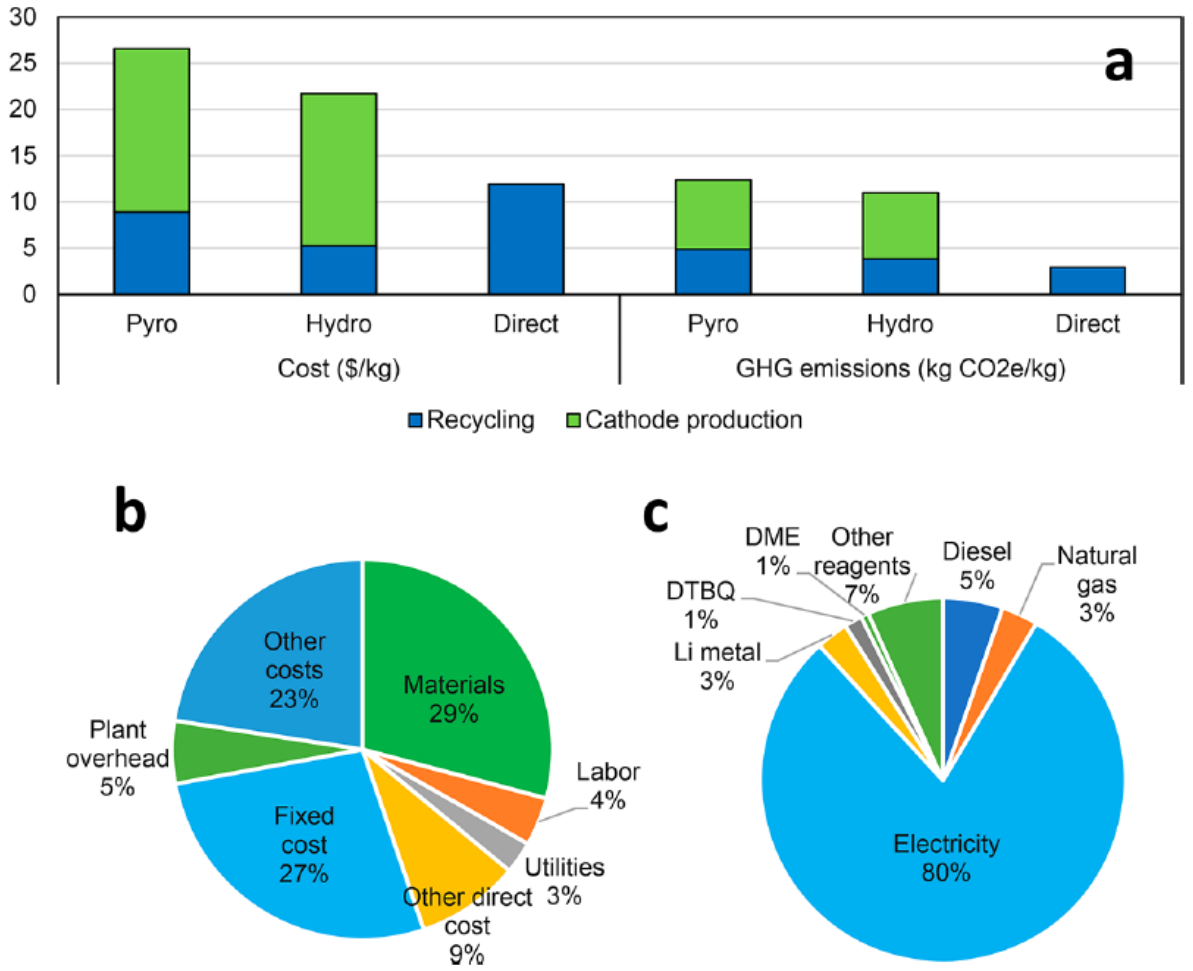
Available for download at:
https://www.anl.gov/amd/everbatt

Courtesy Argonne

EverBatt Application: Informing R&D At ReCell



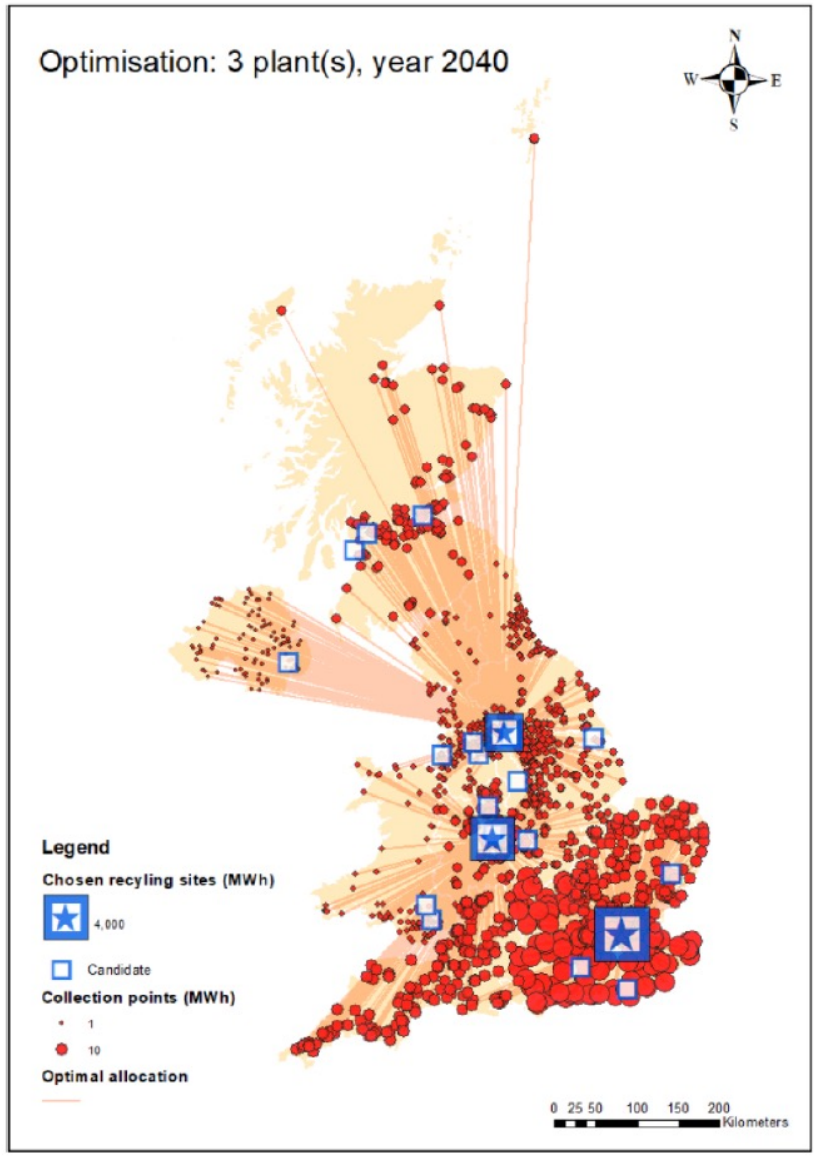
Xu *et al.*, Joule 2020, 4, 2609–2626

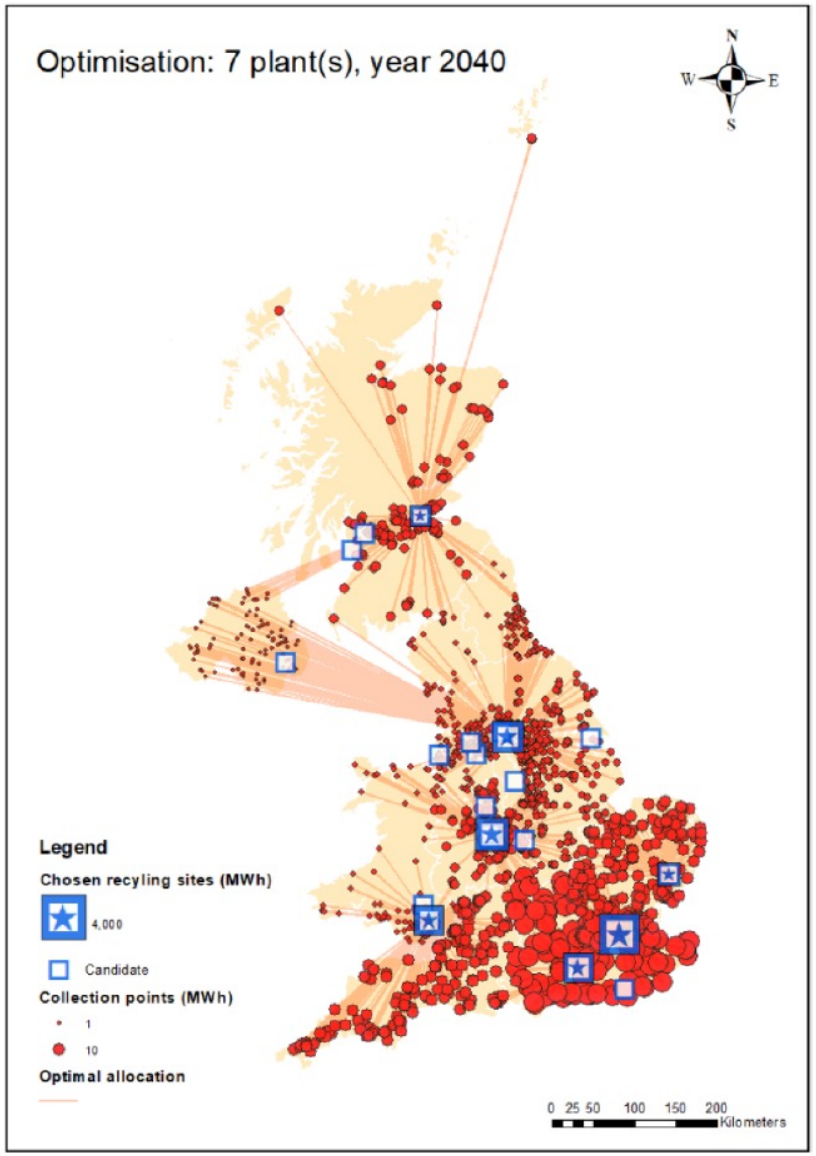


Park *et al.*, ACS Sustainable Chem. Eng. 2021, 9, 8214−8221

EverBatt Application: Planning for Battery Recycling Infrastructure

(Nguyen-Tien *et al*, 2022, https://doi.org/10.1016/j.apenergy.2022.119230)





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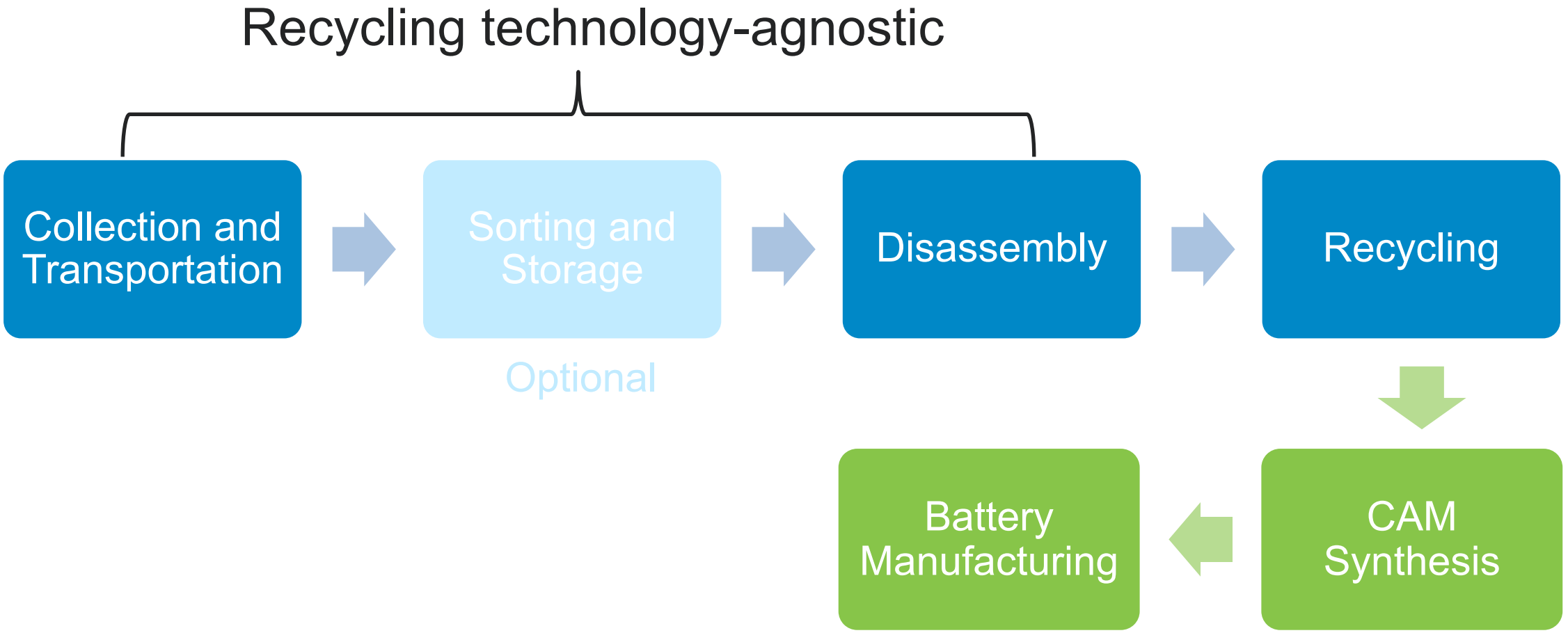
What does battery recycling entail?



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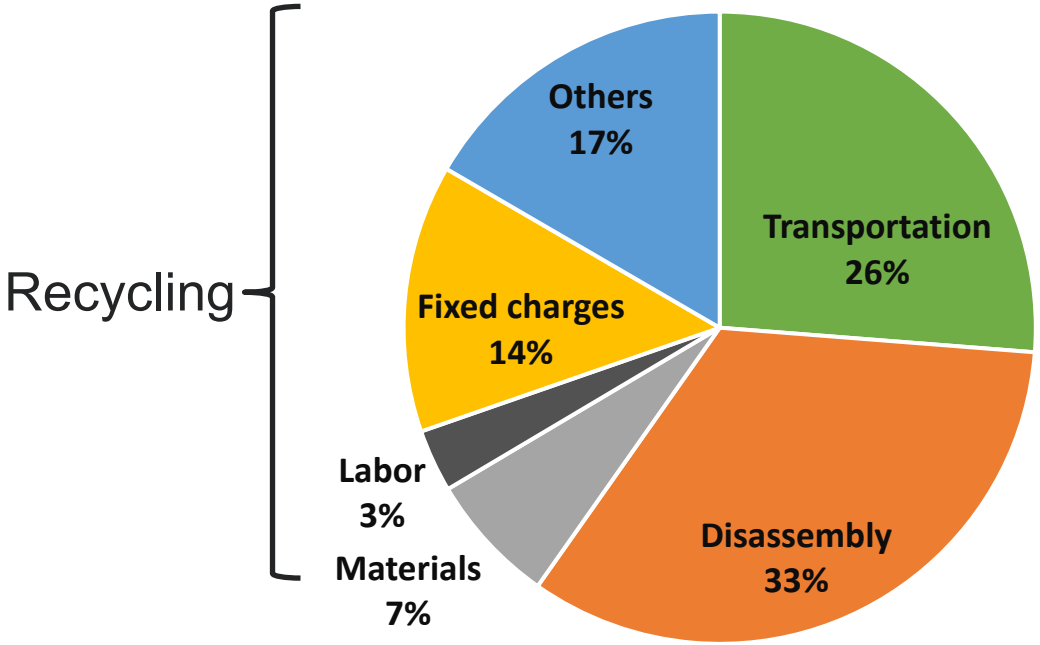
CAM: cathode active material

Why is battery recycling costly?

Battery Recycling Cost Breakdown

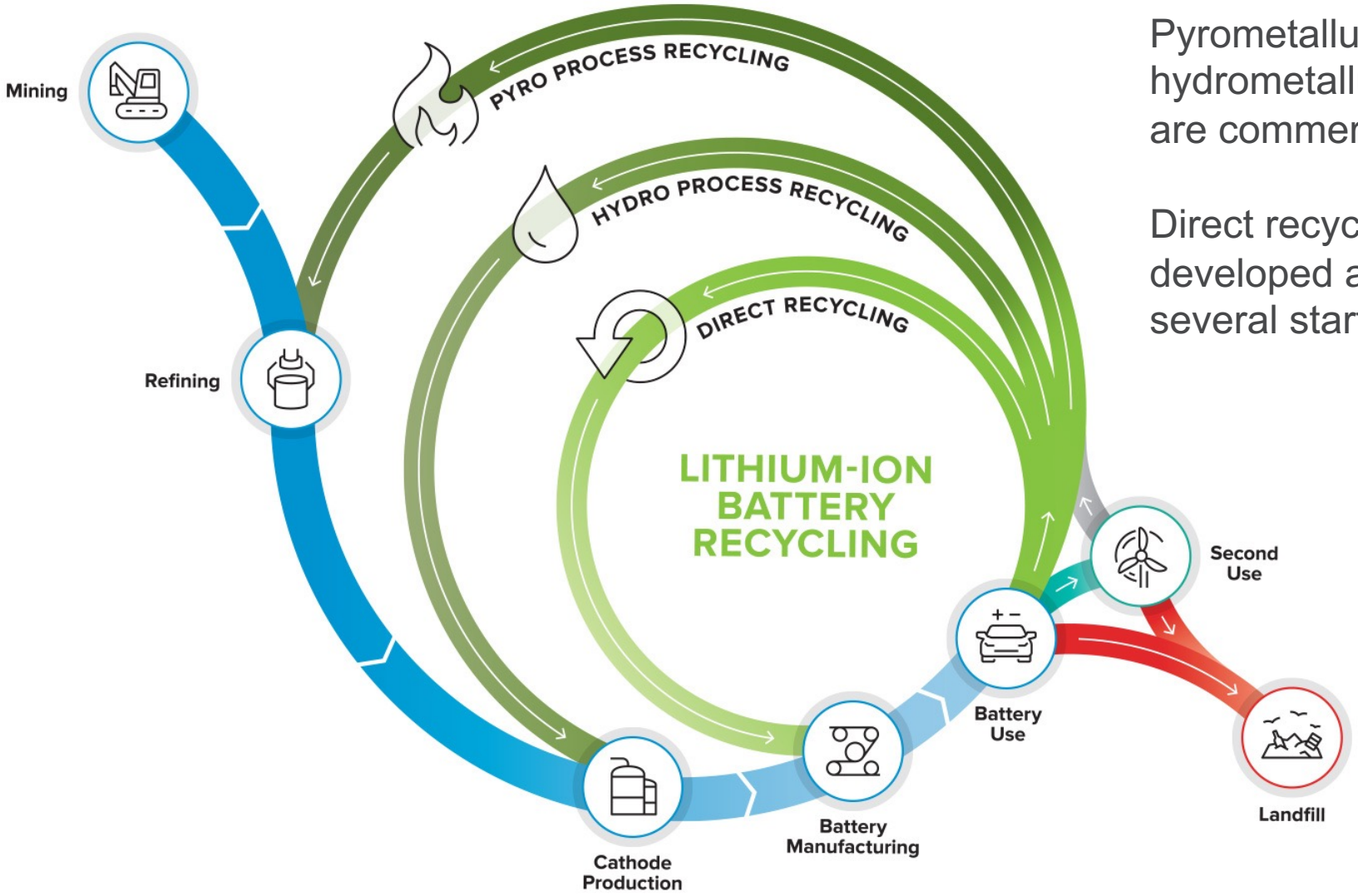


Numbers shown are for illustrative purposes only and will change with assumptions.

- Li-ion batteries are regulated as Class 9 hazardous materials for transportation.
- U.S. Department of Energy launched Battery Recycling Prize to incentivize the development of novel logistics solutions.
- Technologies to render batteries inert before transportation are being developed.

- EV battery disassembly is labor intensive.
- Emerging EV batteries designs such as CTC and CTB will further complicate disassembly.
- Robotic disassembly is being developed.
- Design for disassembly should receive more attention.

Battery Recycling Technologies Overview

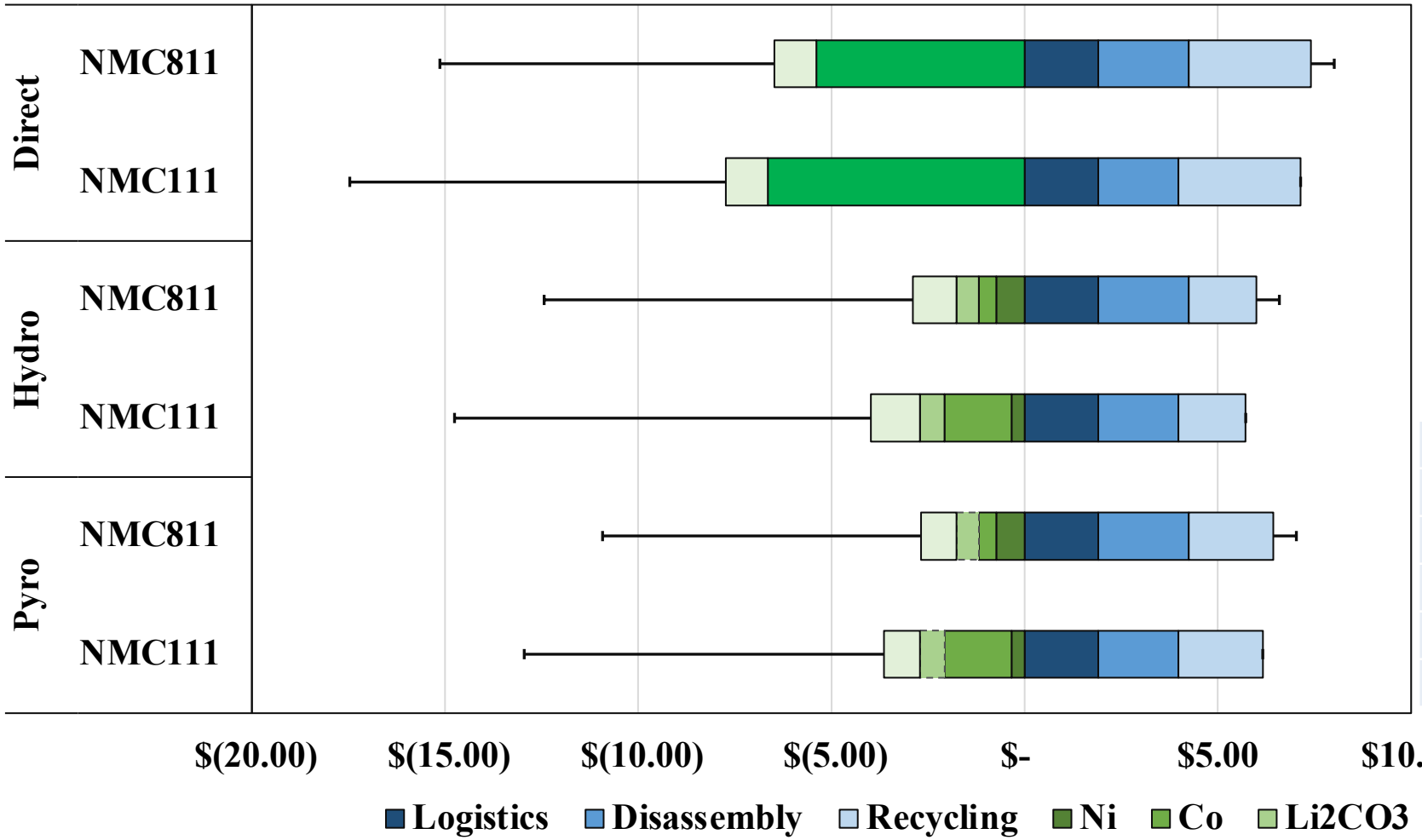


Pyrometallurgical (pyro) and hydrometallurgical (hydro) are commercialized.

Direct recycling is being developed at ReCell and several startup companies.

Comparison of Recycling Economics

Direct recycling can generate a higher revenue by preserving cathode structure. The switch to Ni-rich chemistries will reduce revenue for recycling.

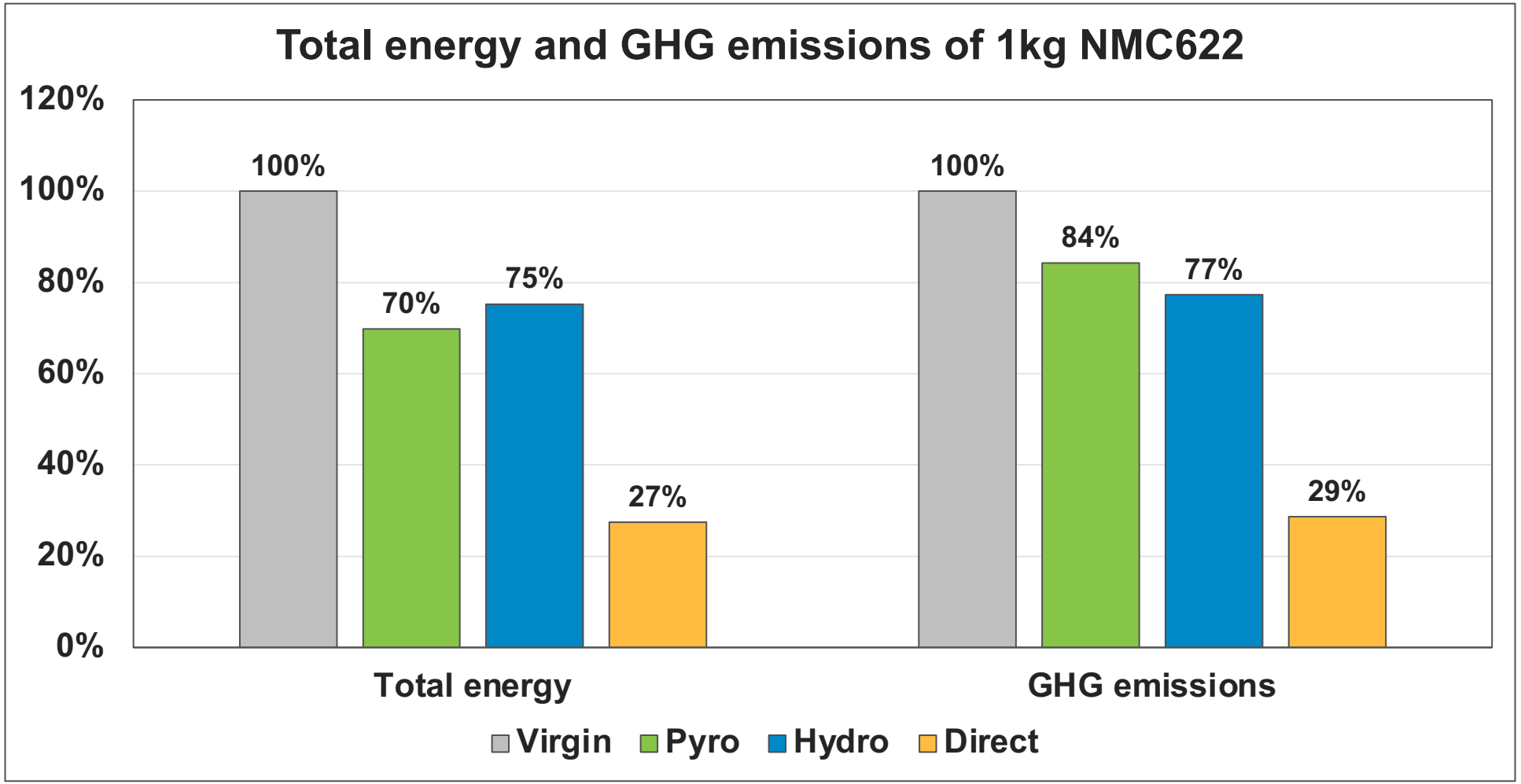


Blue denotes costs per kg battery recycled;
Green denotes revenues per kg battery recycled;
Colored bars represent minimum values;
Black bars represent maximum values.

Material unit cost	Max (/kg)	Min (/kg)
Ni	$ 50.0	$ 5.0
Co	$ 115.0	$ 25.0
Li_2CO_3	$ 17.0	$ 5.2
NMC111	$ 52.5	$ 21.3
NMC811	$ 50.2	$ 19.3

Comparison of Environmental Impacts

Recycling helps reduce environmental impacts compared with virgin production, regardless of technology.



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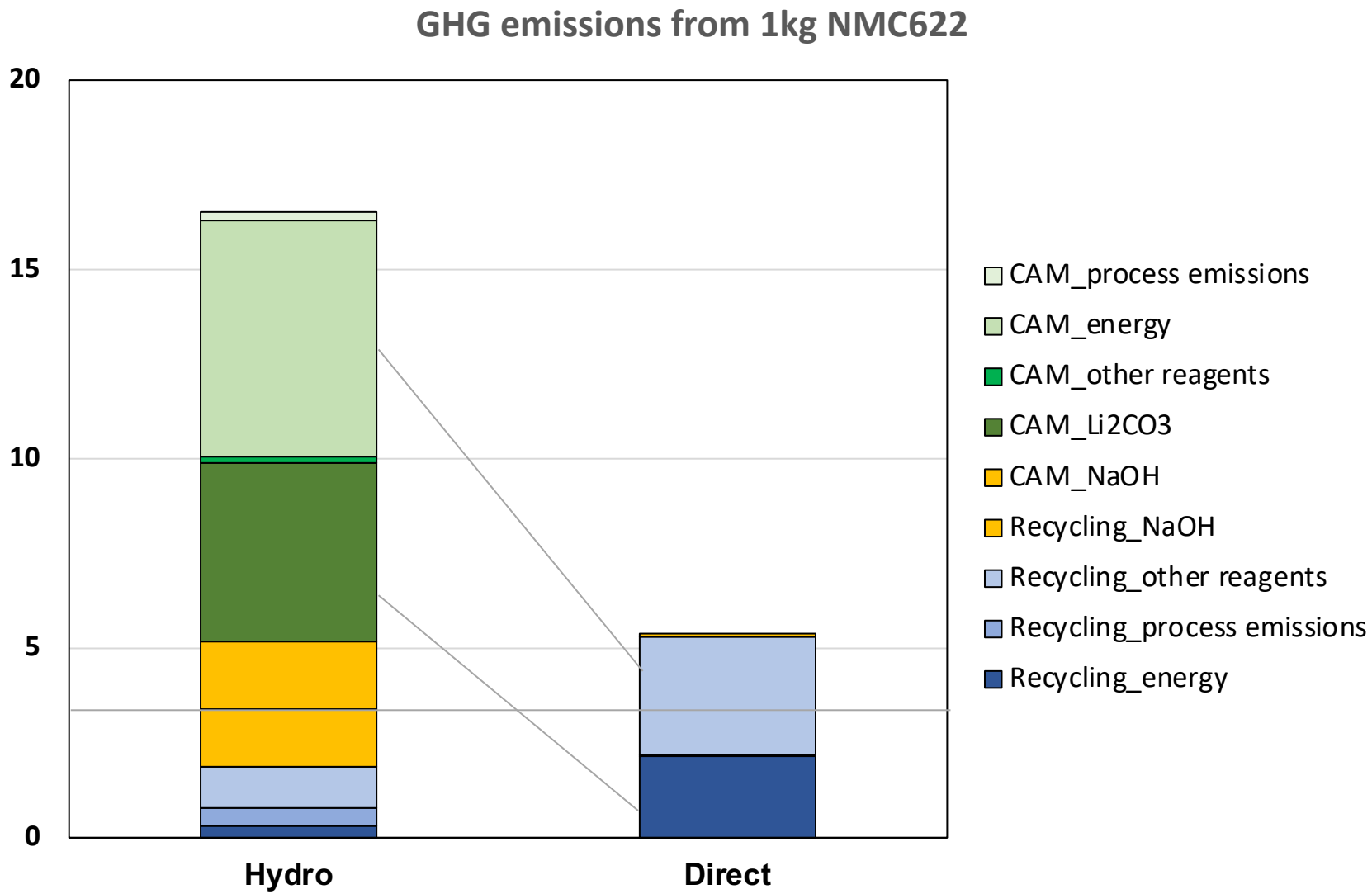
Recycling GHG Emissions Breakdown

Direct recycling uses less energy and reagents and thus emits less CO2. NaOH use is a hot spot.



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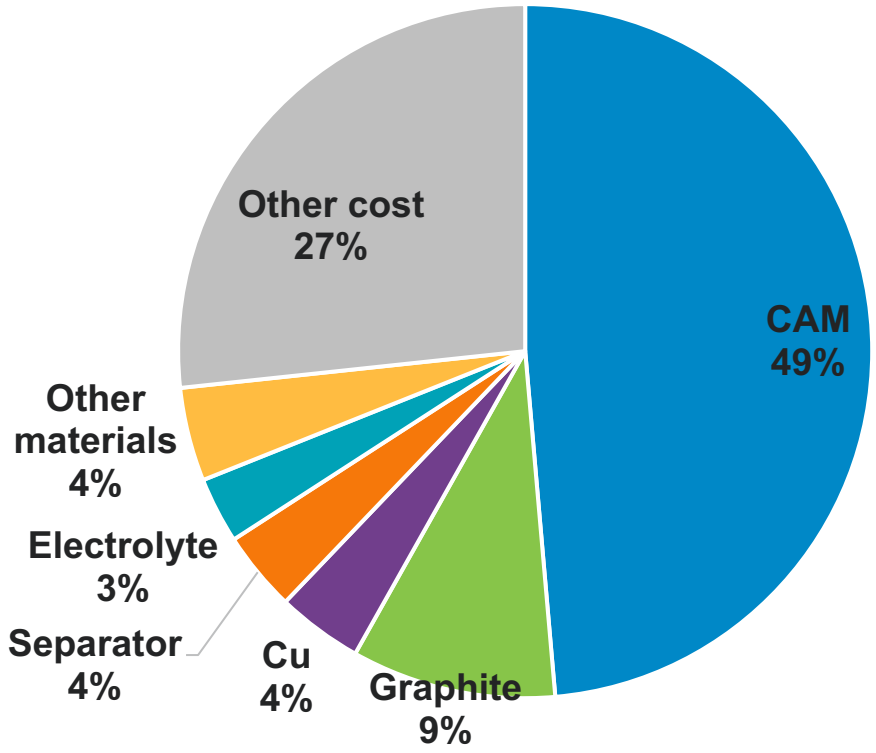
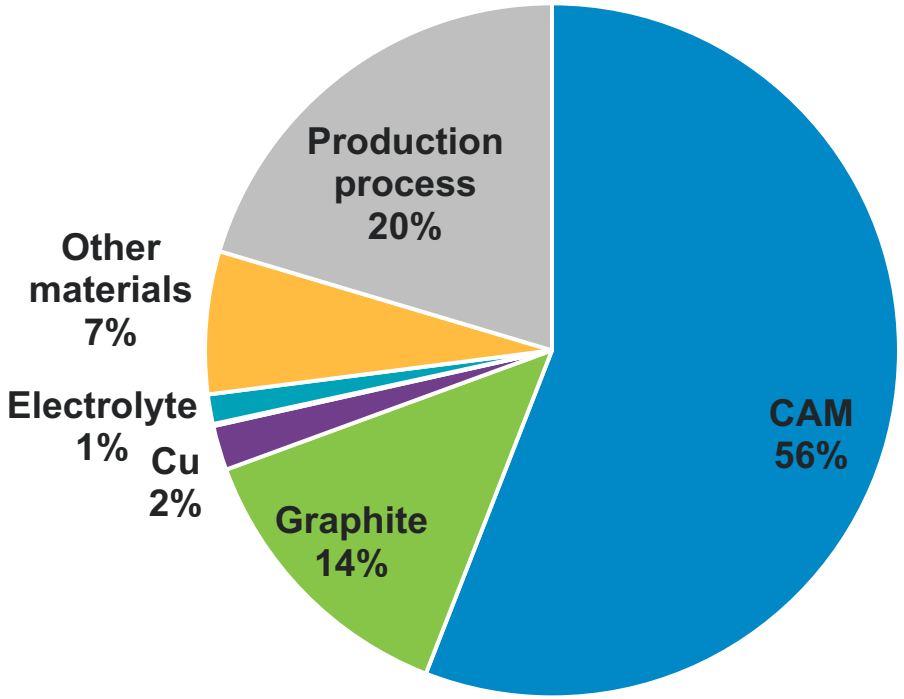
Opportunities for Improvement

Current recycling technologies focus on CAM. What about other materials? Where do they go if not recycled?

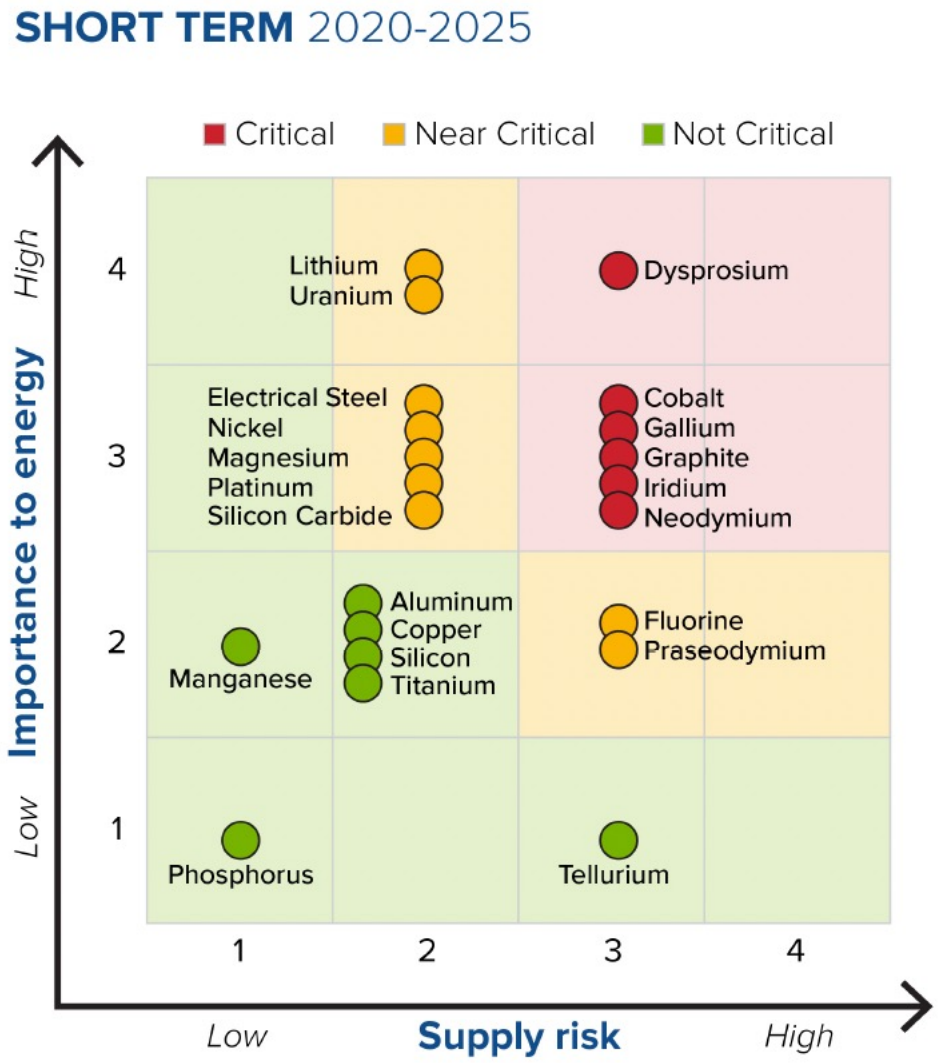
NMC622 cell cost breakdown

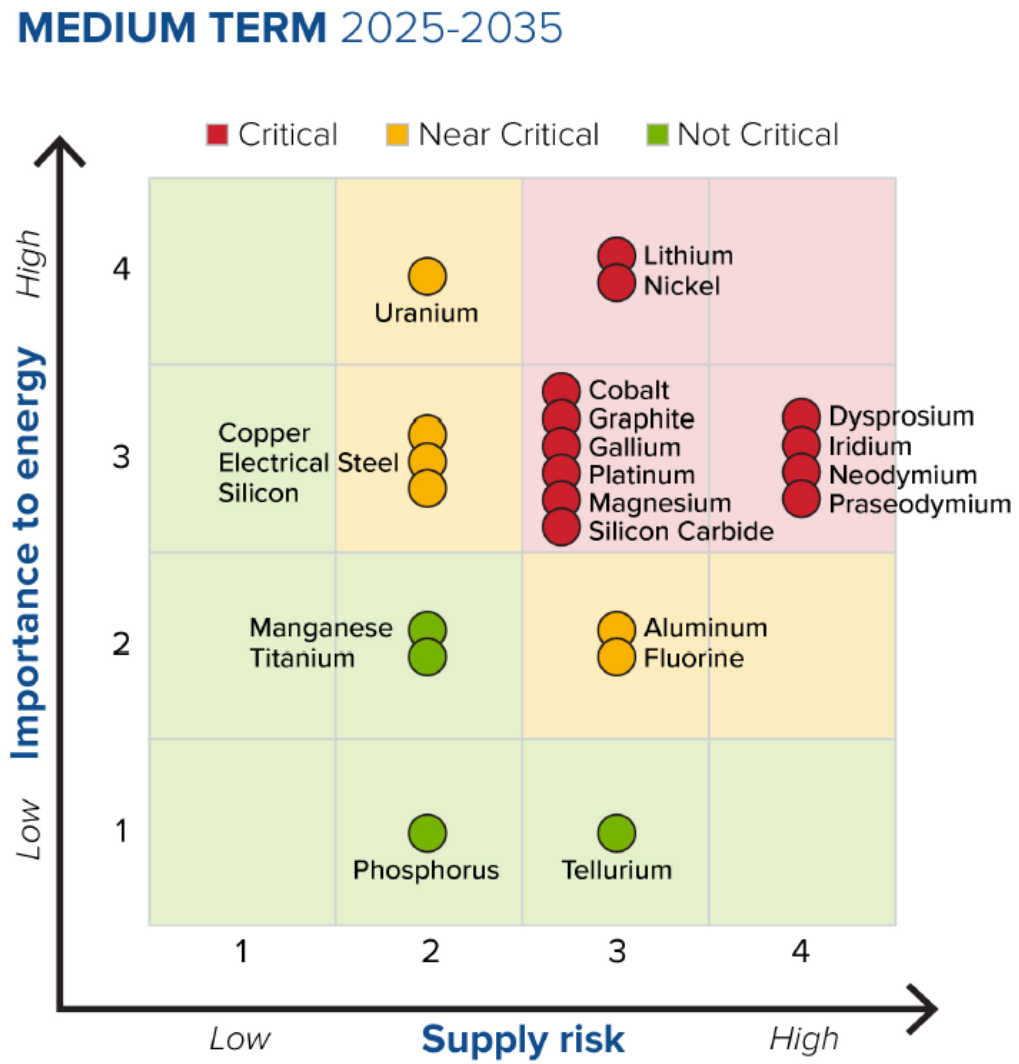


NMC622 cell GHG breakdown



What about other technologies and the embodied materials?





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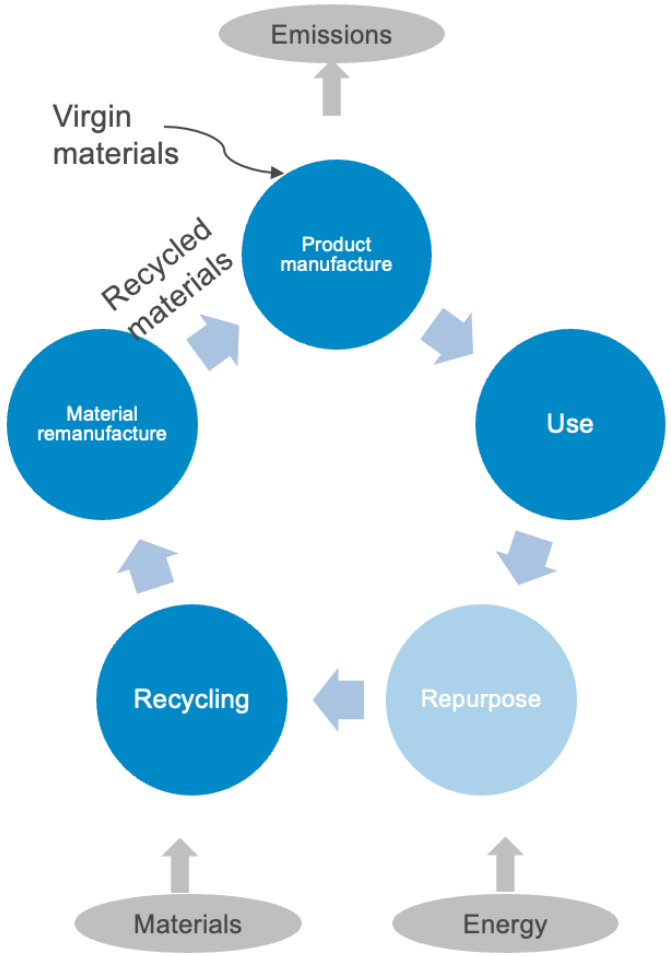
Source: DOE Draft Critical Materials Assessment Report

Beyond Battery Recycling: EverGreen Suite

Closed-loop recycling models for decarbonization technologies to enable a circular economy



- **EverBESS**: recycling of stationary battery energy storage systems (BESS)
  - Funded by Office of Electricity
  - Evaluate recycling of batteries (LIBs and flow batteries) and other BESS components
- **EverHydrogen**: recycling of electrolyzers and fuel cells
  - Funded by HFTO
  - Will support R&D at the fuel cell/electrolyzer Recycling and Recovery Consortium
- **EverLWMaterial**: recycling of vehicle lightweighting materials, particularly Al
  - Funded by VTO
  - Evaluate recycling of different Al alloys proposed for vehicle lightweighting
- **EverSolar, EverWind, Ever…**

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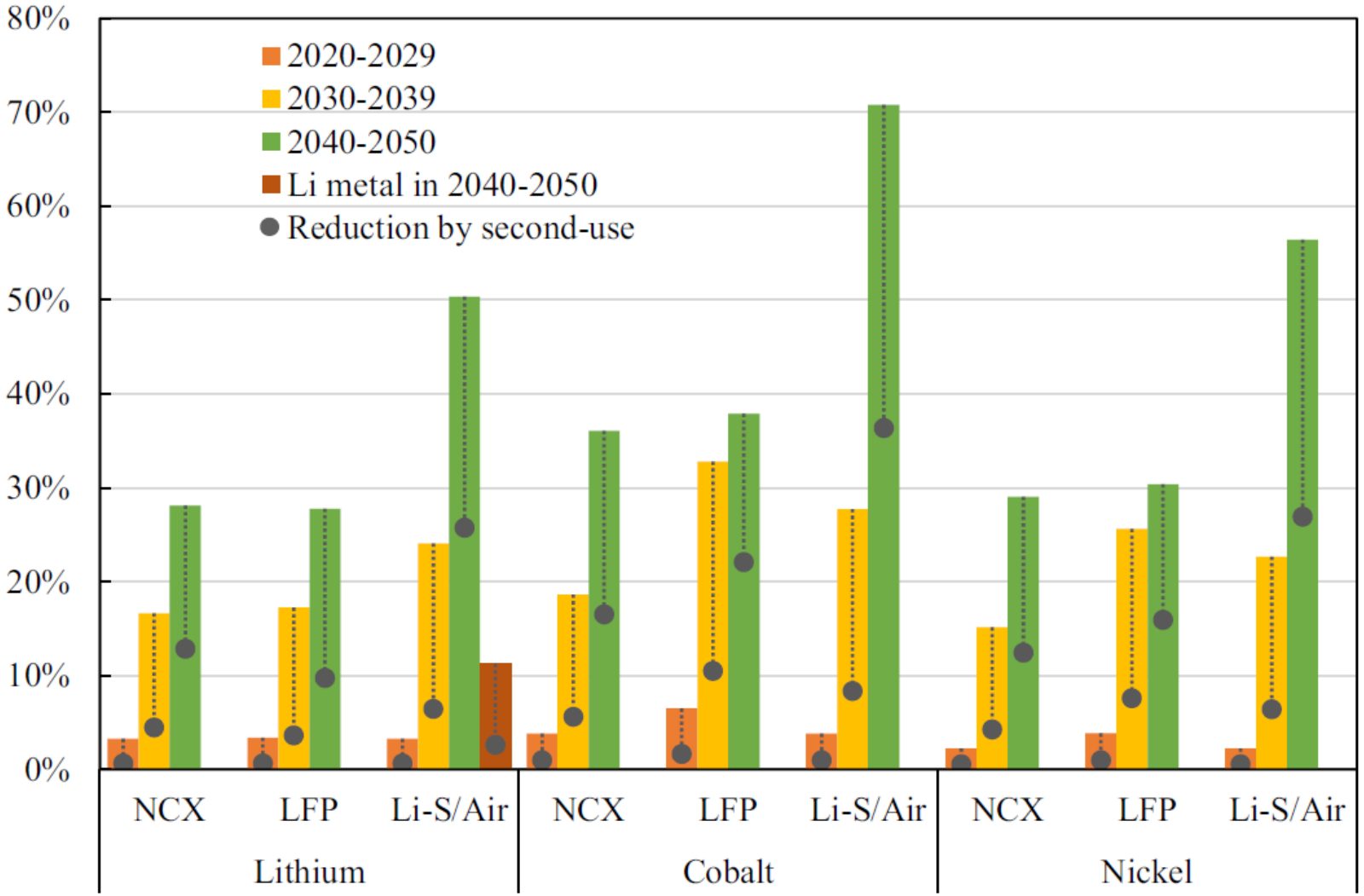
Recycling alone is not enough to solve the global EV battery material supply problem.



(Xu *et al*, 2020, https://doi.org/10.1038/s43246-020-00095-x)

Food for thought

- Closed-loop recycling (i.e., recovering materials from spent batteries and incorporating them back into the battery supply chain) can help us move towards more sustainable batteries and a circular economy, but what else do we need to fully enable a circular economy for batteries?
- Direct recycling process shows great potential to improve the economics and environmental impacts of battery recycling. Technologies that strive to preserve the most value of the material/product with minimal processing should be explored for remanufacturing and recycling.
- Conventional TEA and LCA are product/technology-oriented. Should material-oriented TEA/LCA be explored for circular economy?
- The best way to reuse/recycle a material/product may involve another sector. How do we facilitate a circular economy among sectors?

Thank you!

If you have any questions, please contact me at: qdai@anl.gov

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