

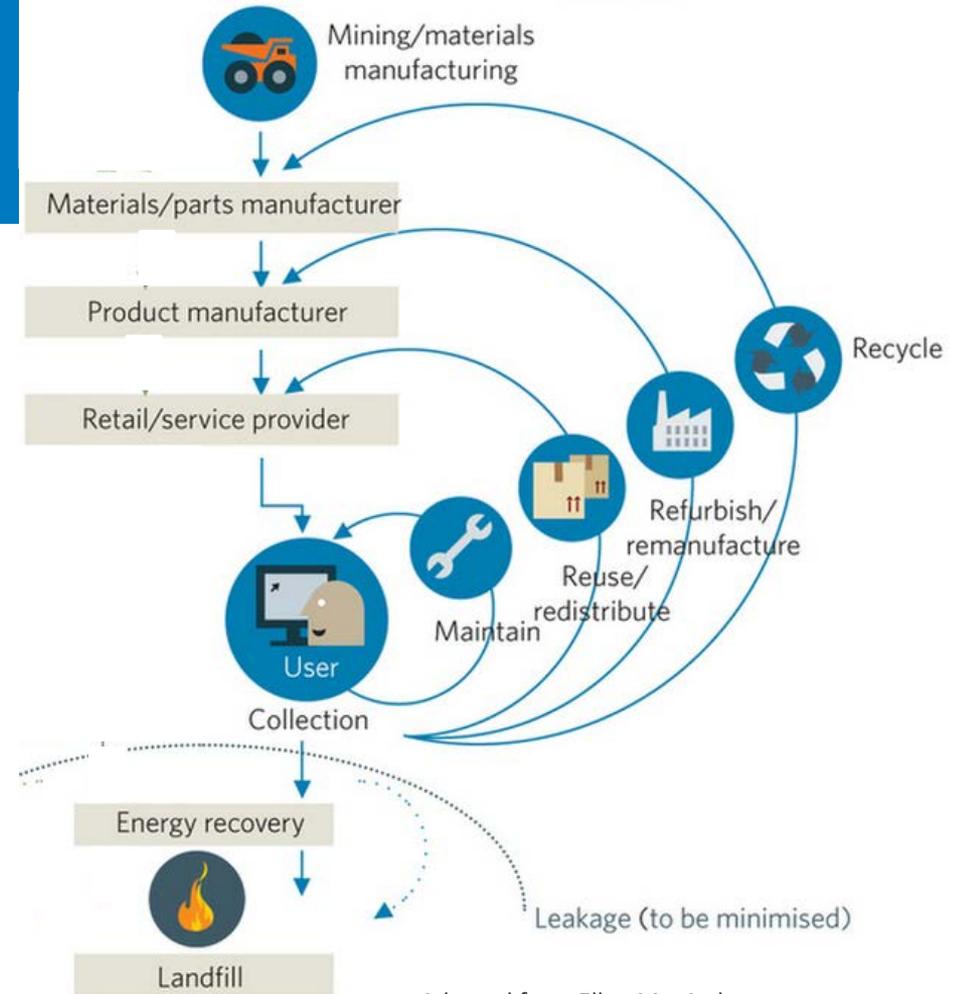


Moving toward a circular economy of materials for clean manufacturing

Garvin Heath, PhD
CEMAC Annual Meeting 2019

Circular Economy: Today's Session

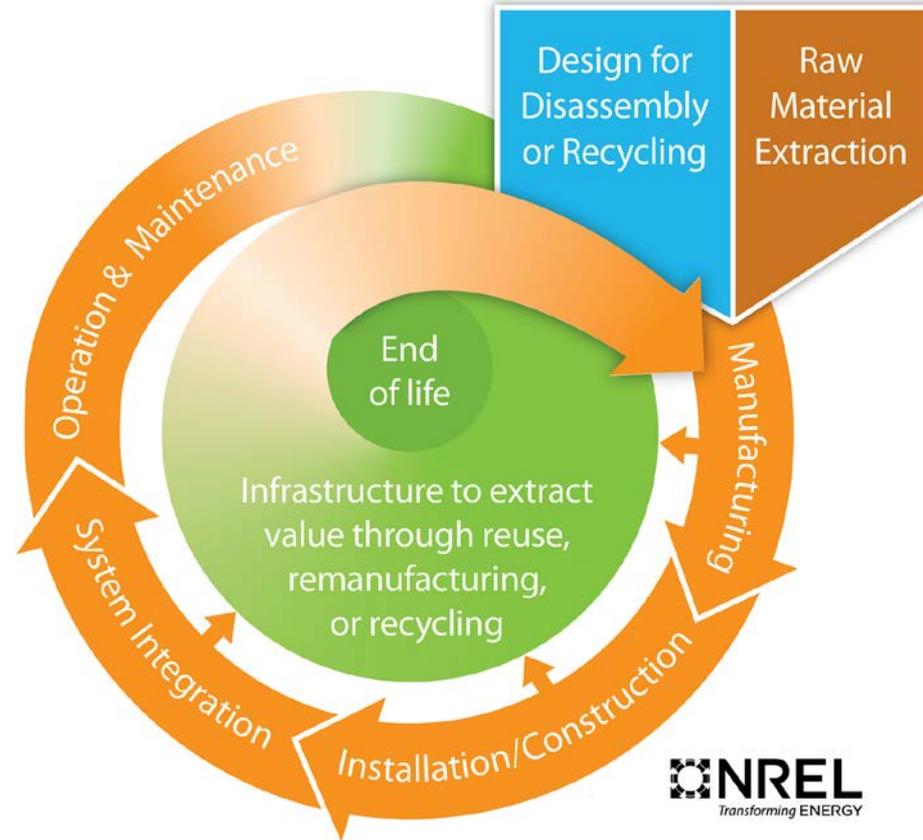
- NREL's early forays
- Success story:
Schneider Electric
- Expansive vision for at
a country level:
Netherlands



NREL: Circular Economy for Energy Materials

- Focus on energy technologies and their materials
- Attention to product design and maintaining/enhancing reliability, durability, performance
- Beginning with recycling-focused efforts applied to specific energy technologies; developing a more comprehensive, integrated strategy
 - Examples: photovoltaics, batteries

Value Chain for Clean Energy Technologies



ReCell - Lithium Ion Battery Recycling R&D Center



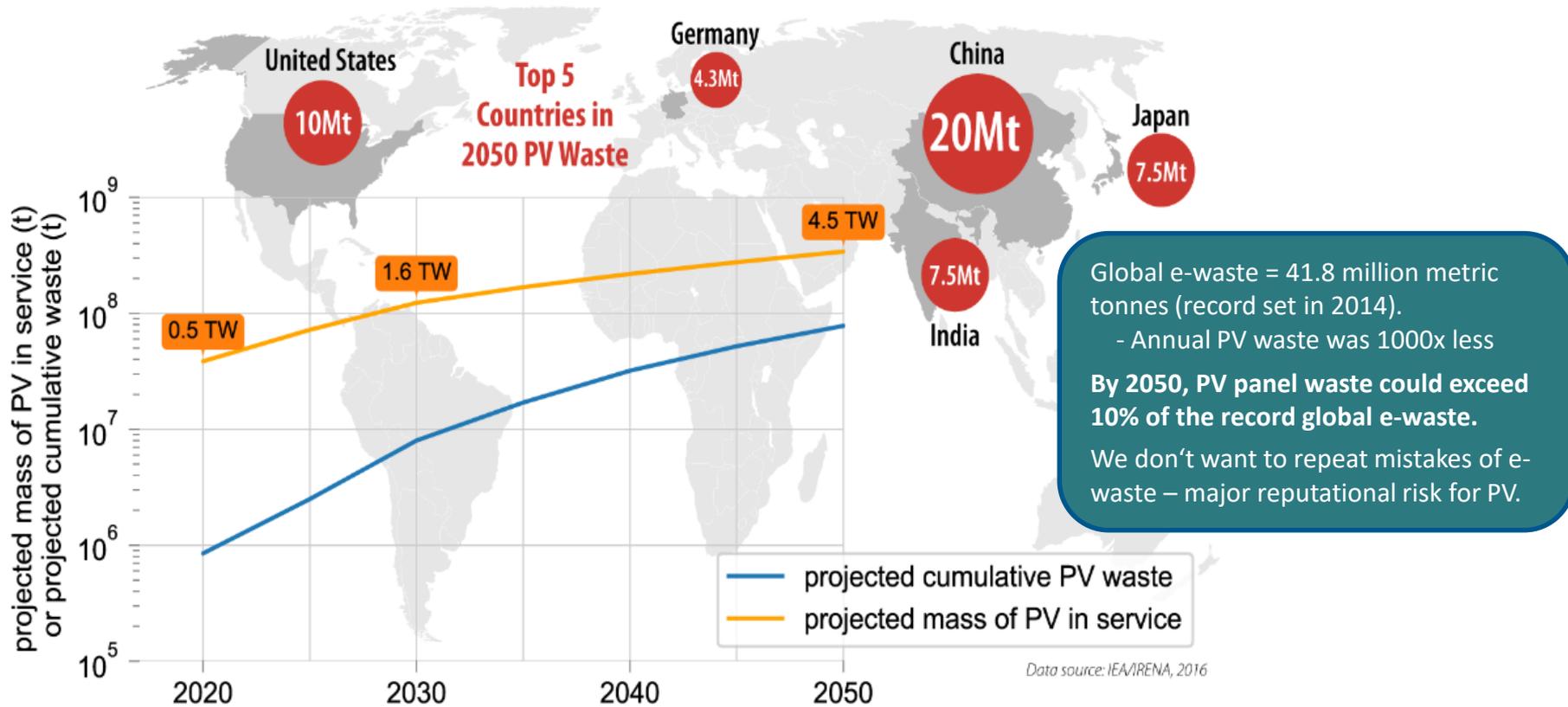
- The ReCell Center, the Department of Energy's first advanced battery recycling R&D center, will develop cost-effective, flexible processing techniques to extract maximum value from current lithium-ion and future battery chemistries at end-of-life.
 - ReCell is a collaboration of researchers from industry, academia and national laboratories
- Accelerate the growth of a profitable recycling market for spent EV batteries
- Develop cost-effective, novel recycling techniques
 - Using less energy-intensive processing methods and
 - Capturing more metals and other high-value materials in forms that make reuse easier.
- CEMAC's supply chain analysis tools provides a birds-eye view of the interconnections between raw material availability, primary manufacture, recycling, and demand.

ReCell Goals: Turning Waste into Savings



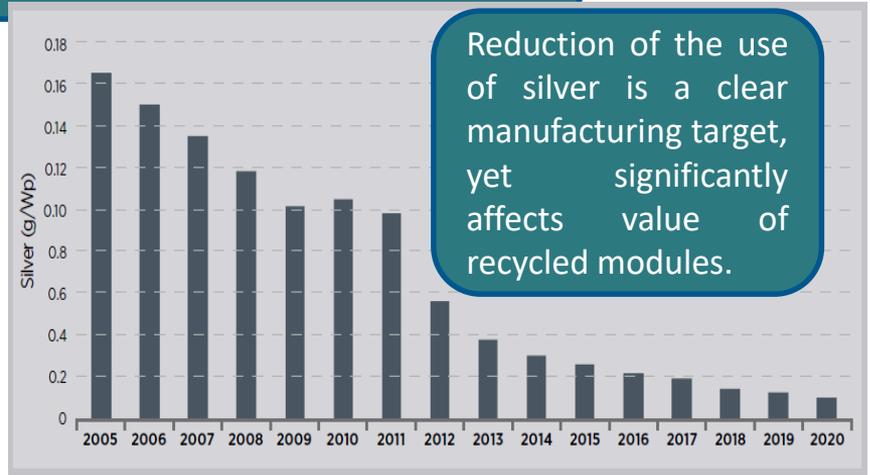
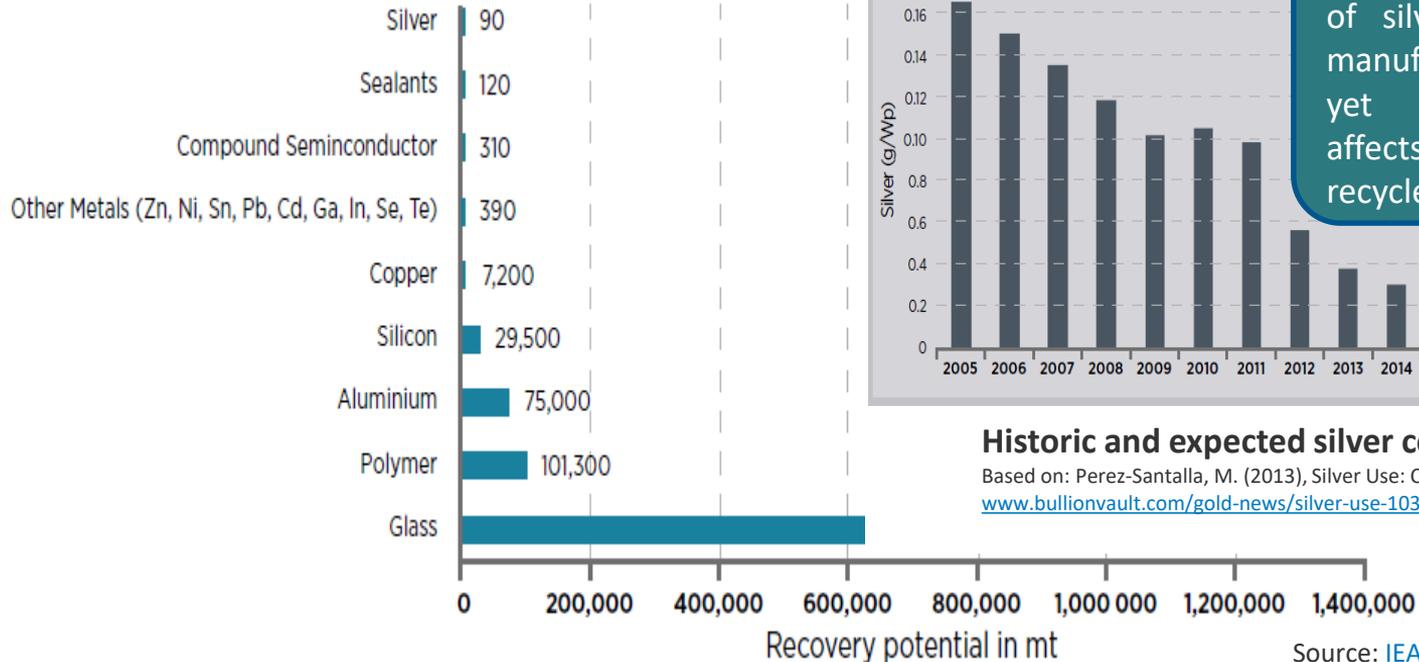
- Manufacturing costs are 5 - 30 percent less using recycled cathode material.
- By decreasing material costs, recycling will help reduce electric vehicle battery pack cost to the DOE goal of \$80/kWh.
- New separation techniques can recover more material for use in reconstituted batteries.
- Recycled lithium and cobalt provides a reliable supply chain to US manufactures, reducing reliance on foreign supplies of critical materials.

Low Volumes Now, PV Waste Will be Significant Challenge in Future



Why Recycle Modules? ... Recovery of Valuable or Toxic Materials

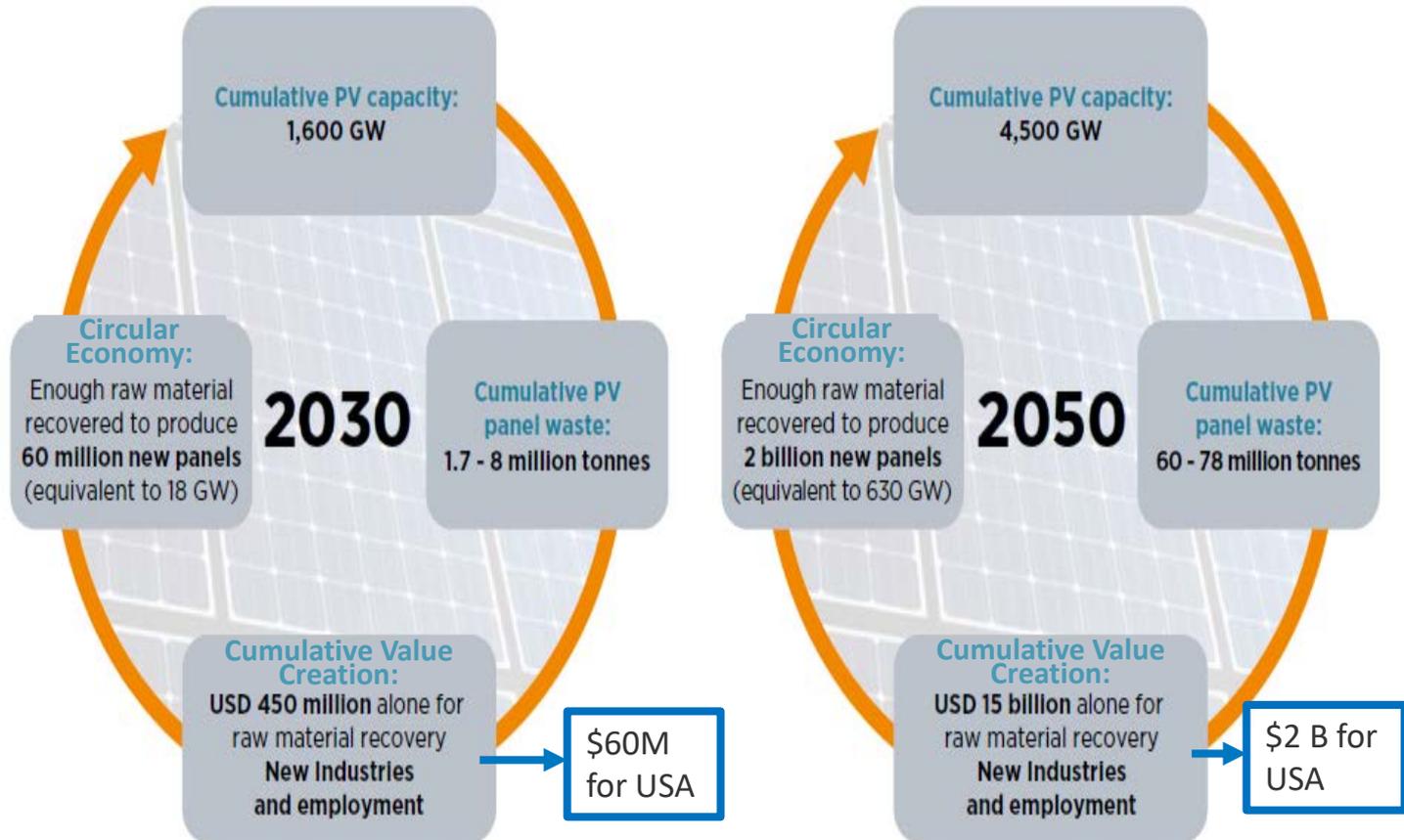
Cumulative technical potential for end-of-life material recovery (under the regular-loss scenario and considering anticipated changes to module design, like dematerialization)



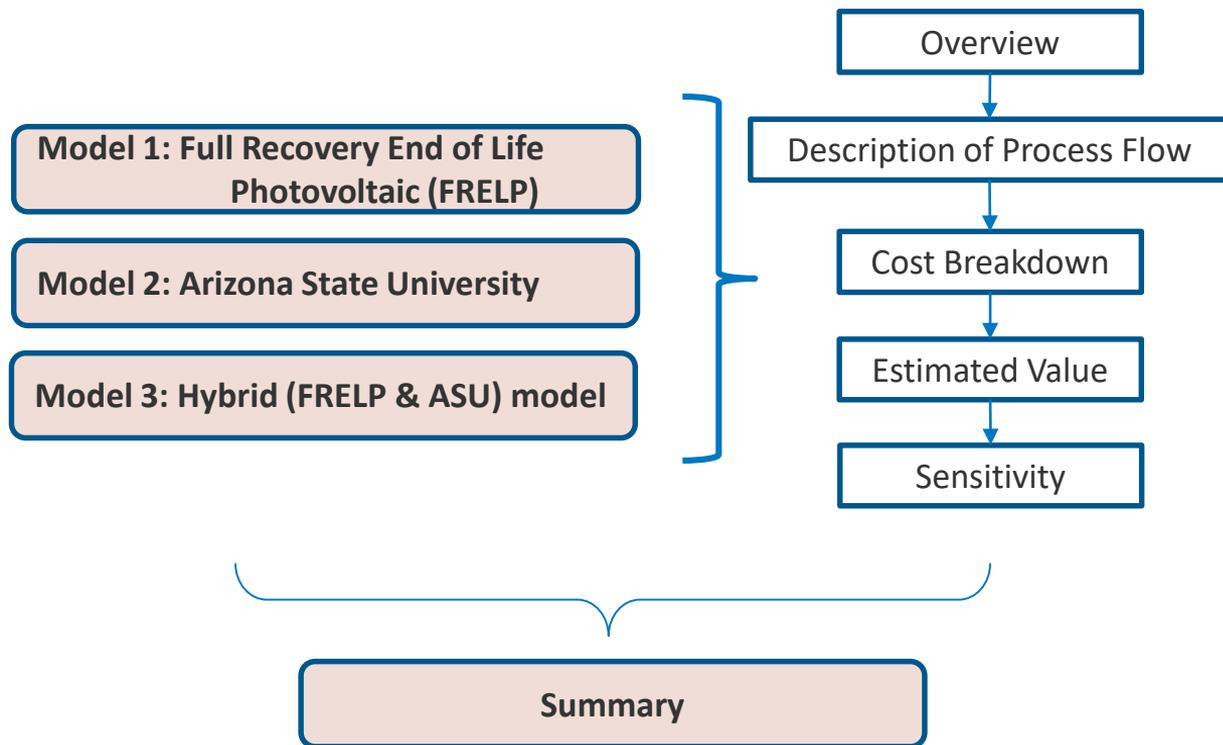
Reduction of the use of silver is a clear manufacturing target, yet significantly affects value of recycled modules.

Historic and expected silver consumption per Wp
Based on: Perez-Santalla, M. (2013), Silver Use: Changes & Outlook, www.bullionvault.com/gold-news/silver-use-103020132

Potential Value Creation – A New Waste Management Industry?



Techno-Economic Analysis of Advanced Recycling Processes to Discern Cost Drivers and Identify R&D Targets for c-Si

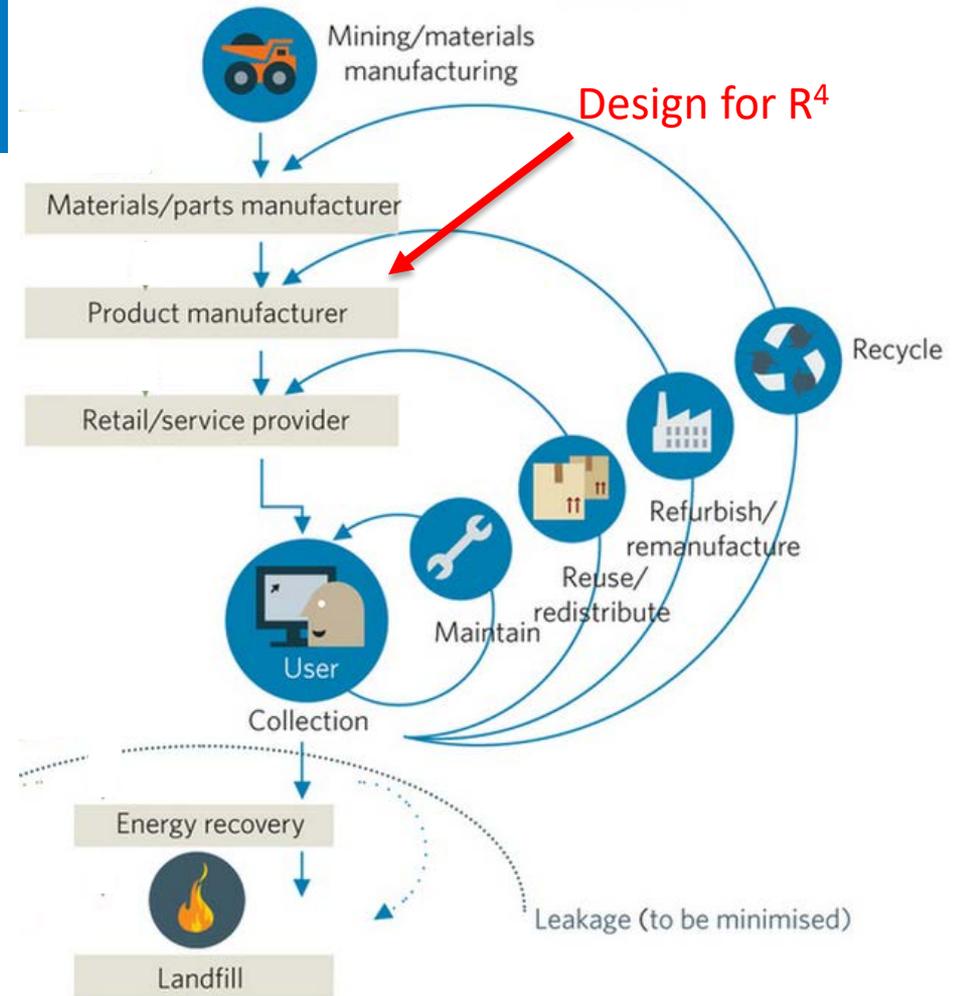


Indicative Year 1 Costs and Revenue – Surcharge is Required, Improvements to Yield and Purity Can Improve Economics

Figure removed because it is still under development

Broader Issues of PV in the Circular Economy

- Ultimately, consider recycling technologies as one step in a system from dismantling at the place of operation to the recovered materials returning to markets
- Further, recycling is but one circular economy option, with other at higher preference, though issues remain to be illuminated and addressed as to their efficacy, feasibility and affordability
- Millions of modules have been or will be deployed in the near future, which must be addressed as they were designed,
 - The next wave of deployment, designing new modules for increased circularity will be imperative



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Thank you

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