


Supply Chains and the Energy Transition

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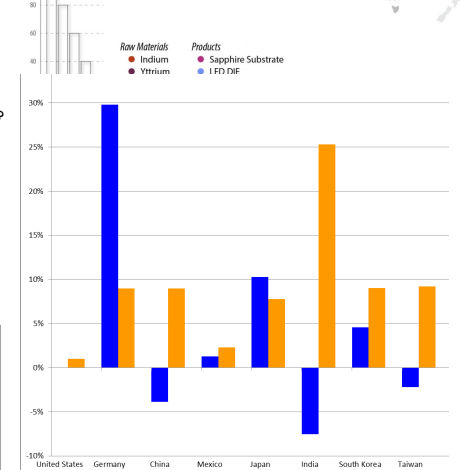
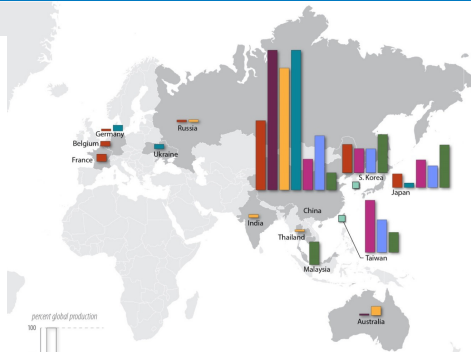
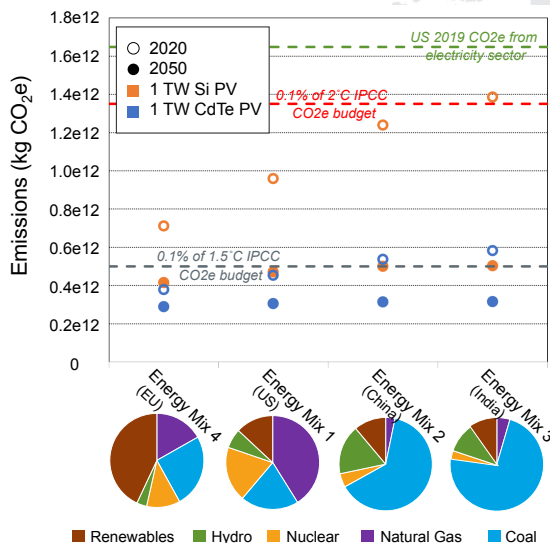
Energy and the Economy: Reshuffling the Energy Deck
The Petroleum Club, Oklahoma City, OK
November 7, 2023

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- 1** What we do
 - 2** Global Trade and value-add: LED case study
 - 3** Beyond cost-Carbon now matters: Photovoltaics (PV) example
 - 4** Rising demand and global trade: Electric Vehicle (EV) batteries illustration

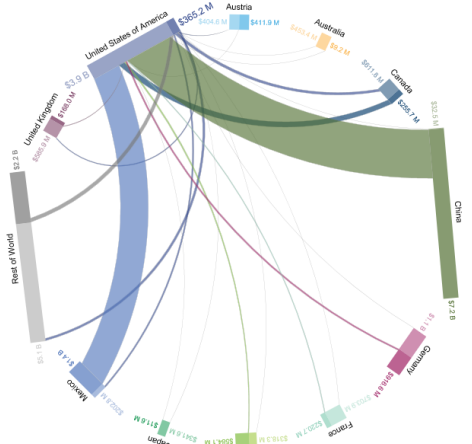
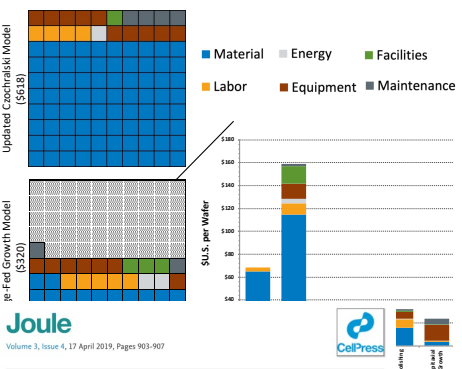
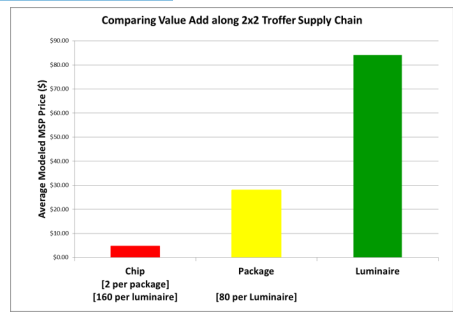
Techno-economic, Manufacturing Decarbonization, and Supply Chain

Provide analysis to put research problems in context and analytically show technology potential. With early TRLs, in collaboration with researchers, put together models. The models serve three purposes:

- 1) Cost & Price
 - i. Highlight manufacturing process/es that add the most cost
 - ii. Predict the minimum sustainable price to compete with current state of art
 - iii. Estimate effects of technical breakthroughs on entire systems costs
- 2) Demonstrate embodied carbon impact of grid mix and technology choices
- 3) Understand supply chain and trade flow implications

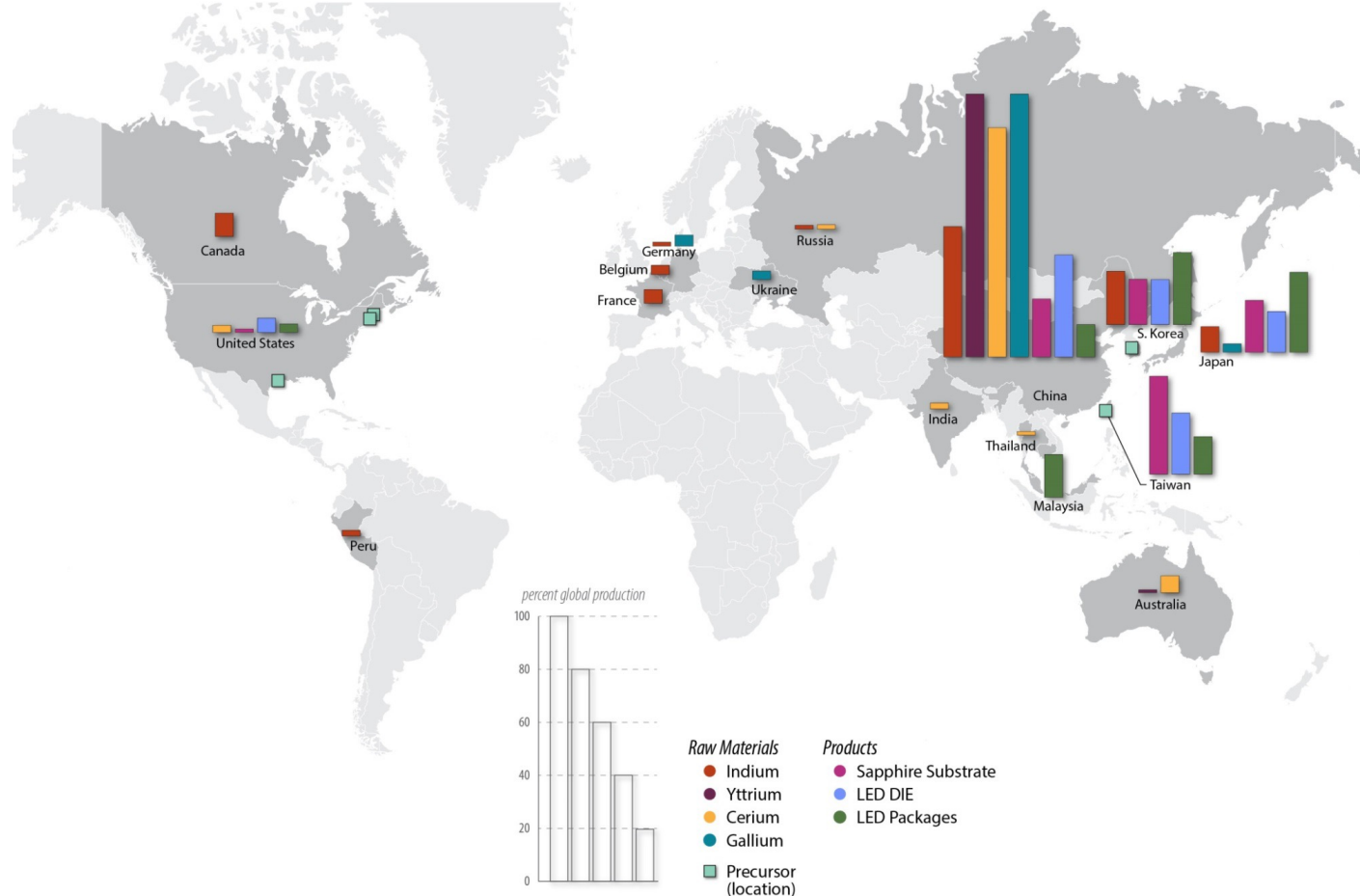


H. M. Wikoif, S. B. Reese, and M. O. Reese, "Embodied energy and carbon from the manufacture of cadmium telluride and silicon photovoltaics," *Joule*, vol. 6, no. 7, pp. 1710–1725, Jul. 2022, doi: [10.1016/j.joule.2022.06.006](https://doi.org/10.1016/j.joule.2022.06.006).



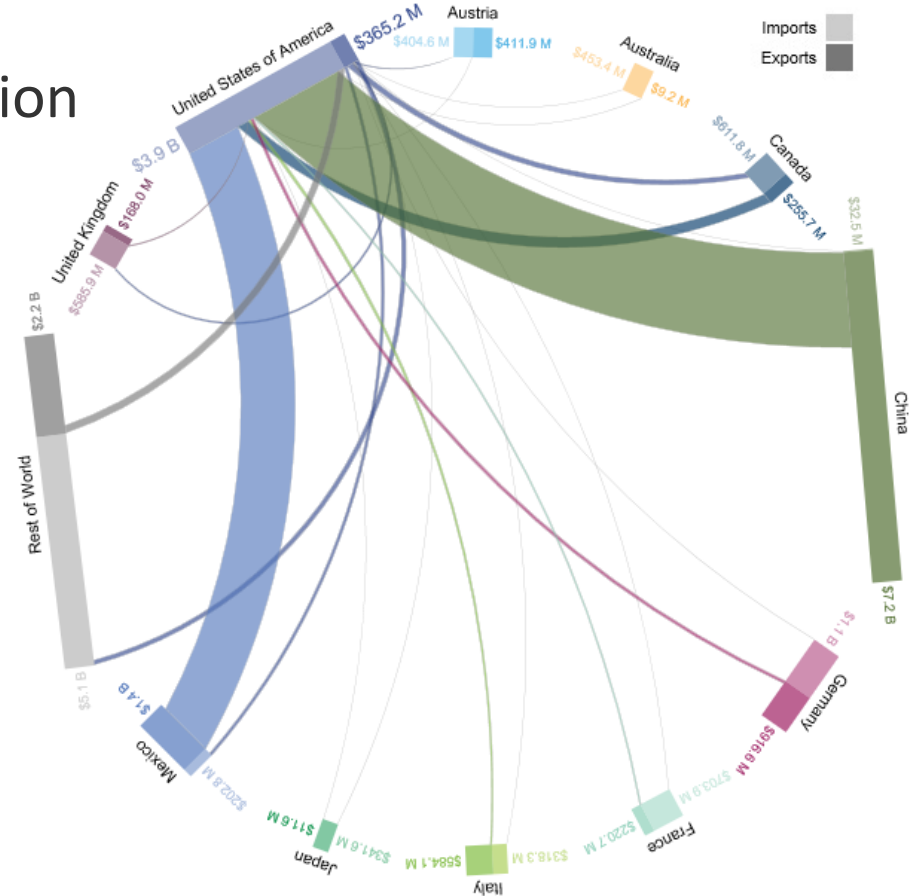
Global Trade and value-add: LED case study

Manufacturing Landscape: Light-emitting Diodes [LED] (2015)



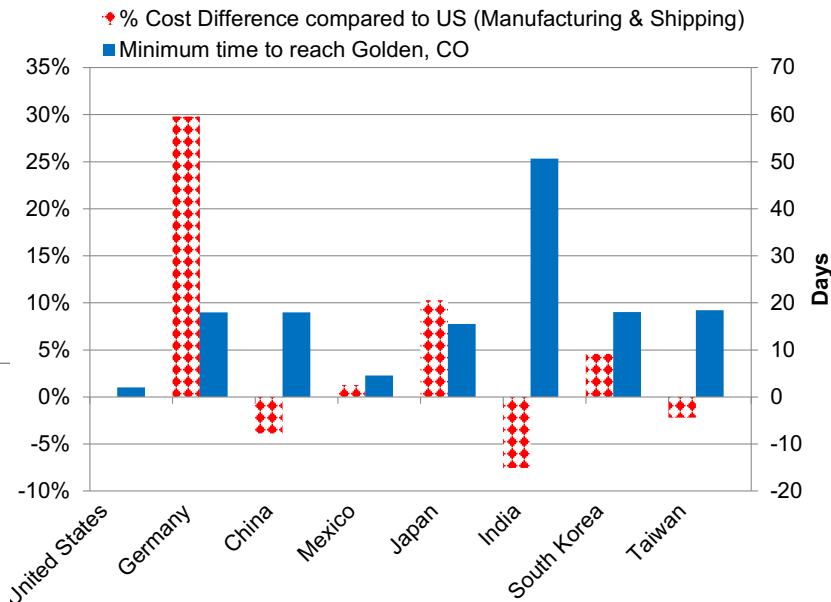
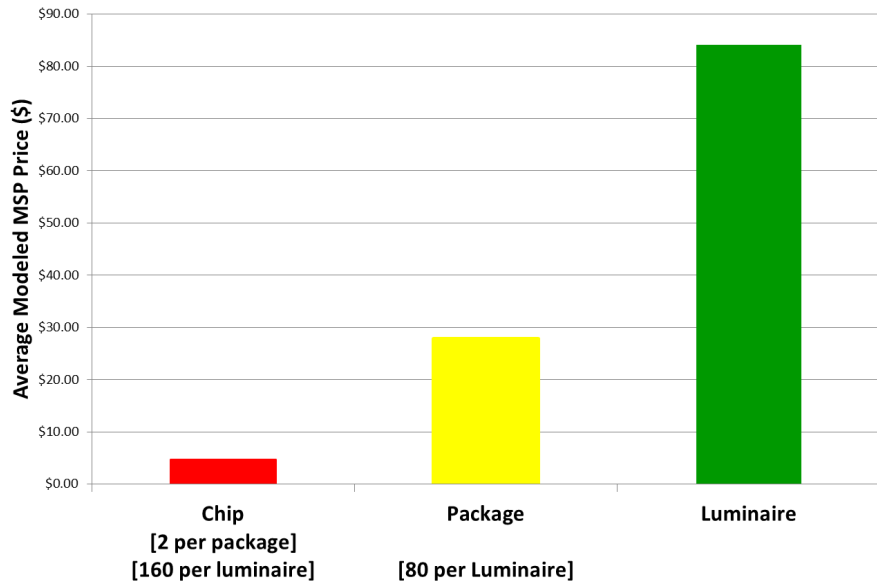
Trade Flow: U.S. Luminaires (2015)

- U.S. luminaire market-\$17.3 billion
- US **imported** \$3.9 billion
- Therefore US domestically **manufactured** ~\$13 billion in lighting products
- **77%** of total revenue sold



Value Add

Comparing Value Add along 2x2 Troffer Supply Chain

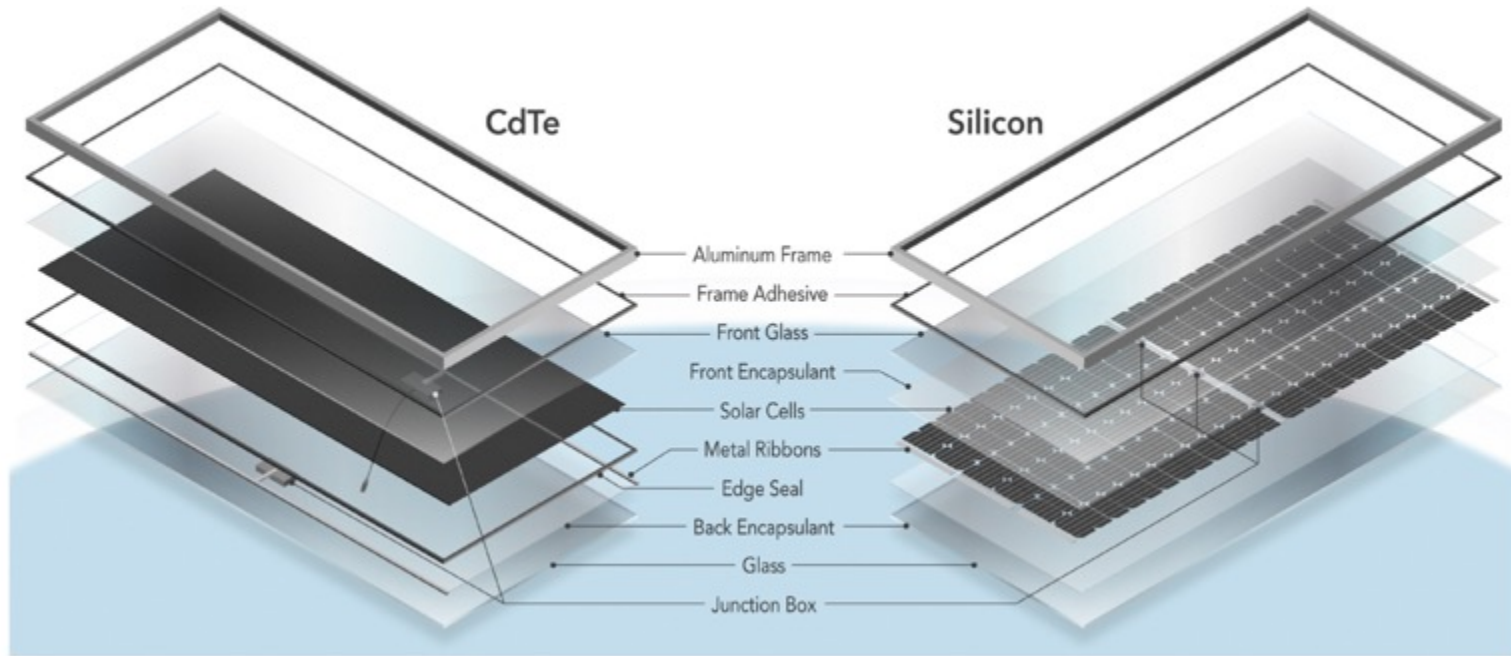


Beyond cost-Carbon now matters: Photovoltaics (PV) example

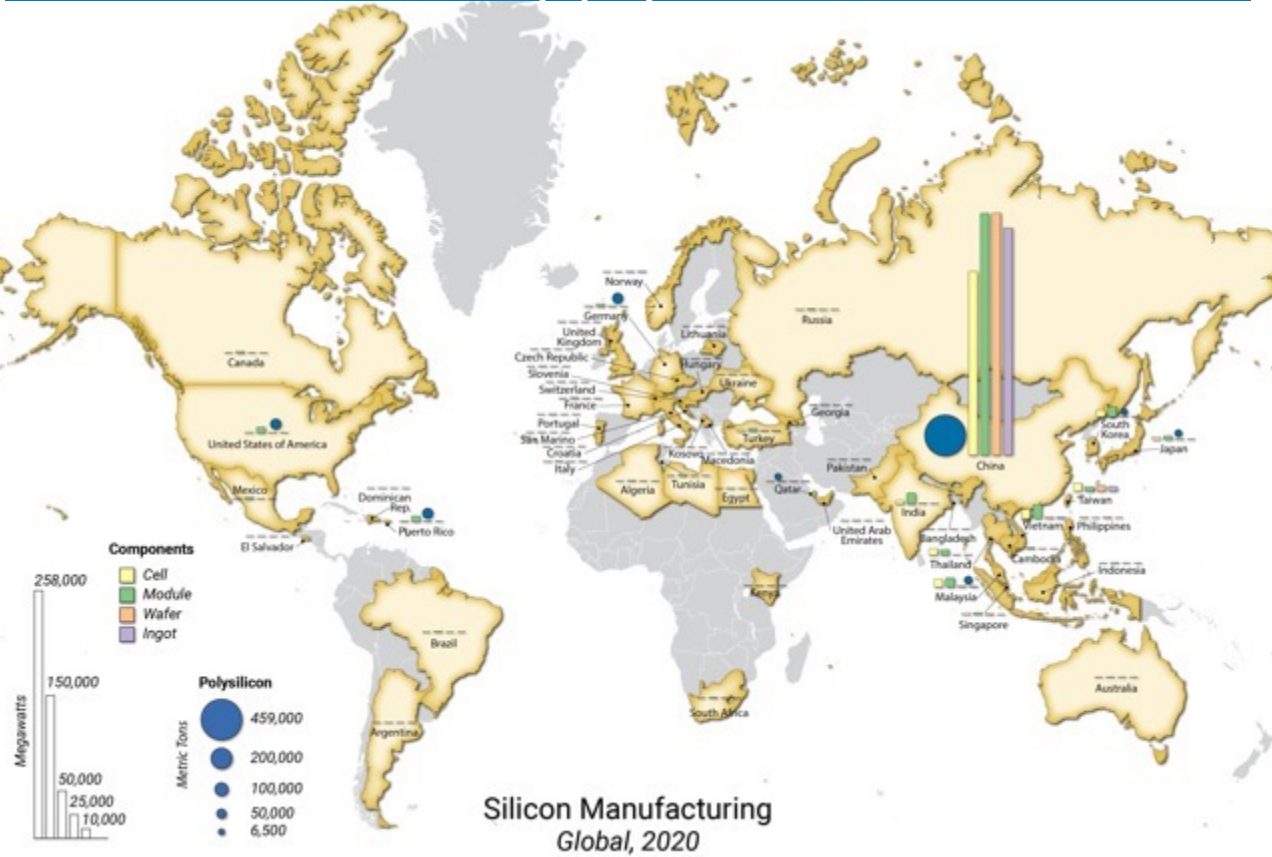
Commercially available PV Technologies

cadmium telluride (CdTe)

crystalline silicon (Si)

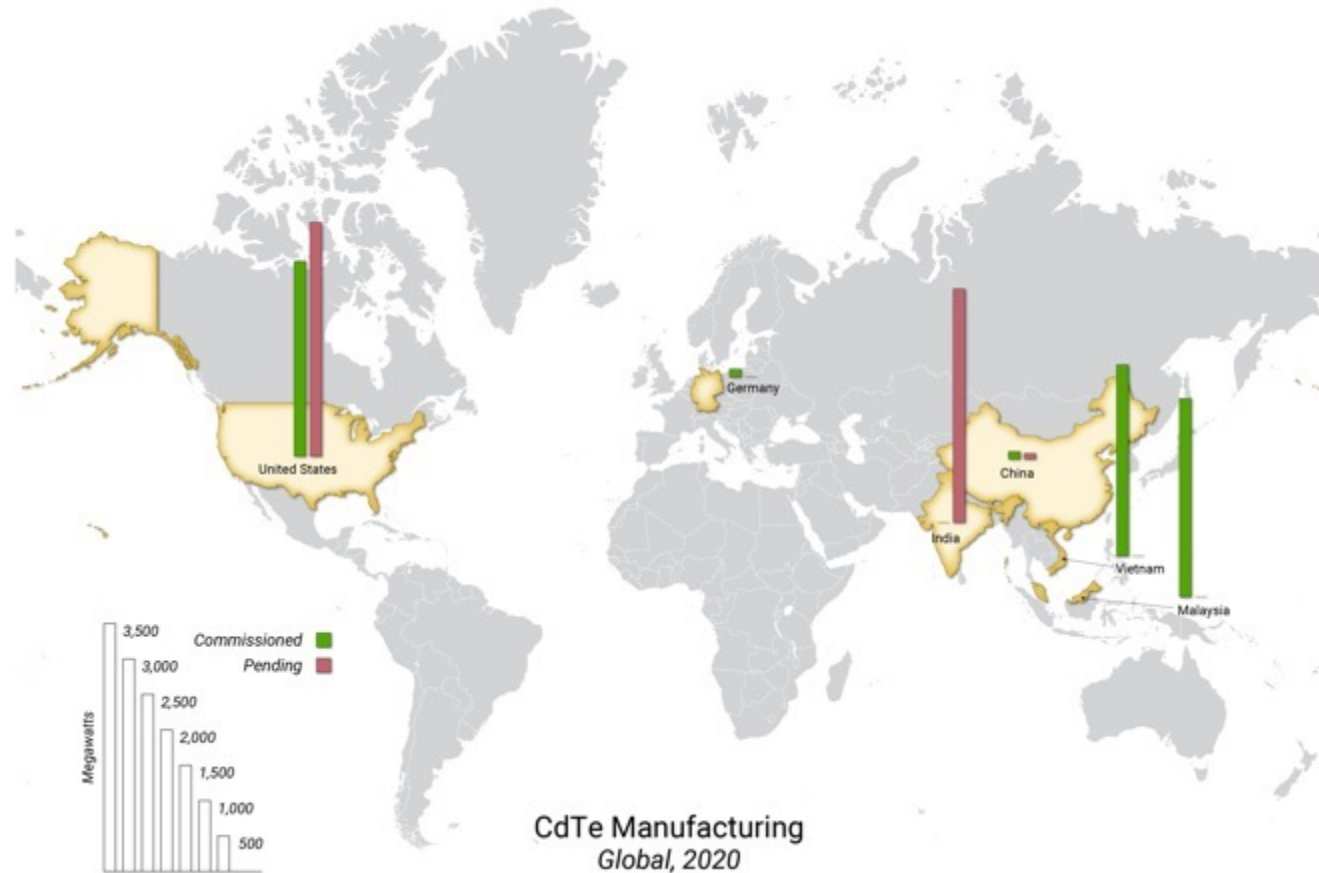


Si Supply Chain



- Silicon based solar cells are most dominant, 90%+ of global market
- Majority of entire Si value chain is manufactured in China

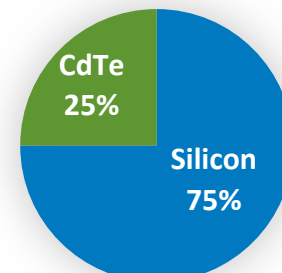
CdTe Supply Chain



Major manufacturing of CdTe in USA and southeast Asia.

- Silicon based solar cells are most dominant, 90%+ of global market.
- CdTe is 40% of the U.S. axis-based tracking market, and ~25% of cumulative U.S. installations >1 MW.

US Installations >1MW

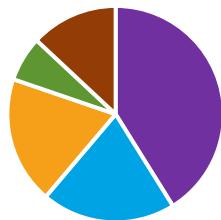


PV Module Embodied Carbon

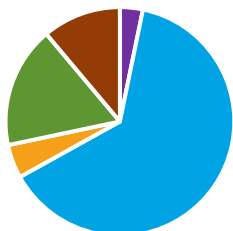
European Union
(2020)



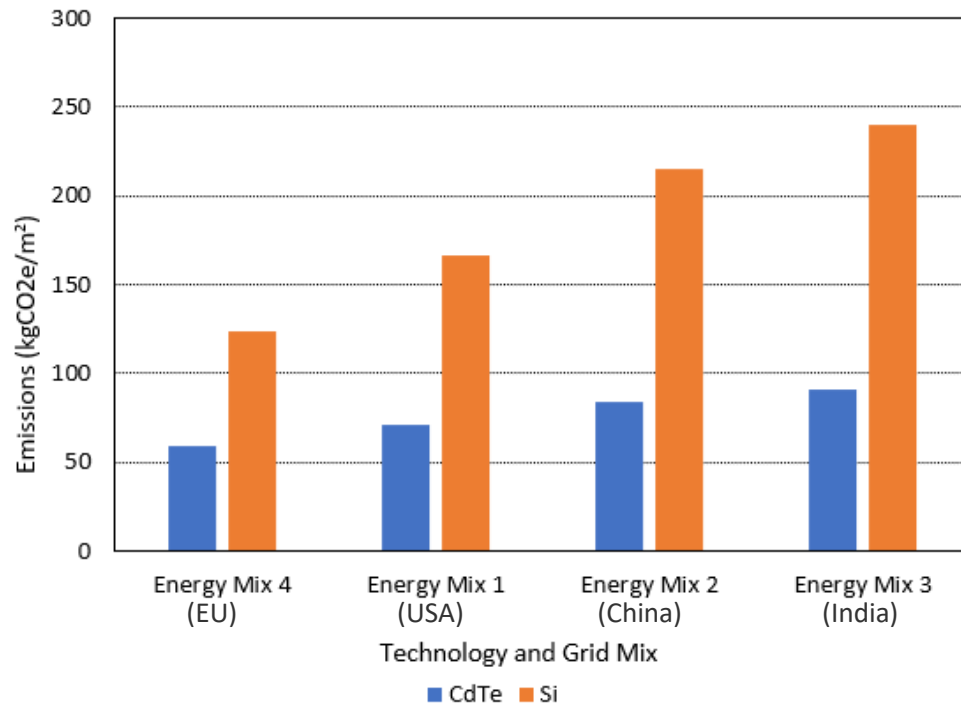
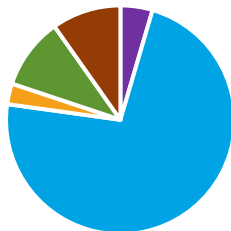
USA (2020)



China (2020)

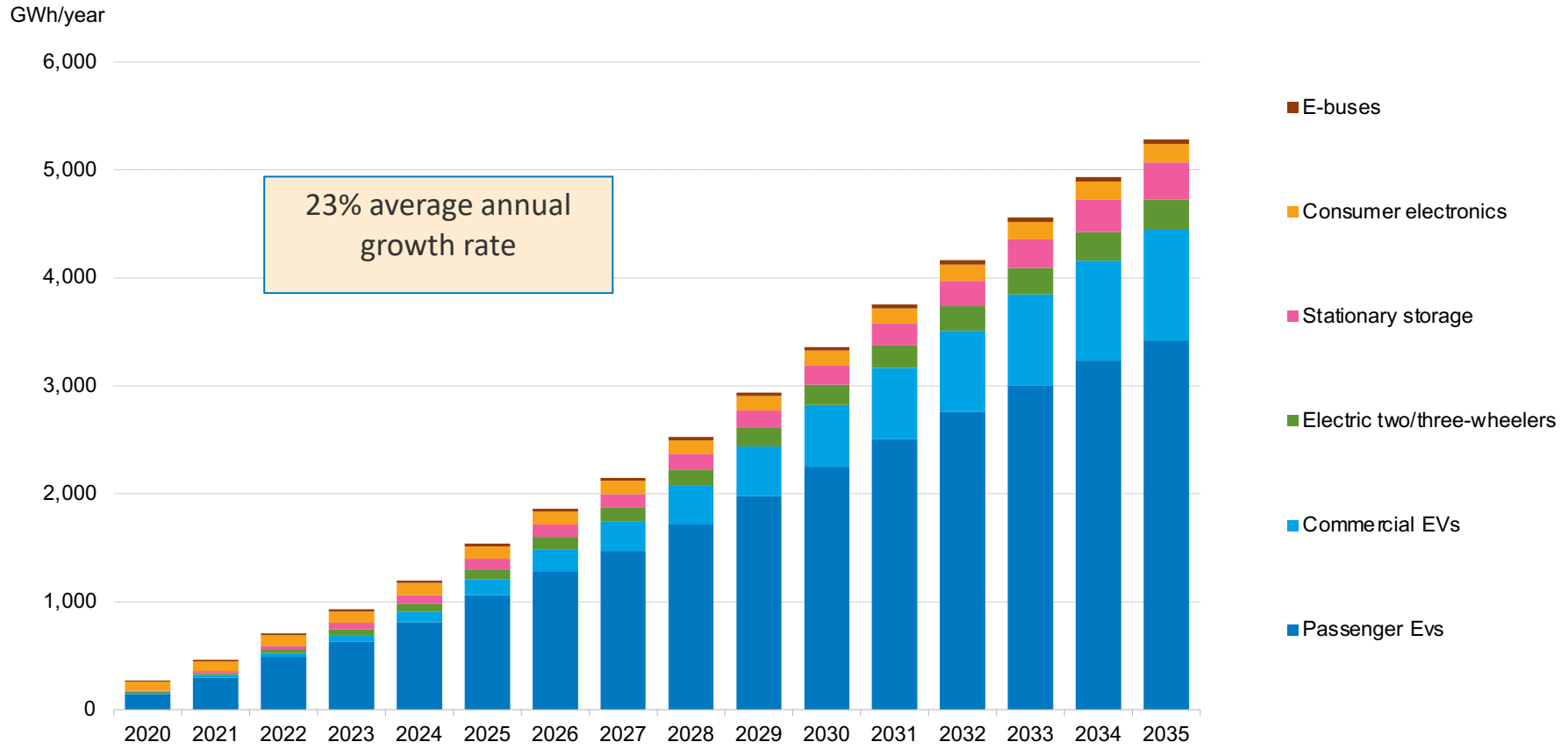


India (2020)



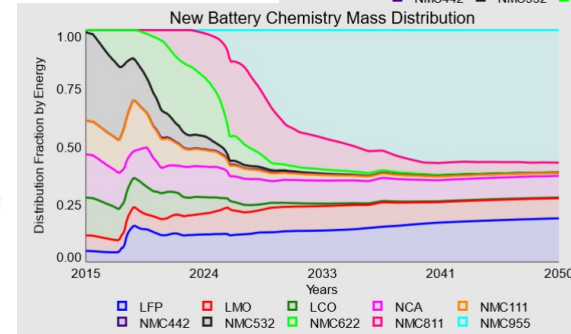
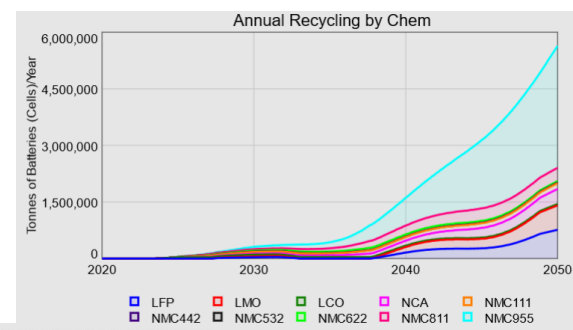
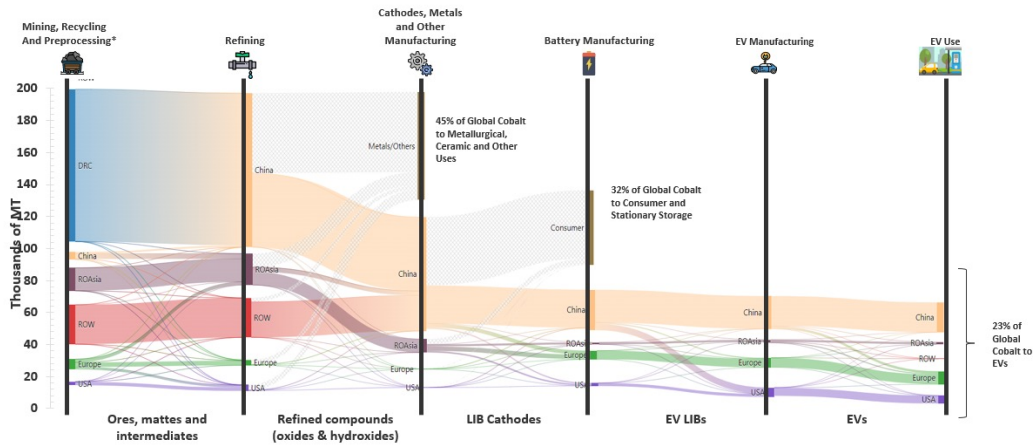
Rising demand and global trade: Electric Vehicle (EV) batteries illustration

Projected Global Demand for Lithium-ion Batteries



Source: BNEF Electric Vehicle Outlook 2022

2021 Global Cobalt Supply Chain Flows



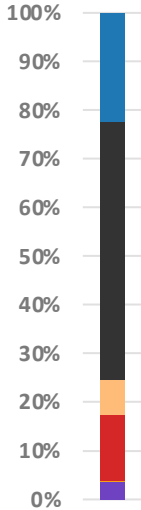
LIBRA – Lithium-Ion Battery Resource Assessment Model



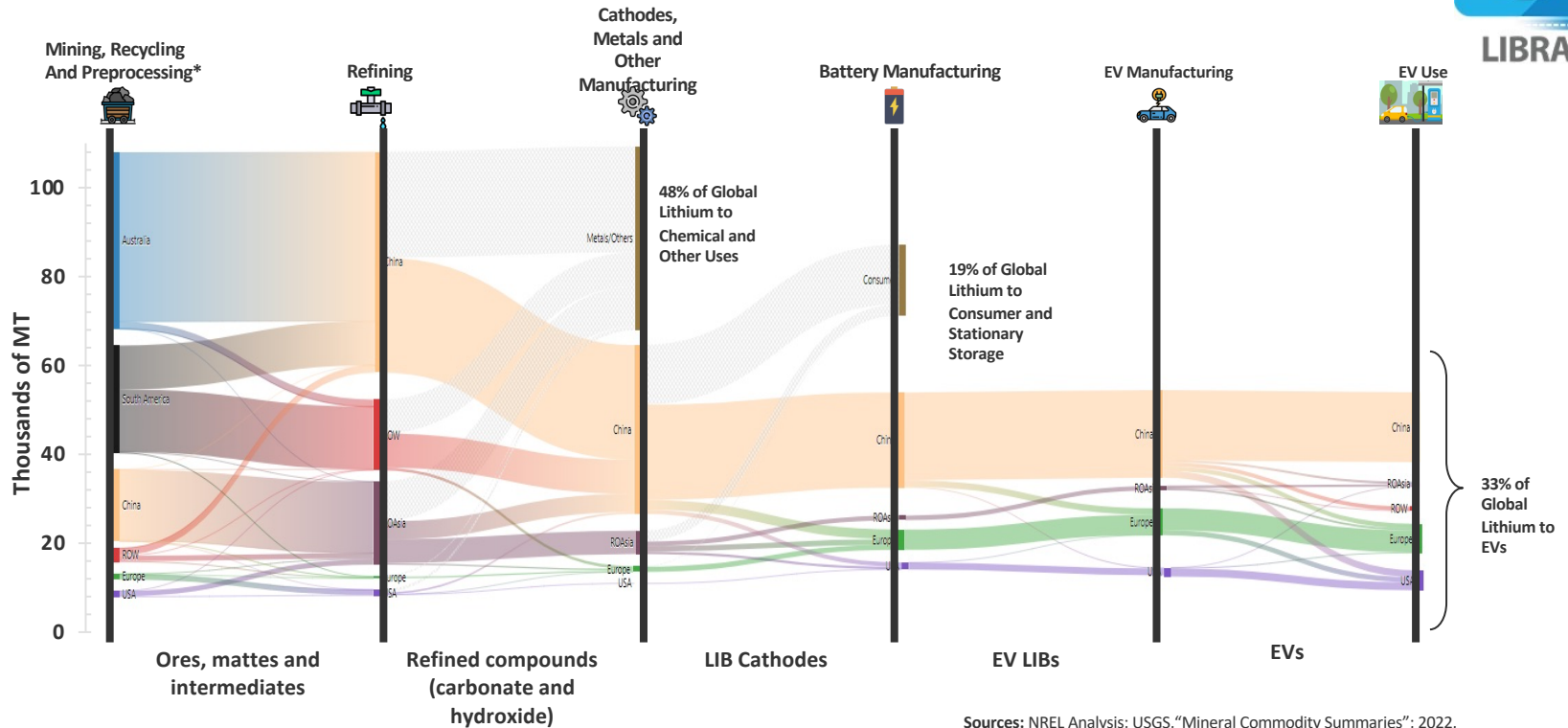
LIBRA is a system-dynamics model that evaluates the macro-economic viability of the battery manufacturing, use, and recycling industries across the global supply chain under differing dynamic conditions

2021 Global Lithium Supply Chain Flows

2021 Estimated Global Li Reserves



Total 2.1 million tonnes Li reserves



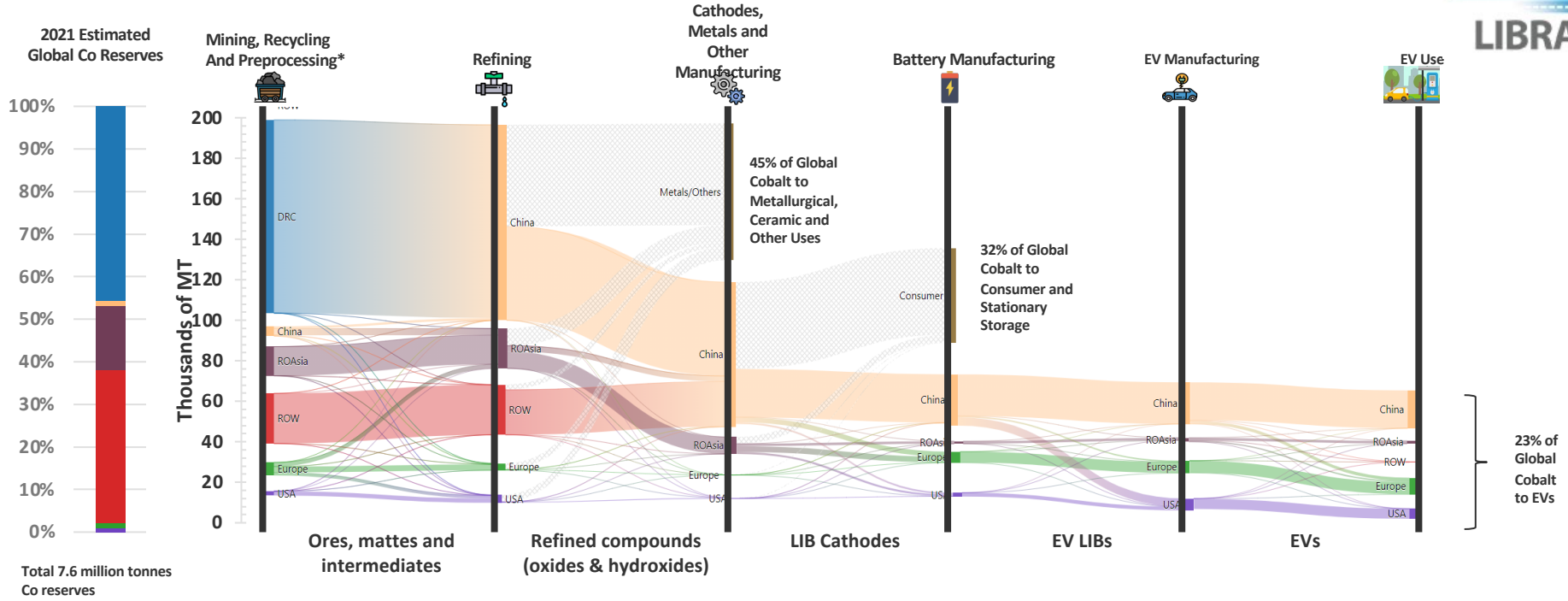
***Mining and Preprocessing products:**

- Lithium carbonate and hydroxide from brines, hard rock (e.g., spodumene) and other sources

ROAsia – Rest of Asia
ROW – Rest of World

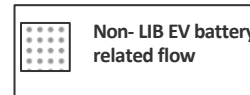
Sources: NREL Analysis; USGS, "Mineral Commodity Summaries"; 2022, <https://doi.org/10.3133/mcs2022>; International Trade Centre, a joint agency of the World Trade Organization and the United Nations, <https://www.intracen.org/>, "Global Cobalt Outlook 2020-2030" and Battery Material Manufacturing database, <https://www.bnef.com>; Resources and Energy Quarterly, Lithium, March 2022, www.industry.gov.au/OCE

2021 Global Cobalt Supply Chain Flows



- *Mining, Recycling and Preprocessing products:**
- Ores: naturally occurring solids containing cobalt
 - Mattes and Intermediates: (30-100% Co)

ROAsia – Rest of Asia
 ROW – Rest of World
 DRC – Democratic Republic of the Congo

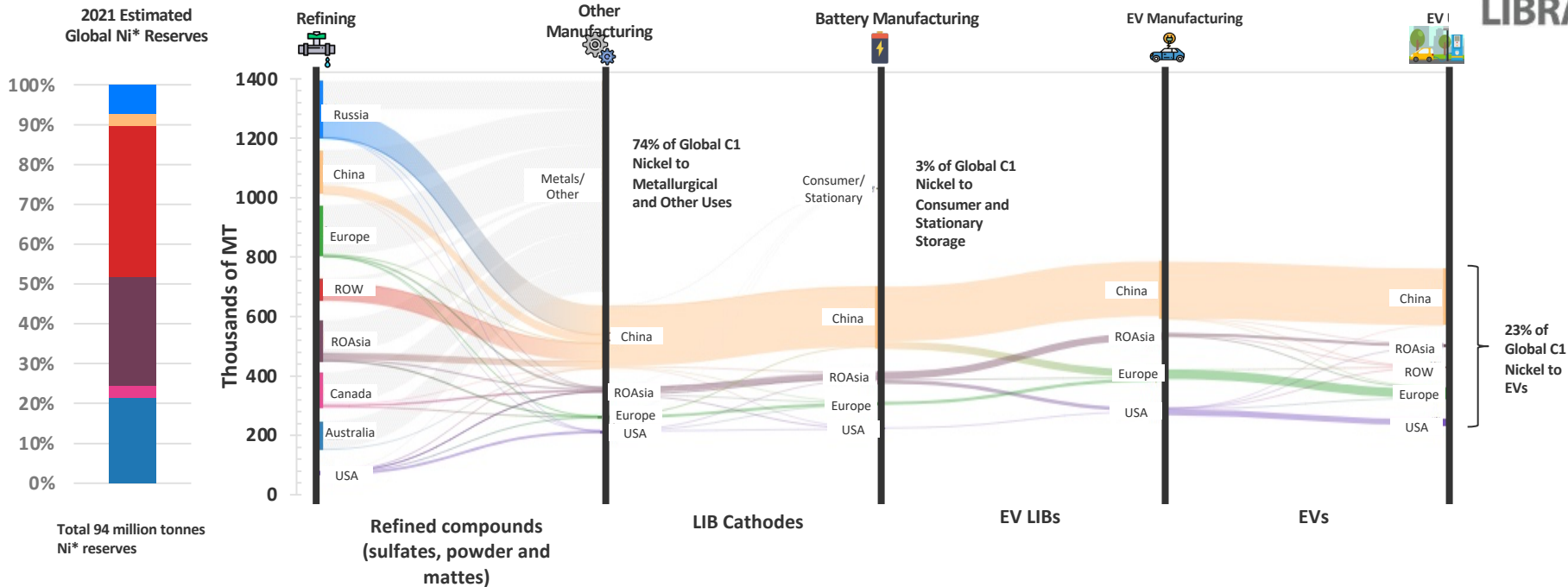


Sources: NREL Analysis; USGS, "Mineral Commodity Summaries"; 2022, <https://doi.org/10.3133/mcs2022>; International Trade Centre, a joint agency of the World Trade Organization and the United Nations, <https://www.intracen.org/>, "Global Cobalt Outlook 2020-2030" and Battery Material Manufacturing database, <https://www.bnef.com>

2021 Global Class 1* Nickel Supply Chain Flows



LIBRA



*Class 1 Ni is a refined product and in general has been obtained from sulfide deposits. The reserves shown are for all terrestrial nickel deposits (laterite and sulfide). Refining and flows are estimates based on reported refined products (i.e., Class 1 or 2).

ROAsia – Rest of Asia
ROW – Rest of World

Non- LIB EV battery related flow

Sources: NREL Analysis; USGS, "Mineral Commodity Summaries"; 2022, <https://doi.org/10.3133/mcs2022>; International Trade Centre, a joint agency of the World Trade Organization and the United Nations, <https://www.intracen.org/>, "Global Cobalt Outlook 2020-2030" and Battery Material Manufacturing database, <https://www.bnef.com>

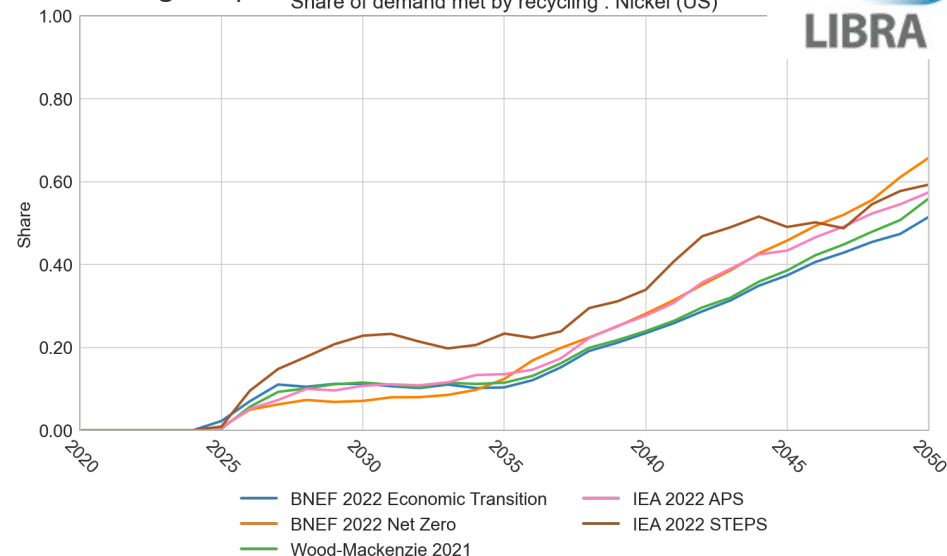
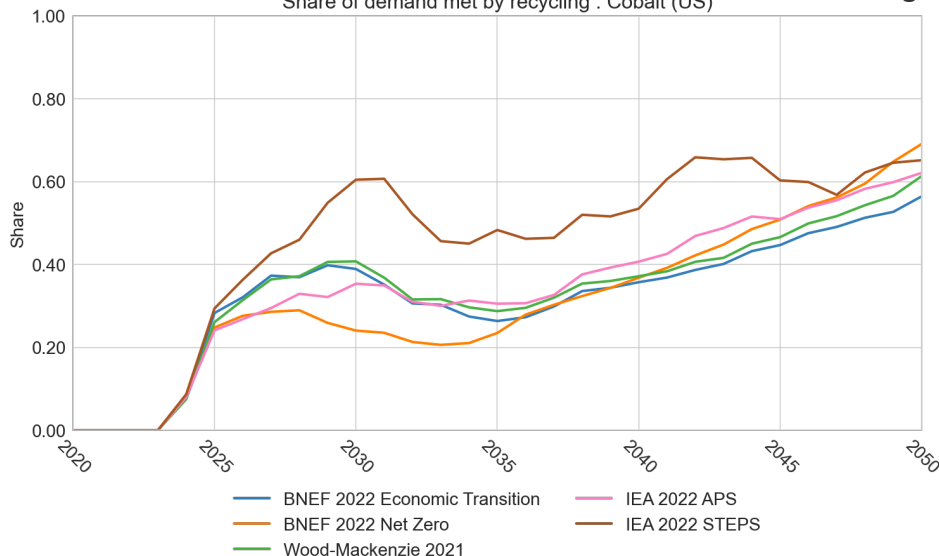


Recycling to meet demand

*Including Manufacturing Scrap

Share of demand met by recycling : Cobalt (US)

Share of demand met by recycling : Nickel (US)

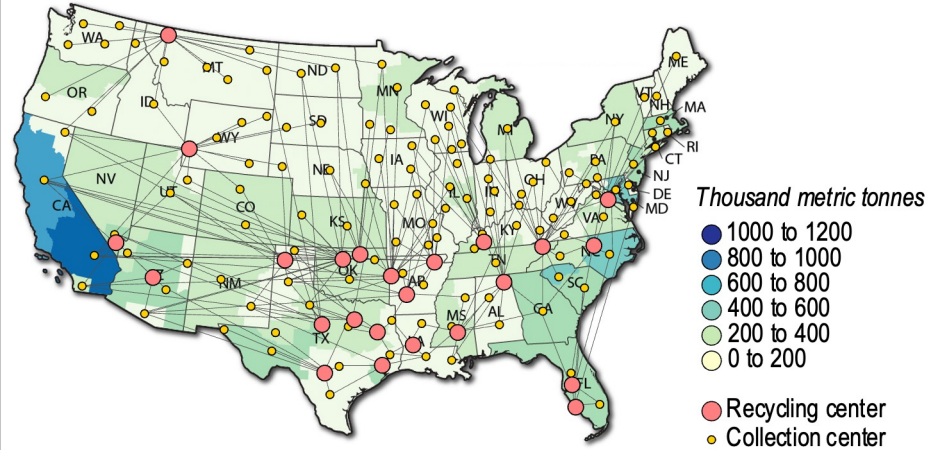
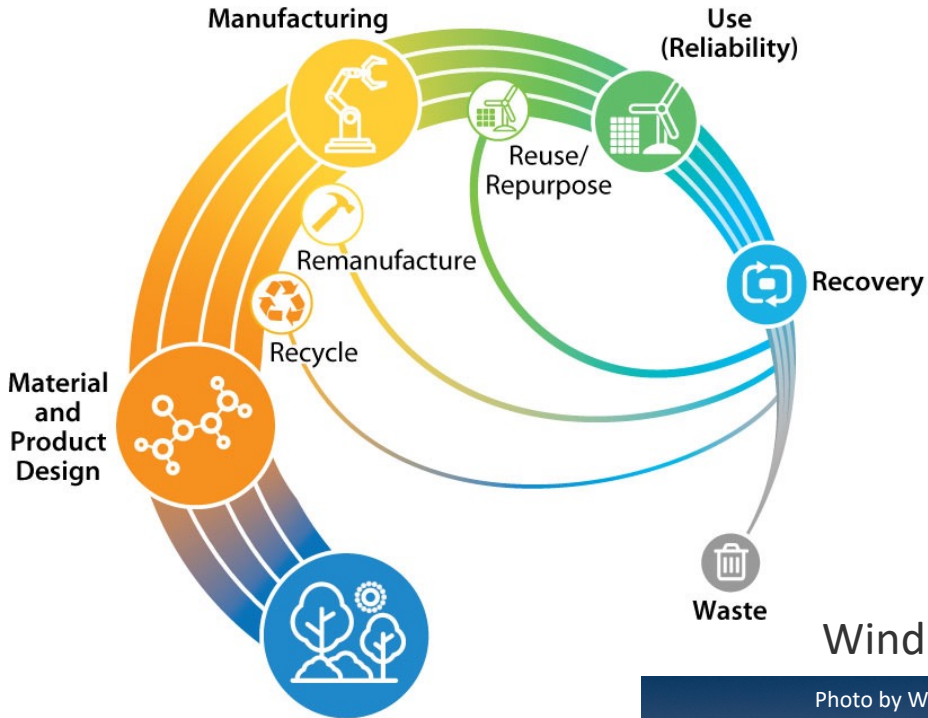


EV_Sales_Projection_Sensitivities_3398acd_8122022

EV_Sales_Projection_Sensitivities_3398acd_8122022

- There is a lower share of cobalt and nickel recovered for the Net Zero scenario because the growth in EV sales is so rapid the industry has trouble keeping up given the time required to build new plants
- The share of demand met for nickel grows at a greater rate because of chemistry changes

Conclusion

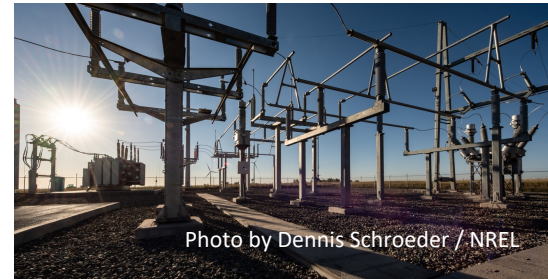


PV Deployment and Recycling Citing

Wind



Transmission





Thank You

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