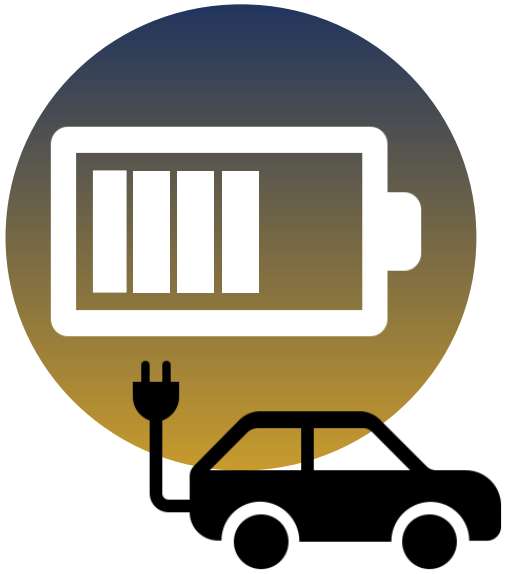

Setting the scene - Used EVs and end-of-life batteries in Lower- and Middle-Income Countries

UNEP Global Electric Mobility Programme "Used Electric Vehicles, Battery End-of-Life & Circularity – Africa Workshop

April 24-26, 2024

Prof. Alissa Kendall

University of California, Davis

ITS UCDAVIS INSTITUTE OF TRANSPORTATION STUDIES

UCDAVIS CIVIL AND ENVIRONMENTAL ENGINEERING

Outline of this talk

- Lithium-ion battery (LIB) technology and impacts across the life cycle
- Geography of the LIB life cycle and projections of used 2nd Hand EV flows to Africa
- Projections of end-of-life (EoL) LIBs in Africa and potential used cases
- Repairability of EVs
- Q&A (20 min)

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Lithium Ion Battery (LIB) Technology

- LIBs are the key enabling technology for electric vehicles (EVs). They have the advantage of high power and energy density compared to other battery chemistries.
- LIBs are often differentiated by their cathode chemistries, which can have significant effects on the minerals needed to manufacture them, and their performance.

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LIB Technology

- LIB cells are comprised of four key parts: anode, cathode, separator and electrolyte. Cells are assembled into modules, which are then assembled into packs.
- Anodes are typically made of graphite and separators are polymers

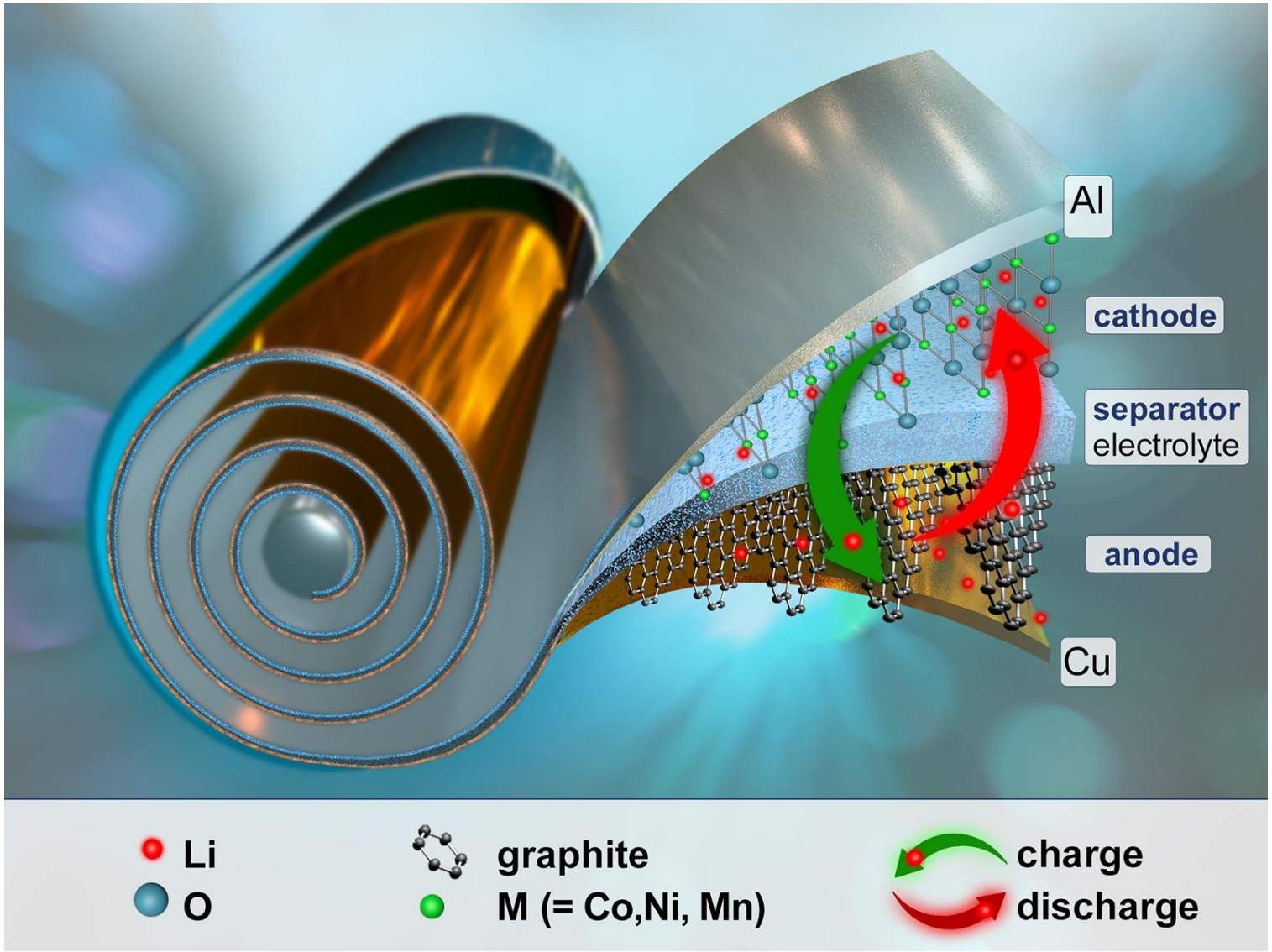

Image credit: *Principle of a lithium-ion battery. © Reiner Müller, FRM II / TUM*

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Cathodes come in a variety of chemistries. Three are shown here

N = Nickel

M = Manganese

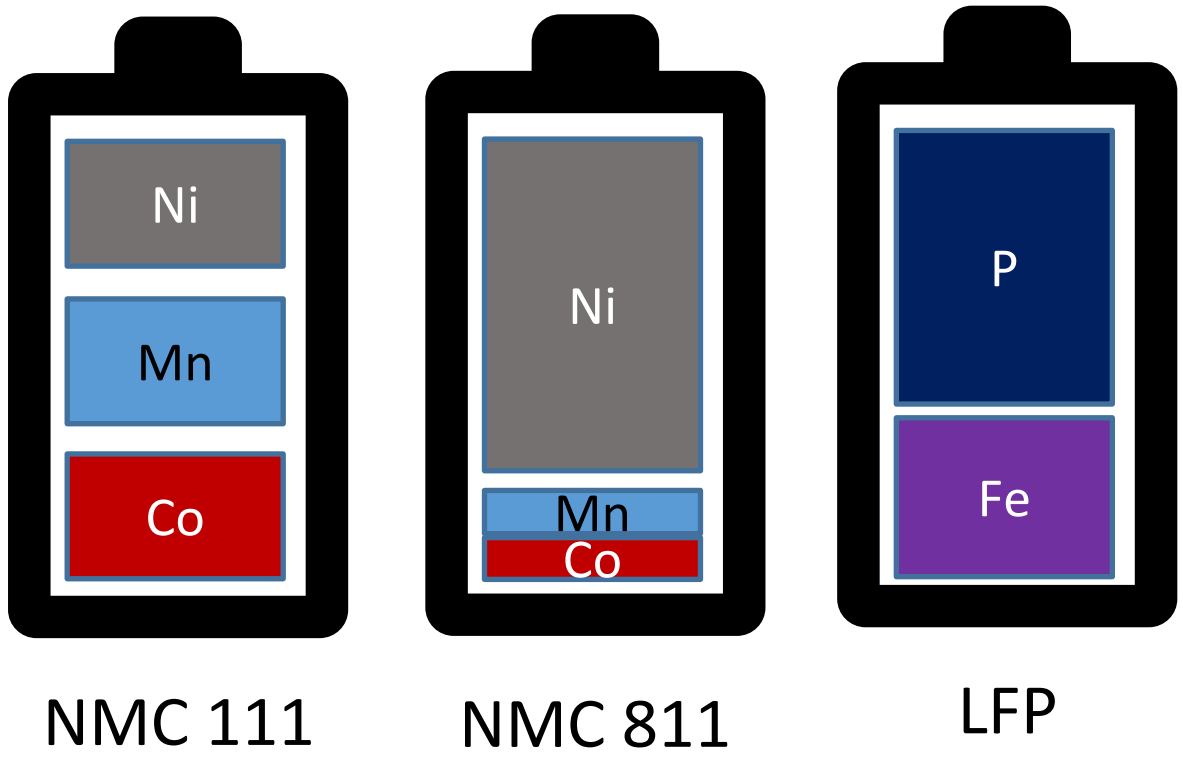
C = Cobalt

L = Lithium

F = Iron

P = Phosphate

The numbers following the letters show the relative proportion of each mineral



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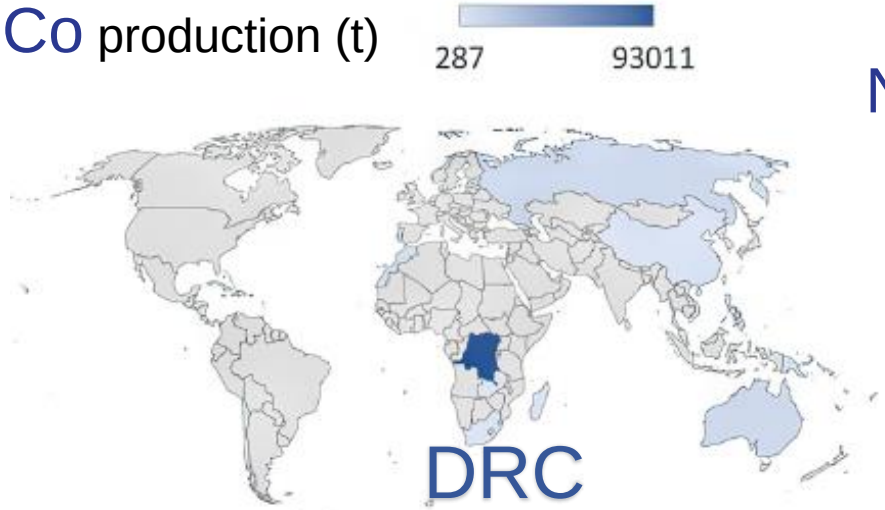
Global distribution of raw materials and manufacturing for LIBs

LIB Manufacturing (GWh)

Li production (t)

Co production (t)



Ni production (t)

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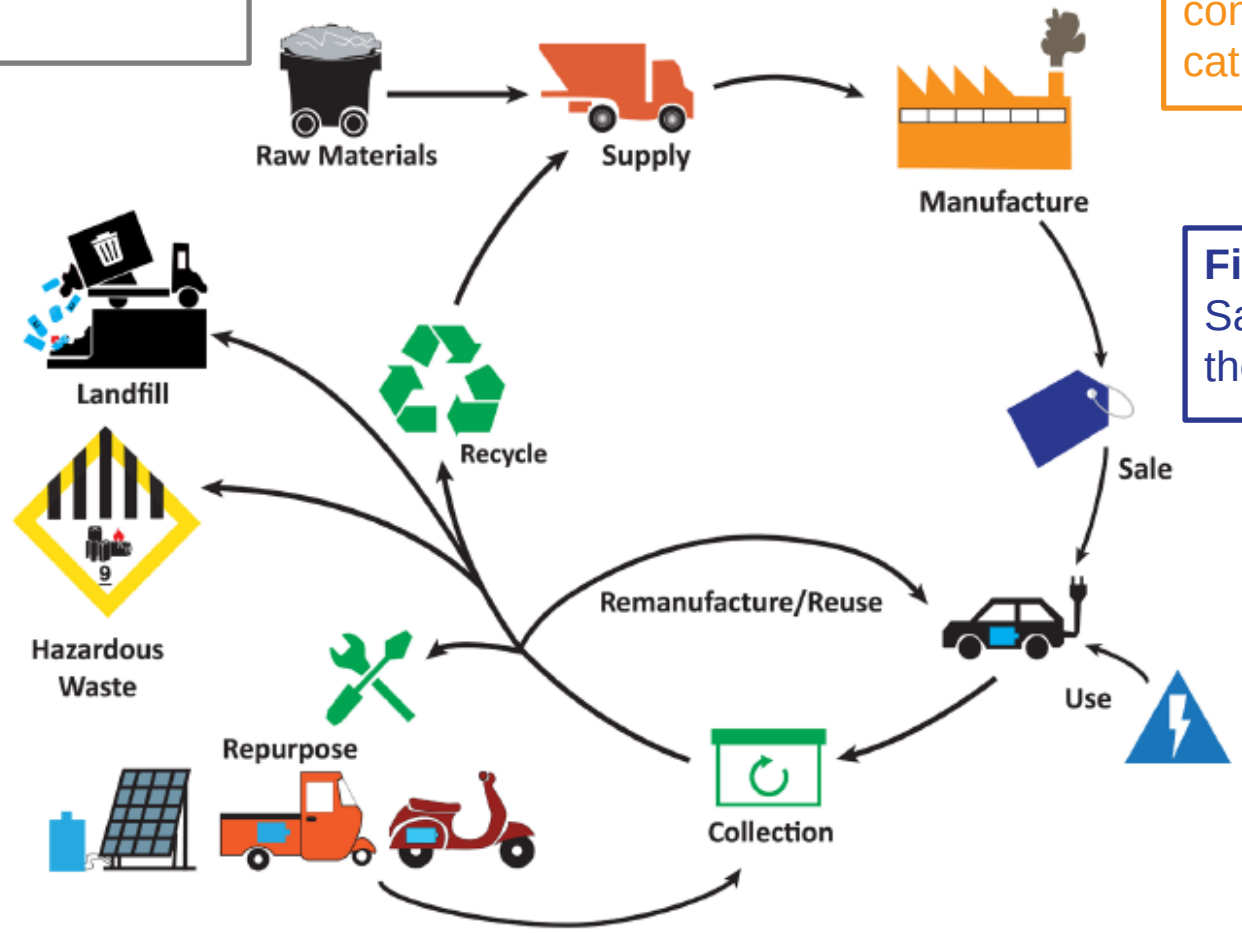
The Electric Vehicle Battery Life Cycle

Raw Materials
Rapid growth in demand means expansion and new mines.
Inequitable distribution of benefits and harms

Recycling
-Global recycling infrastructure is concentrated in China, growing in S Korea, EU, US

Repurposing/Second-Life
-Many of the barriers to repair are also barriers to safe and efficient repurposing
-Ultimately recycling still required



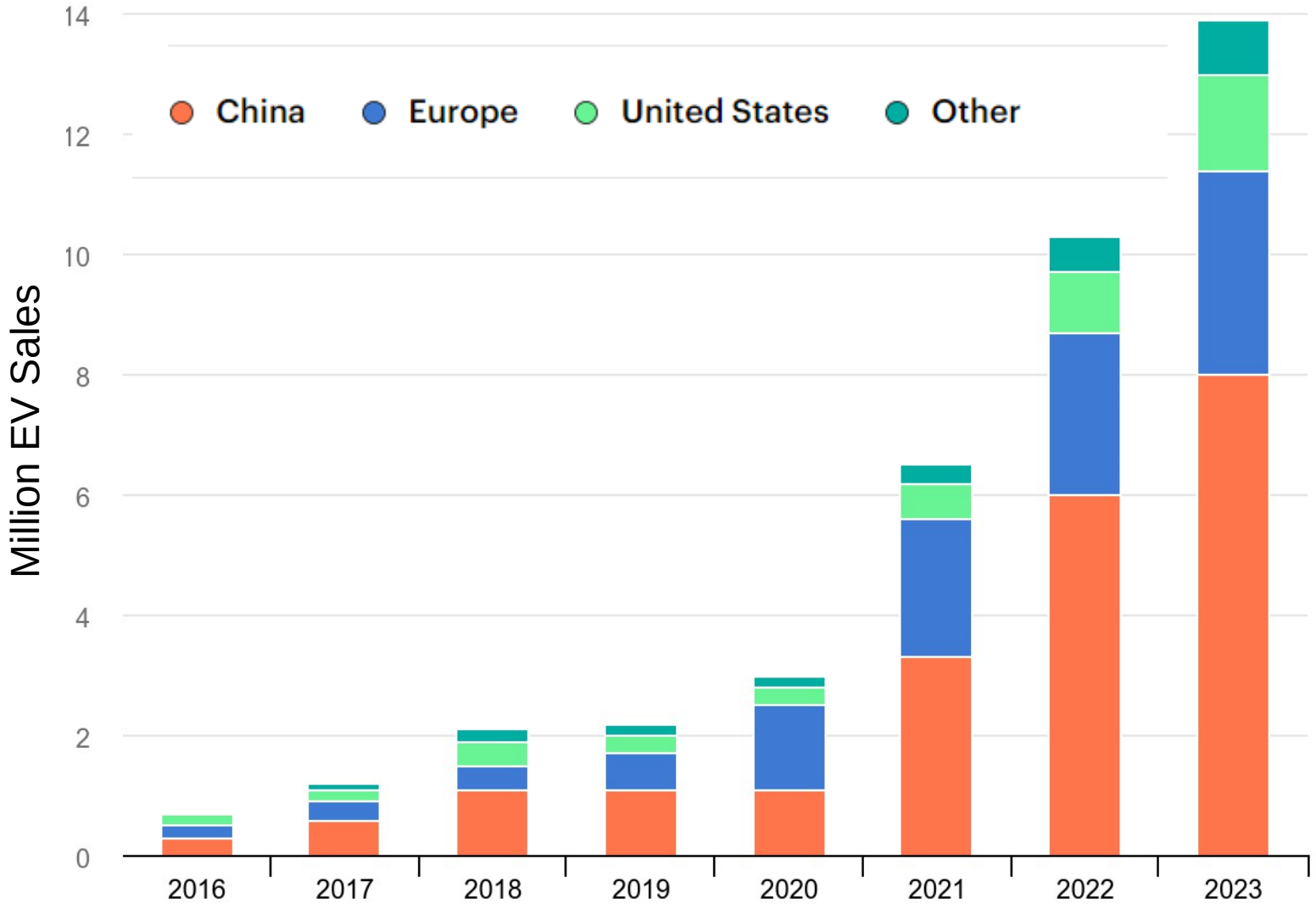
Manufacture
Battery manufacturing is concentrated in China, especially cathode manufacturing.

First Sale
Sales are largest in China, then the EU and then the US

EV Use
-It all depends on the grid
-EV batteries degrade, reducing range and decreasing performance.
–EVs may be exported from their original country of sale, for resale
- They can't be fixed and repaired in the same way as an engine.

New EV Sales, Global

- New EV Sales are dominated by China, followed by EU and US.



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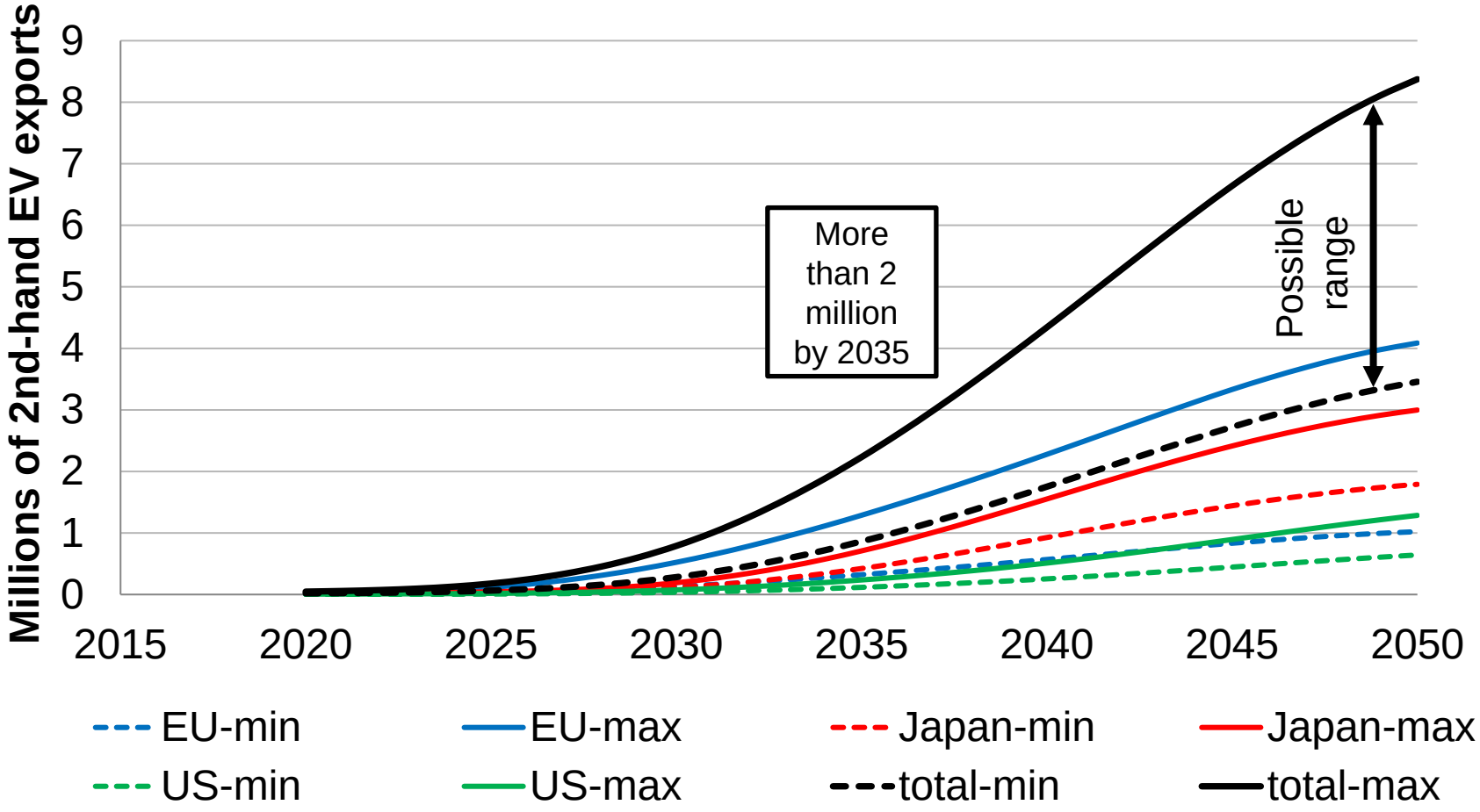
Vehicles may not stay in their original country of sale, many are traded internationally.



More than 8 million used EVs traded by 2050 – that is more than 4 million tonnes of battery material

These data reflect predicted exports only from EU, US and Japan. China began allowing used vehicle exports starting in 2019, and will likely be an important source of used EVs in the future.

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Kendall et al. 2023. https://escholarship.org/uc/item/7m2536mp

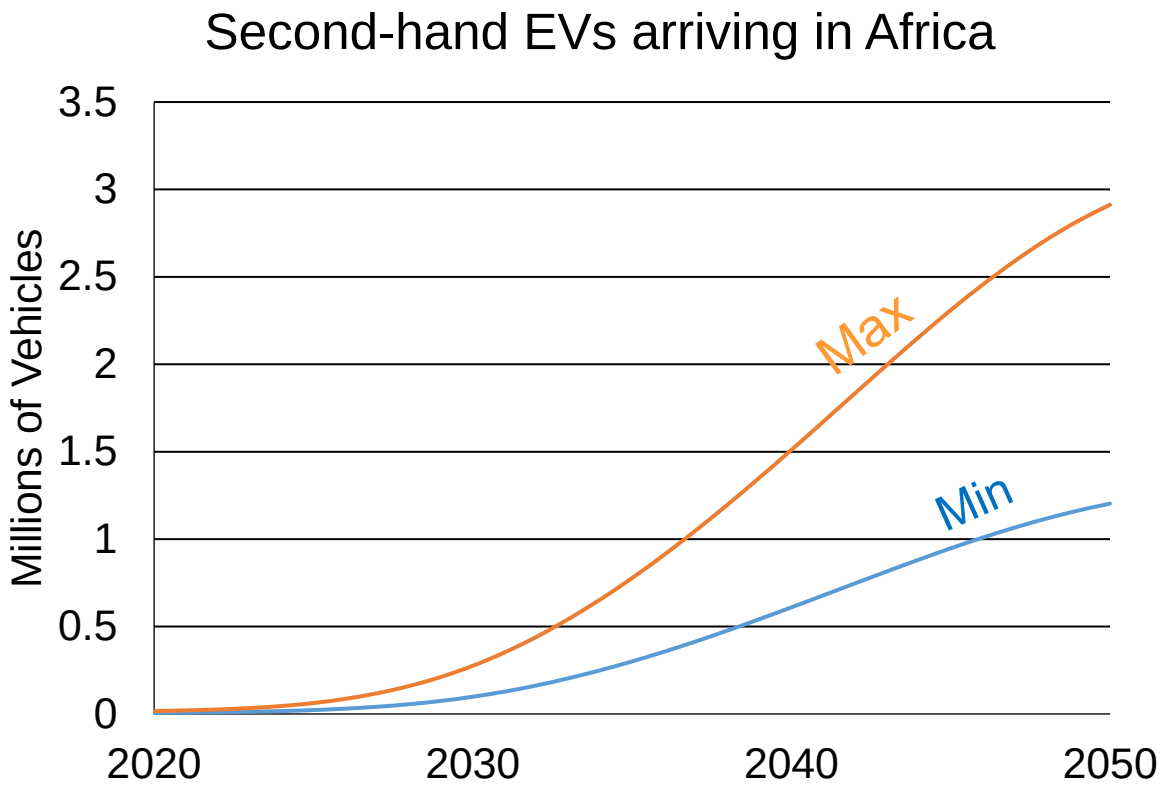
What happens to LIBs during use, and what about repair?

- Batteries degrade over time and we measure degradation by “state of health” (SOH) - defined by percent of current capacity divided by the initial capacity.
  - SOH moves in one direction: down. And is caused by battery cycling (charge-discharge cycles), time, and environmental conditions.
- So can we repair batteries? Not very easily.
  - Unlike an engine or transmission, it is hard to repair, rebuild, and remanufacture batteries, especially when you’re not working with/for the original equipment manufacturer (OEM). However, it’s happening anyway and could present safety hazards to workers and drivers
  - Every EV battery is managed by a proprietary Battery Management System (BMS), a BMS will determine how the vehicle can use/operate the battery. BMS are crucial for understanding battery operation and condition, but typically access to the BMS is limited by the OEM.

Uses and Second-hand trade

Based on EV adoption targets and second-hand vehicle export rates

- Nearly 3 million EVs may arrive in Africa by 2050, from EU, Japan and U.S.
- Second-hand EV exports are increasing from S Korea, but even more importantly China (as the leading adopter of EVs globally),and these exports are not included in this estimate, so this number may significantly underestimate actual imports of used EVs to Africa



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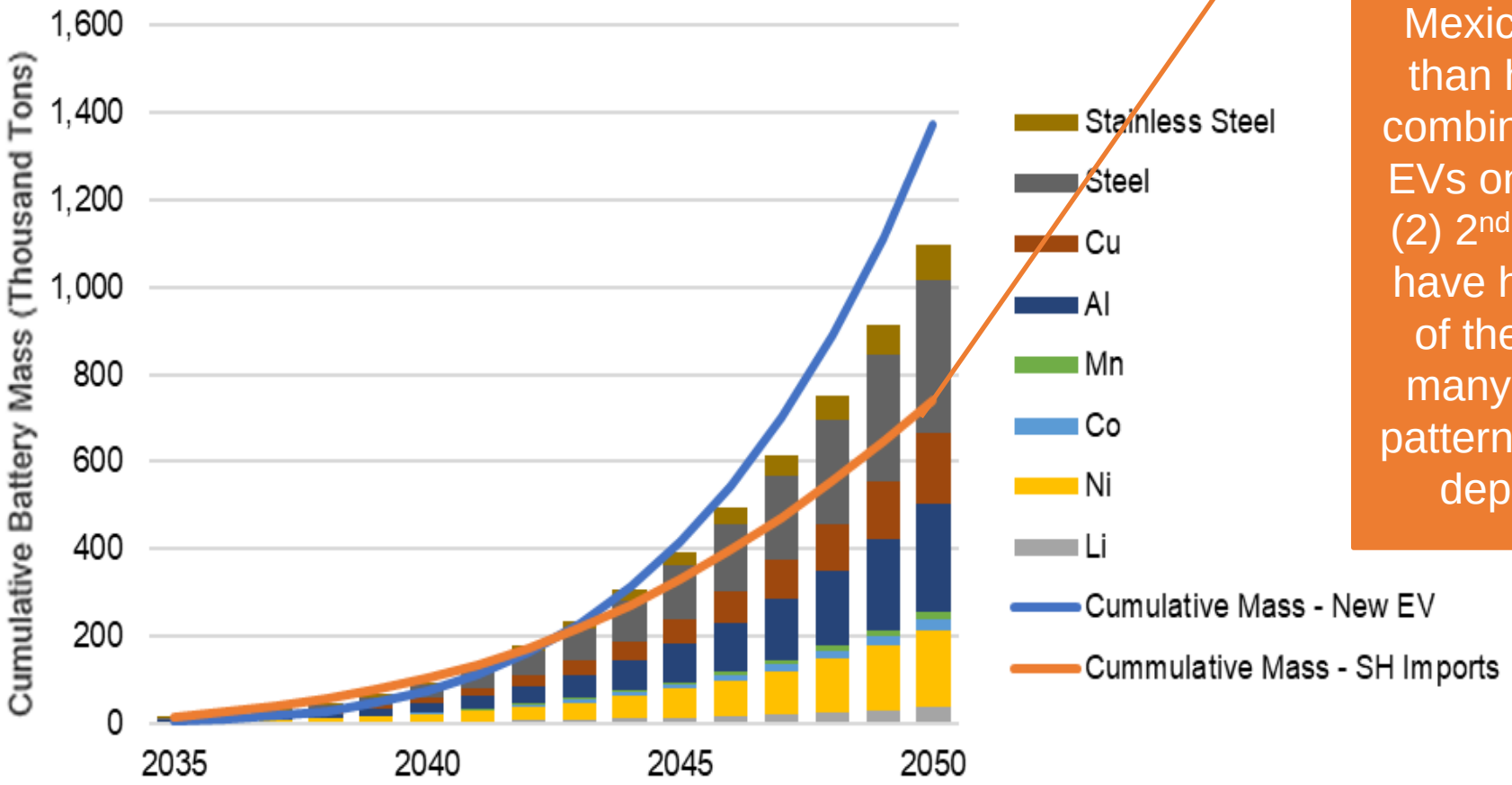
But we do know that repair happens…

Image credit: Francisco Olguin Pares, 2024

- We have good evidence from, for example, hybrid vehicle batteries, that second-hand vehicle batteries get repaired – that means they get disassembled, reassembled, used cells might be harvested from one battery and put into another.
  - HEV batteries are NiMH chemistries – not LIBs. They are much less likely to catch fire.
- Mechanics hack BMS systems, often to extend the operating range of batteries. This provides better performance in the short run, but can lead to operation of batteries in ways that increase risk of catastrophic failures and fire

Battery Material Flows in Mexico from New and Used EVs



While 2nd hand imports make up just a few percent of EVs on the road in Mexico in 2050, they comprise more than half of retired battery mass! A combined effect of (1) many of the first EVs on the road are 2nd hand imports. (2) 2nd hand EVs are from the US and have huge batteries, and (3) because of their age at import, they only last many fewer years on the road. This pattern will be echoed in other markets dependent on 2md hand imports

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What can we do with retired EV LIBs?

- We can **reuse** with or without repair, in another EV
- We can **repurpose** in a different (lower demand) application
- We can **recycle,** where we recover the constituent materials
    - Different kids of recycling. Most new recycling facilities being built are hydrometallurgical. An intermediate product of hydro, black mass, is shown on the right.

Images from B2U and Li-Cycle

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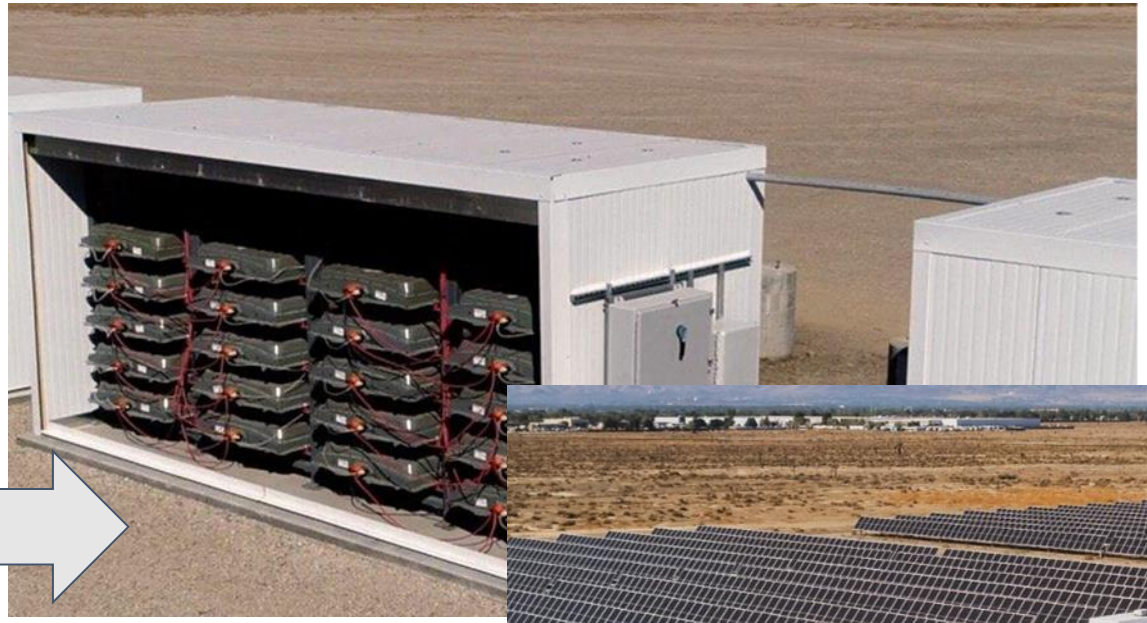
Repurposing in “second-life” application

- An EV puts a high demand on a battery – both for energy storage capacity and power.
- A battery that may be unusable in an EV may still have sufficient storage and power for less demanding applications, like in stationary applications for back-up power or supporting renewables on the grid.
    - Batteries may be reused with changes only to the BMS (i.e. no changes to the physical battery, or might be reconfigured or repaired (i.e. have bad cells replaced with good ones) prior to repurposing. The second case will have more significant labor (and cost) implications, has the potential to improve battery condition, but also has safety risks if not done correctly.

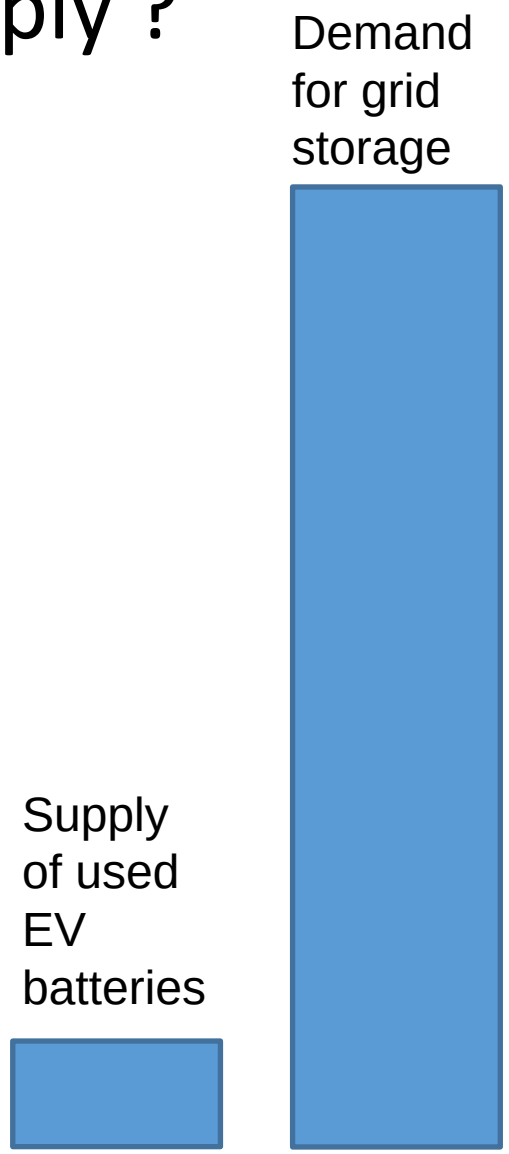
Repurposing without changes to the battery



https://www.bloomberg.com/news/features/2018-06-27/where-3-million-electric-vehicle-batteries-will-go-when-they-retire?leadSource=uverify%20wall. And, B2U Storage Solutions https://www.b2uco.com/

Repurposing: How does demand for stationary battery energy storage systems (BESS) align with supply ?

- We looked at one country, Kenya, to see whether repurposed batteries from secondhand EVs would have a robust repurposing market by comparing the future electricity grid BESS demand to battery capacity arriving in secondhand EVs
- Kenya will yield 40–111 MWh of battery capacity available in used EV batteries in 2030, substantially lower than the 1000 MWh of total demand for BESS capacity in 2030
- This does not mean a *used* battery is the best choice for grid storage needs, but it does mean that spent EV batteries might find a good repurposing market



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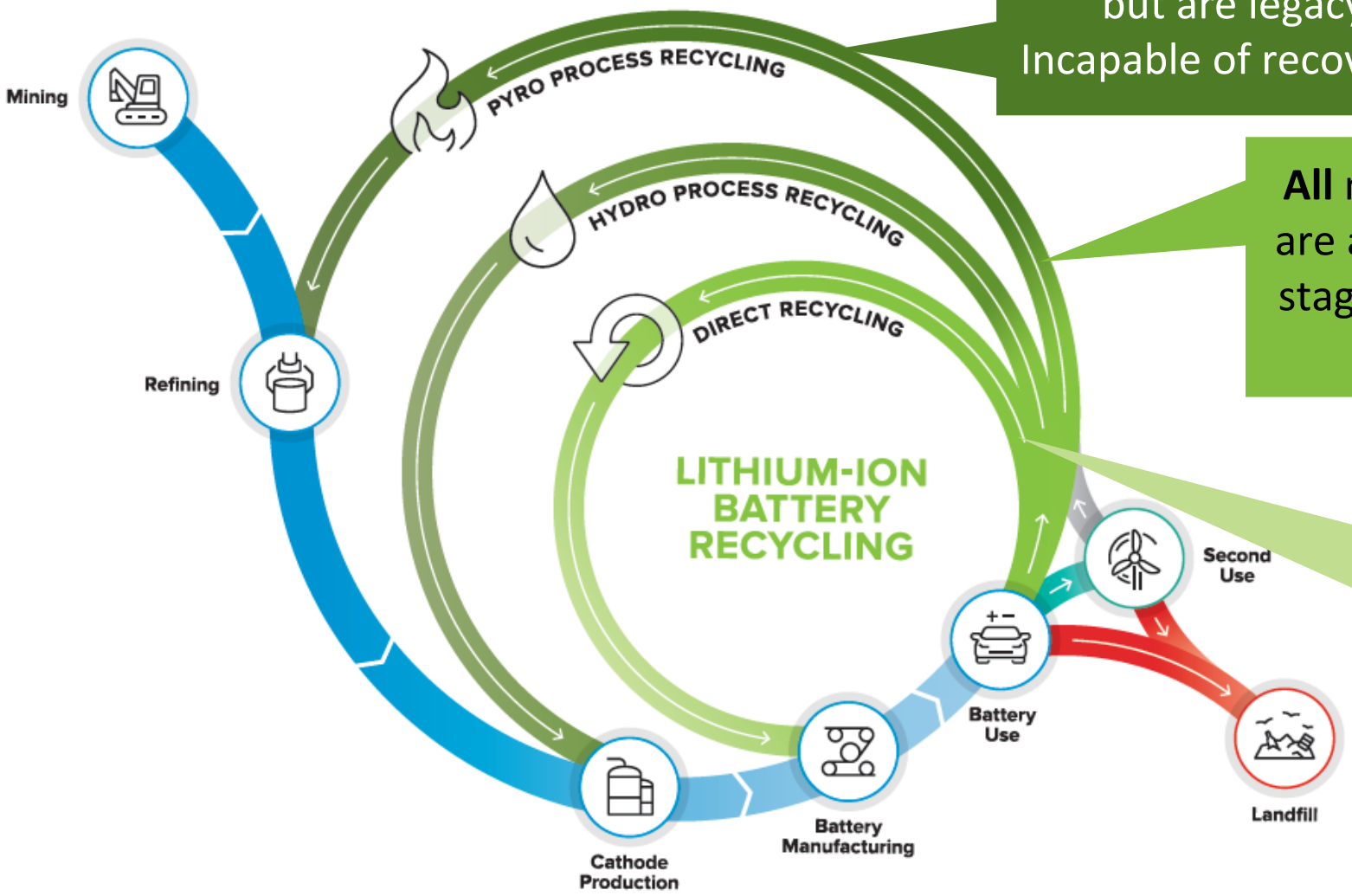
Repurposing just slows down the process for final end-of-life processing

- Repurposing extends the useful life of a battery, but does not eliminate the need for final disposition – which will either be recycling or disposal on land. There are few land disposal options that are safe, given the risk of fire caused by aged and damaged LIBs
- When few EV batteries are arriving at end-of-life, the economics of recycling are difficult
- What are the risks of improper disposal?

The Risks of Improper LIB disposal

- Without recycling, the alternatives for disposal include stockpiling and discarding on land.
  - Stockpiling presents a risk because LIBs, and particularly aged or damaged LIBs, pose a risk of fire or even explosion.
    - LIB fires emit toxic gasses: from furans and dioxins to hydrogen sulfide and SO_2. Such fires have already occurred around the world (Harper et al. 2019).
  - Batteries are discarded on land, can result in massive quantities of e-waste, which if managed like other e-waste flows, could be processed in informal environments that threaten the health of all, including children and other vulnerable populations (World Health Organization 2021).

Recycling Technologies



Pyrometallurgical plants exist, but are legacy facilities. Incapable of recovering Lithium.

All new recycling plants being built are all **Hydrometallurgical**. Two key stages – black mass generation and recovery/refining

Direct recycling is not yet commercialized. It would allow for direct reuse or upgrading of cathode compounds.

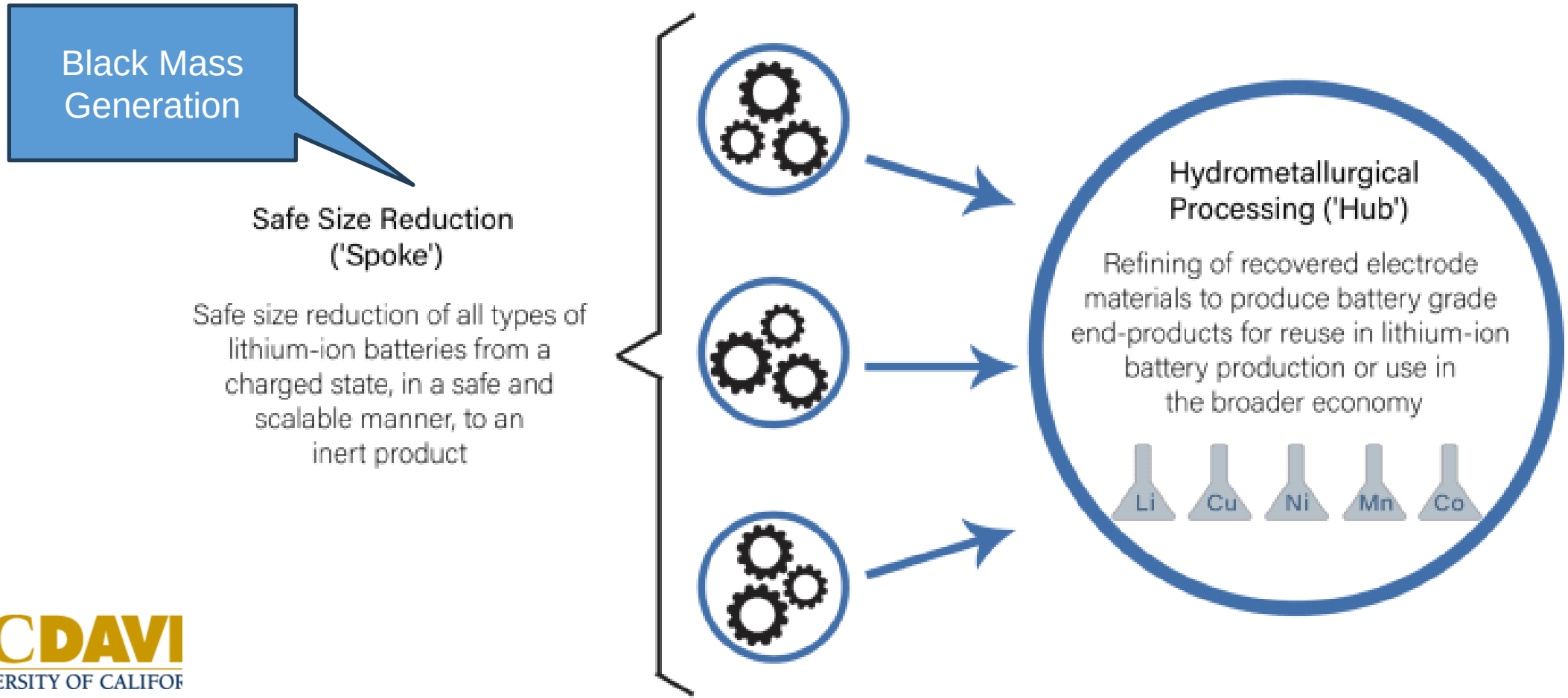
Image: ReCell (www.recellcenter.org)

Black mass – enabling new models for recycling?

- Hydrometallurgical recyclers have started de-linking (geographically) the collection and first step of recycling (black mass generation), and the ultimate recovery of minerals
- The production of black mass converts waste batteries into a material that can be much more efficiently and safely transported, and can provide some value closer to where the batteries are collected.
  - Much lower investment cost for a black mass facility than a hydrometallurgical facility and could help regions retain some value from waste batteries that are collected and processed.
  - Global recycling companies are setting up black mass facilities in one region, with recycling facilities in another. If black mass is commodified, we could envision less vertical integration and more diversified supply sources for black mass.

Li-Cycle's "Hub and Spoke" model

- Li-Cycle is one company that is pioneering a hub-and-spoke model. Other companies are doing the same



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Hydrometallurgical Processing at Large Scale

- https://www.metso.com/globalassets/insights/blog/mining-and-metals/hydromet_units2.jpg?preset=blog-post-image-lg_no-crop_webp

Q&A

- Contact information: amkendall@ucdavis.edu

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