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PV Modules End of Life Management
Setting the Stage

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EPA Sustainable Materials Management Webinar

August 22, 2019

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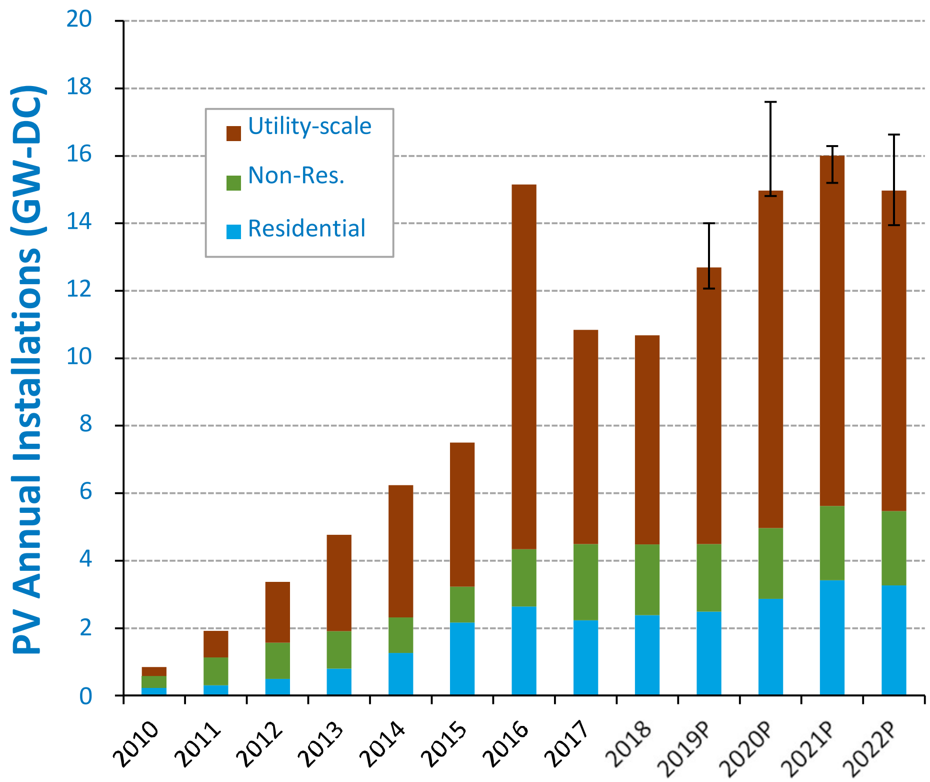
Annual U.S. Photovoltaic (PV) Demand Projections

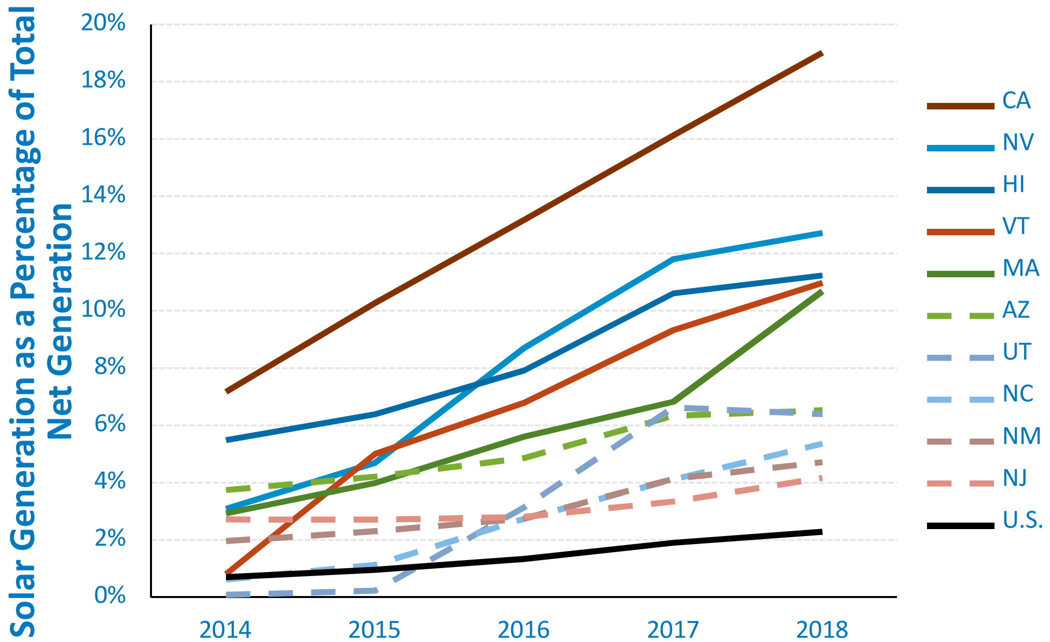


Note: P = projection. Bar represents median projection. Error bars represent high and low projections.
Data sources: BNEF (December 2018); Goldman Sachs (03/13/19); Wood Mackenzie Power & Renewables (March 2019).

- Analysts estimate U.S. solar installations in 2019 will be between 12 GW and 14 GW—a significant increase over 2017–2018.
  - Most of the growth is expected to come from the utility-scale sector.
- The median analyst projection predicts that 59 GW of PV will be installed between 2019 and 2022 in the United States, which is close to the same amount installed cumulatively at the end of 2018.

Source: Feldman and Margolis. 2019. "Q4 2018/Q1 2019 Solar Industry Update", NREL/PR-6A20-73992.

Solar Generation as a Percentage of Total, 2014–2018



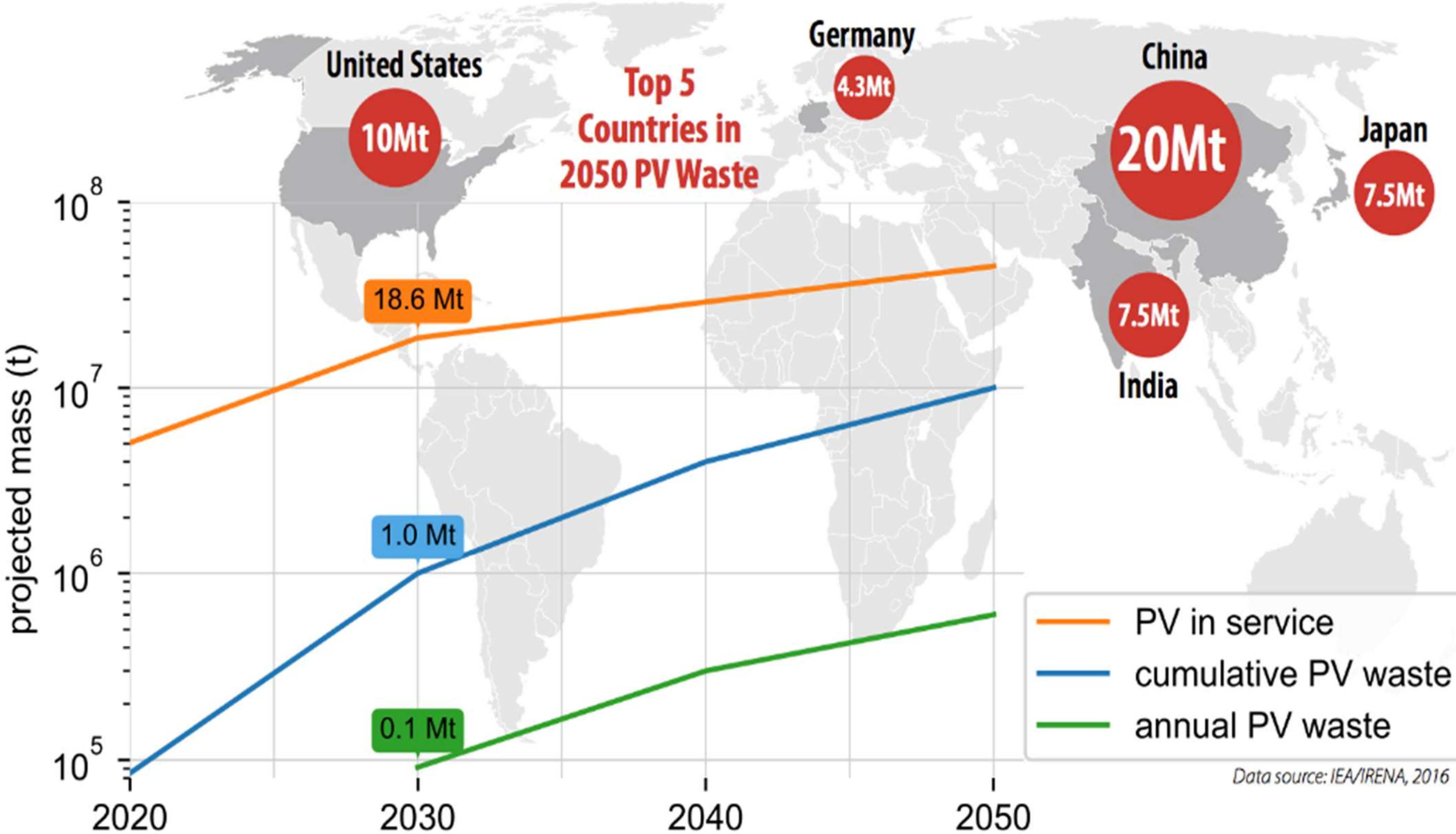
Note: EIA monthly data for 2018 are not final. Additionally, smaller utilities report information to EIA on a yearly basis, and therefore, a certain amount of solar data has not yet been reported. "Net Generation" includes DPV generation. Net generation does not take into account imports and exports to and from each state and therefore the percentage of solar consumed in each state may vary from its percentage of net generation.
Data source: U.S. Energy Information Administration, "Electricity Data Browser." Accessed April 3, 2019.

- The 10 states with the highest percentage of solar penetration generated at least 4.0% of their energy from solar in 2018.
  - California led the way at 19.0% in 2018, representing a 165% increase from 2014 (7.2%).
- In 2018, the United States as a whole produced approximately 2.3% of its electricity using solar technologies.
  - This represents an approximate 3X growth from 2014 (0.7%).

Source: Feldman and Margolis. 2019. "Q4 2018/Q1 2019 Solar Industry Update", NREL/PR-6A20-73992.

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

Projection of U.S. end-of-life (EOL) PV module mass



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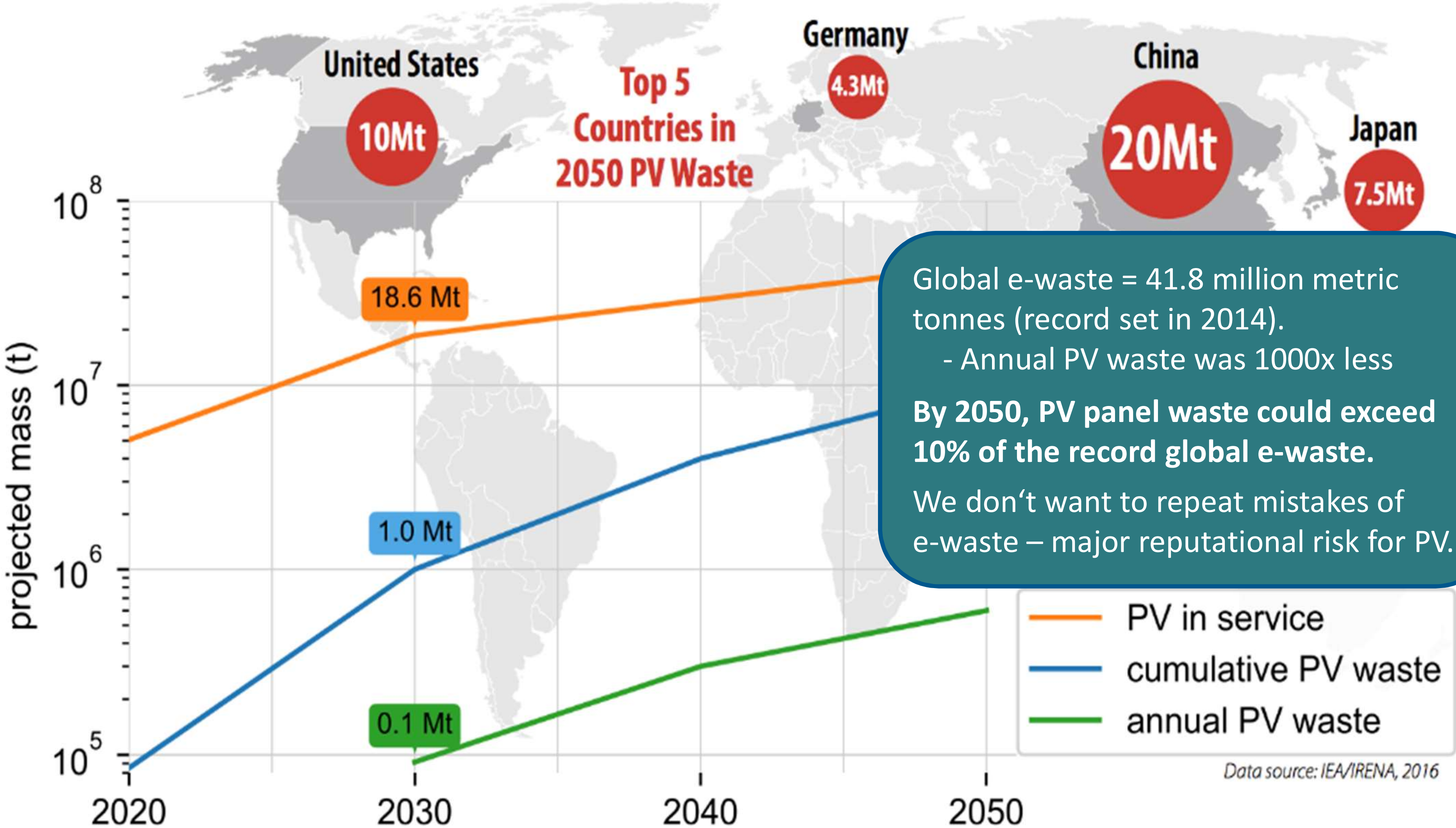


Global e-waste = 41.8 million metric tonnes (record set in 2014).

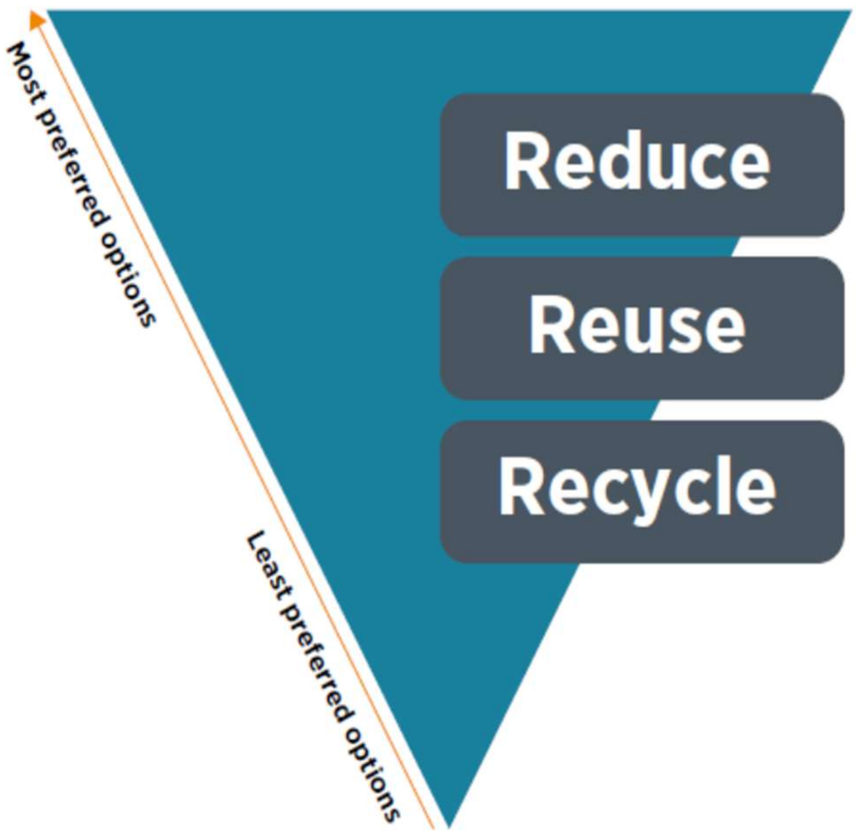
- Annual PV waste was 1000x less

By 2050, PV panel waste could exceed 10% of the record global e-waste.

We don‘t want to repeat mistakes of e-waste – major reputational risk for PV.

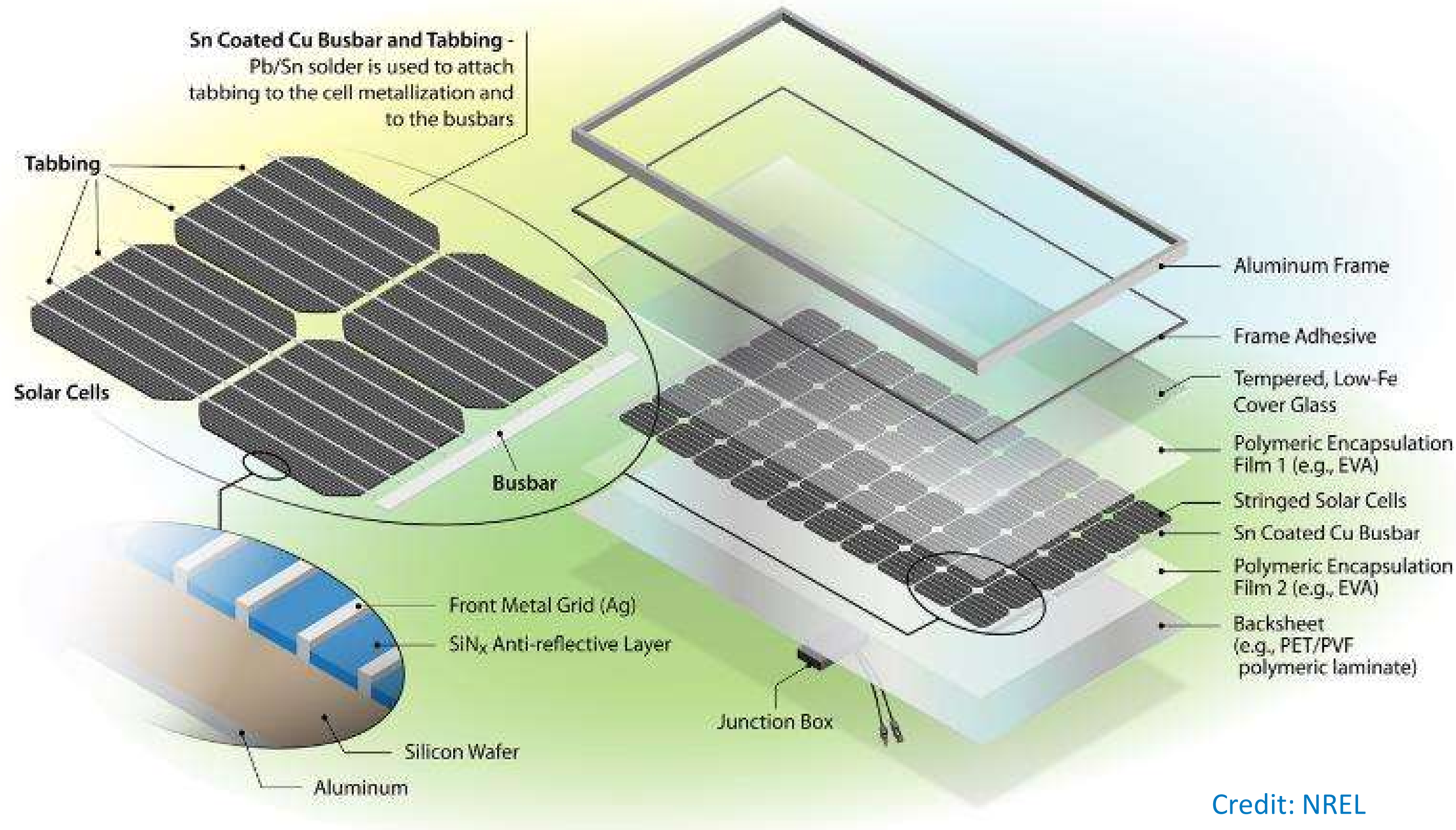
What Do We Do with EOL PV? The 3 Rs of Waste Management

- PV R&D has set priority topics for material use **reduction** or substitution for different components commonly used in today‘s PV panels (e.g., Si, Ag)
- **Reusing** modules (potentially preceeded by repairing) is conceivable, but practically and economically challenging
- **Recycling** processes for thin-film and crystalline silicon PV panels have been developed and to some extent implemented on industrial scale (outside US mostly), but more development is needed
- Significant recovery potential for different material streams can be realized through ***high-value recycling*** which is not common today



Source: IEA/IRENA, 2016

Module Construction and Constituents – Crystalline Silicon (>90% of market share)

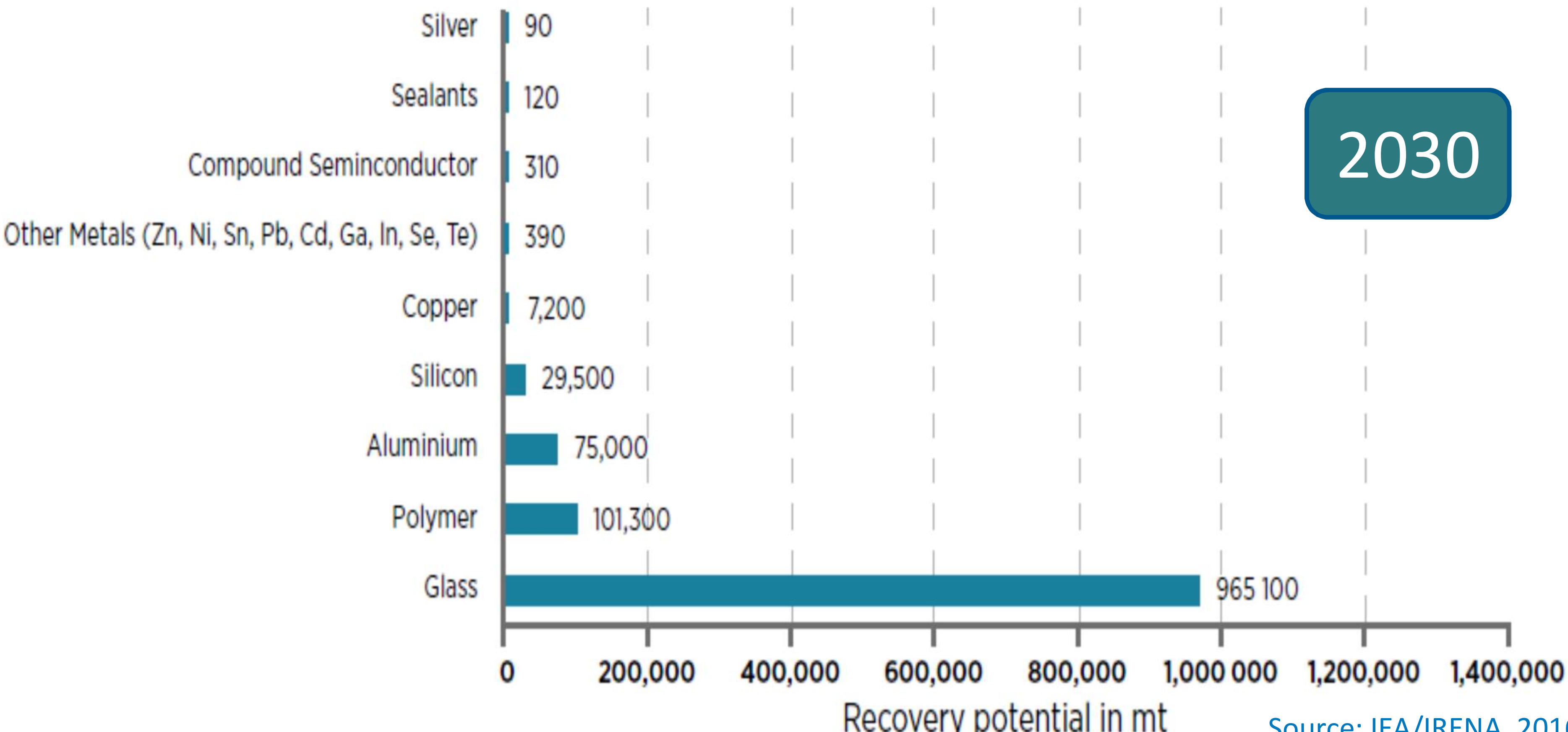


Credit: NREL

- **Bulk materials**: glass (~75%w), aluminum frame, copper wire, plastic junction box
- **Minor constituents with value**: silver, (internal) copper
- **Minor constituents with hazard**: lead (not all modules), fluorine-containing encapsulants
- **Other materials**: silicon (how much value?); various plastic adhesives, laminates, encapsulants
- **Critical materials** (not all in every module): aluminum, tin, tellurium (even in Si modules), antimony (in some glass), gallium and indium (thin film only)

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)



Source: [IEA/IRENA, 2016]

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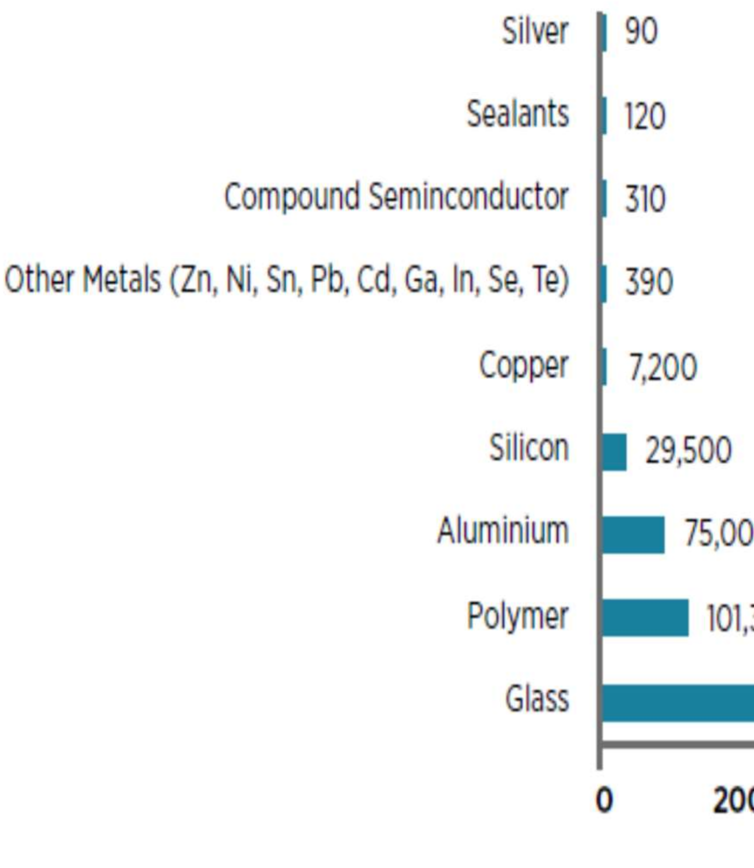
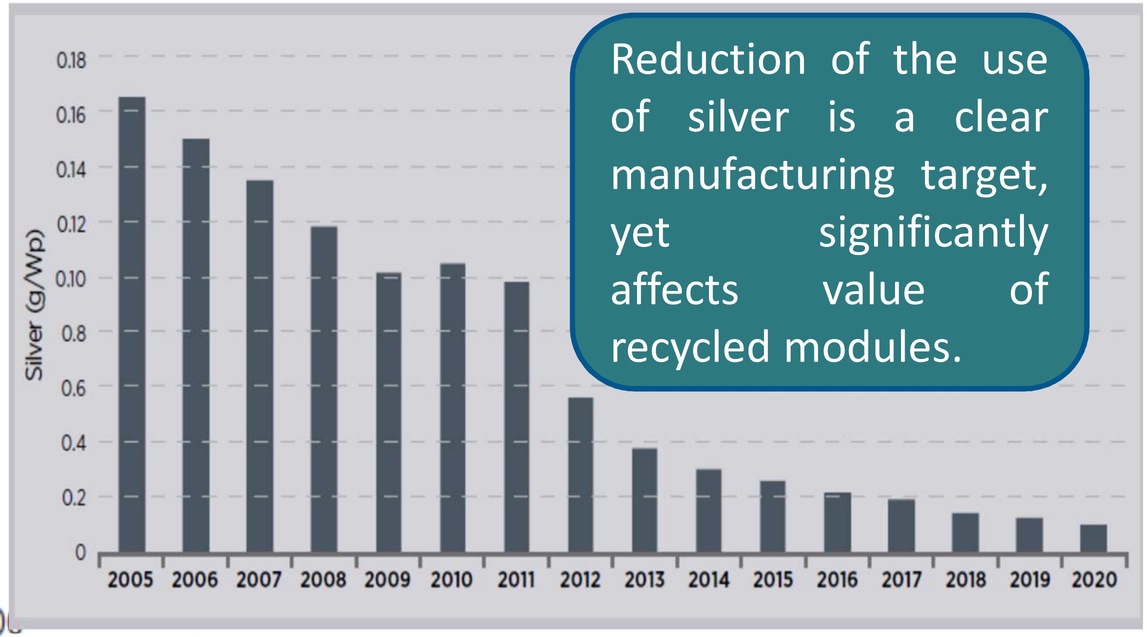




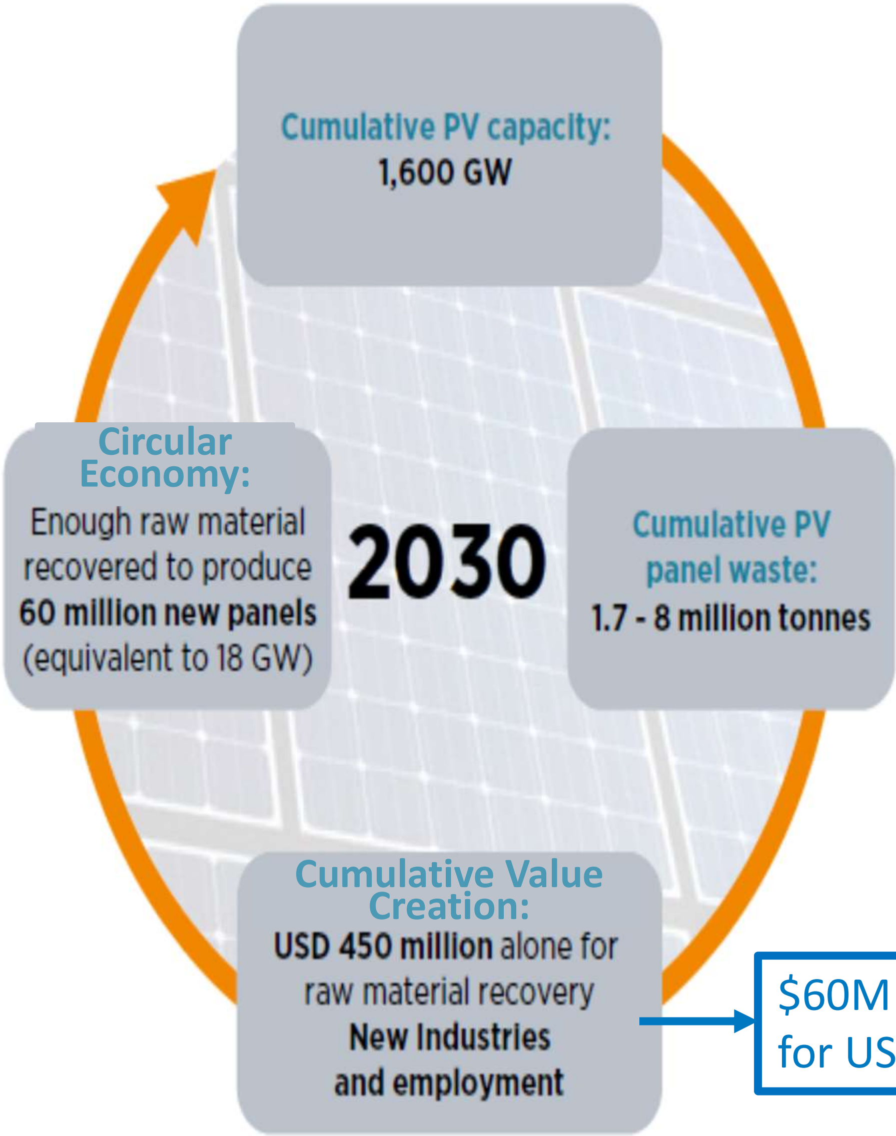
Reduction of the use of silver is a clear manufacturing target, yet significantly affects value of recycled modules.

Historic and expected silver consumption per Wp

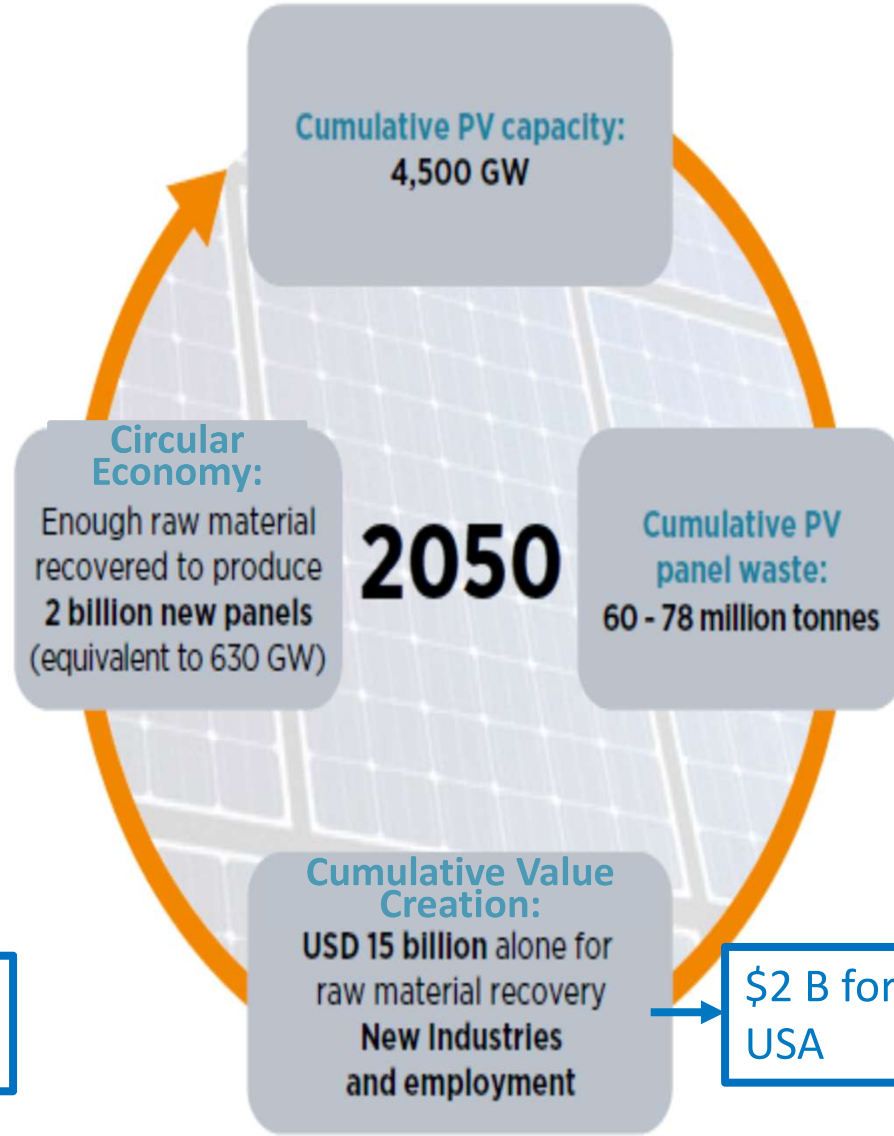
Based on: Perez-Santalla, M. (2013), Silver Use: Changes & Outlook, www.bullionvault.com/gold-news/silver-use-103020132

Source: IEA/IRENA, 2016

Potential Value Creation – A New Waste Management Industry?



$60M for USA



$2 B for USA

Source: IEA/IRENA, 2016

Trends in PV Recycling Technologies

Review of all available research – patents, publications, government R&D plans

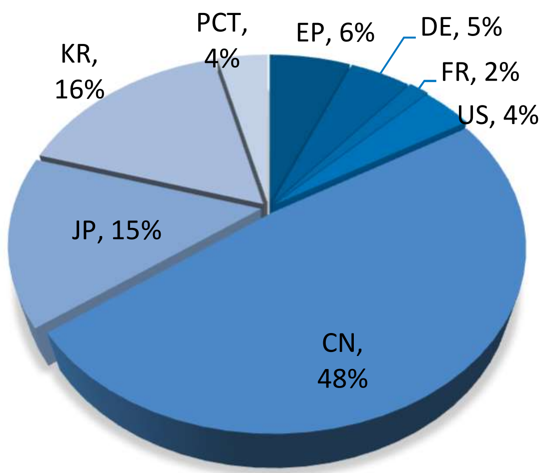


Fig. 2-2 Cumulative number of patent filings on c-Si PV module recycling by country/region (1995-2016)

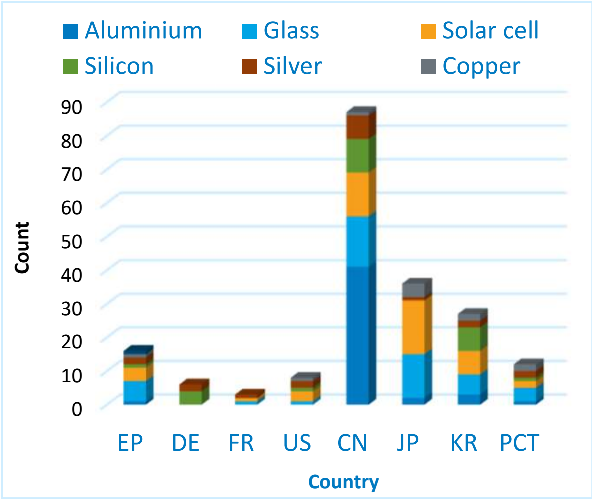
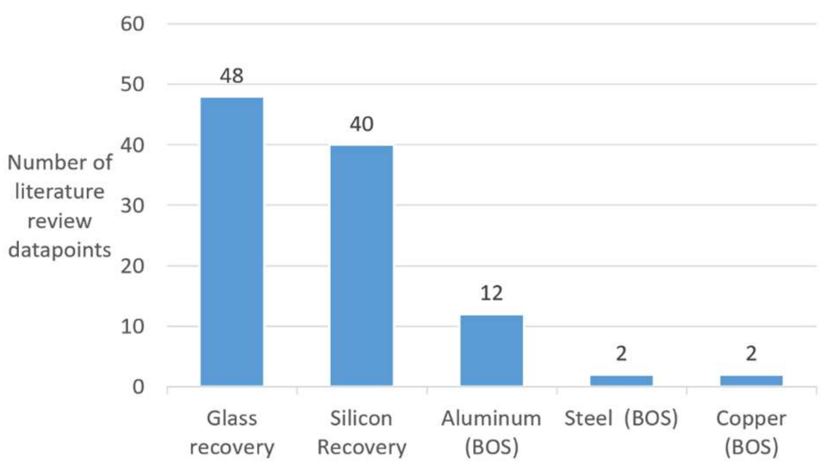
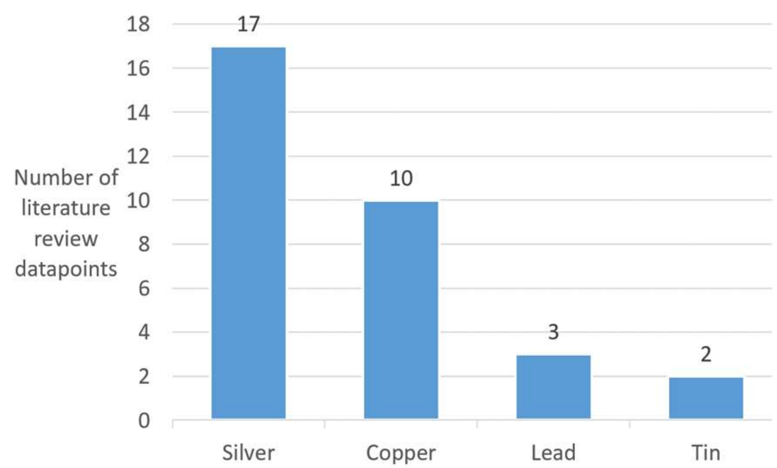


Fig. 2-11 Recovered materials for c-Si PV module recycling patents by country





IEA PVPS Task 12, 2018: *End-of-Life Management of Photovoltaic Panels: Trends in PV Module Recycling Technologies*

Trends in PV Recycling Technologies

Takeaways

1. US is far behind other countries especially in public sector support
2. Most effort to-date has been focused on easiest material targets and not integrated to recover all toxic and valuable materials in one, integrated process ("high value recycling")
3. No one process for c-Si module recycling has emerged as preferred, and "high value recycling" for c-Si has yet to be established in the US
4. A recycling R&D roadmap could focus efforts toward economical and effective high-value recycling technologies, especially for c-Si PV

What are the Environmental Benefits of Recycling PV Modules? Life Cycle Assessment of Current Photovoltaic Module Recycling

Introduction

- c-Si PV modules are currently treated in recycling plants designed for glass, metals or electronic waste. Only the bulk materials glass, aluminum and copper are recovered; the cells and other materials are incinerated.
- CdTe PV modules are recycled in dedicated facilities. The semiconductor material (Cd and Te) is recovered in addition to glass and copper.

Approach for LCA

- Life cycle inventories
    - c-Si PV module recycling based on a survey among current European recyclers (3 glass recyclers, 1 metal recycler)
    - CdTe PV module recycling by First Solar
- Impact assessment method used in the European Product Environmental Footprint (PEF) pilot phase: ILCD Midpoint 2011

Citation: P. Stolz, R. Frischknecht, K. Wambach, P. Sinha, G. Heath, 2018, *Life Cycle Assessment of Current Photovoltaic Module Recycling*, IEA PVPS Task 12, International Energy Agency Power Systems Programme, Report IEA-PVPS T12-13:2018.

Environmental Benefits – With and Without Credits

Environmental impacts of end of life of PV modules (no credits, just “recycling”)

- Current generation treatment of c-Si and CdTe PV modules causes a small share (<5 %) of the total environmental impacts of residential rooftop PV systems.
- The contribution of PV module recycling is highest in the impact category climate change (from transport, electricity supply, and waste disposal).

Net environmental impacts of PV material recovery (with credits, aka “avoided burden”)

- Recovery of glass, metals, and semiconductor material from PV modules causes lower environmental impacts than the extraction, refinement and supply of the respective materials from primary resources.
    - 28% to 750x lower across the categories considered (mineral resources highest)

Thank you!

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Collaborators:
IEA PVPS Task 12 experts
NREL PV Reliability group and techno-economic modelers

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