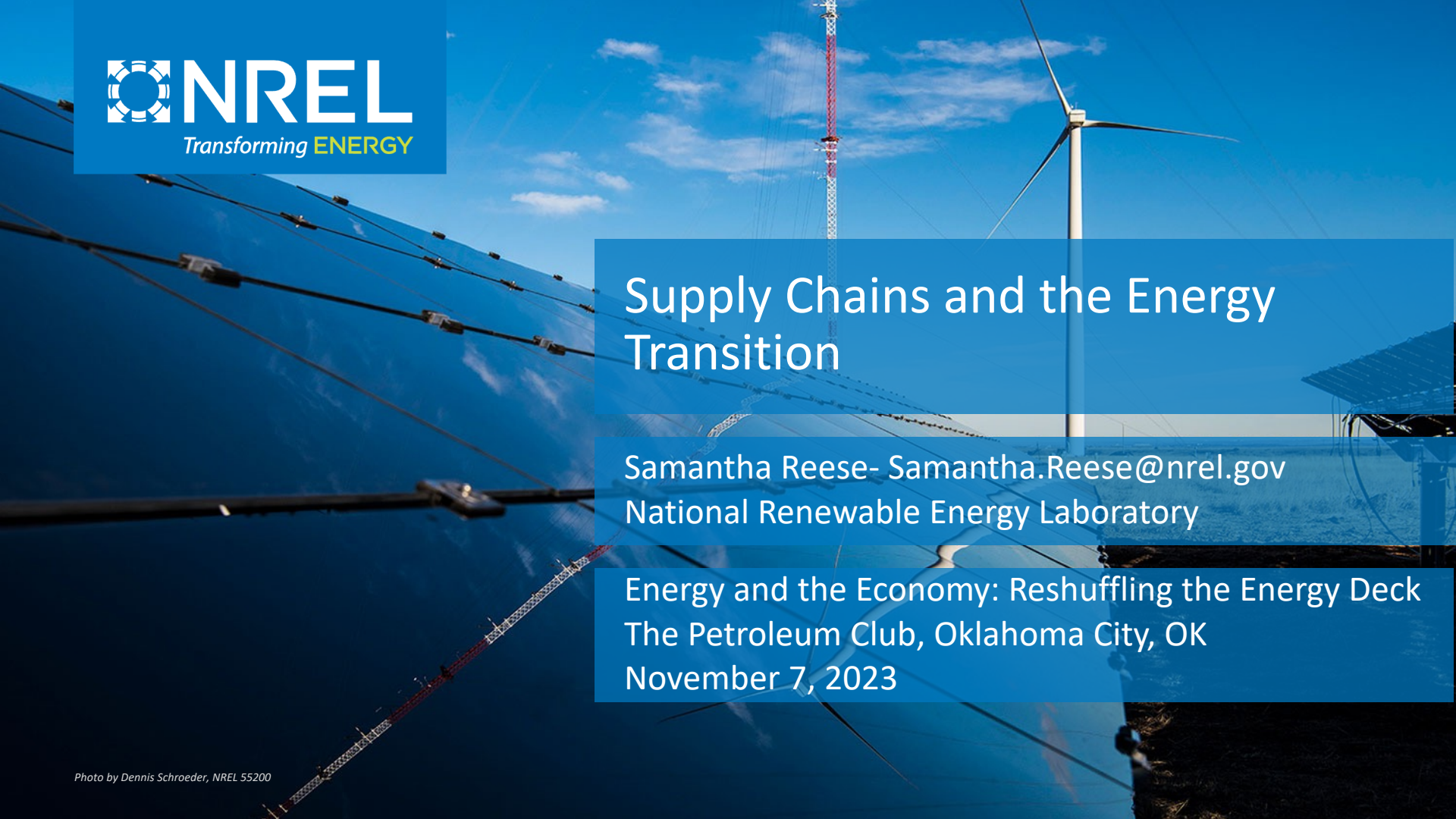


Supply Chains and the Energy Transition

Samantha Reese- Samantha.Reese@nrel.gov
National Renewable Energy Laboratory

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

Photo by Dennis Schroeder, NREL 55200

1 What we do

2 Global Trade and value-add: LED case study

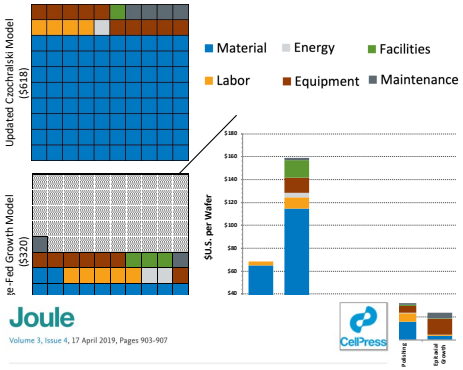
3 Beyond cost-Carbon now matters: Photovoltaics (PV) example

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:

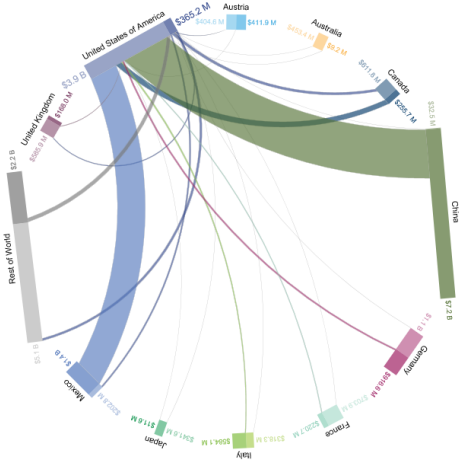
1) Cost & Price
   - i. Highlight manufacturing process/es that add the most cost
   - ii. Predict the minimum sustainable price to compete with current state of art
   - iii. Estimate effects of technical breakthroughs on entire systems costs
2) Demonstrate embodied carbon impact of grid mix and technology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

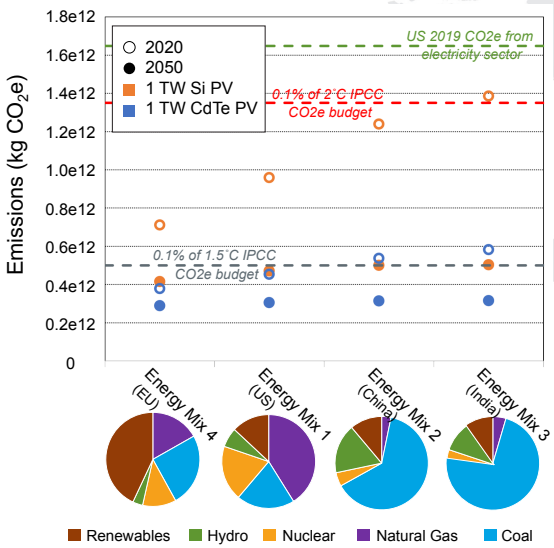


Future Energy

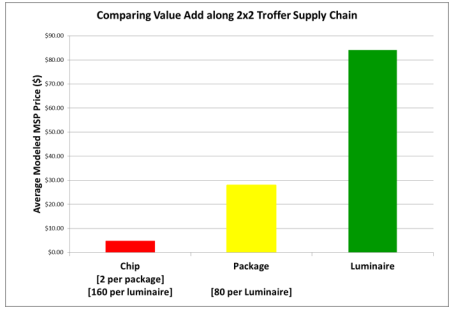
How Much Will Gallium Oxide Power Electronics Cost?

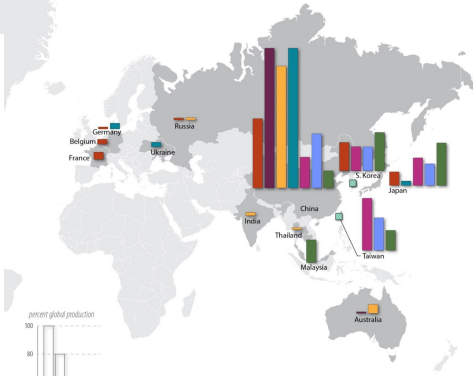
Samantha B. Reese [1], Timothy Remo [1], Johney Green [2], Andriy Zakutayev [3],

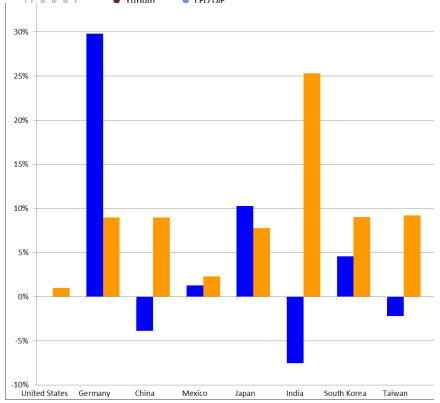




H. M. Wikoff, S. B. Reese, and M. O. Reese, "Embodied energy and carbon from the manufacture of cadmium telluride and silicon photovoltaics," *Joule*, vol. 6, no. 7, pp. 1710–1725, Jul. 2022, doi: 10.1016/j.joule.2022.06.006.







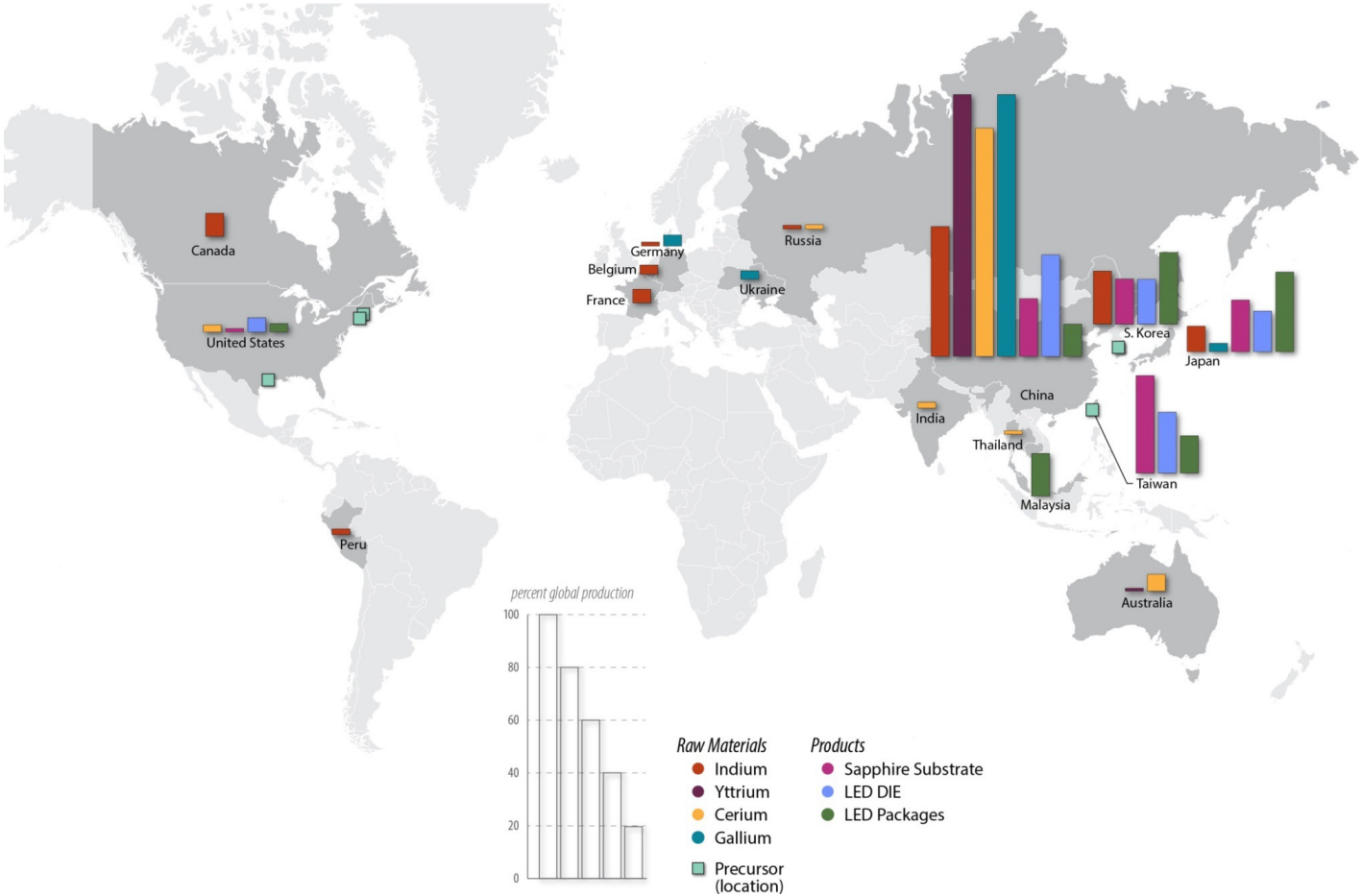
% Cost Difference compared to US (Manufacturing & Shipping)

Minimum time to reach Golden, CO

Reese, S.B., Horowitz, K., Mann, M. and Remo, T., 2020. Research note: LED lighting–A global enterprise. *Lighting Research & Technology*, *52*(7), pp.849-855.

Global Trade and value-add: LED case study

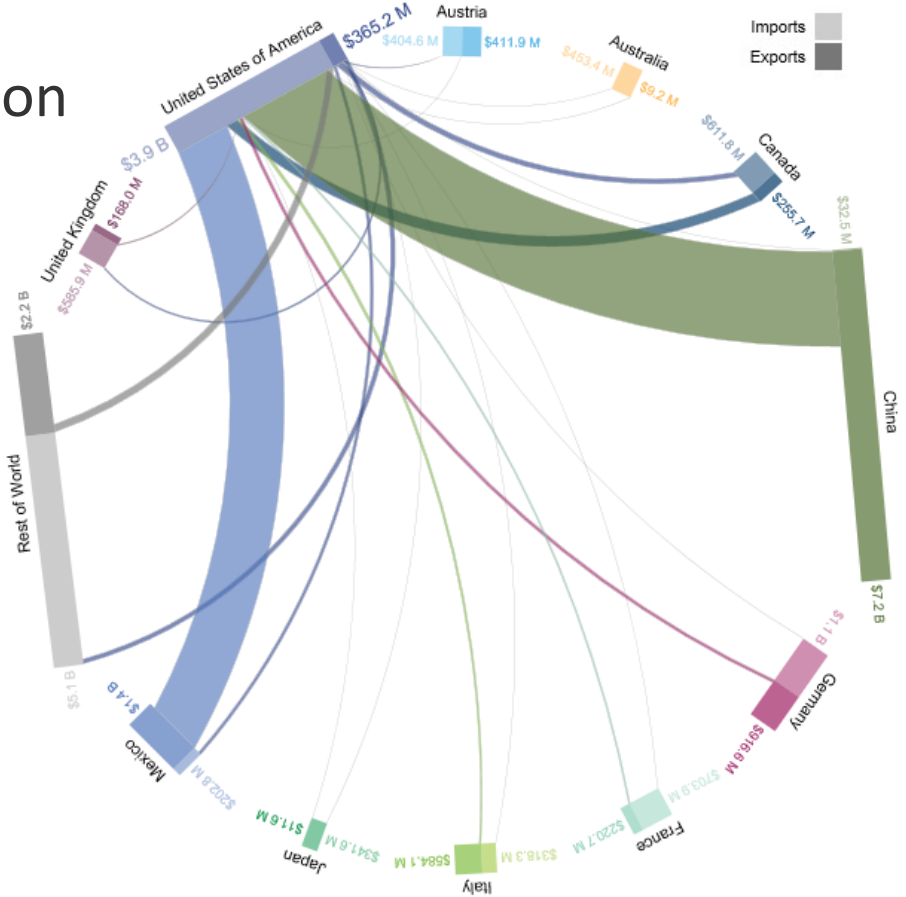
Manufacturing Landscape: Light-emitting Diodes [LED] (2015)



Reese, S.B., Horowitz, K., Mann, M. and Remo, T., 2020. Research note: LED lighting–A global enterprise. *Lighting Research & Technology*, *52*(7), pp.849-855.

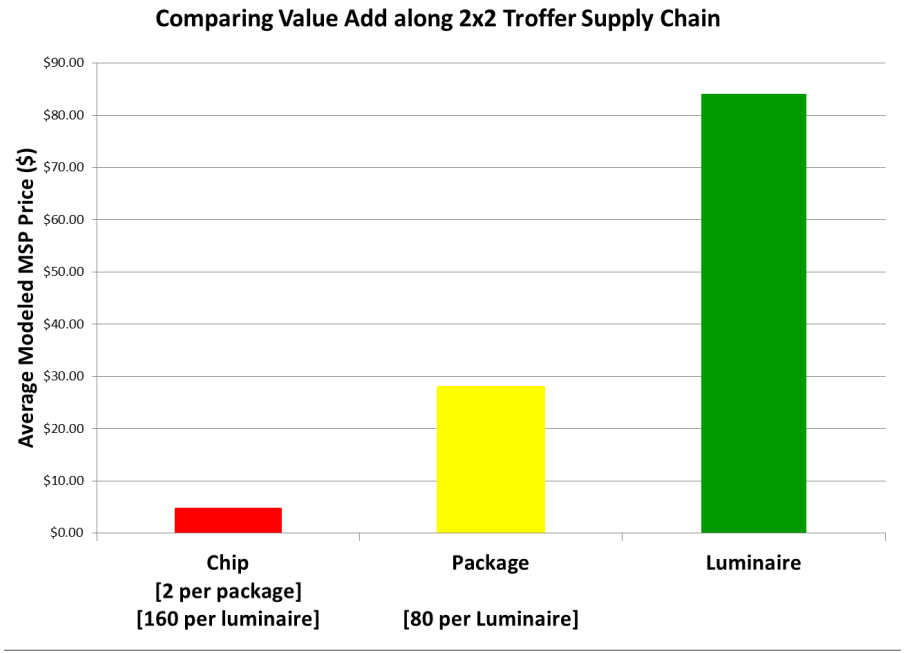
Trade Flow: U.S. Luminaires (2015)

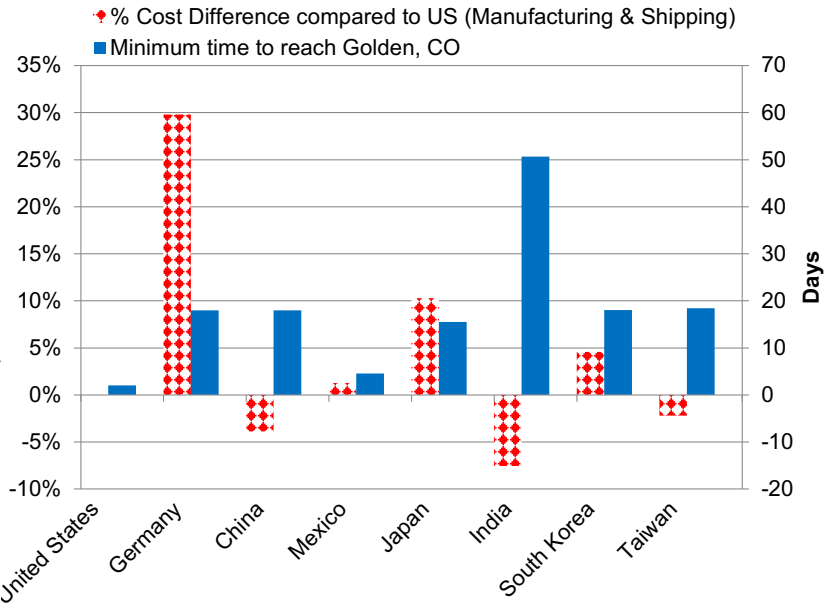
- U.S. luminaire market-$17.3 billion
- US **imported** $3.9 billion
- Therefore US domestically **manufactured** ~$13 billion in lighting products
- **77%** of total revenue sold



Reese, S.B., Horowitz, K., Mann, M. and Remo, T., 2020. Research note: LED lighting–A global enterprise. *Lighting Research & Technology*, *52*(7), pp.849-855.

Value Add





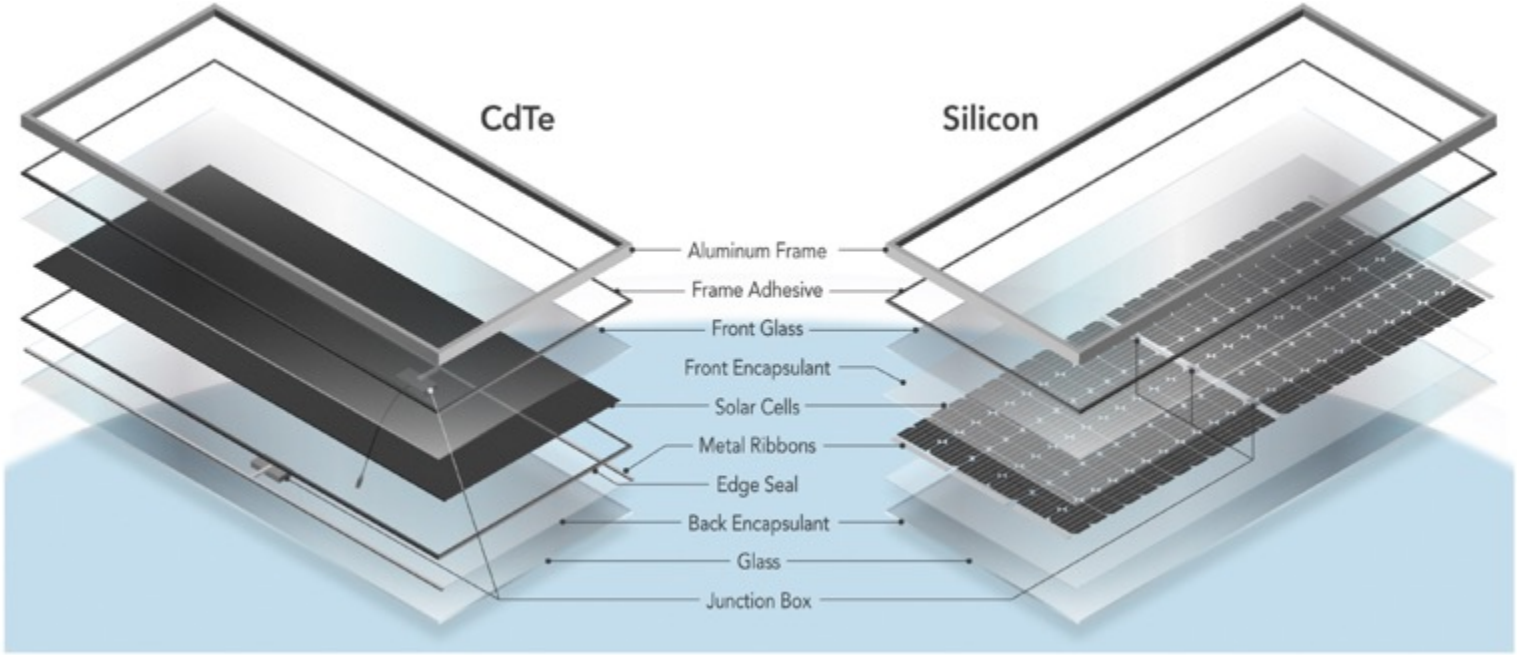
Reese, S.B., Horowitz, K., Mann, M. and Remo, T., 2020. Research note: LED lighting–A global enterprise. *Lighting Research & Technology*, *52*(7), pp.849-855.

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

Commercially available PV Technologies

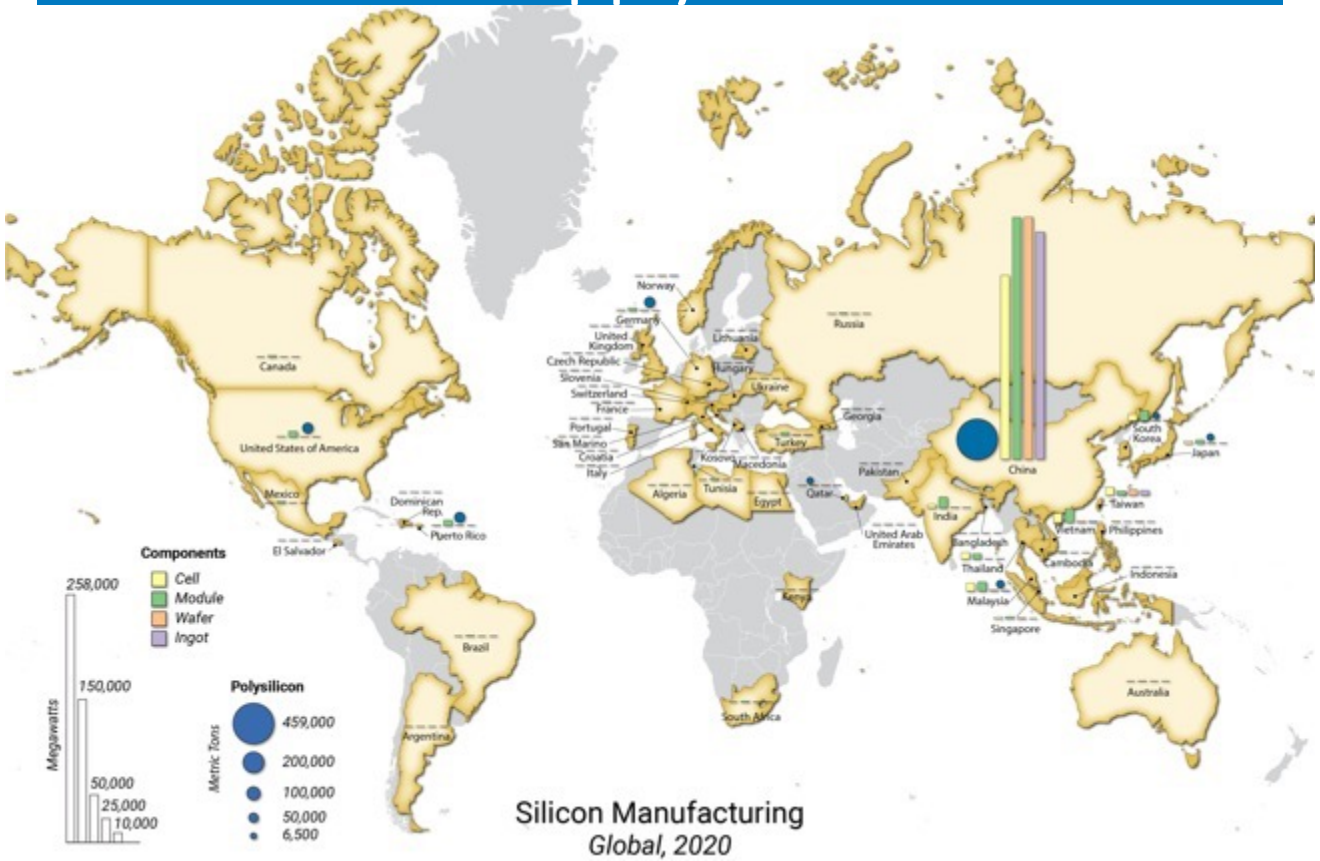
cadmium telluride (CdTe)

crystalline silicon (Si)



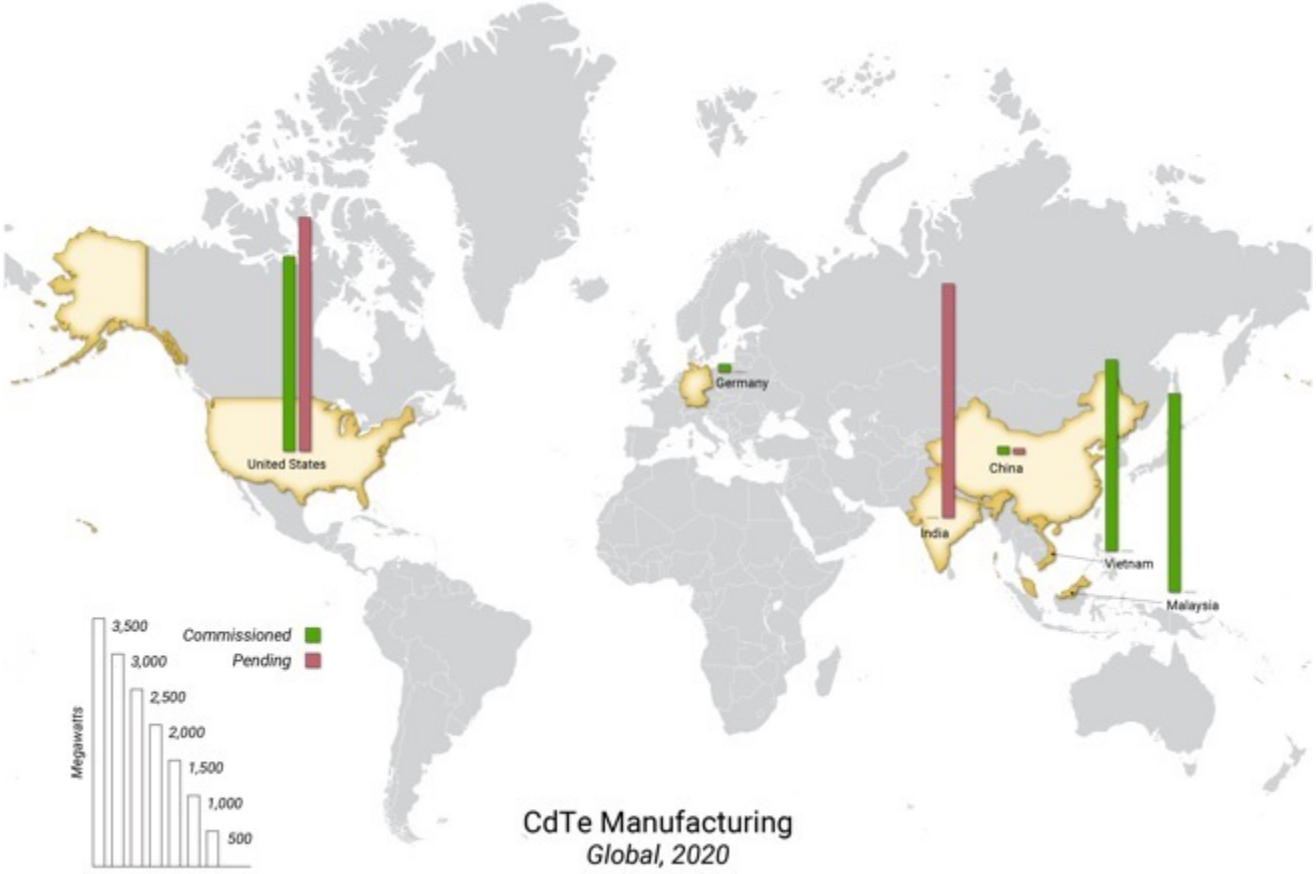
Wikoff, Hope M., Samantha B. Reese, and Matthew O. Reese. "Embodied energy and carbon from the manufacture of cadmium telluride and silicon photovoltaics." *Joule* 6, no. 7 (2022): 1710-1725. https://doi.org/10.1016/j.joule.2022.06.006.

Si Supply Chain

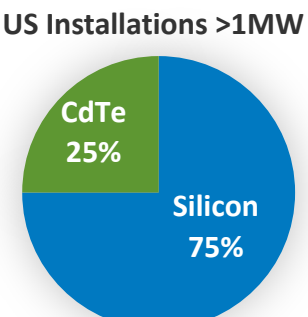


- Silicon based solar cells are most dominant, 90%+ of global market
- Majority of entire Si value chain is manufactured in China

CdTe Supply Chain



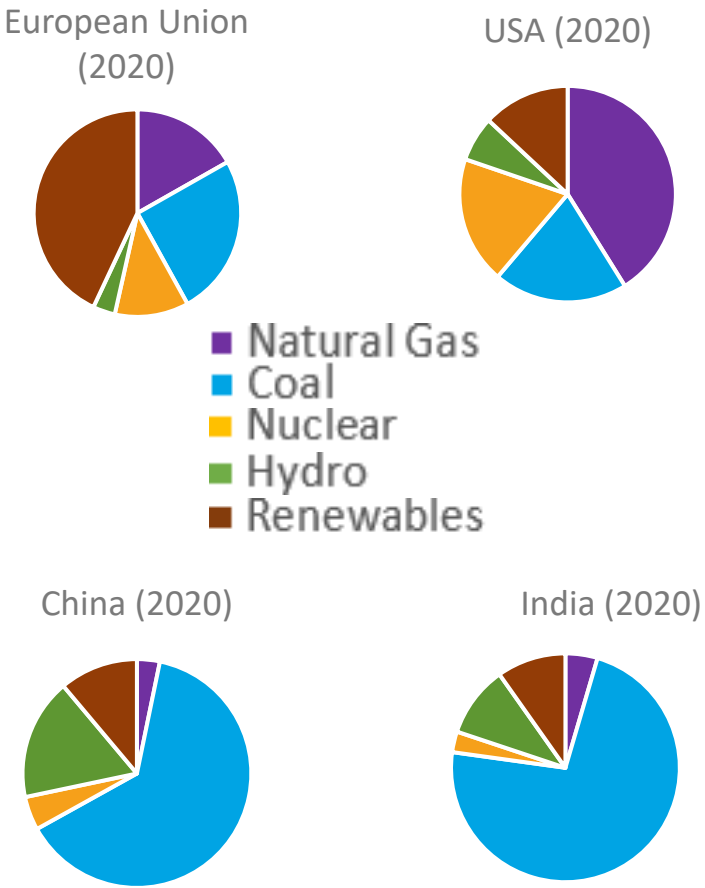
- Silicon based solar cells are most dominant, 90%+ of global market.
- CdTe is 40% of the U.S. axis-based tracking market, and ~25% of cumulative U.S. installations >1 MW.

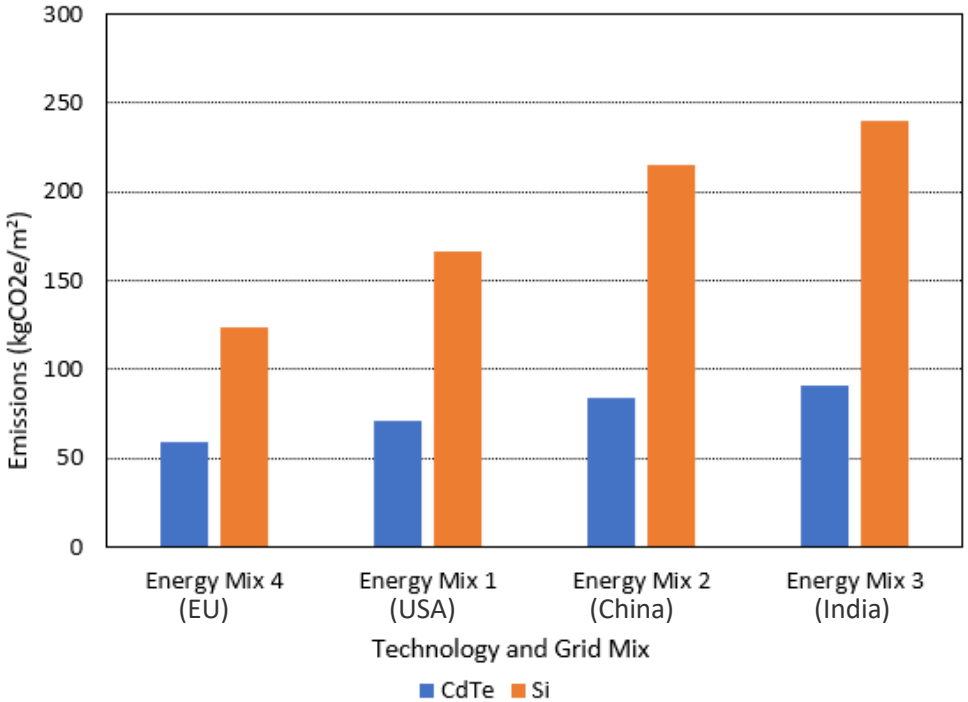


Major manufacturing of CdTe in USA and southeast Asia.

Wikoff, Hope M., Samantha B. Reese, and Matthew O. Reese. "Embodied energy and carbon from the manufacture of cadmium telluride and silicon photovoltaics." *Joule* 6, no. 7 (2022): 1710-1725. https://doi.org/10.1016/j.joule.2022.06.006.

PV Module Embodied Carbon

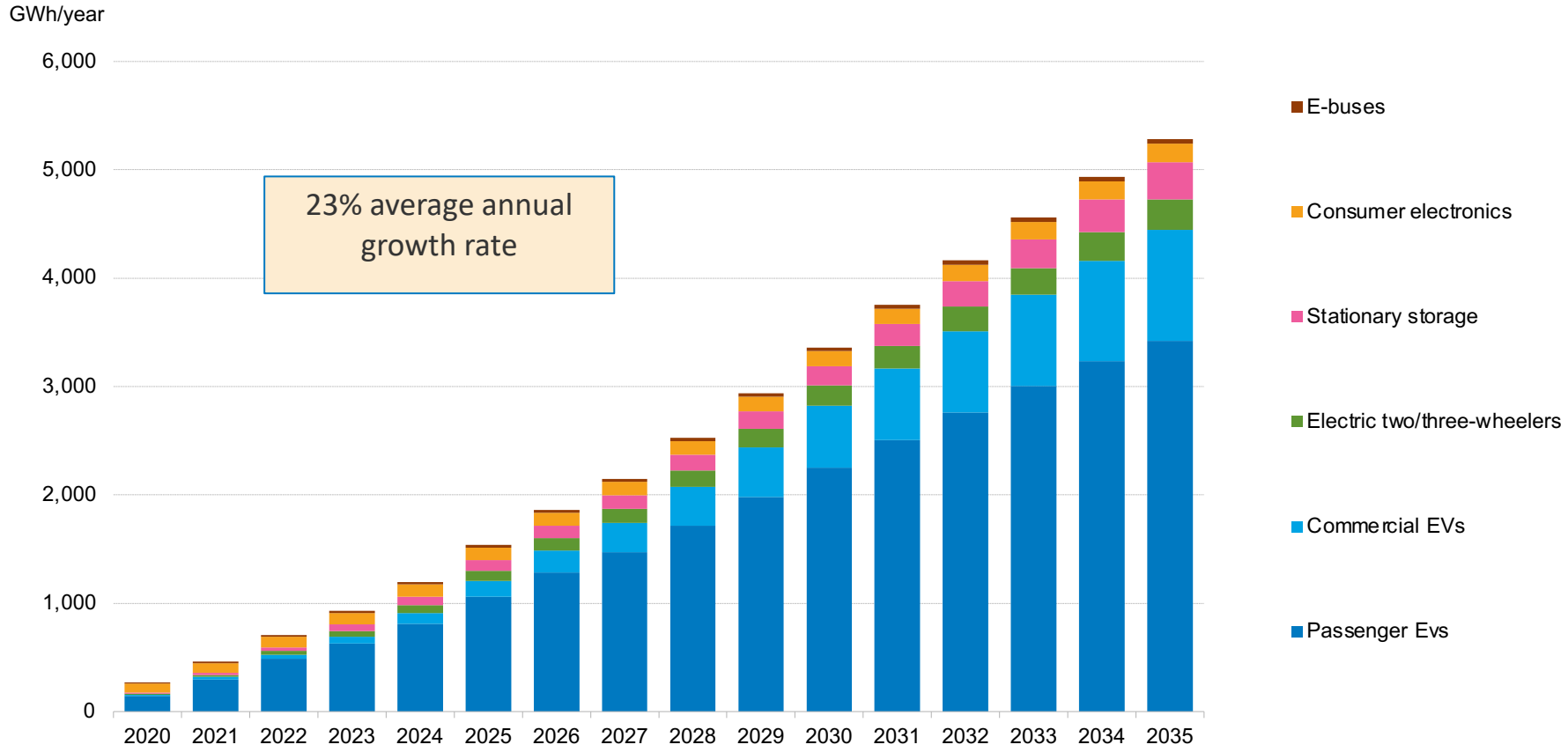




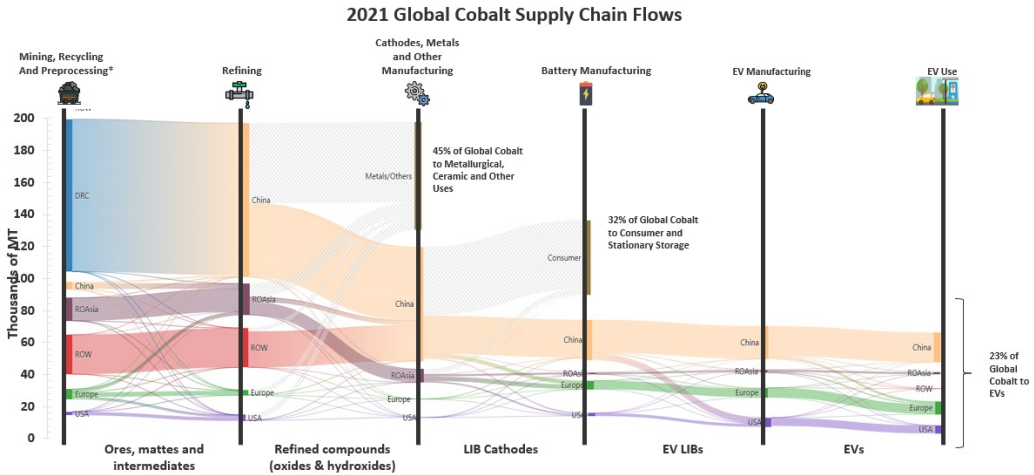
Wikoff, Hope M., Samantha B. Reese, and Matthew O. Reese. "Embodied energy and carbon from the manufacture of cadmium telluride and silicon photovoltaics." *Joule* 6, no. 7 (2022): 1710-1725. https://doi.org/10.1016/j.joule.2022.06.006.

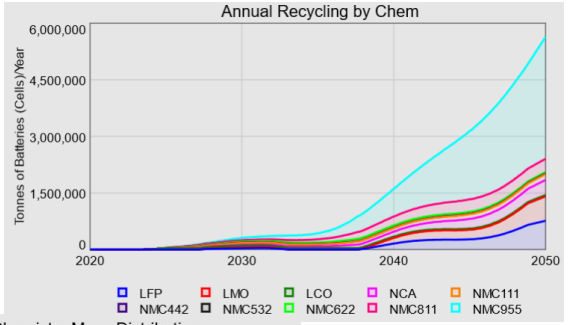
Rising demand and global trade: Electric Vehicle (EV) batteries illustration

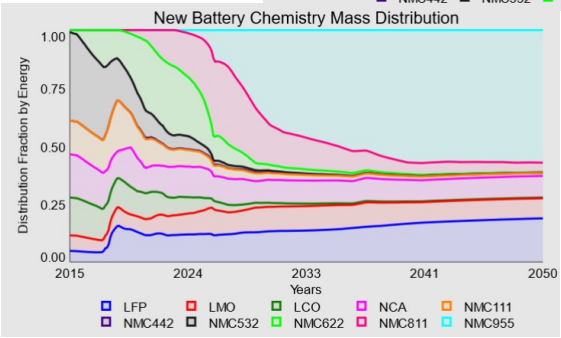
Projected Global Demand for Lithium-ion Batteries



Source: BNEF Electric Vehicle Outlook 2022







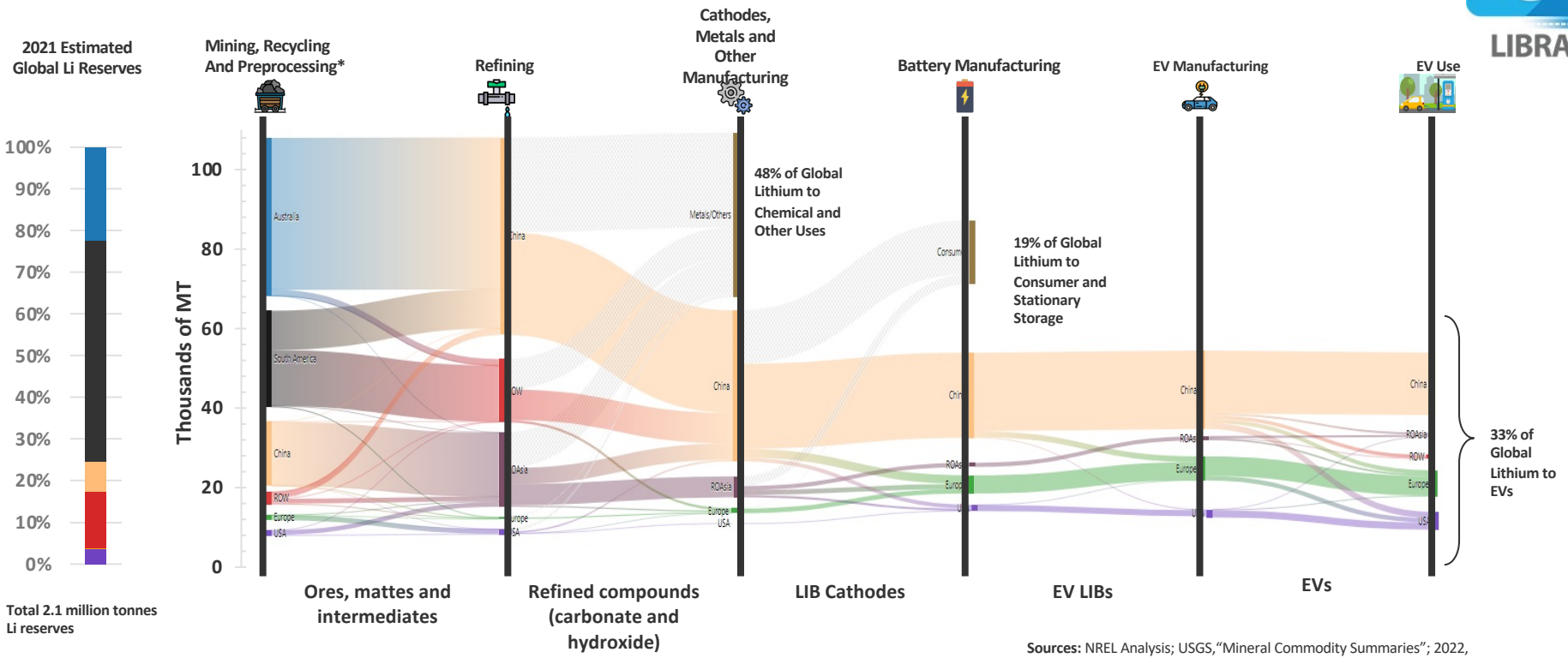
LIBRA – Lithium-Ion Battery Resource Assessment Model

LIBRA

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

Contact: margaret.mann@nrel.gov

2021 Global Lithium Supply Chain Flows



***Mining and Preprocessing products:**

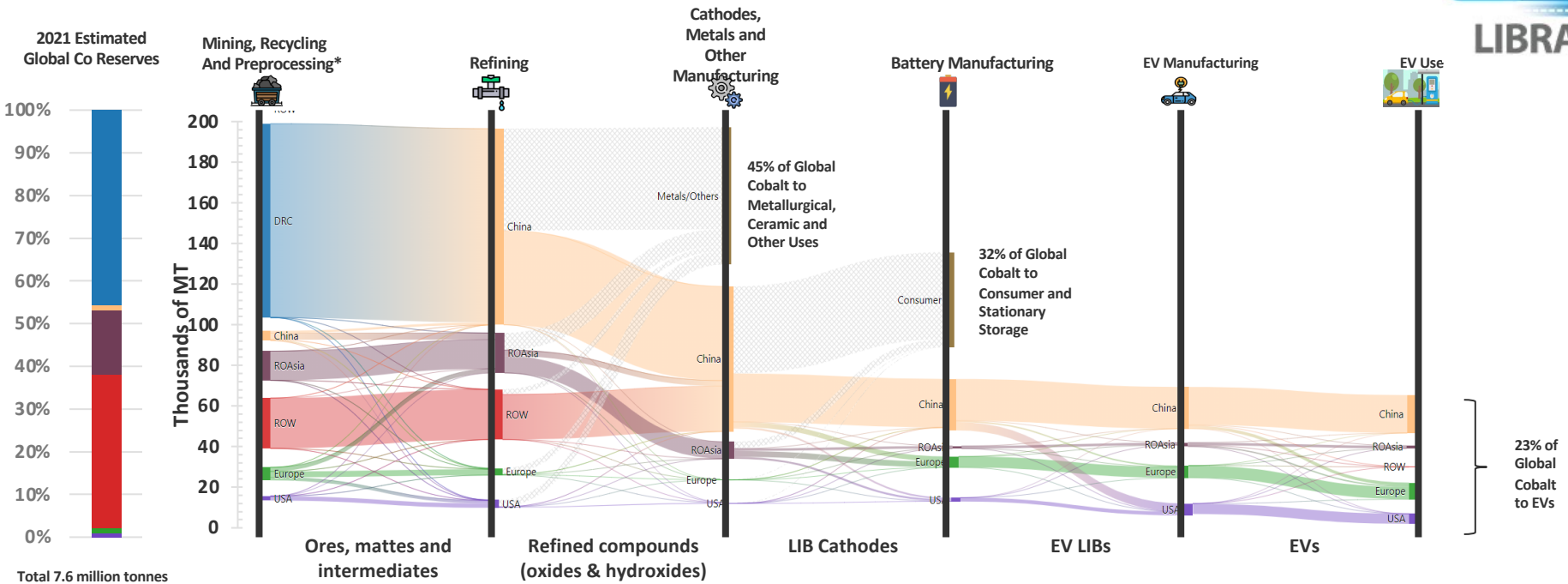
- Lithium carbonate and hydroxide from brines, hard rock (e.g., spodumene) and other sources

ROAsia – Rest of Asia
ROW – Rest of World

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; Resources and Energy Quarterly, Lithium, March 2022, www.industry.gov.au/OCE

2021 Global Cobalt Supply Chain Flows



***Mining, Recycling and Preprocessing products:**

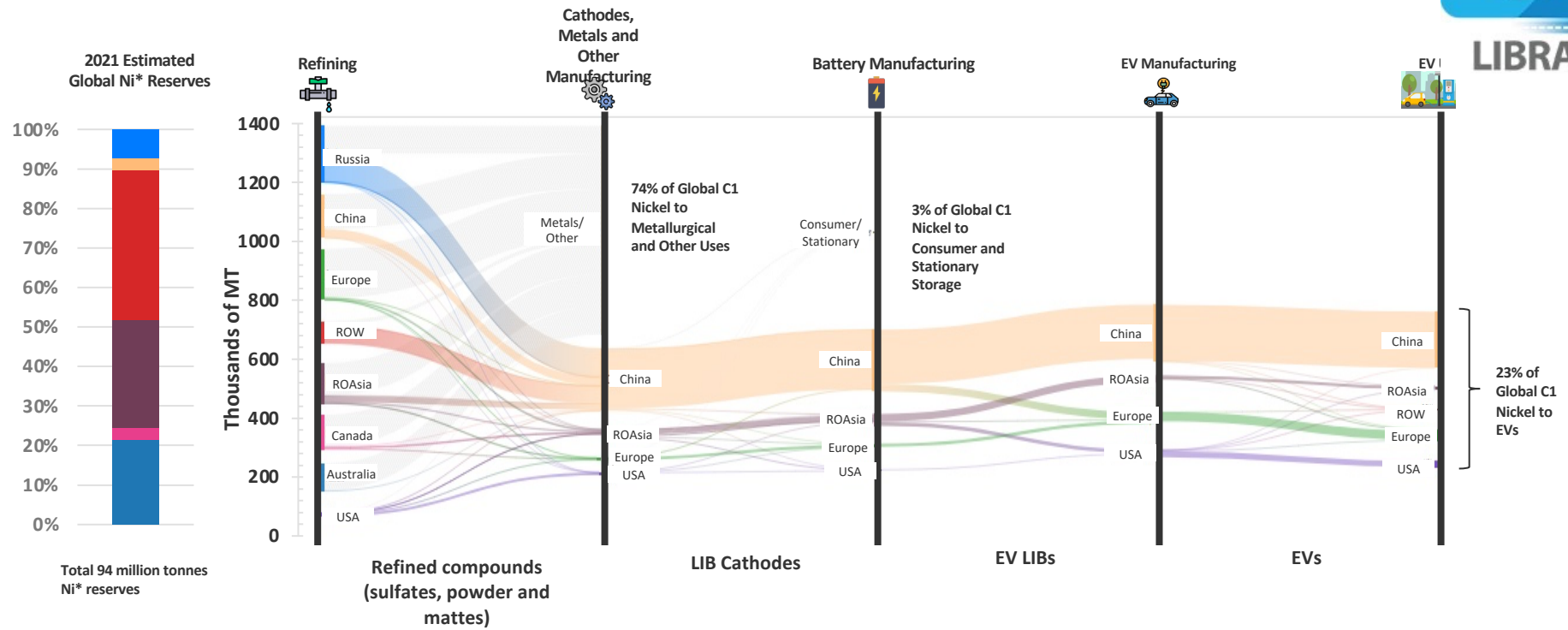
- Ores: naturally occurring solids containing cobalt
- Mattes and Intermediates: (30-100% Co)

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

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

2021 Global Class 1* Nickel Supply Chain Flows



*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.

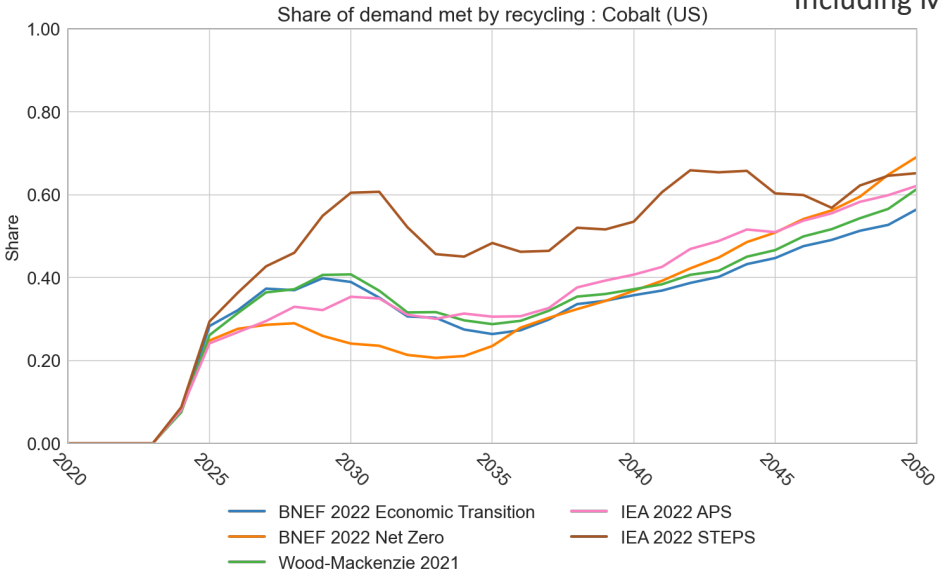
ROAsia – Rest of Asia
ROW – Rest of World

Non- LIB EV battery related flow

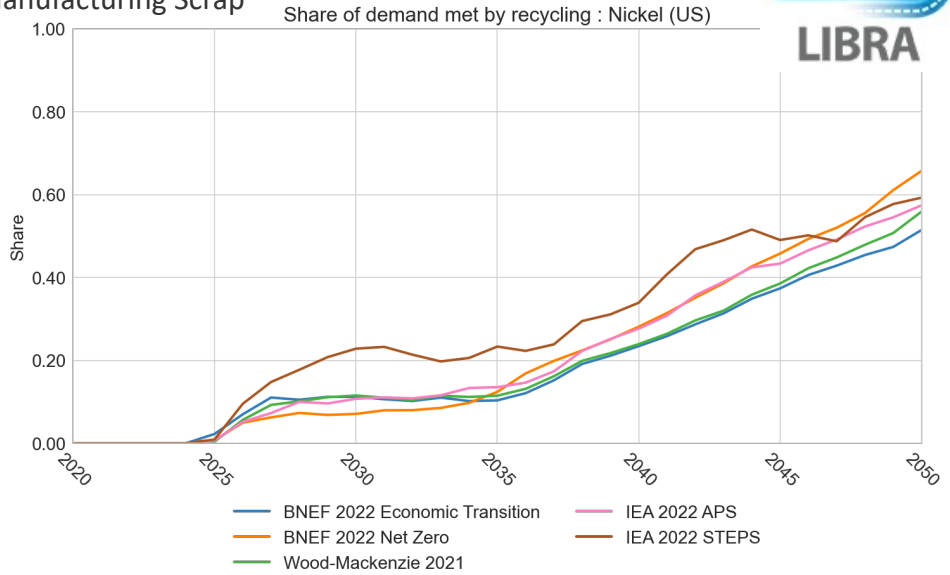
Sources: NREL Analysis; USGS,"Mineral Commodity Summaries"; 2022, https://doi.org/10.3133/mcs2022; International Trade Centre, a joint agency of the World Trade Organization and the United Nations, https://www.intracen.org/ , "Global Cobalt Outlook 2020-2030" and Battery Material Manufacturing database,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

Recycling to meet demand

*Including Manufacturing Scrap



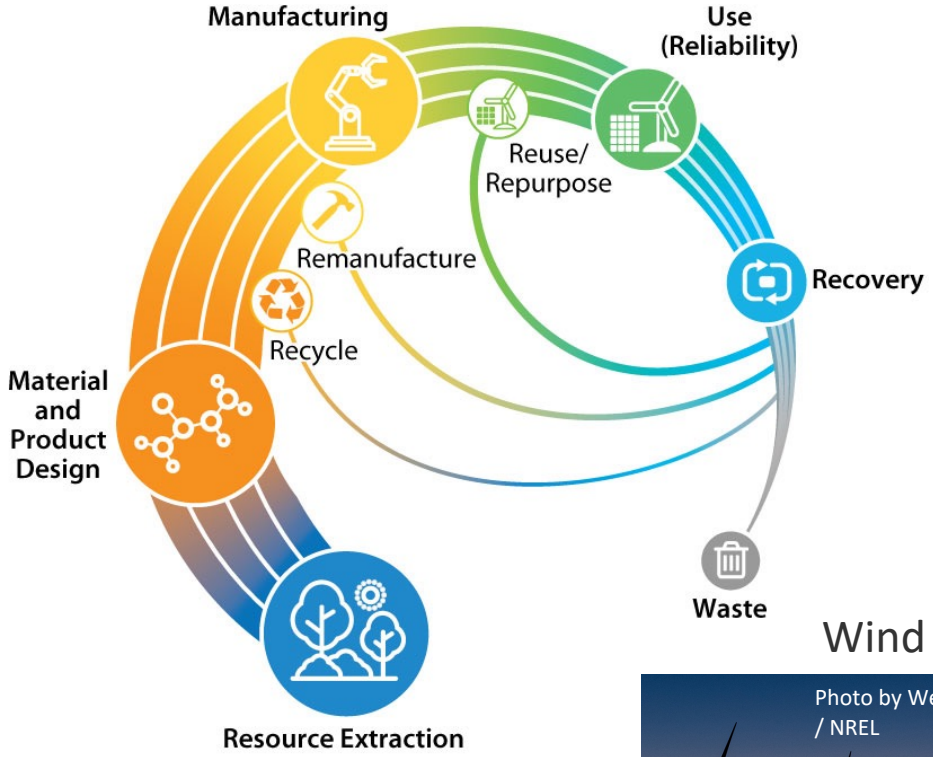
EV_Sales_Projection_Sensitivities_3398acd_8122022

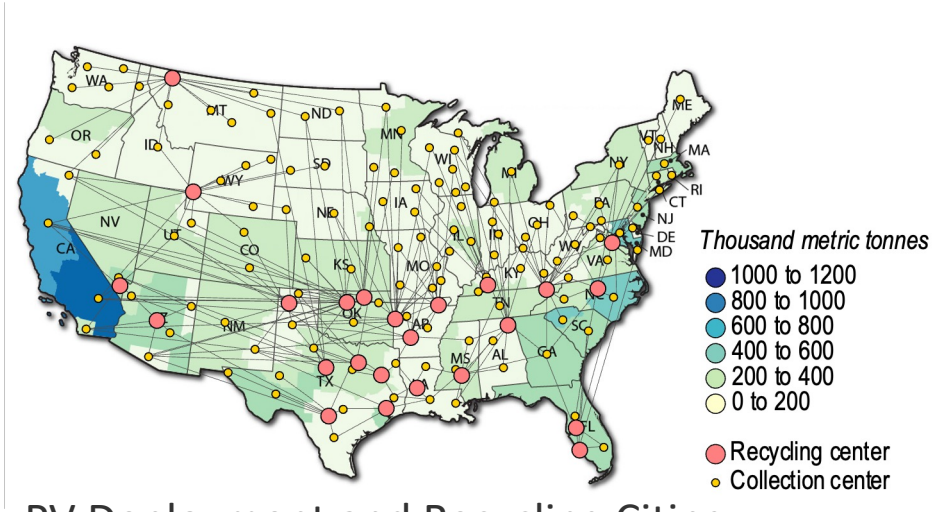


EV_Sales_Projection_Sensitivities_3398acd_8122022

- 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

NREL

Transforming ENERGY

Thank You

Samantha.Reese@nrel.gov

NREL/PR-6A20-88007

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Industrial Energy and Decarbonization Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.