

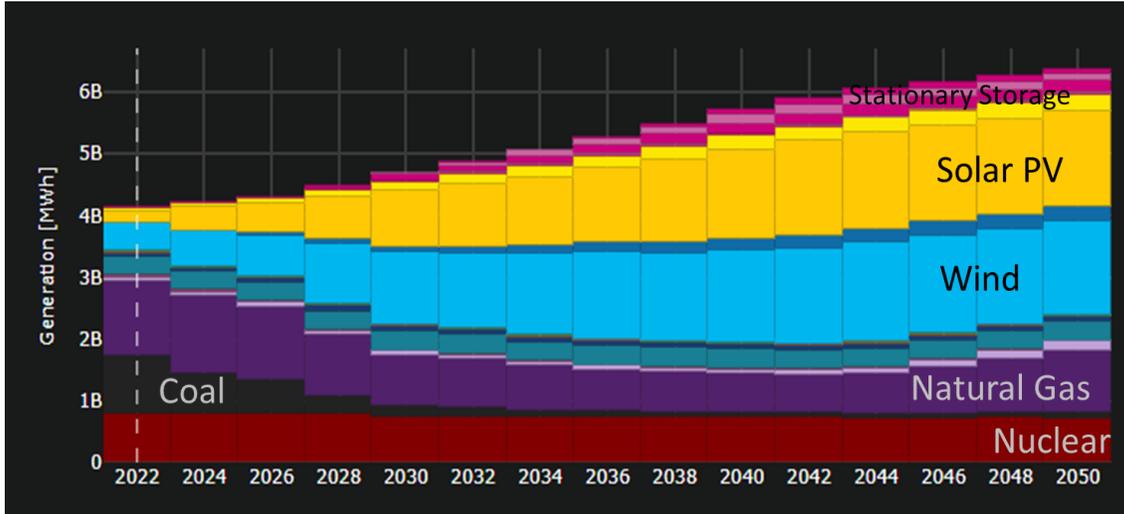
Battery Supply Chain Dynamics

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Projected Economically-Viable Growth of Clean Energy



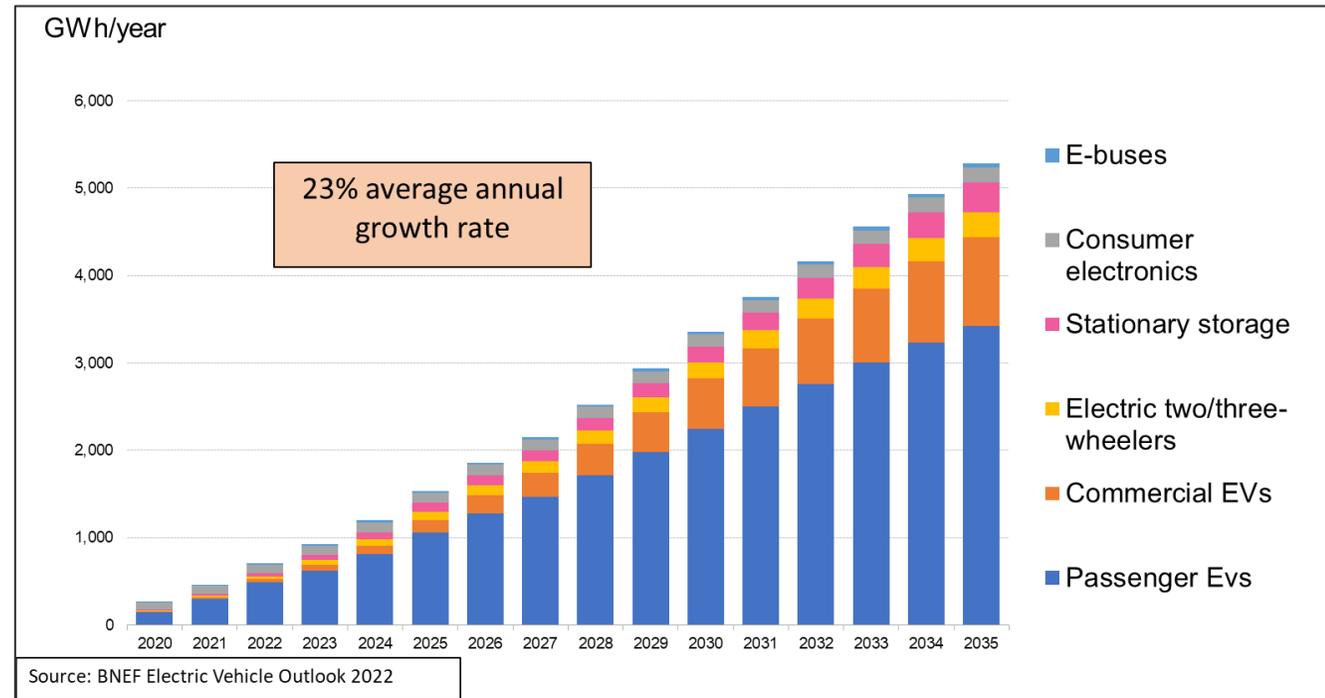
<https://www.nrel.gov/analysis/standard-scenarios.html>

Mid-case, new technologies included, current policies

- Where will all the materials come from?
- What will it cost to build the manufacturing facilities?
- What about recycling?

Market-viable growth of clean energy is expected to be very high

- Costs have become competitive
- Decarbonization is essential
- Economic security is essential



High Level Framework for Supply Chain Analysis

1. Characterization of the current, evolving, and future

- Market size, location, companies
- Raw materials availability and processing
- Recycled material availability
- Manufacturing size, location, companies
- Trade flows

2. Risks to U.S. competitiveness – current, evolving, and future

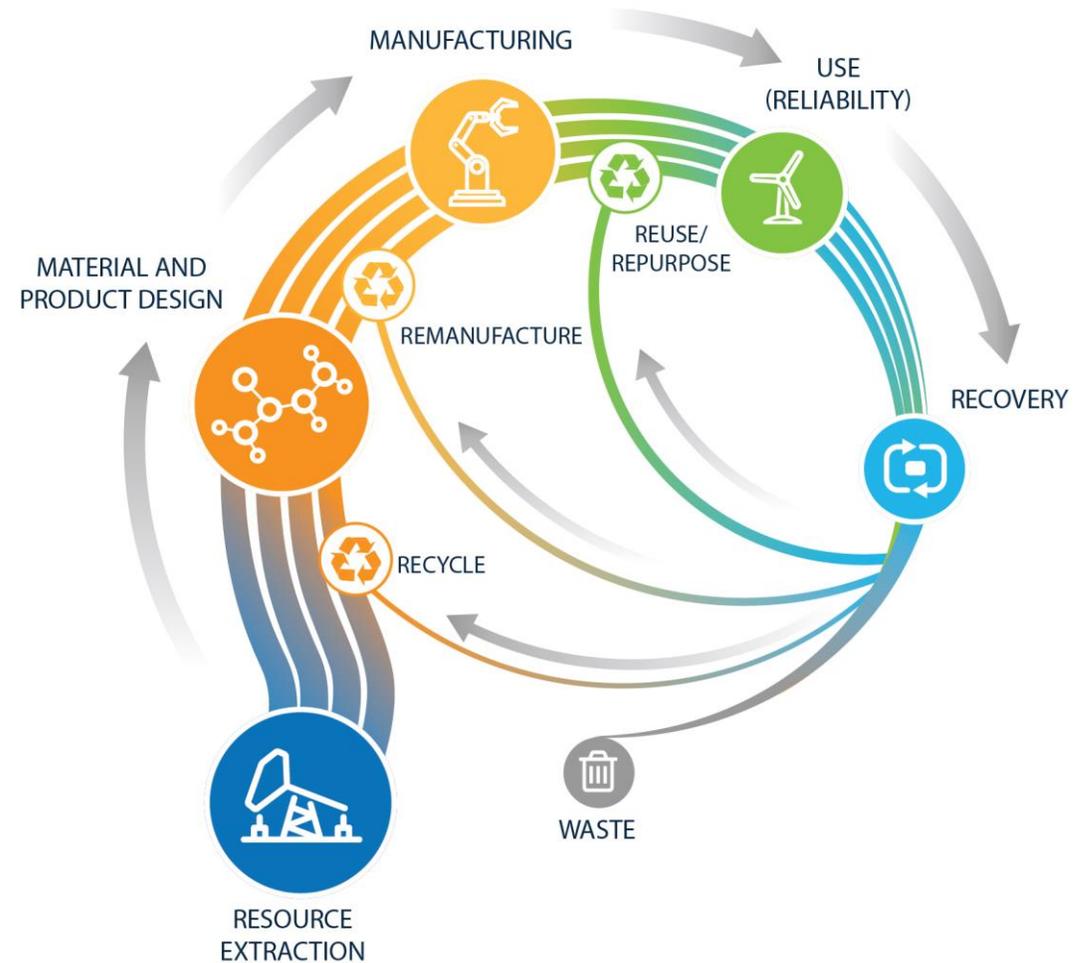
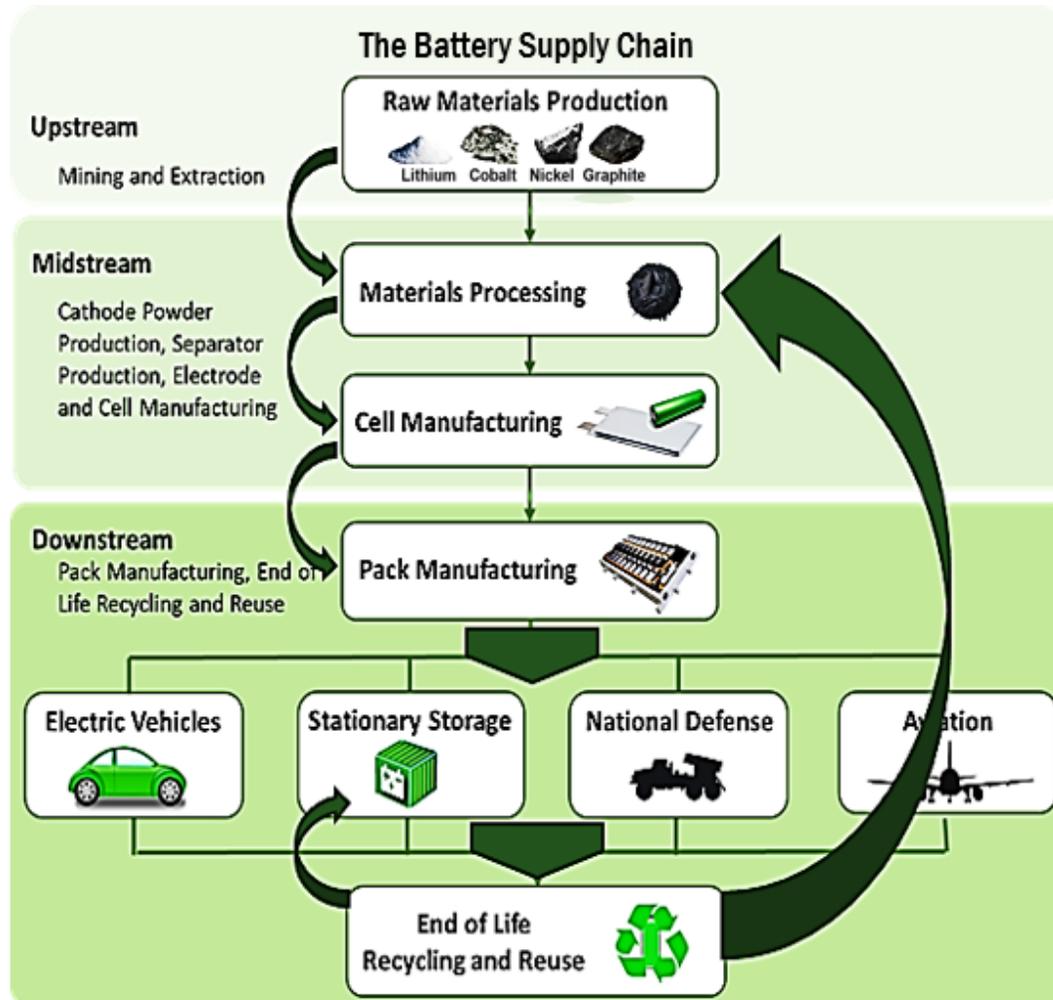
- Investments across the supply chain, in the U.S. and globally
- Investment costs
- Infrastructure
- Incumbency
- Government incentives
- Evolving trade flows

3. Opportunities – when and how to act

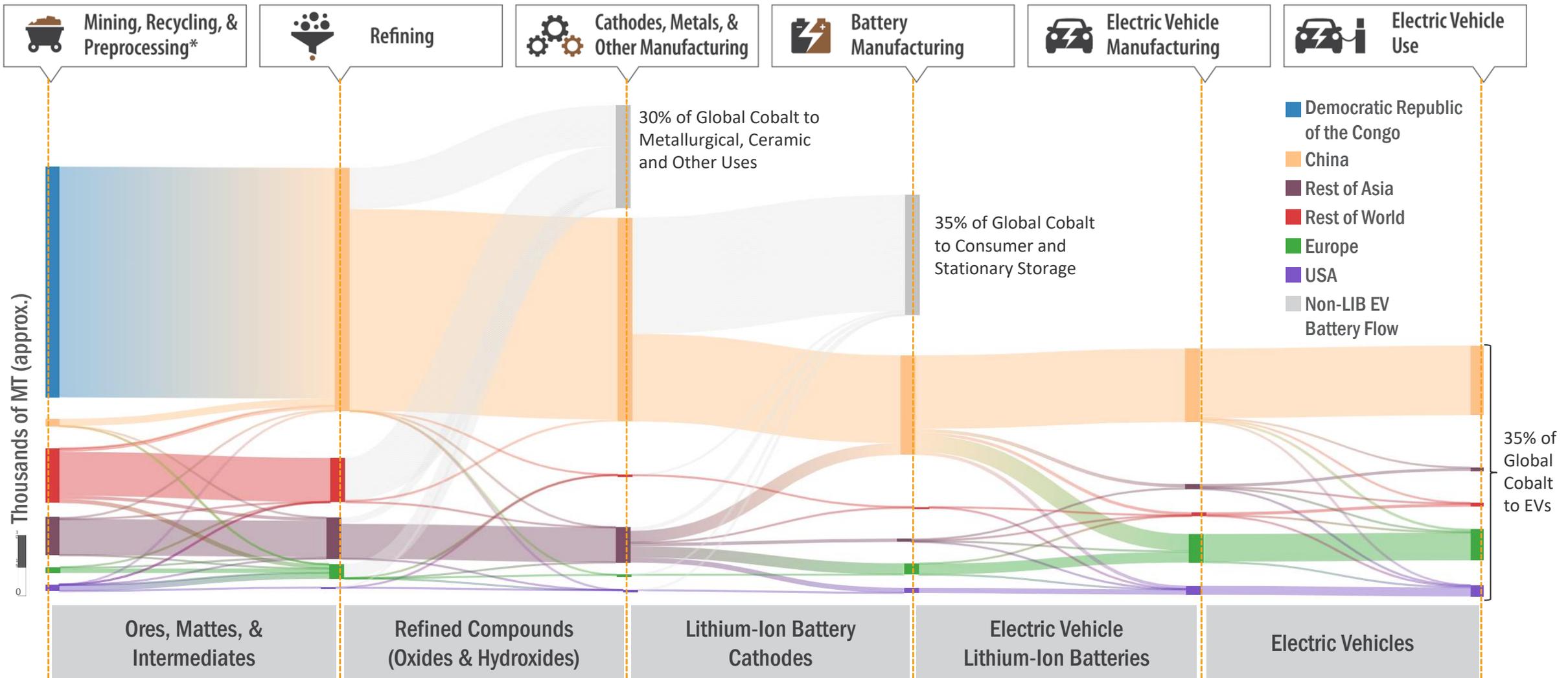
- Policy
- Investments
- Workforce

Analysis of the global supply chain helps us understand where the gaps are to meet future demands.

The Battery Supply Chain is Complex, Global, and Circular



2022 Global Cobalt Supply Chain Flows

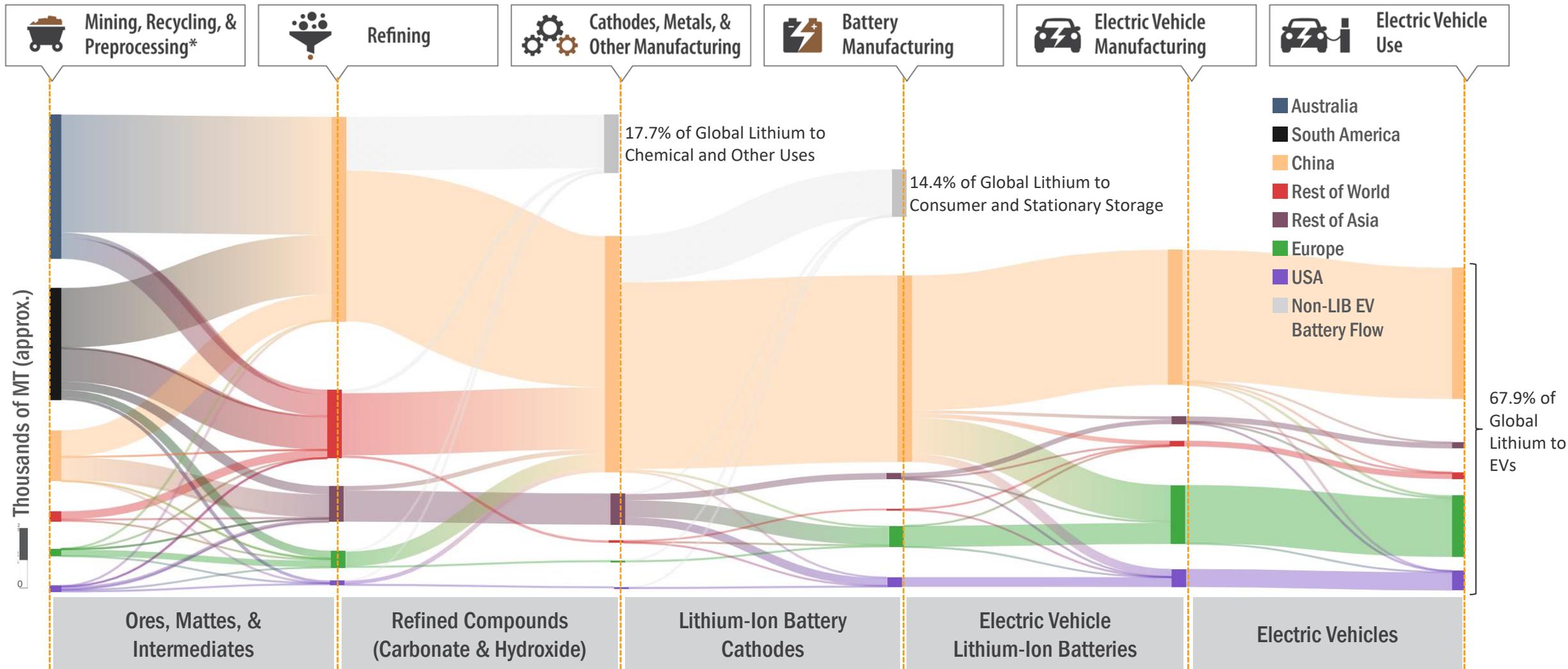


*Mining, Recycling, & Preprocessing products:

- Ores: naturally occurring solids containing cobalt
- Mattes and Intermediates: (30-100% Co)

Sources: NREL Analysis; USGS, "Mineral Commodity Summaries"; 2023, <https://doi.org/10.3133/mcs2023>; UN COMTRADE Database, <https://comtradeplus.un.org/>, "Global Cobalt Outlook 2020-2030", 1H 2023 Battery Materials Outlook, 2023 Long Term Electric Vehicle Outlook, and Battery Material Manufacturing database, <https://www.bnef.com>.

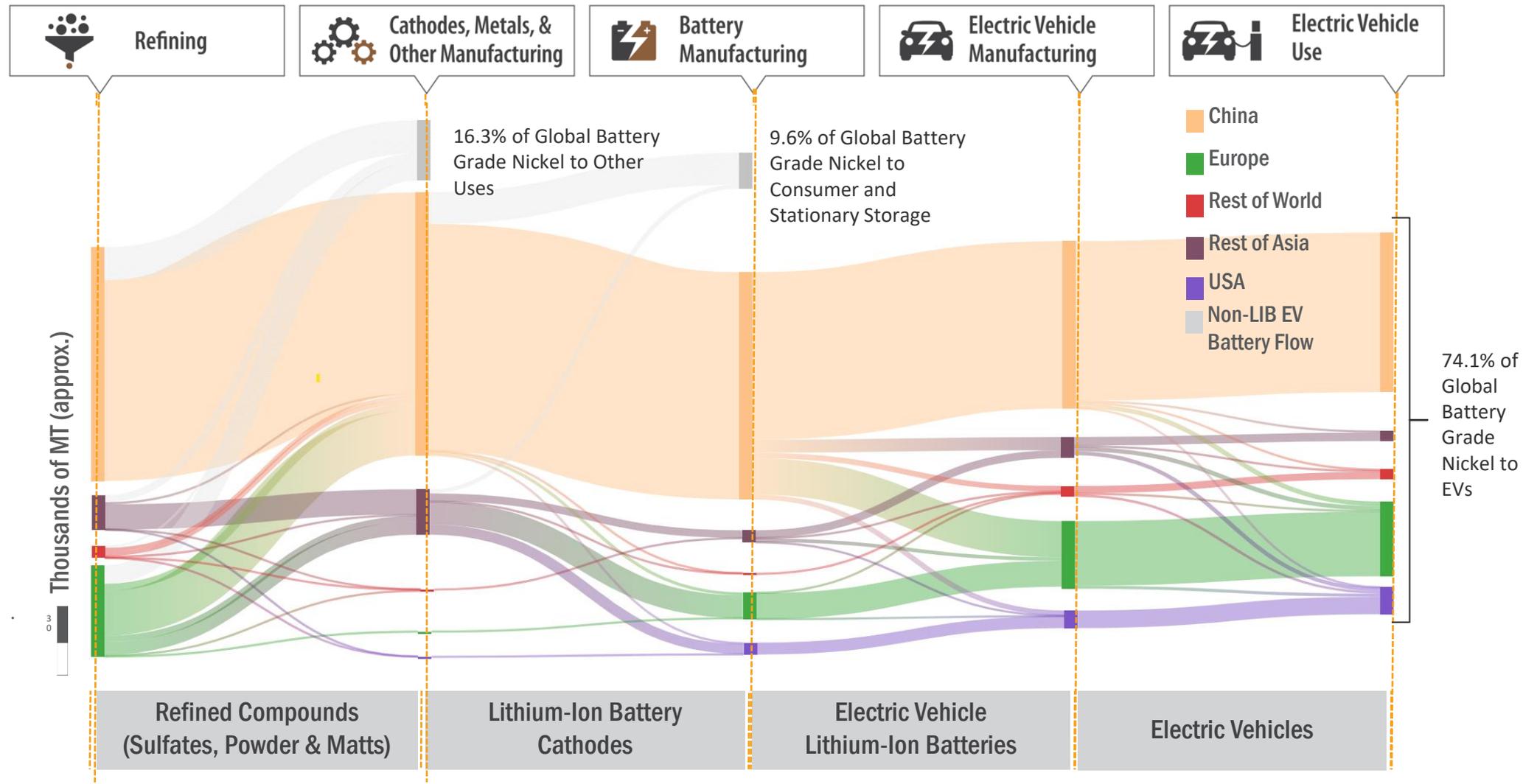
2022 Global Lithium Supply Chain Flows



*Mining & Preprocessing products:
 • Lithium carbonate and hydroxide from brines, hard rock (e.g., spodumene) and other sources

Sources: NREL Analysis; USGS, "Mineral Commodity Summaries"; 2023, <https://doi.org/10.3133/mcs2023>; UN COMTRADE Database, <https://comtradeplus.un.org/>, "Global Lithium Outlook 2020-2030", 1H 2023 Battery Materials Outlook, 2023 Long Term Electric Vehicle Outlook, and Battery Material Manufacturing database, <https://www.bnef.com>.

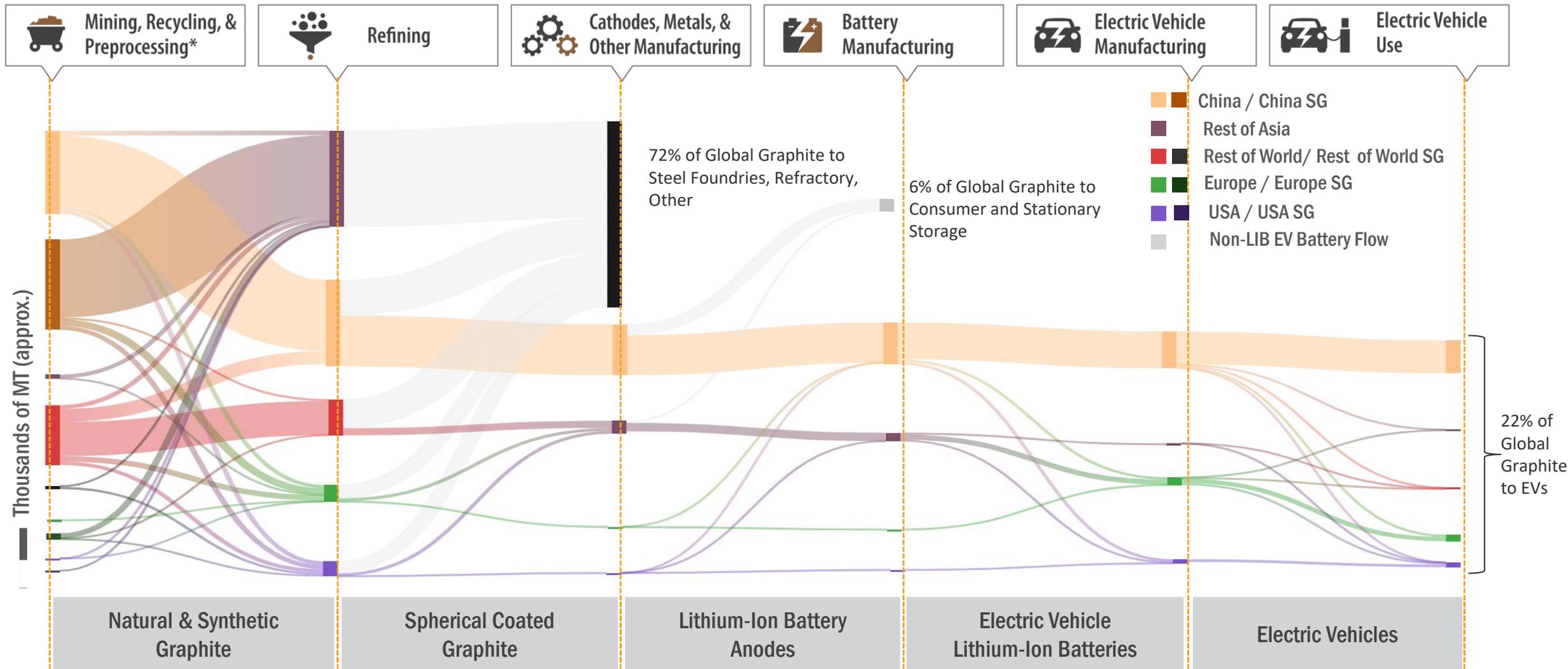
2022 Global Class 1 Nickel Supply Chain Flows



*Battery grade is nickel sulfate and is a subset of Class 1 nickel

Sources: NREL Analysis; USGS, "Mineral Commodity Summaries" 2023, <https://doi.org/10.3133/mcs2023>; UN COMTRADE Database, <https://comtradeplus.un.org/> "Global Nickel Outlook 2020-2030", 1H 2023 Battery Materials Outlook and Battery Material Manufacturing Database, <https://www.bnef.com/>;

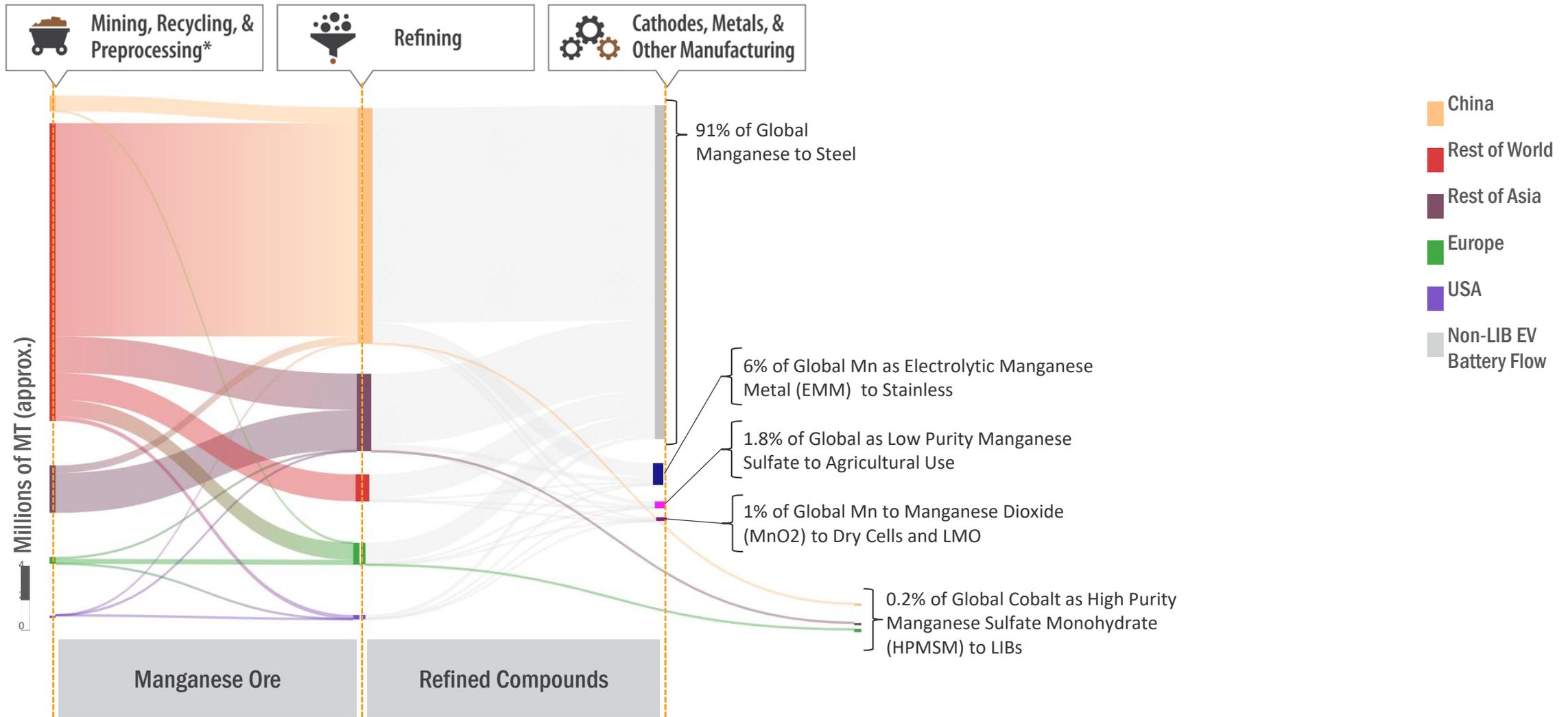
2022 Global Graphite Supply Chain Flows



*Flows and stocks shown in mining and preprocessing are the net exports of natural flake graphite and synthetic graphite, denoted with an SG at the end of the region or country's name

Sources: NREL Analysis; USGS, "Mineral Commodity Summaries" 2023, <https://doi.org/10.3133/mcs2023>; UN COMTRADE Database, <https://comtradeplus.un.org/>; Global Graphite Outlook 2020-2030", 1H 2023 Battery Minerals Outlook and Battery Material Manufacturing database, <https://www.bnef.com>; Miller, G. 2021. "Natural and Synthetic Graphite: A Strategic Review, Presented at Benchmark Week Online 2021, 6 December 2021; Dua, M. "Graphite Market Overview", presented at Benchmark Week 2021, 6 December 2021.

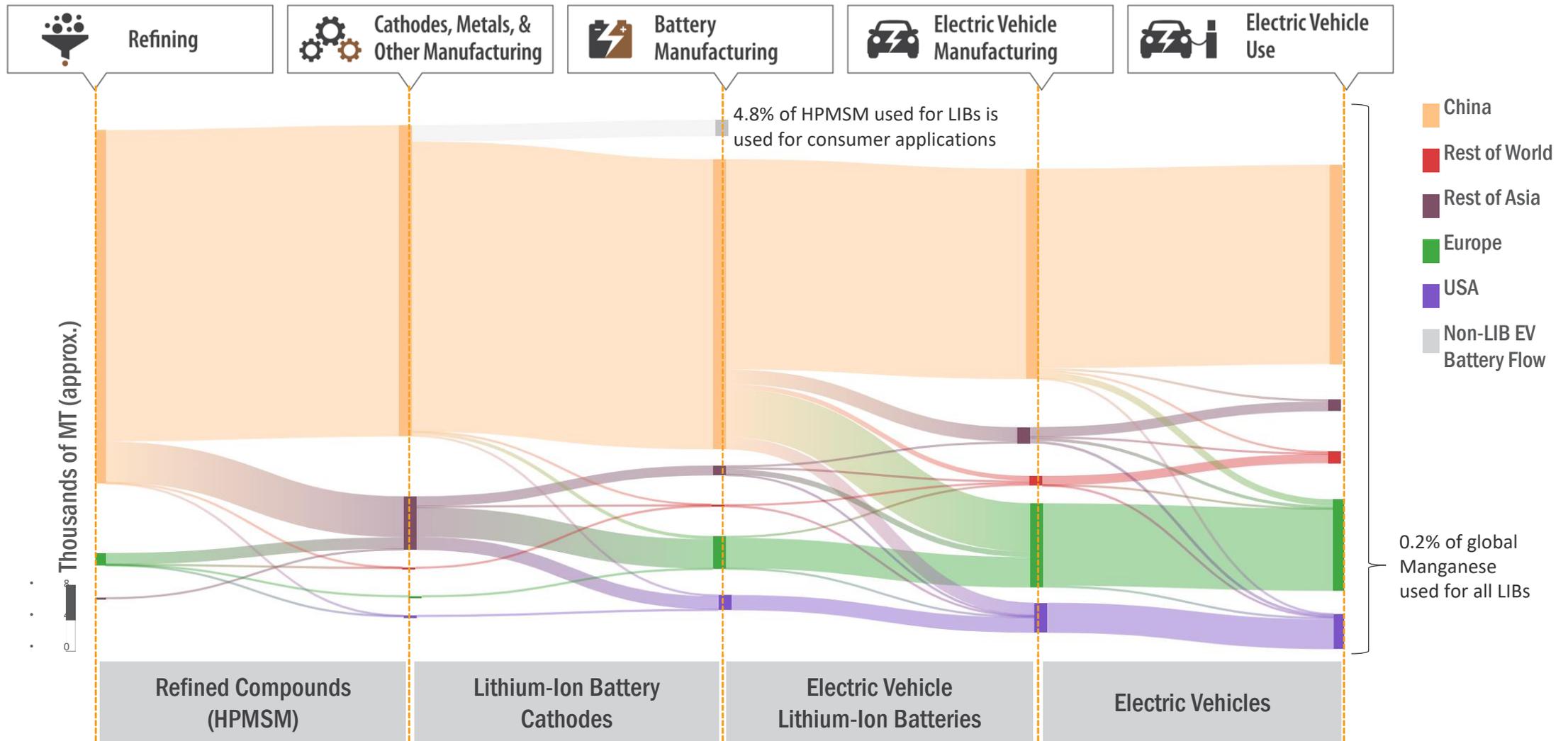
2022 Global Manganese Supply Chain Flows



*Manganese ore contains 39-54% Mn; assumed the average of 46.5%

Sources: NREL Analysis; USGS, "Mineral Commodity Summaries"; 2023, <https://doi.org/10.3133/mcs202>; UN COMTRADE Database, <https://comtradeplus.un.org/>, "Global Manganese Outlook 2020-2030", 1H 2023 Battery Materials Outlook, 2023 Long Term Electric Vehicle Outlook, and Battery Material Manufacturing database, <https://www.bnef.com>

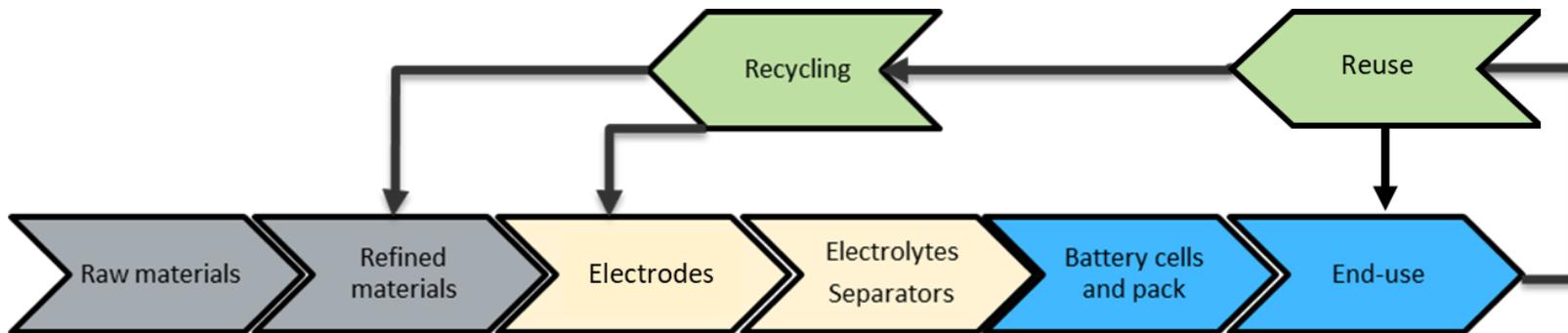
2022 Global Manganese Supply Chain Flows



Sources: NREL Analysis; USGS, "Mineral Commodity Summaries"; 2023, <https://doi.org/10.3133/mcs202>; UN COMTRADE Database, <https://comtradeplus.un.org/>, "Global Manganese Outlook 2020-2030", 1H 2023 Battery Materials Outlook, 2023 Long Term Electric Vehicle Outlook, and Battery Material Manufacturing database, <https://www.bnef.com>

Supply Chains are Interconnected and Dynamic

Investments along the entire supply chain are needed to ensure a reliable and resilient supply chain



Nothing in life (or markets) is ever static. Changes in one part of the system can affect everything across the supply chain. *Some examples:*

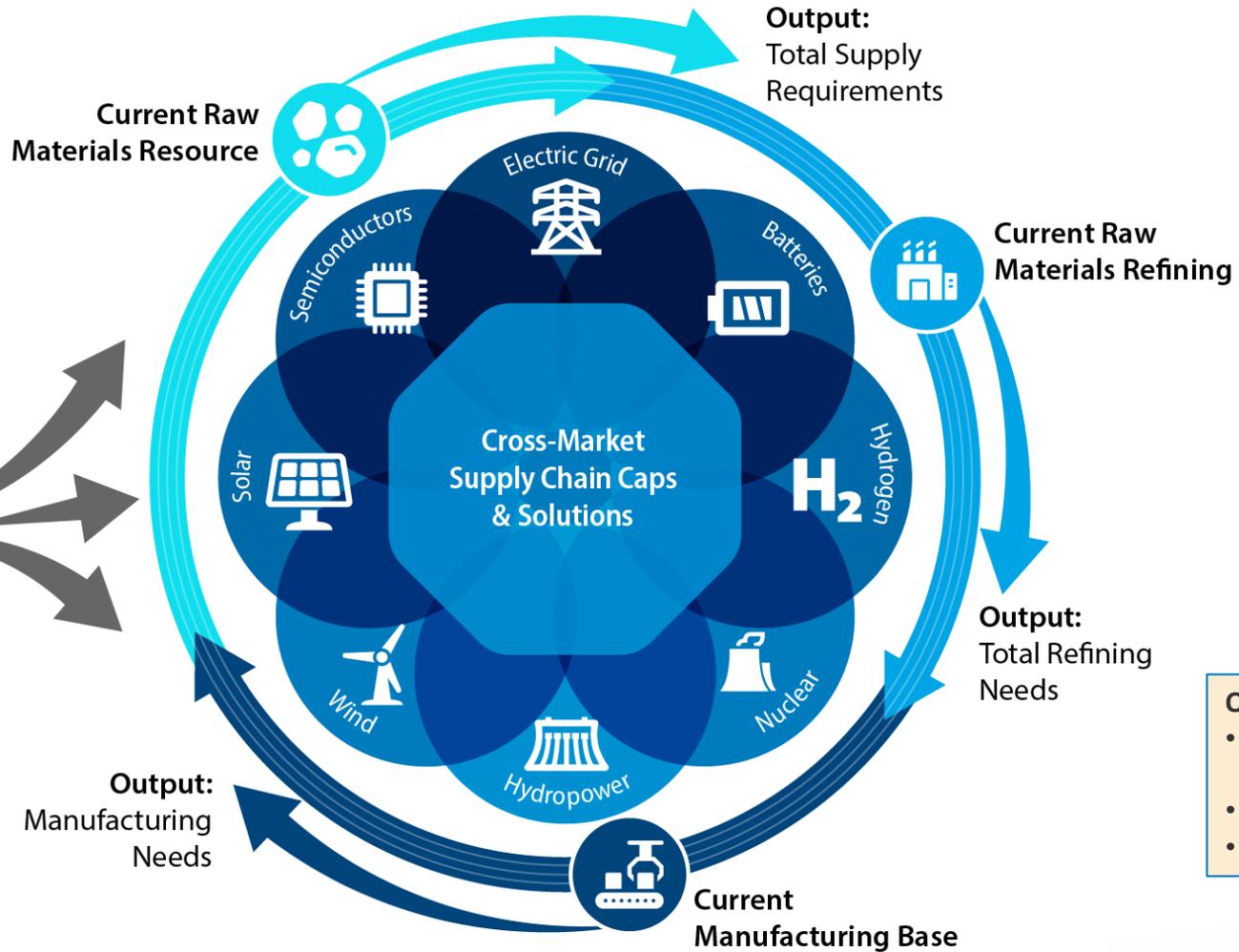
- Prices of raw materials, components, shipping
- Policies on emissions, competitiveness, government investments
- Demand from other sectors
- Public sentiment, NIMBY



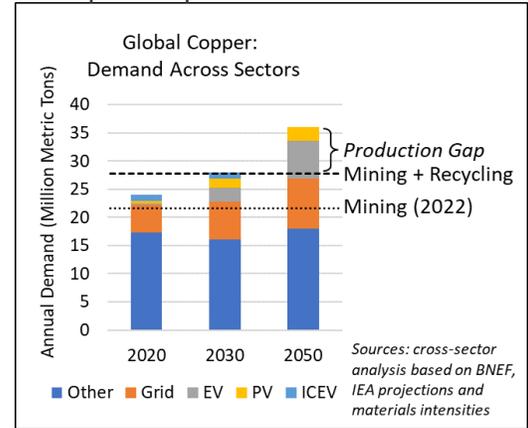
The position of the jack (viability of industry) depends on how the other portions of the cord (the supply chain) are pushed and pulled.

The RING Model: Analysis of Fully Integrated Supply Chains

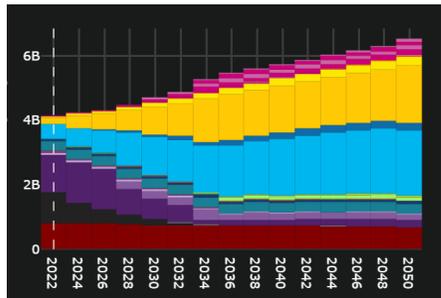
- Inputs**
- Deployment projections
 - Current manufacturing capacity
 - Current material resources & production



Example Output

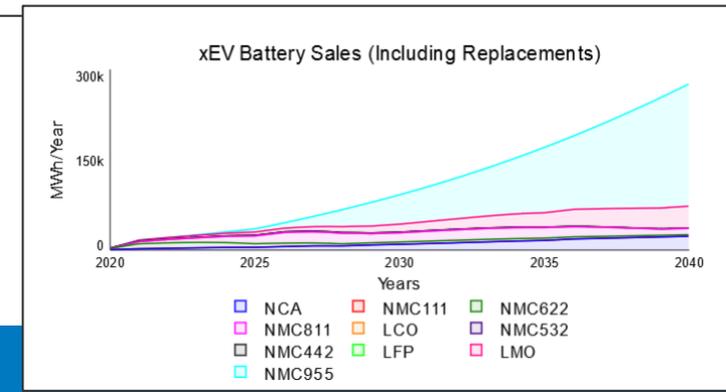
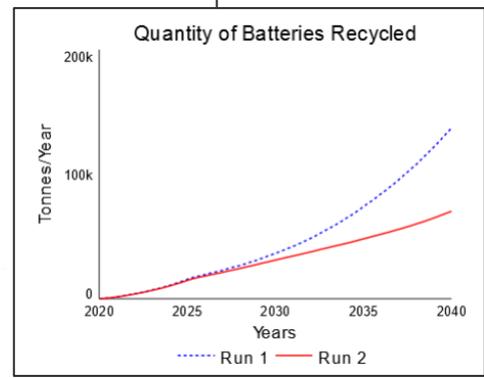
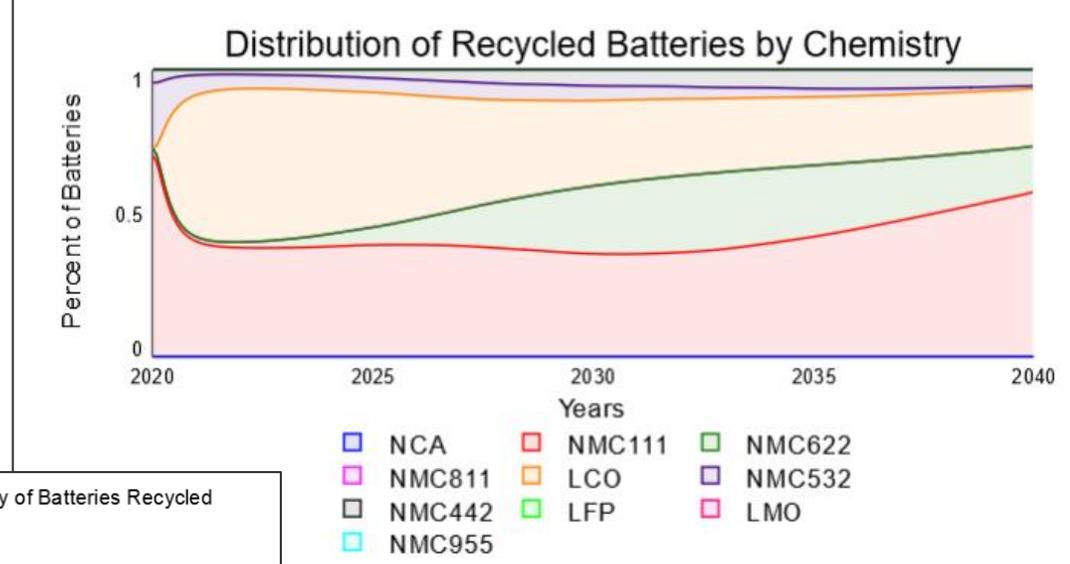
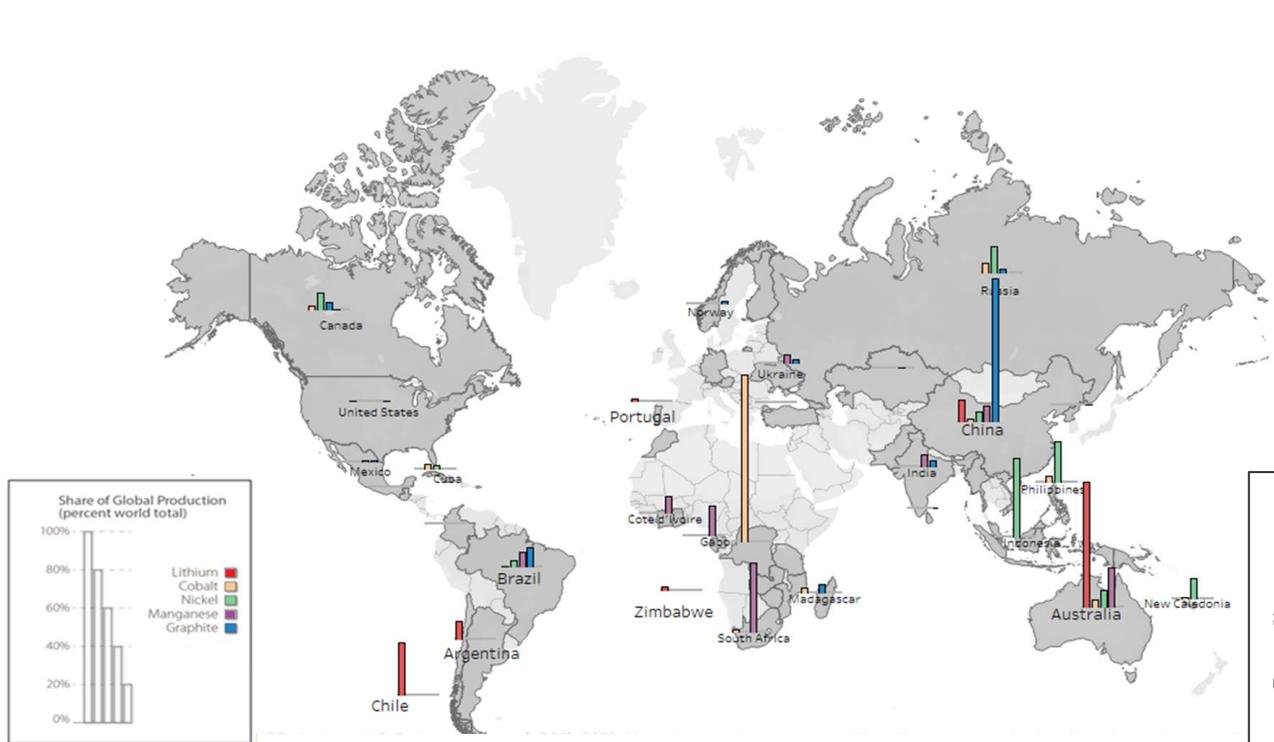


- Outputs:**
- Supply Chain Constraints
 - Resiliency Gaps
 - Investment Needs



Example Demand Projections

Build-out of mining, refining, manufacturing, and recycling needed to meet demands



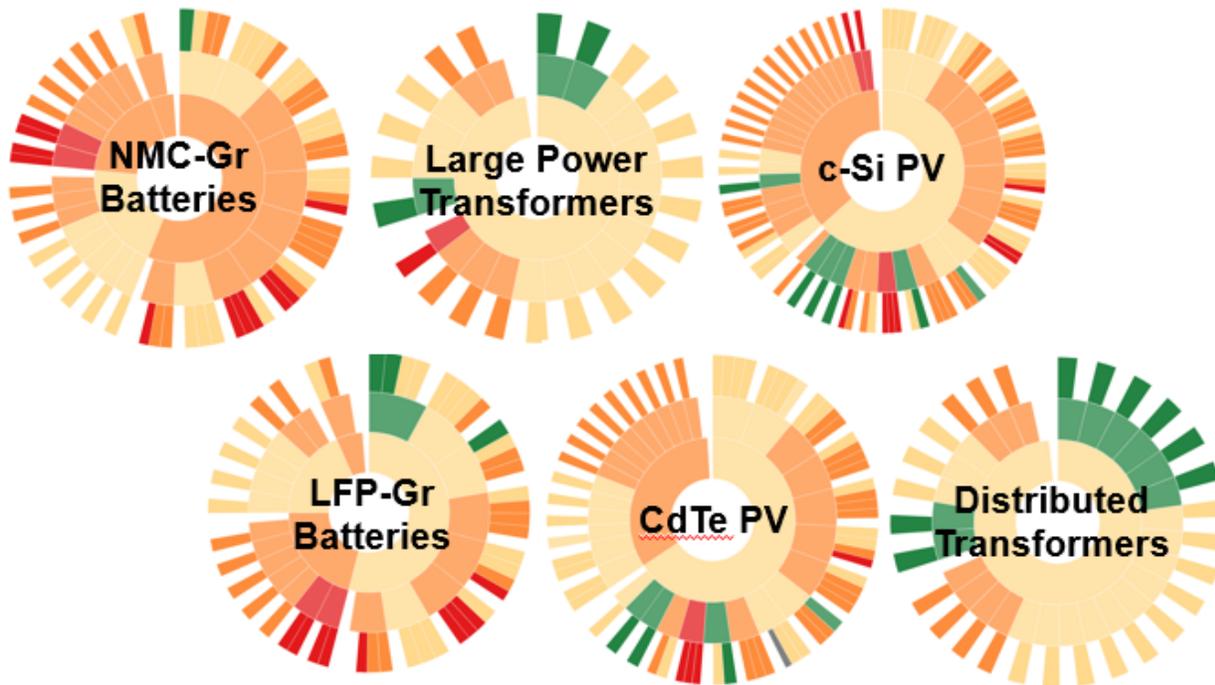
LIBRA – Lithium-Ion Battery Resource Assessment Model



LIBRA is a system-dynamics model that evaluates the economic viability of the battery manufacturing, reuse, and recycling industries across the global supply chain under differing *dynamic* conditions

MESC MMAC Supply Chain Readiness Level

How ready is the United States to meet the manufacturing demand in 2030?



The evaluated technologies all show a low-to-moderate supply chain readiness level, illustrating how further investments are crucial to support the growth across industries.





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