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EV battery chemistries, supply chain vulnerabilities, and circularity potential

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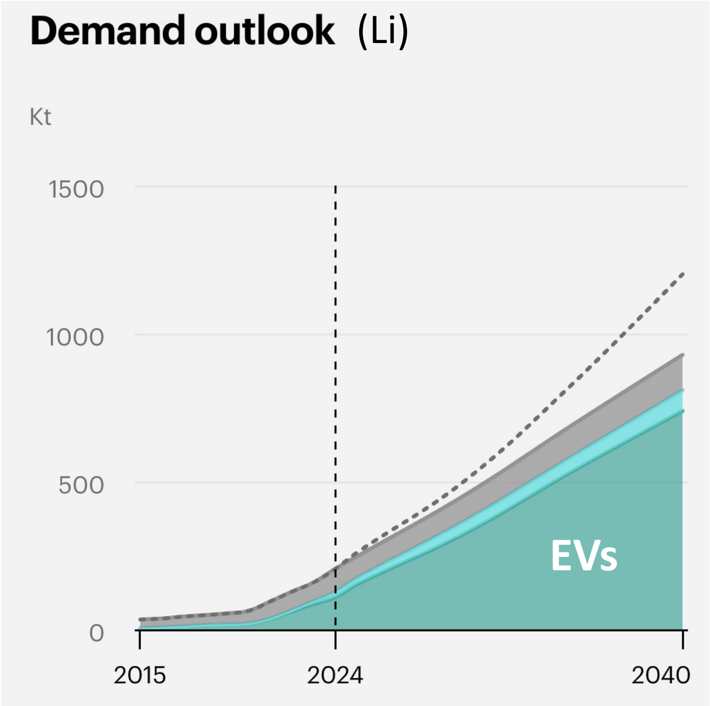
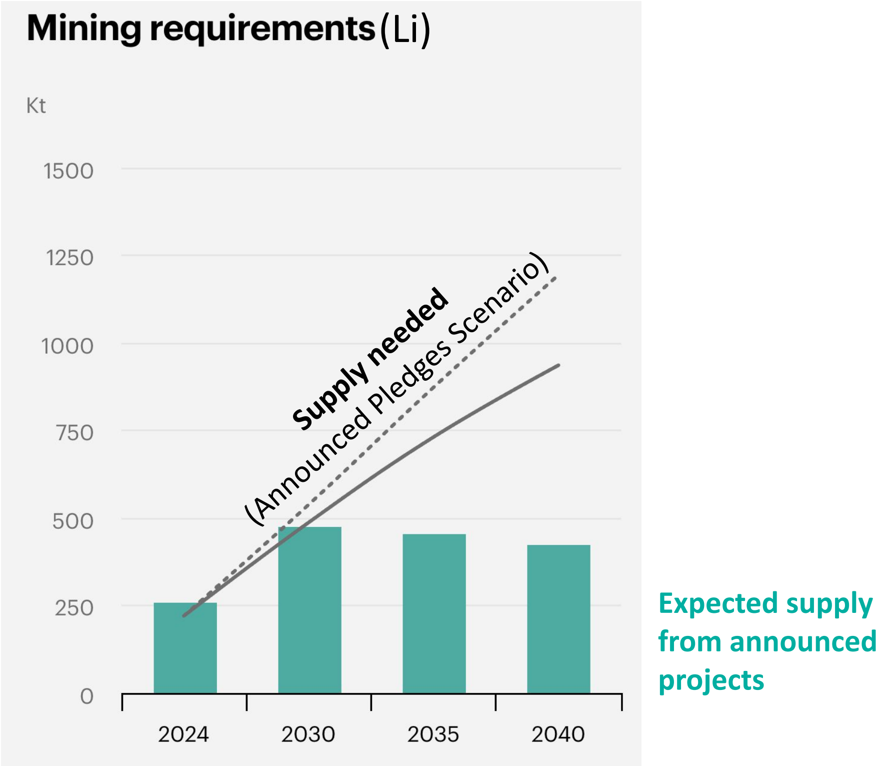
Energy transitions are turning supply chains into bottlenecks



Source: IEA Global Critical Minerals Outlook 2025



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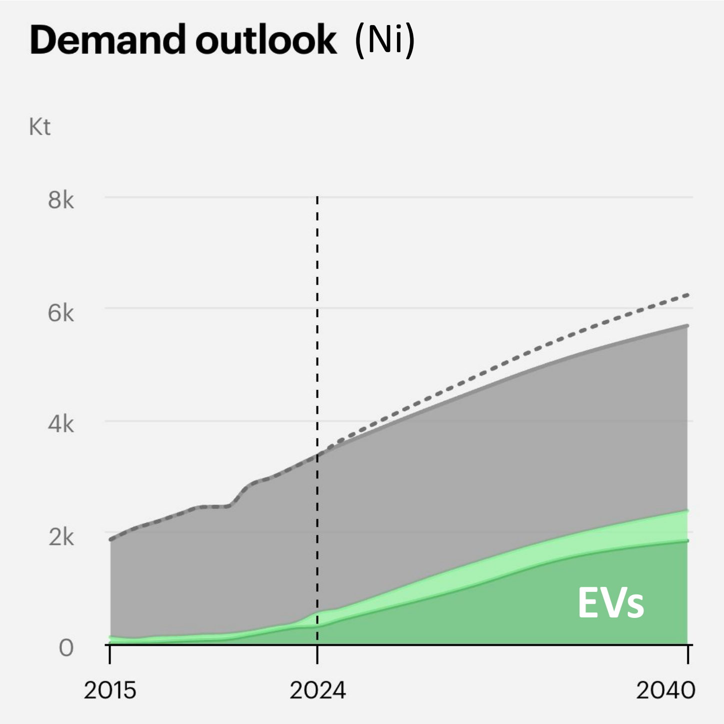
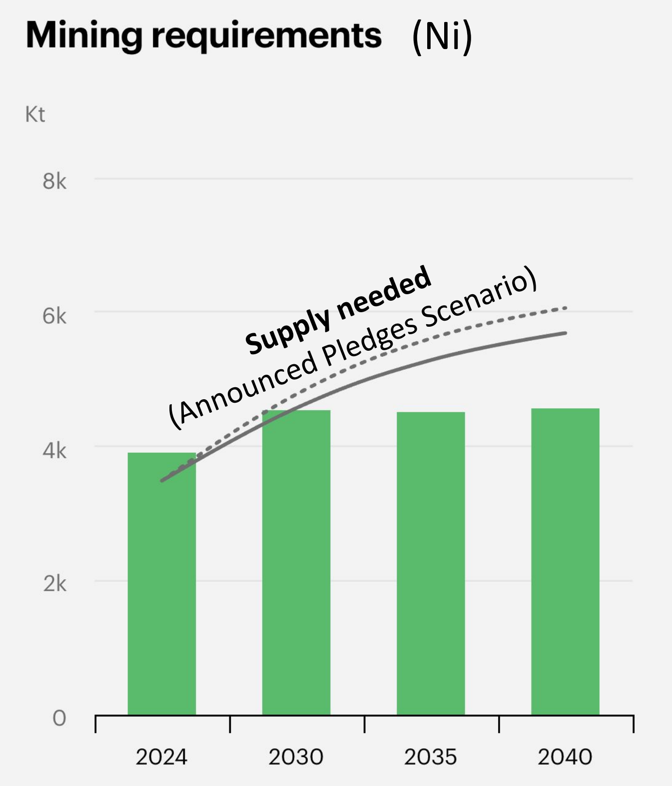
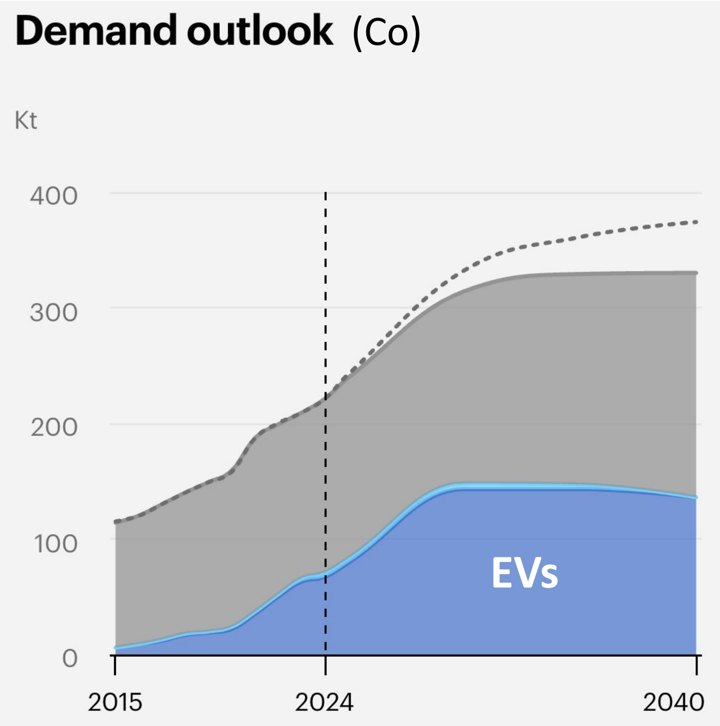




Expected supply from announced projects

Source: IEA Global Critical Minerals Outlook 2025

Energy transitions are turning supply chains into bottlenecks



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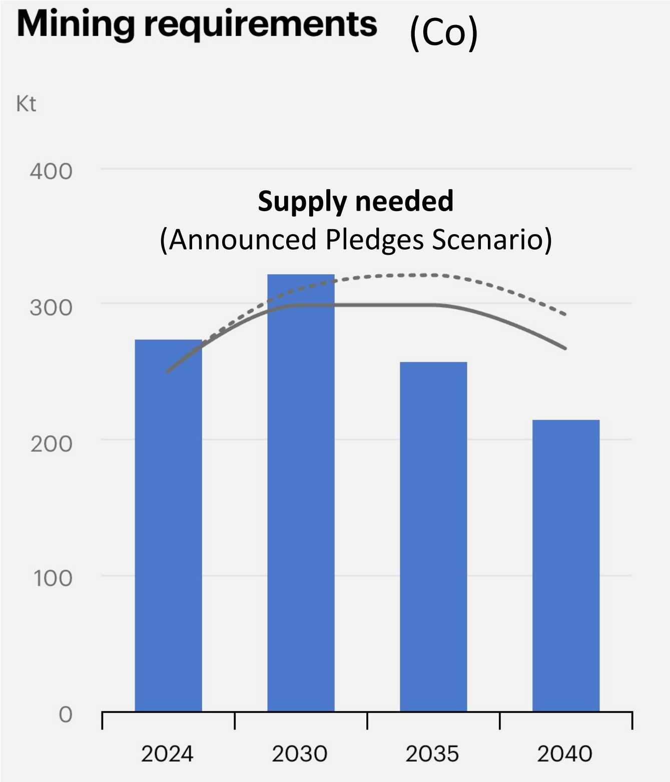
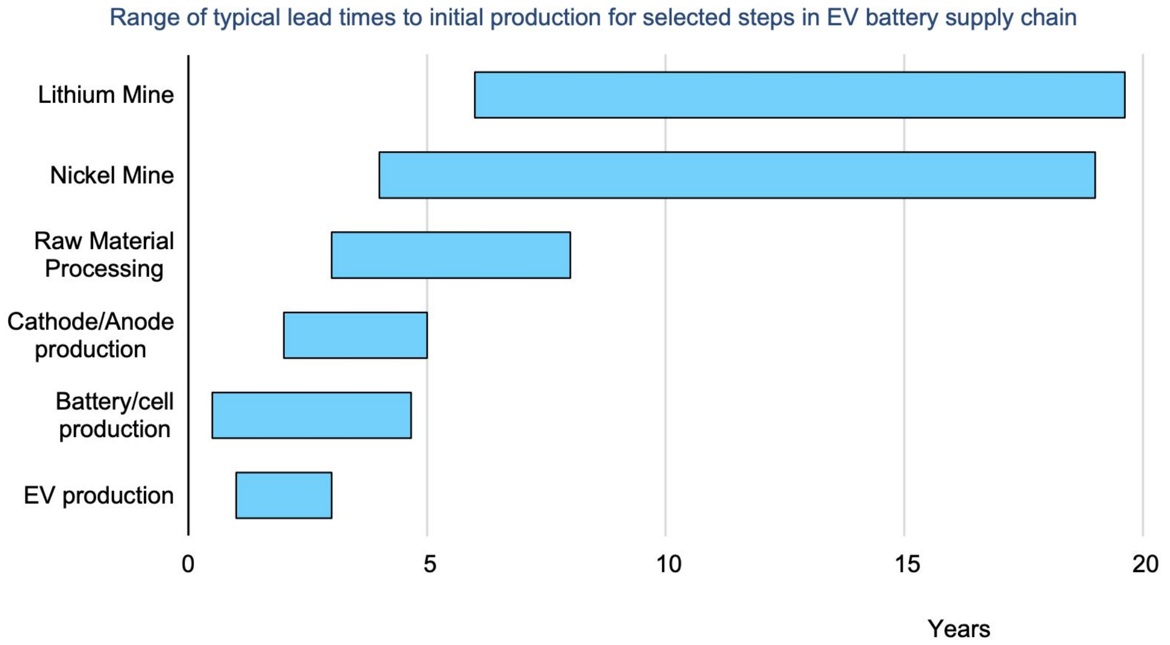


Expected supply from announced projects

Developing material supply chains can take much longer than developing vehicles



Graphics from IEA 2022

New types of vulnerabilities

Oil supply disruptions affect the entire economy immediately

Battery material supply disruptions primarily affect automakers and battery producers

(the rest of the economy can keep driving the vehicles they already have)

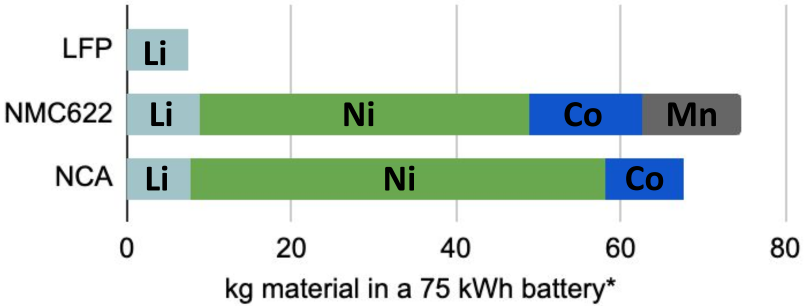
EV manufacturers have battery material options

Battery chemistries differ primarily in **cathode material**, affecting which critical minerals are needed (and how much)

Lithium Iron Phosphate (LFP)

(Lithium) **Nickel Manganese Cobalt** (NMC)

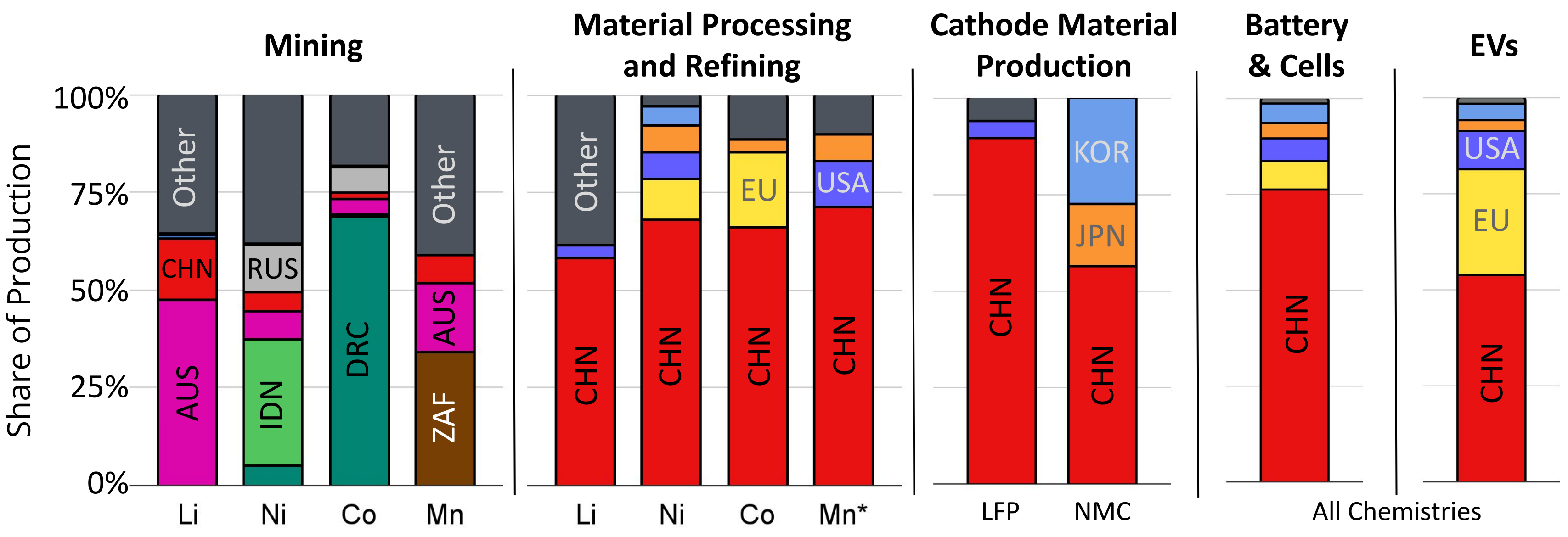
(Lithium) **Nickel Cobalt Aluminum** (NCA)



*For a 75 kWh battery; NMC622 used. Adapted from IEA 2021 analysis

Cheng, A.L., E.R.H. Fuchs, V.J. Karplus and J.J. Michalek (2024) "Electric vehicle battery chemistry affects supply chain disruption vulnerabilities," *Nature Communications* 15 2143.

The supply chain is geographically concentrated



Adapted from IEA 2022, USGS 2022, and Sun et al. 2021; Li: Lithium; Ni: Nickel; Co: Cobalt; Mn: Manganese (*electrolytic manganese dioxide only); CHN: China, AUS: Australia, IDN: Indonesia, RUS: Russia, DRC: Democratic Republic of the Congo, ZAF: South Africa, KOR: Republic of Korea (South Korea), JPN: Japan, USA: United States; EU: European Union; Other: any other country not named here

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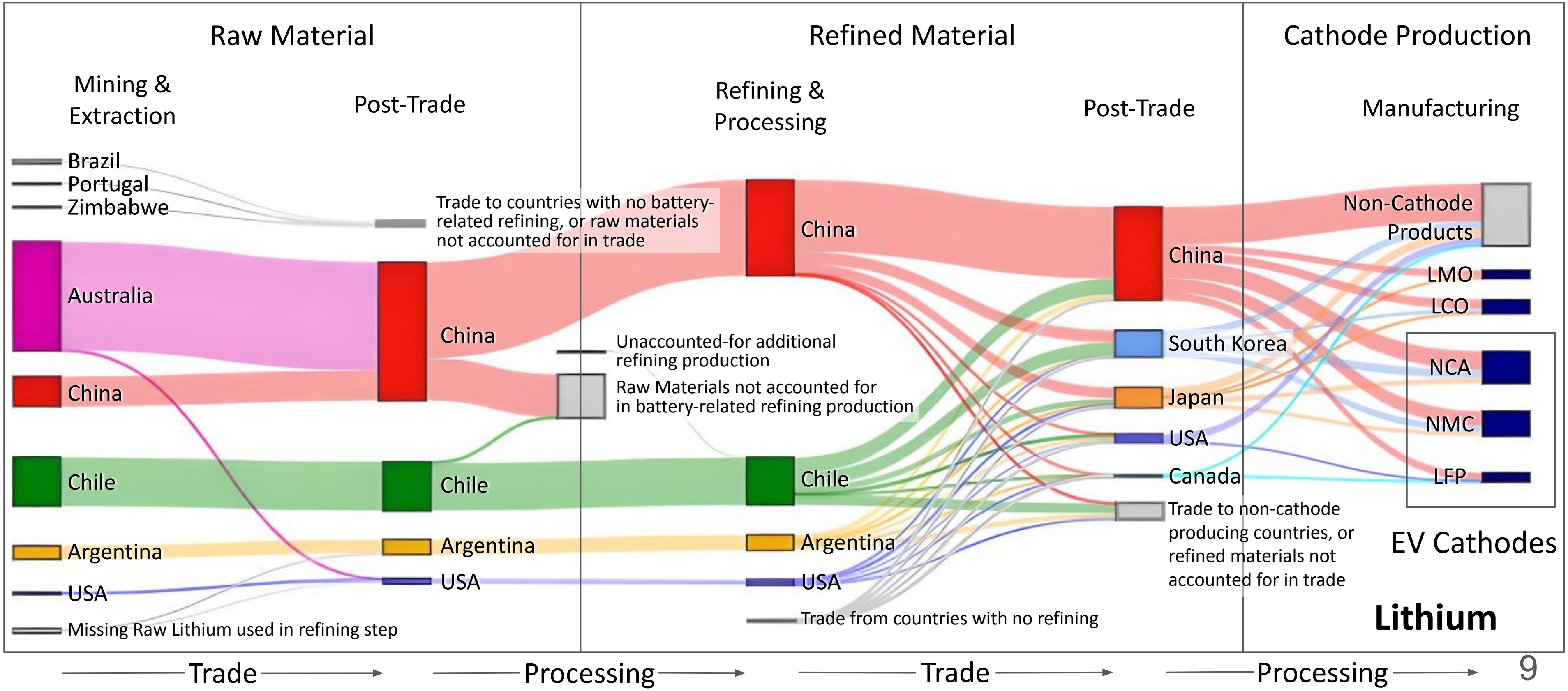
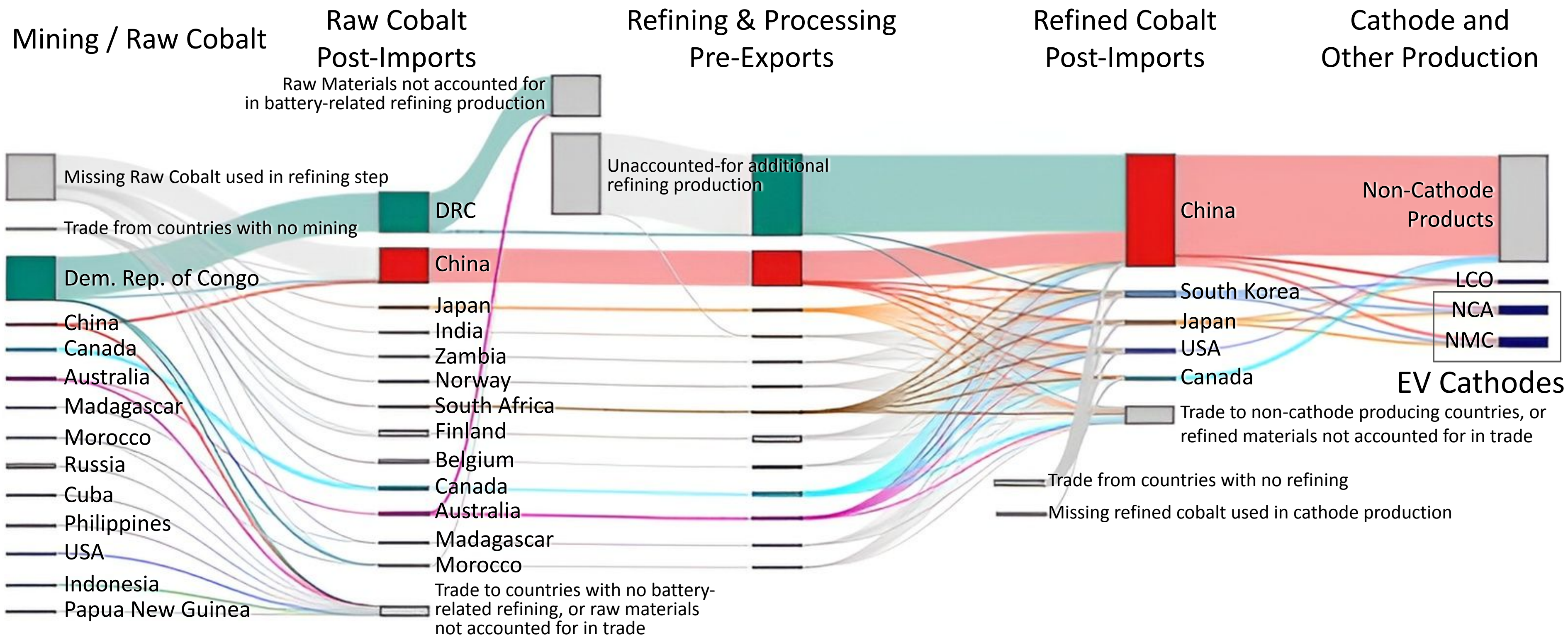
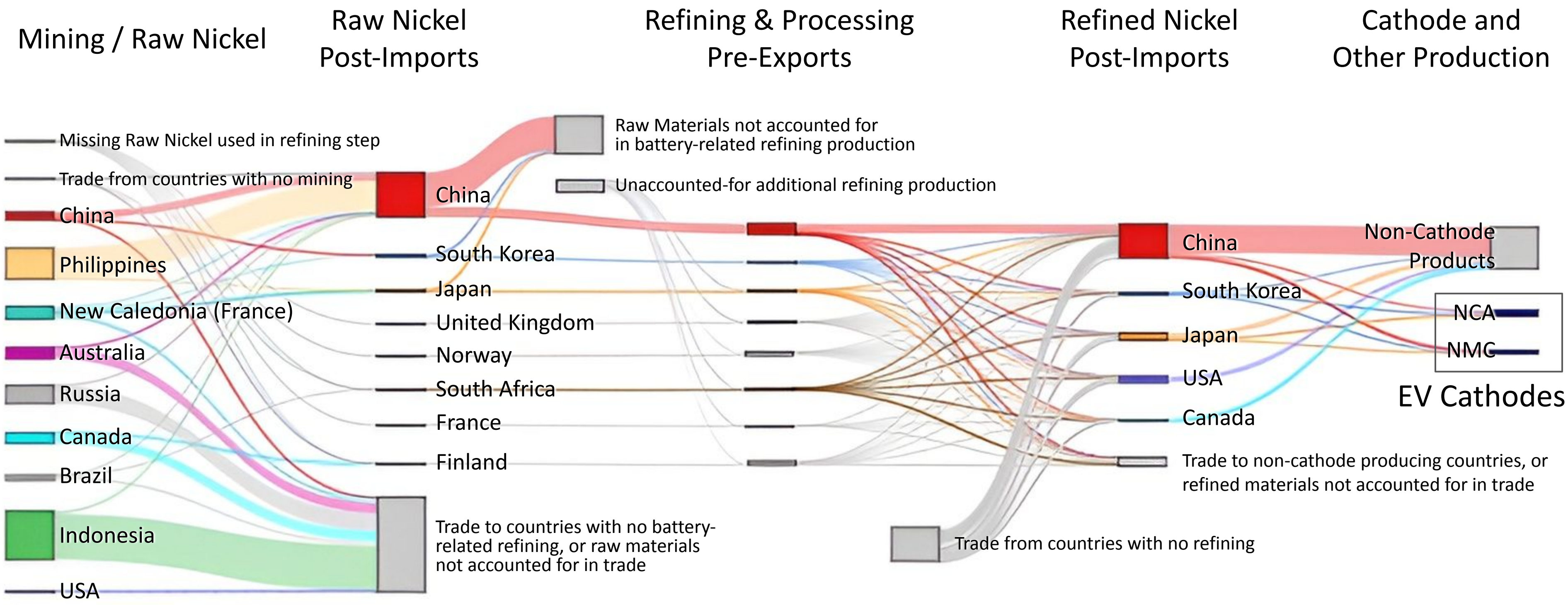
Lithium: China dominates refining and cathode production



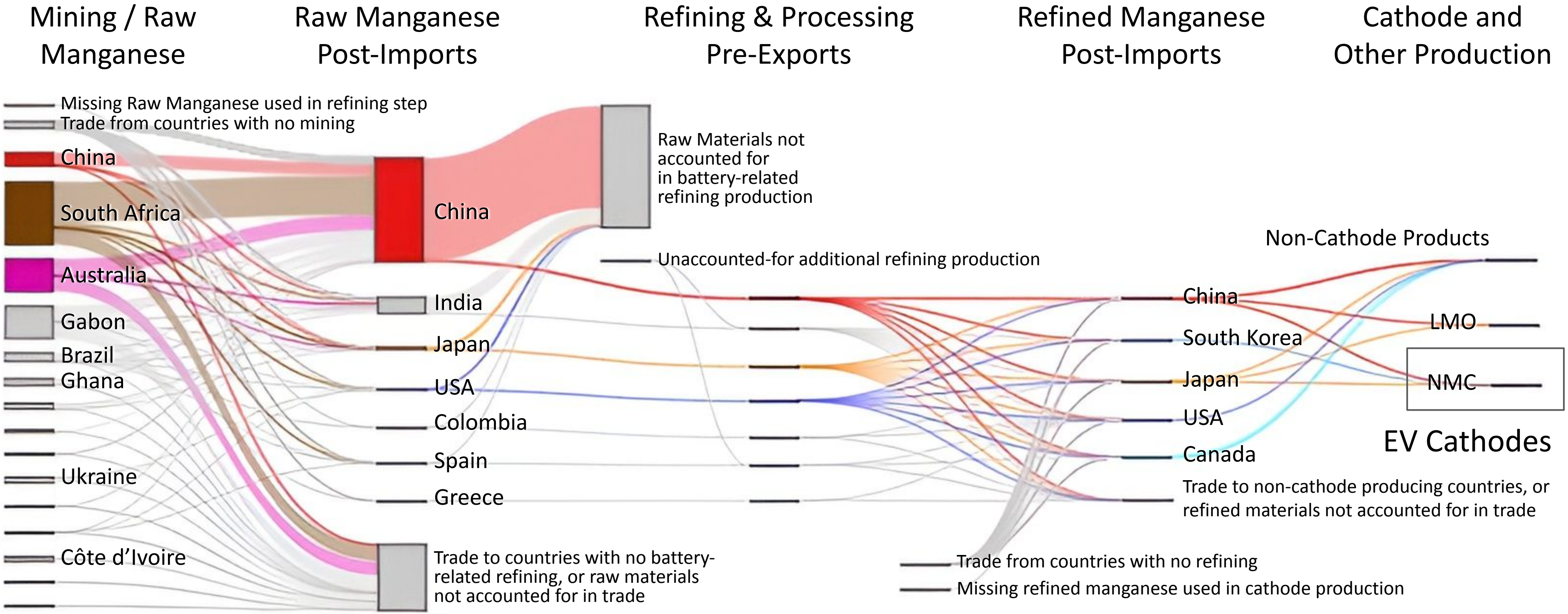
Cobalt: DRC & China dominate throughout



Nickel: Mostly non-cathode uses; cathodes made in CHN, KOR, JPN



Manganese: Vast majority for non-cathode uses



Overall

- NMC has more mineral supply chain disruption risks
- But LFP cathodes, overwhelmingly made in China today, have a single point of failure

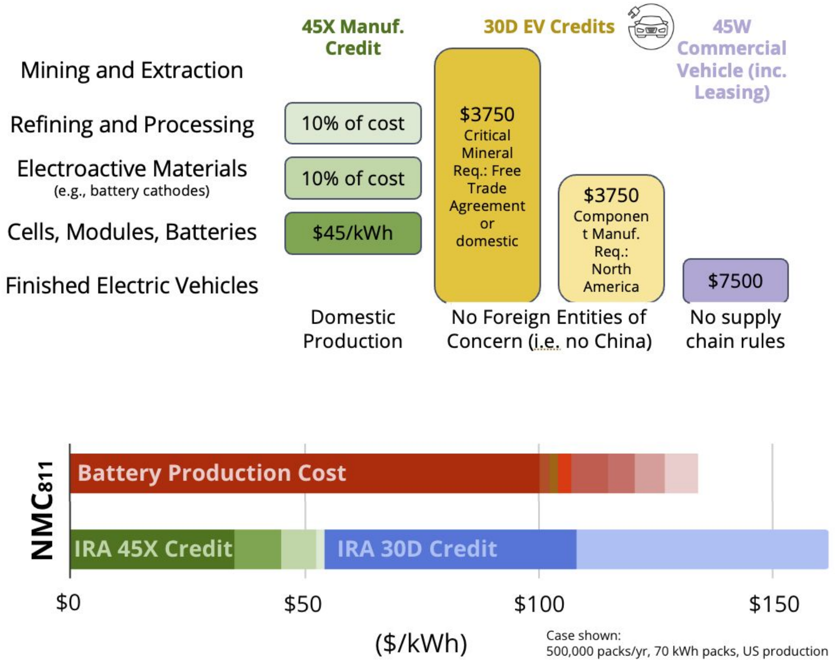
	Critical Mineral	Portion Passing Through China (Base Estimate: Proportional)
LFP	Li	92%
	Overall	**92%**
NMC	Li	78%
	Ni	58%
	Co	70%
	Mn	80%
	Overall	**80%**

So, how can we reduce supply disruption vulnerabilities?

Approach 1) Diversify the supply chain

Inflation Reduction Act

- **Total incentives exceeded battery cost**, but it was hard to qualify for all of them
- Largest incentives only applied to batteries whose supply chains **avoided China entirely**
- **Large growth** in US extraction, processing & especially battery manufacturing projects



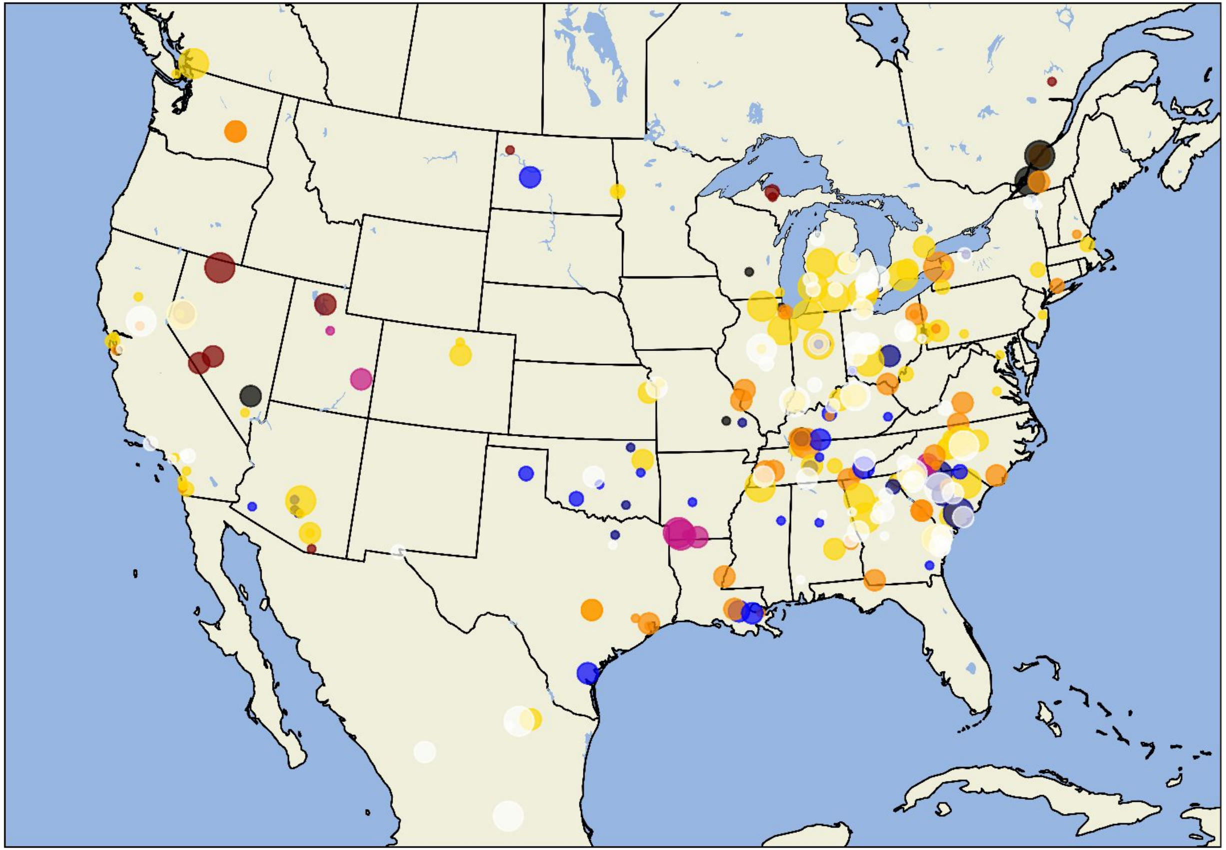
Cheng, A., E. Fuchs and J. Michalek (2024) "US industrial policy may reduce electric vehicle battery supply chain vulnerabilities and influence technology choice," *Nature Energy*, [interactive dashboard].

The IRA appeared to spur the EV battery supply chain in North America, especially manufacturing

(Aug. 2022 - May 2024)

281 Post-IRA EV-related projects identified:

- **12** Mining & extraction
- **40** Materials processing
  - **22** Raw materials refining
  - **18** Recycling*
- **212** Manufacturing
  - **47** Battery components
  - **92** Cells and/or packs
  - **73** EV assembly and/or parts
- **17** other combinations, e.g.
  - **8** both extraction & materials processing



Investments: ∘ $0-$10M ∘ $10-$100M ○ $100-$1B ○ $1B plus

261 in US, **13** in Canada, **7** in Mexico

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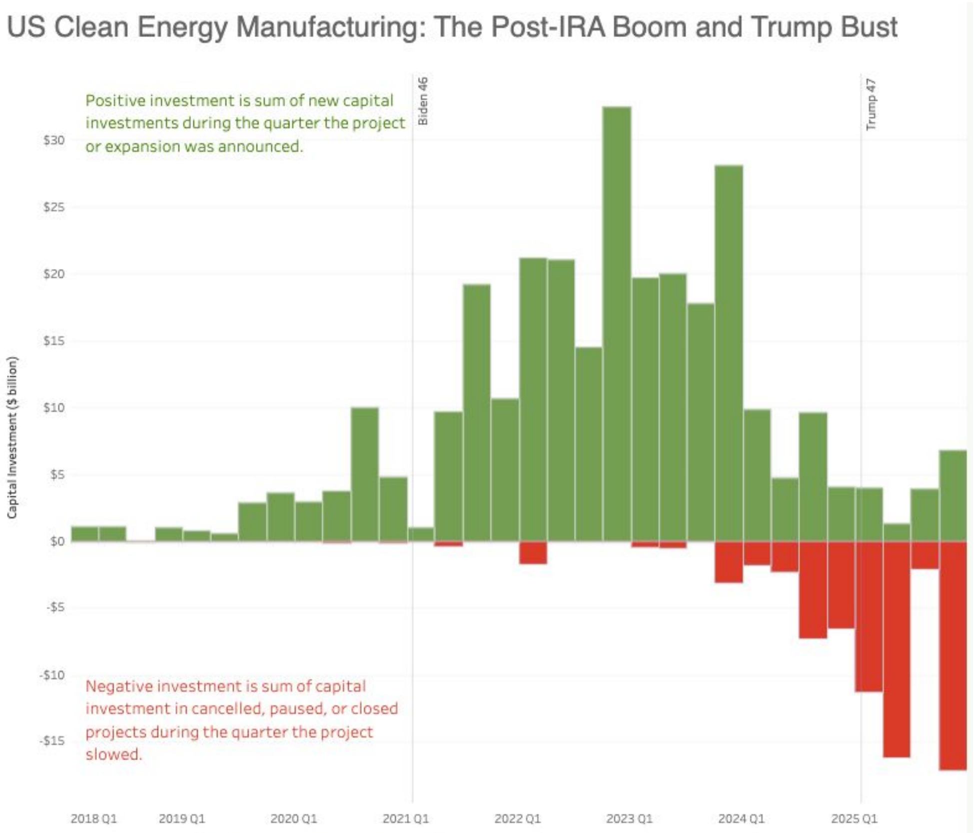
But supply chain onshoring has stalled

One Big Beautiful Bill Act

- Eliminated most of the incentives
- US investment collapsed



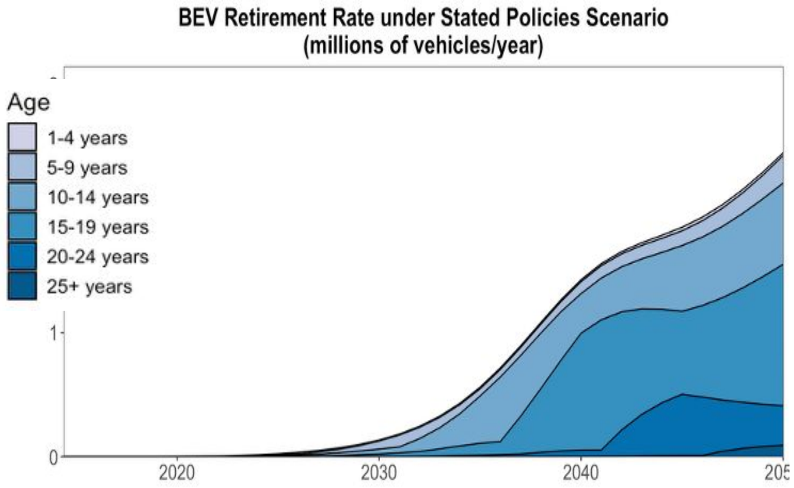
Source: The Big Green Machine, https://www.the-big-green-machine.com a data set maintained by Jay Turner and students, Environmental Studies Department, Wellesley College. Summary statistics above include updates through **12/20/25.** Summary statistics include publicly available information, which is incomplete for some projects, and should be treated as estimates.

Approach 2) Leverage circularity

Unlike oil, which is **consumed**, critical minerals **remain** in batteries after use (also in production scrap)

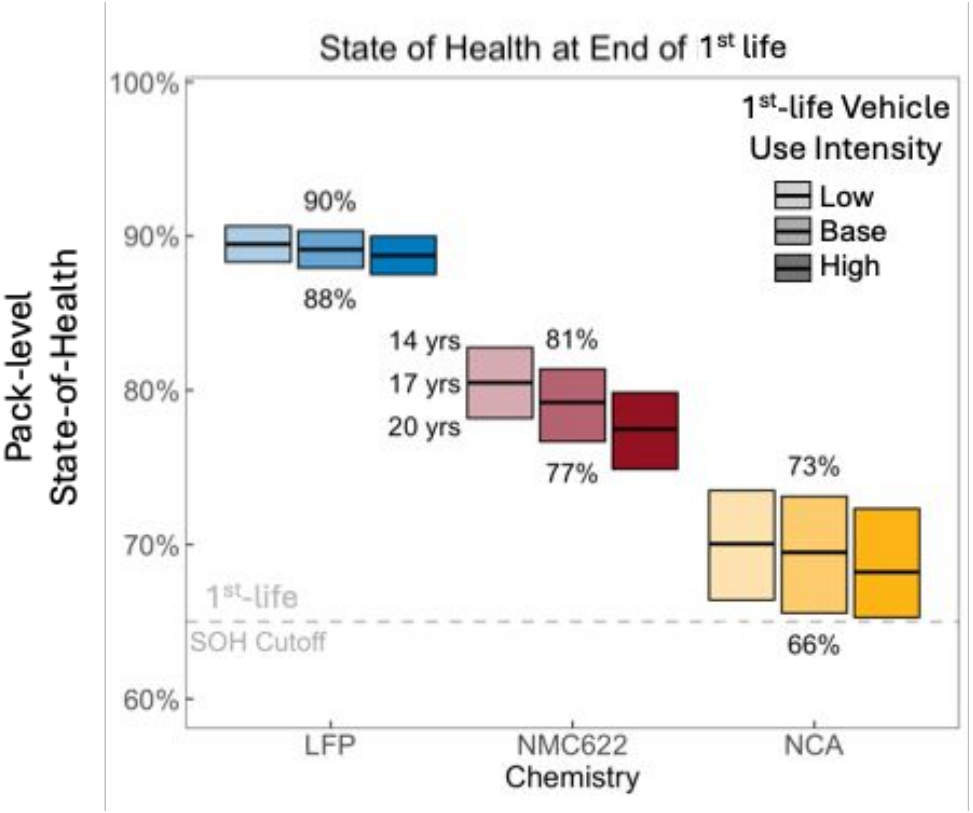
Options

1. **Repurpose** used batteries for other applications
2. **Recycle** to recover raw materials
3. **Dispose** as hazardous waste



Which pathways do economics favor?

Capacity remaining for 2nd life depends on chemistry



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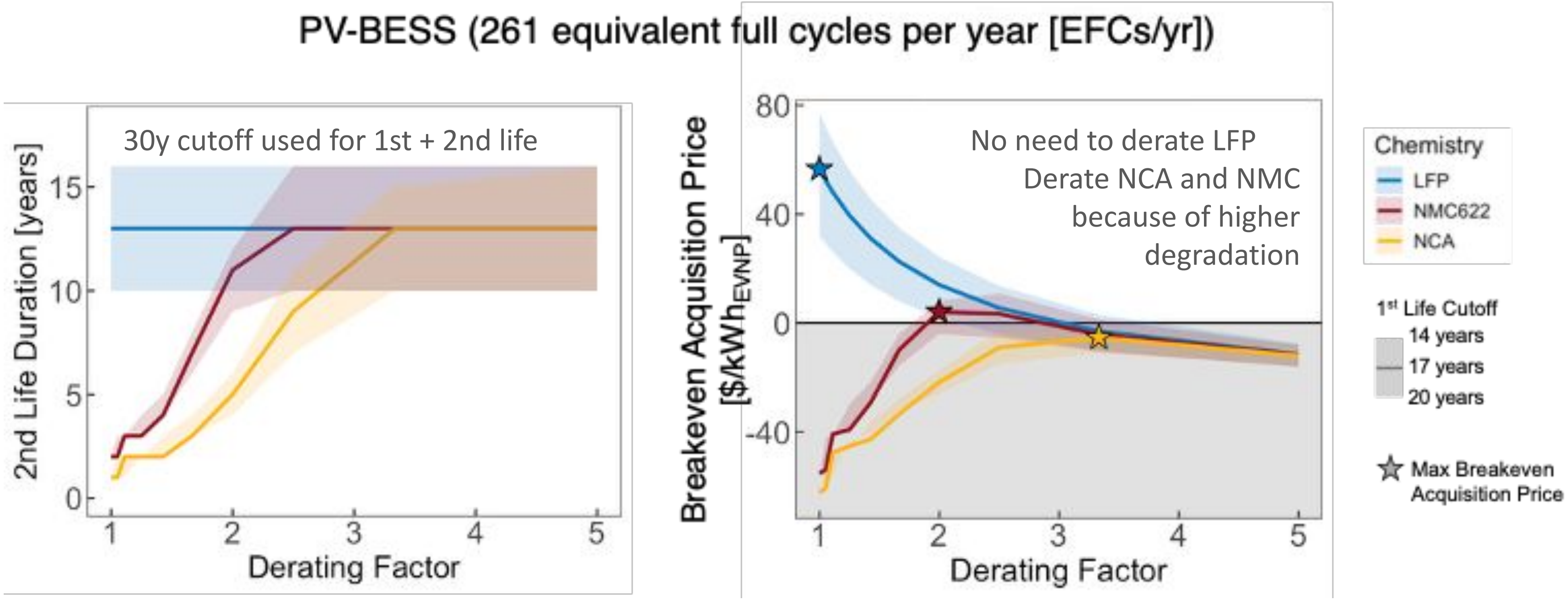
Optimal derating (oversizing) depends on chemistry



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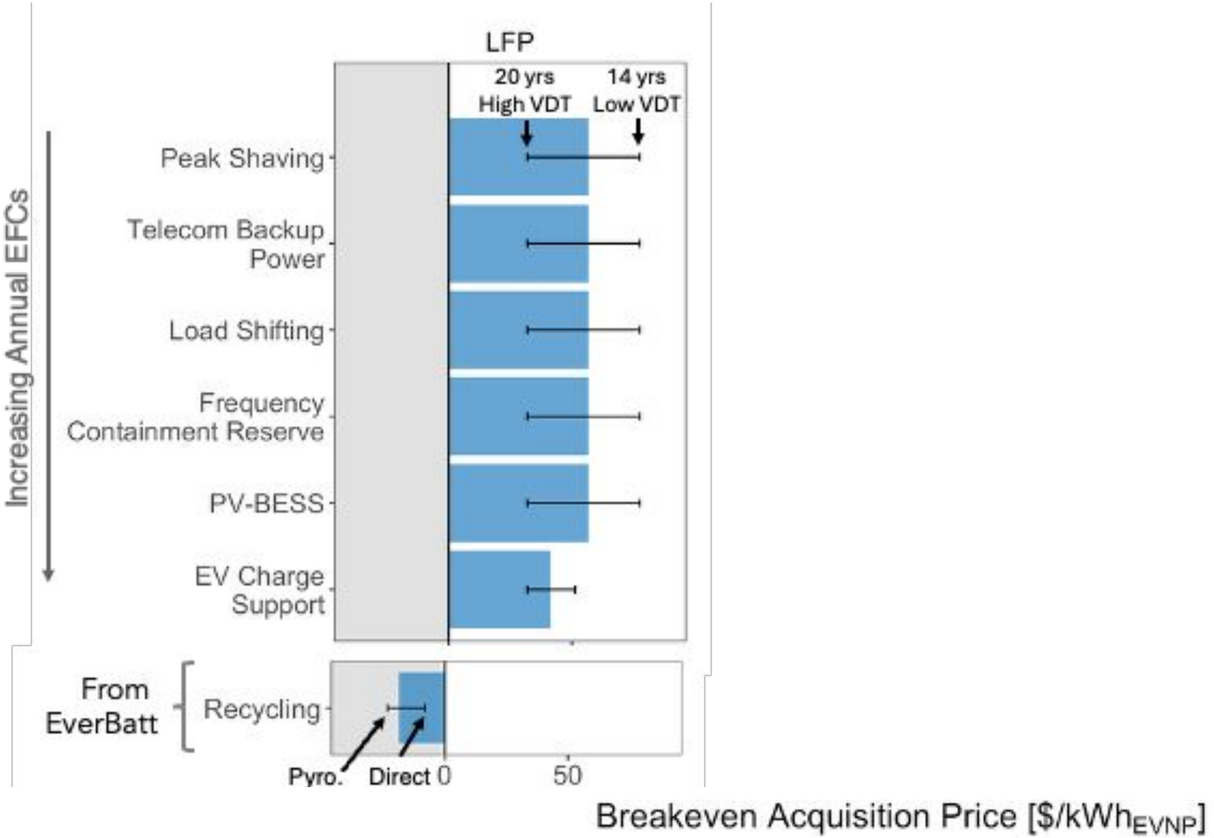
We can quantify the economics using the

Breakeven Acquisition Price

If a repurposing or recycling facility paid this price for used batteries, it would just break even

LFP: Repurposing >> Recycling



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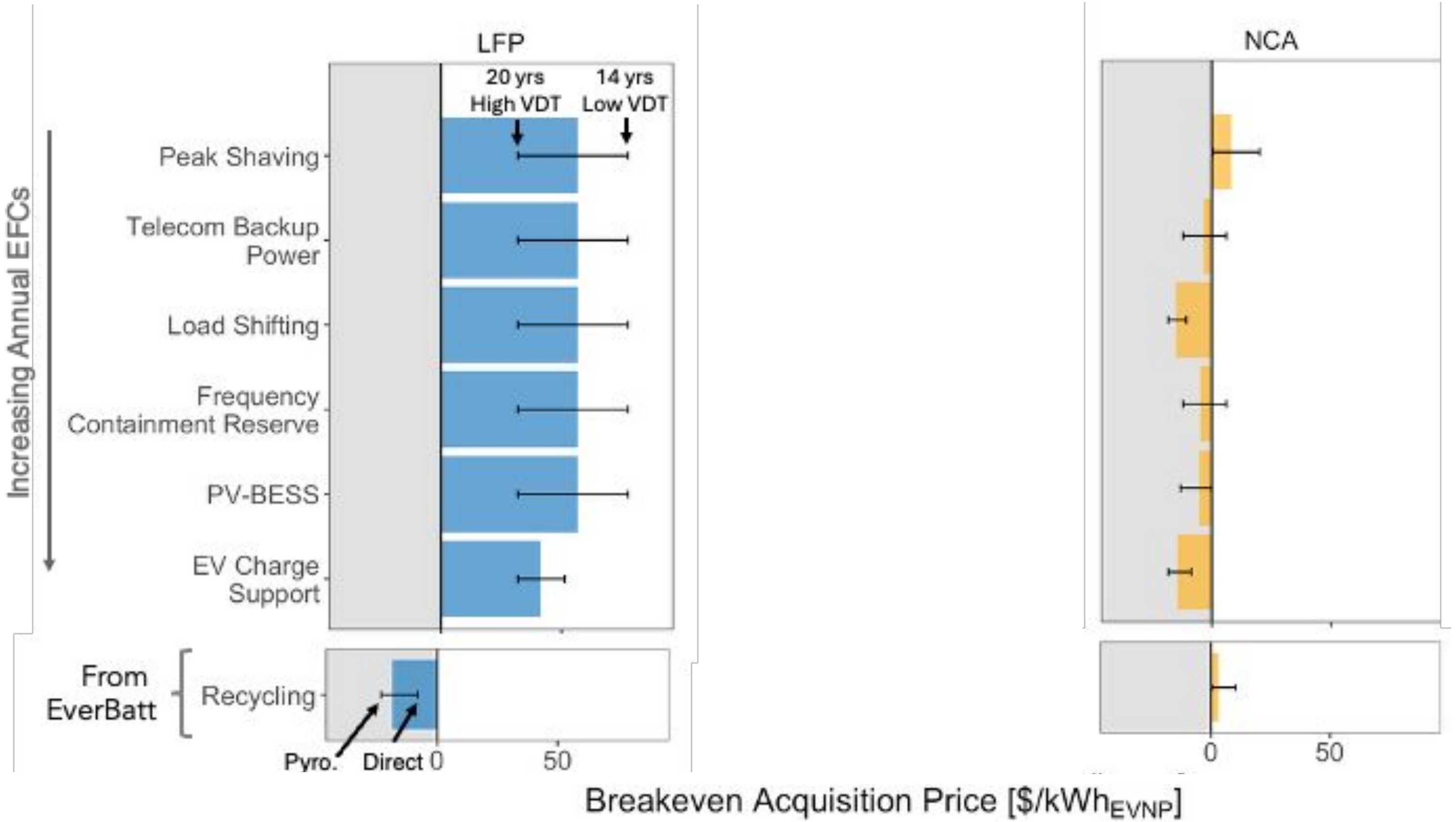
NCA: Repurposing < Recycling



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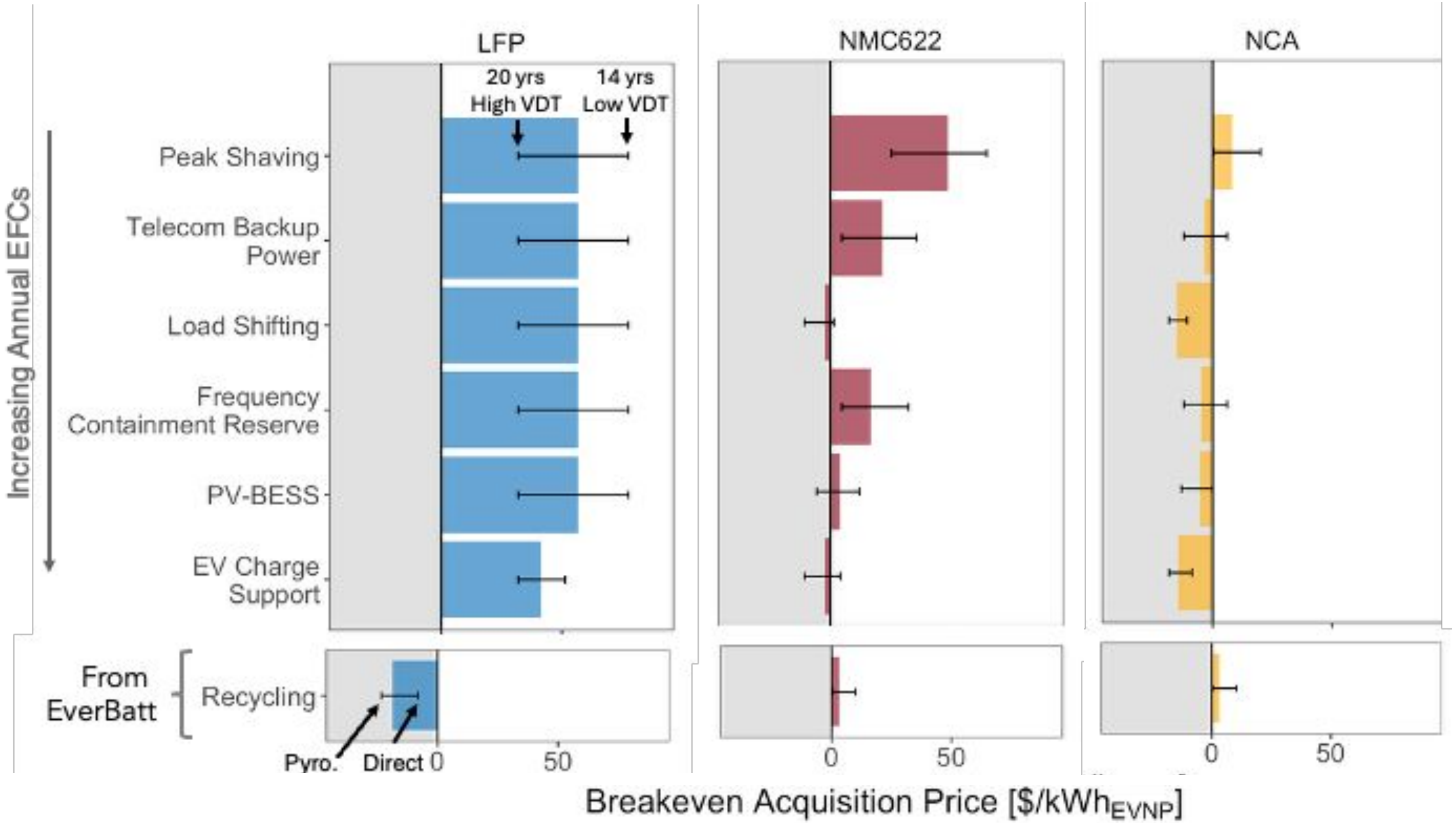
NMC: Depends on 1st life conditions & 2nd life application



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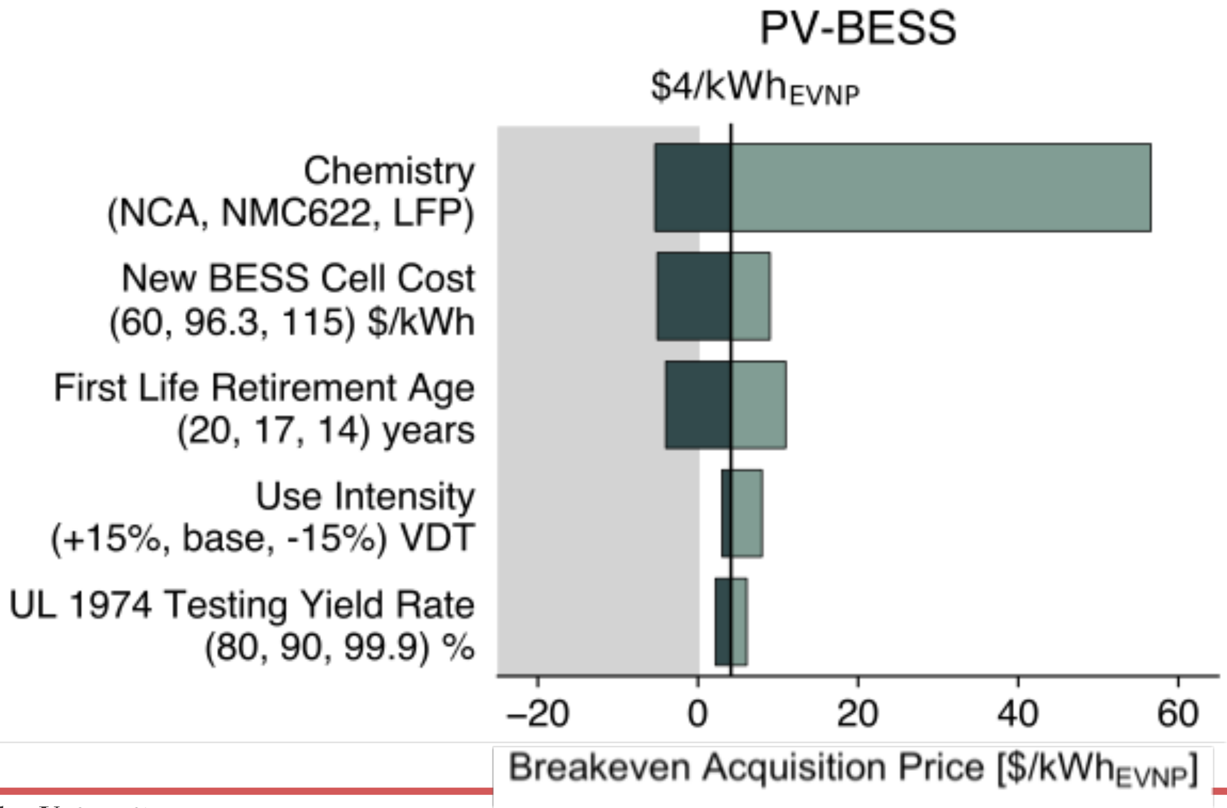
Chemistry is the dominant cost driver



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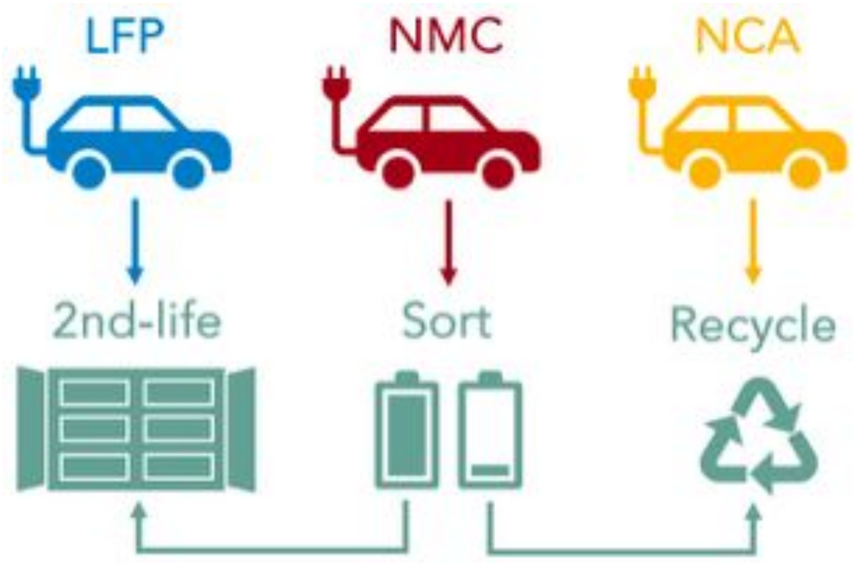
Implied strategy



Repurposing viability hinges on **chemistry**, **use intensity**, and **application** fit

Risks

- Saturation of 2nd-life application markets as more EVs retire
- Customer perceptions of safety and reliability

Opportunities

- Evolution of rapid diagnostic technology
- UL standards

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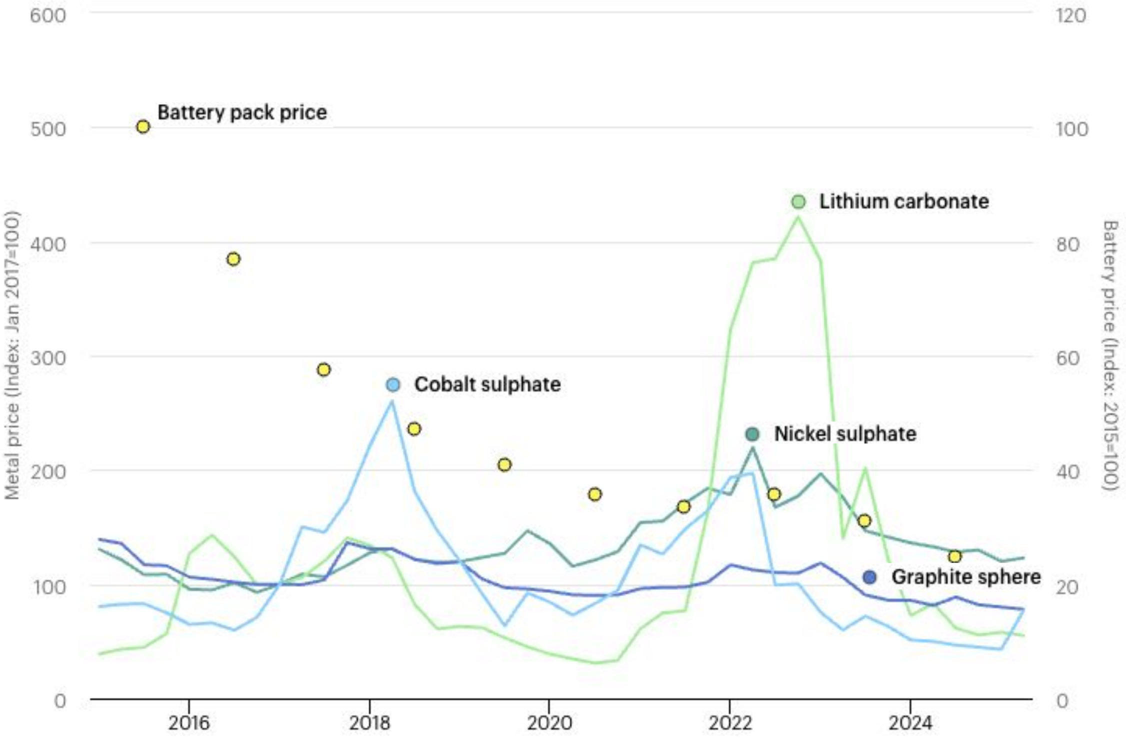
Key uncertainty: future commodity prices

Especially over long time horizons in rapidly changing times with future political conditions and technology breakthroughs unknown, it is hard to predict future pathway viability for tech made today

- **Pyro/Hydrometallurgical recycling:** Will future commodity prices support continued operations?
- **Direct recycling:** Will today's cathode active materials be obsolete by the time they retire?



Take away

EV battery supply chain concentrations create new vulnerabilities

Approaches

- **Diversify & onshore** the supply chain
- **Leverage circularity**

Circularity pathway viability depends on chemistry

- **Repurpose LFP** as stationary storage (long life, low value materials)
- **Recycle NCA** (short life, high value materials)
- **Sort NMC** based on condition & application

Open questions

- When is it in the public interest for policy to encourage circularity? What kind?
- How will timing & quantity of supply & demand affect vulnerabilities?

Thank you

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