Clean Energy States Alliance Webinar

Solar PV Recycling: Issues and Considerations for State Decision-Makers

August 23, 2018

Clean Energy States Alliance

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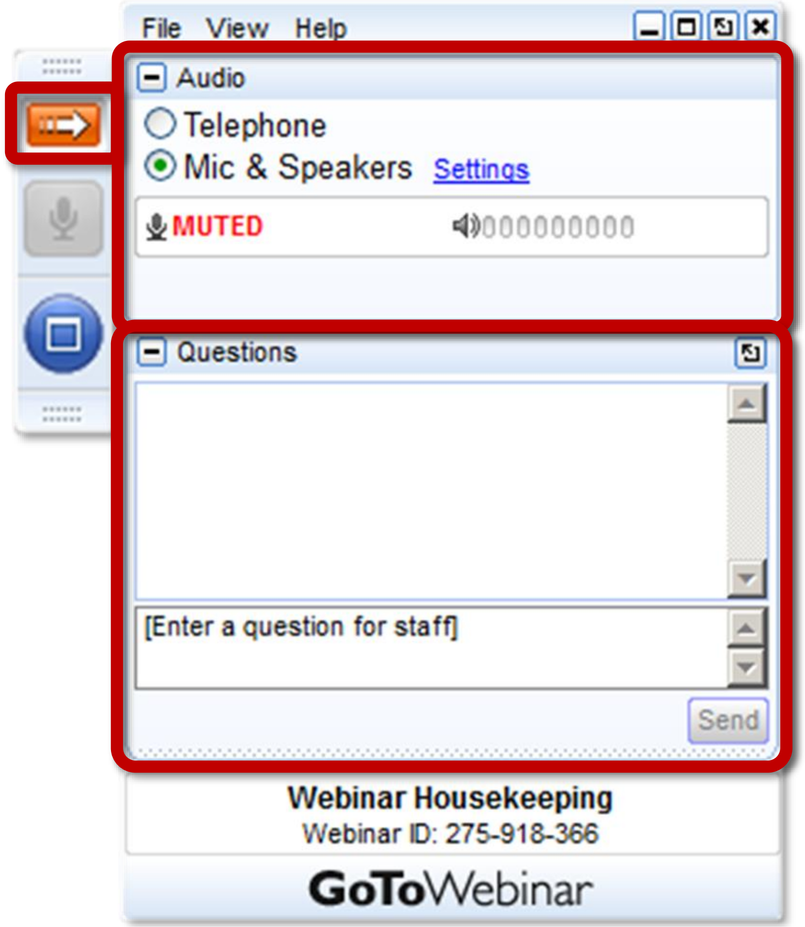

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- The Solar Technical Assistance Team (STAT) is a network of solar technology and implementation experts who provide timely, unbiased, credible, and obkectie expertise to assist poliymakers and regulators in making informed decisions about solar programs and policies

- STAT is a project of the U.S. Department of Energy Solar Energy Technologies Office that is implemented in partnership with NREL.

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https://www.nrel.gov/technical-assistance/states.html

Solar PV Recycling: Issues and Considerations for State Decision-Makers

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Garvin Heath, PhD

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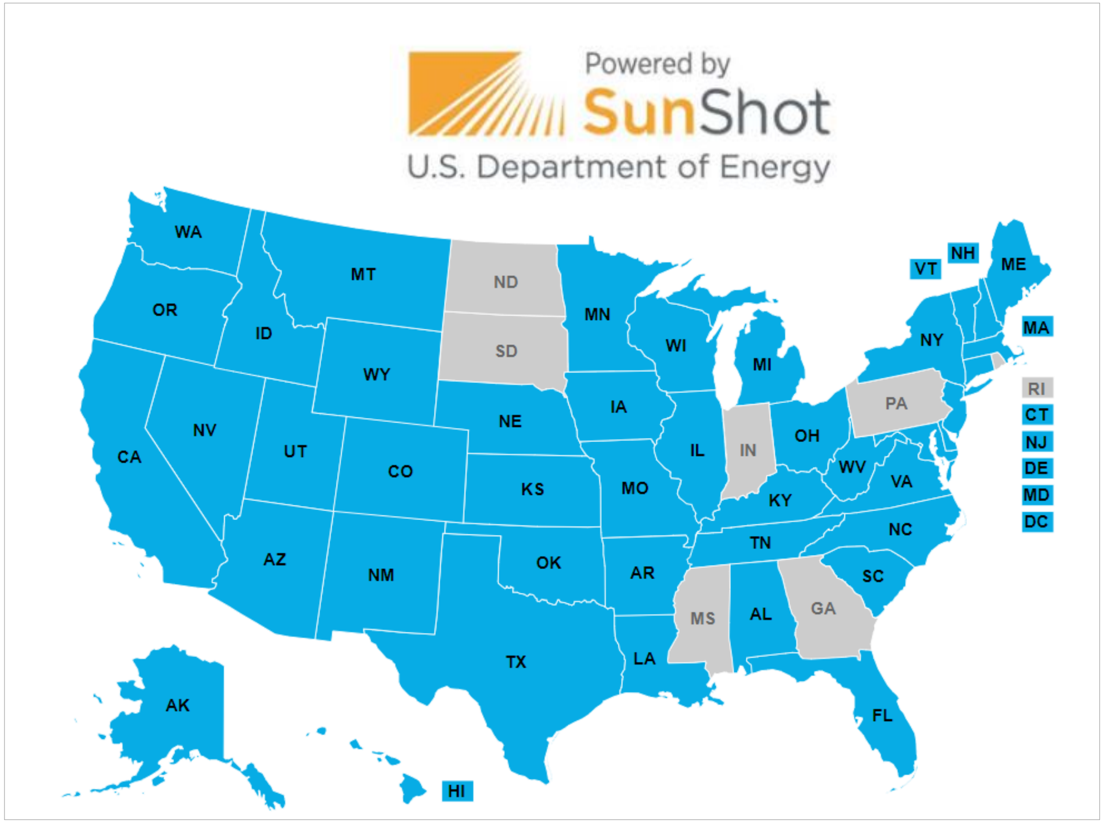

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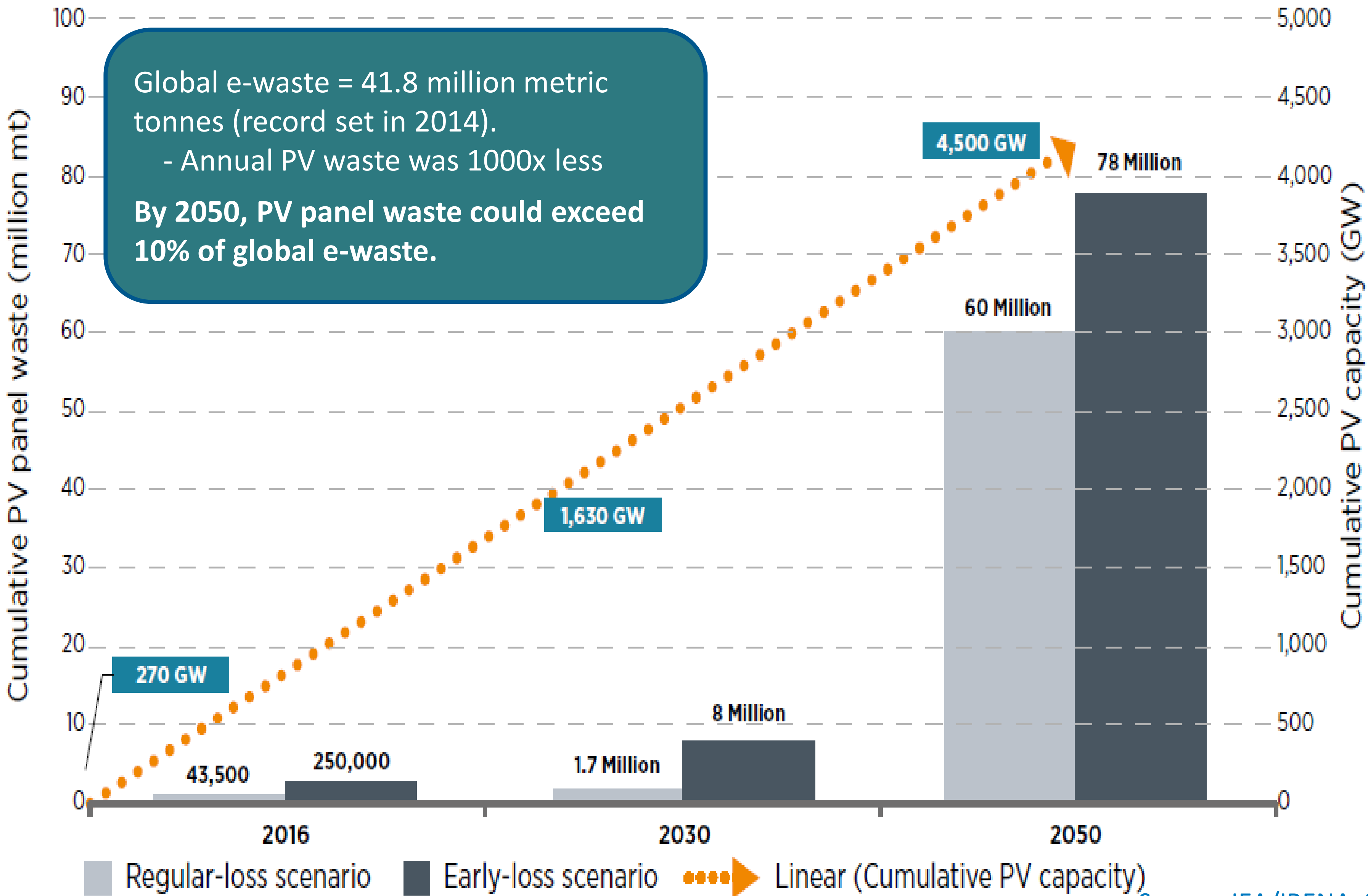
Outline

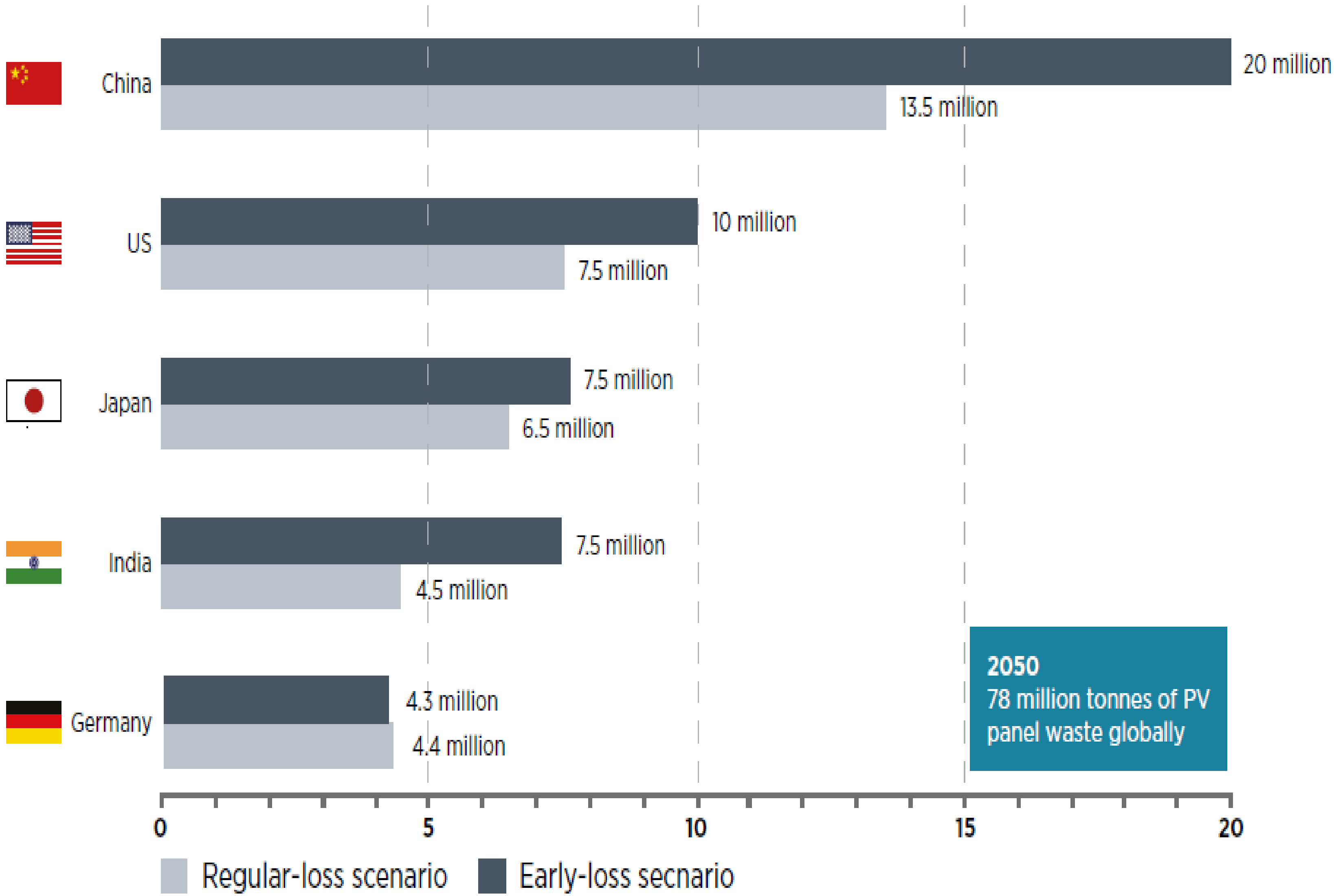
- Motivation and Need for Recycling of Photovoltaic Modules
- Value Creation and Manufacturing Sector Development Potential
- Challenges to Recycling
- Potential Synergistic Trends Enhancing Recycling
- Some Relevant International Research
- Information Gaps States Could Help to Fill

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



Source: IEA/IRENA, 2016

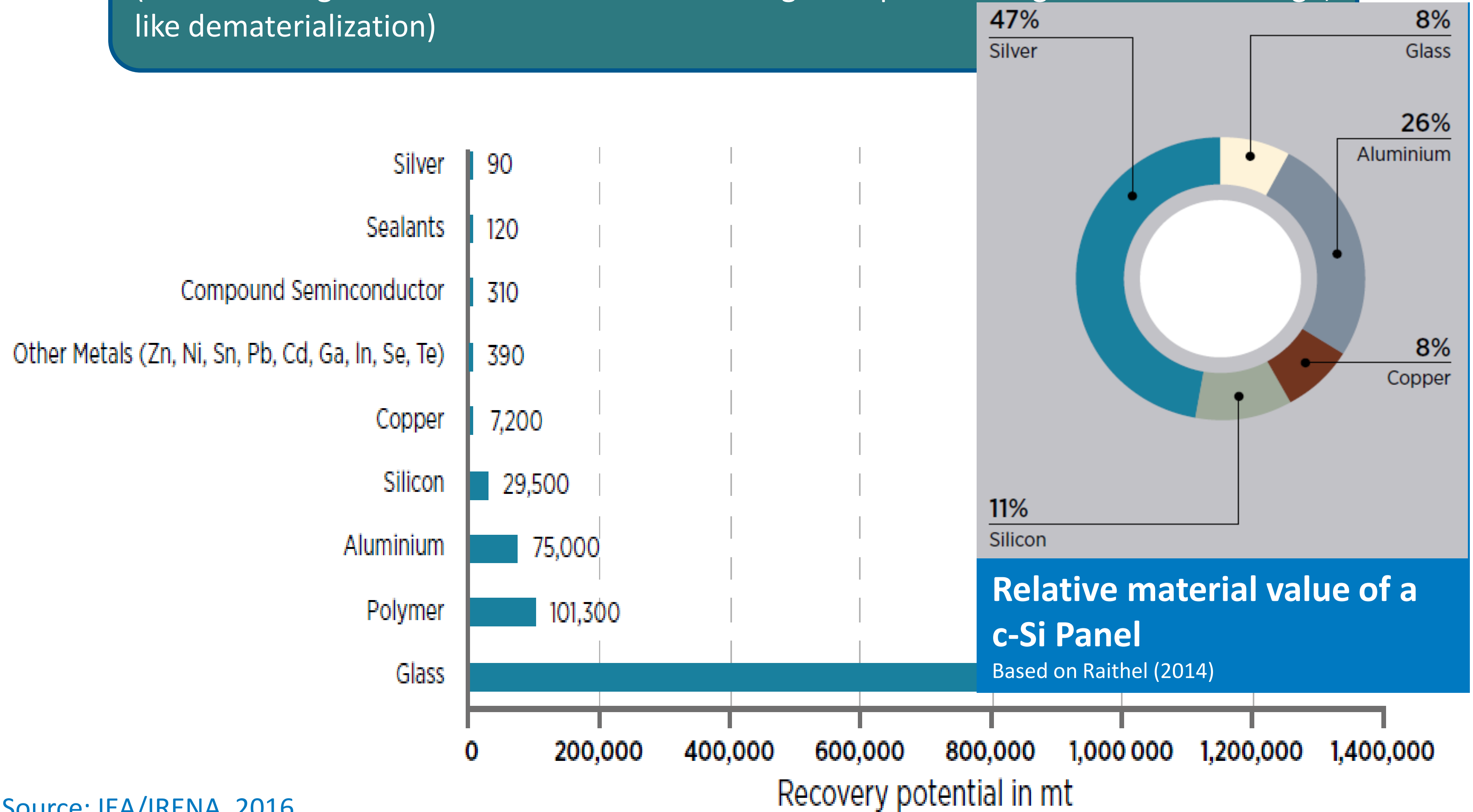
USA Expected As Second Largest PV Waste Volume: Challenge and Opportunity



Source: IEA/IRENA, 2016

Why Recycle Modules?
Recovery of Valuable Materials, Preventing Release of Toxic Materials

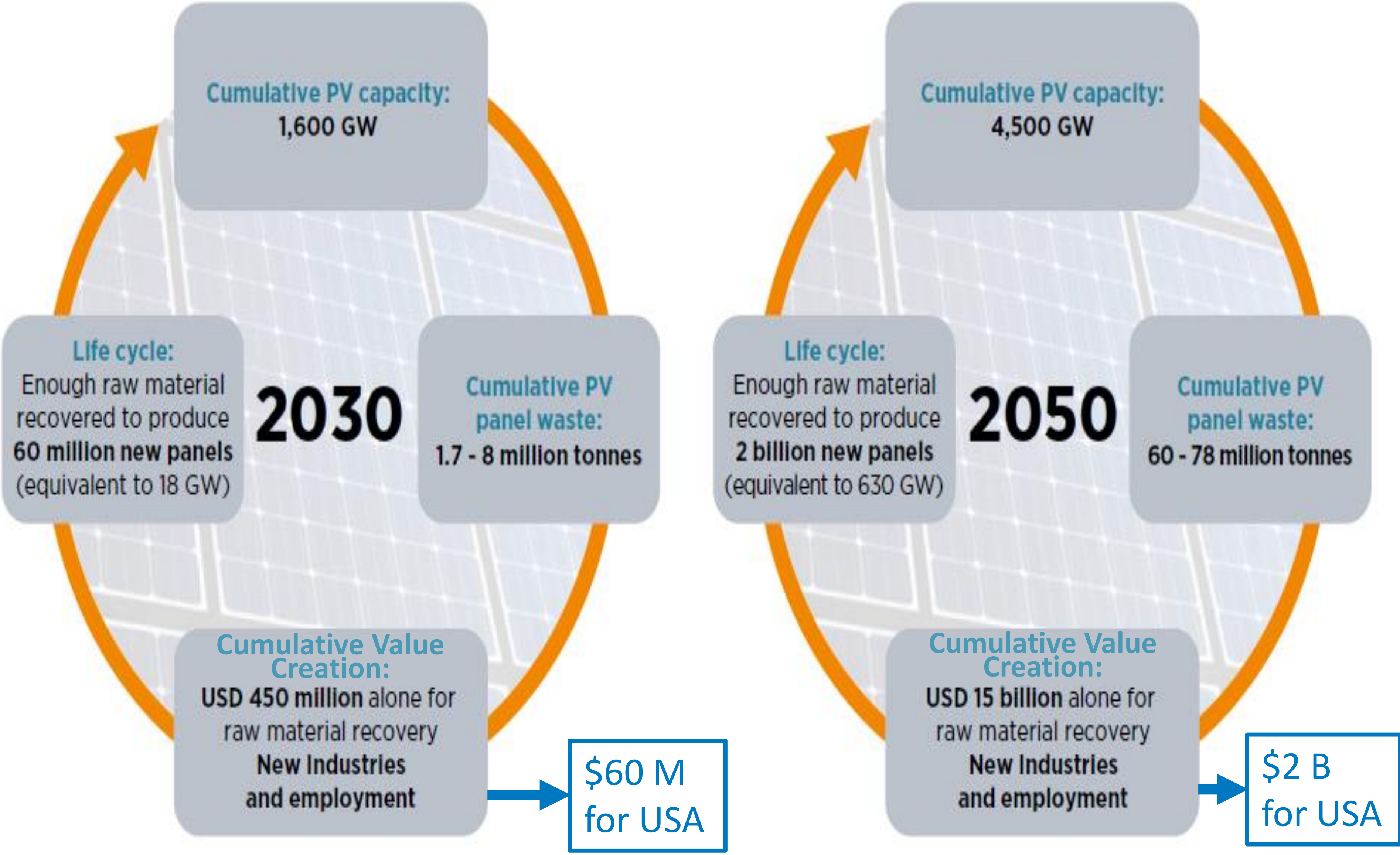
Cumulative technical potential for end-of-life material recovery (under the regular-loss scenario and considering anticipated changes to module design, like dematerialization)



Relative material value of a c-Si Panel
Based on Raithel (2014)

Source: IEA/IRENA, 2016

Potential Value Creation and Circular Economy: A Whole New Waste Management Industry?



Source: IEA/IRENA, 2016

Extending the Value Chain – Cooperation Among New Partners Will Be Important to Create a Vibrant Industry

R&D Organisations

- Public and private institutions
- Producers

Repair/Re-use services industry

- Producers
- Independent services partners
- Producer-dependent contract and service partners (e.g. installation and construction companies
- Waste collectors and companies
- Pre-treatment companies

Recycling treatment industry

- Public waste utilities and regulators
- Waste management companies
- Pre-treatment companies
- Producers

Optimal PV recycling industry will integrate features and actors from energy and waste sectors

Source: IEA/IRENA, 2016

Challenges

Waste Management and Recycling

Challenges are to prepare the technologies, systems and policies to manage decommissioning and disposal of end-of-life modules that can

- Minimize costs and
- Minimize environmental impacts, while
- Maximizing materials recovery.

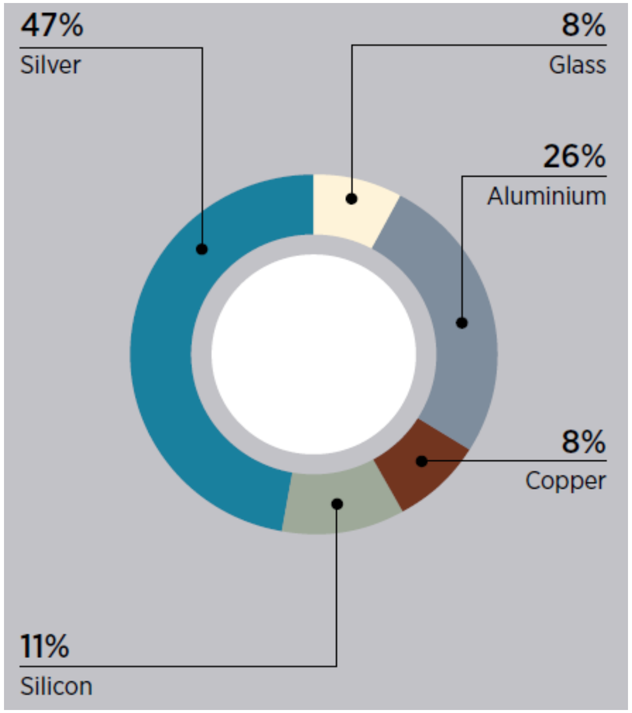
Design for Recycling

Conversely, one way to facilitate economical recycling and maximize material recovery is to design new modules that

- Increase speed and ease of dismantling,
- Improve rate and purity of recovered materials, and
- Reduce waste.

A Challenge to the Value Proposition: Dematerialization

From a value standpoint, silver is by far the most expensive component per unit of mass of a c-Si panel – consuming today about 15% (incl. losses) of the global silver production.
Reduction of the use of silver is a clear manufacturing target, yet significantly affects value of recycled modules.



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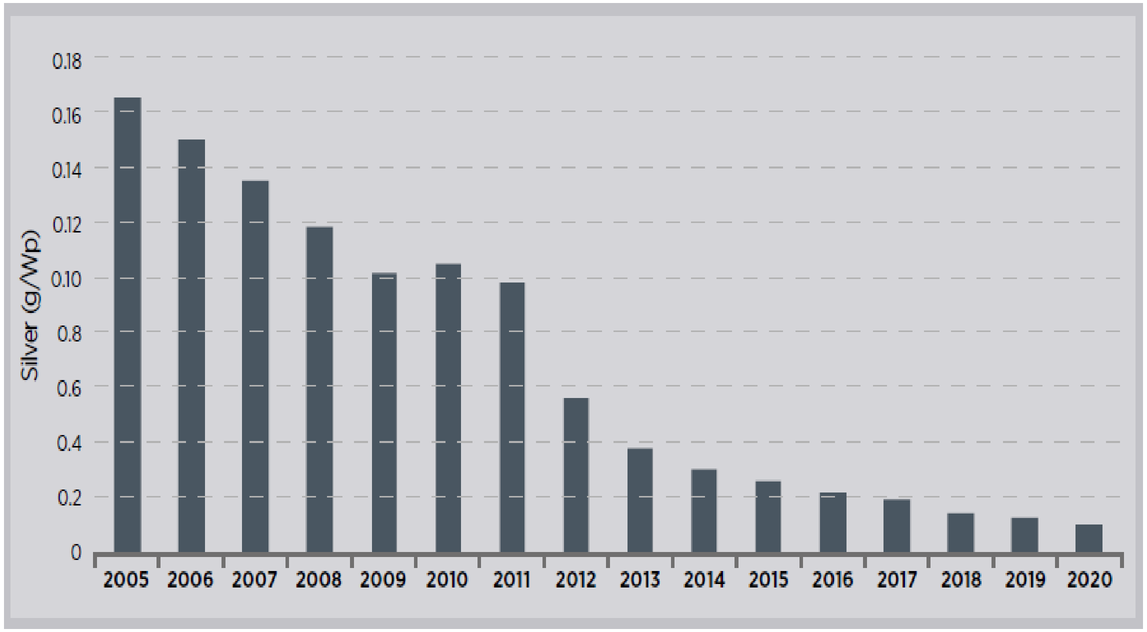


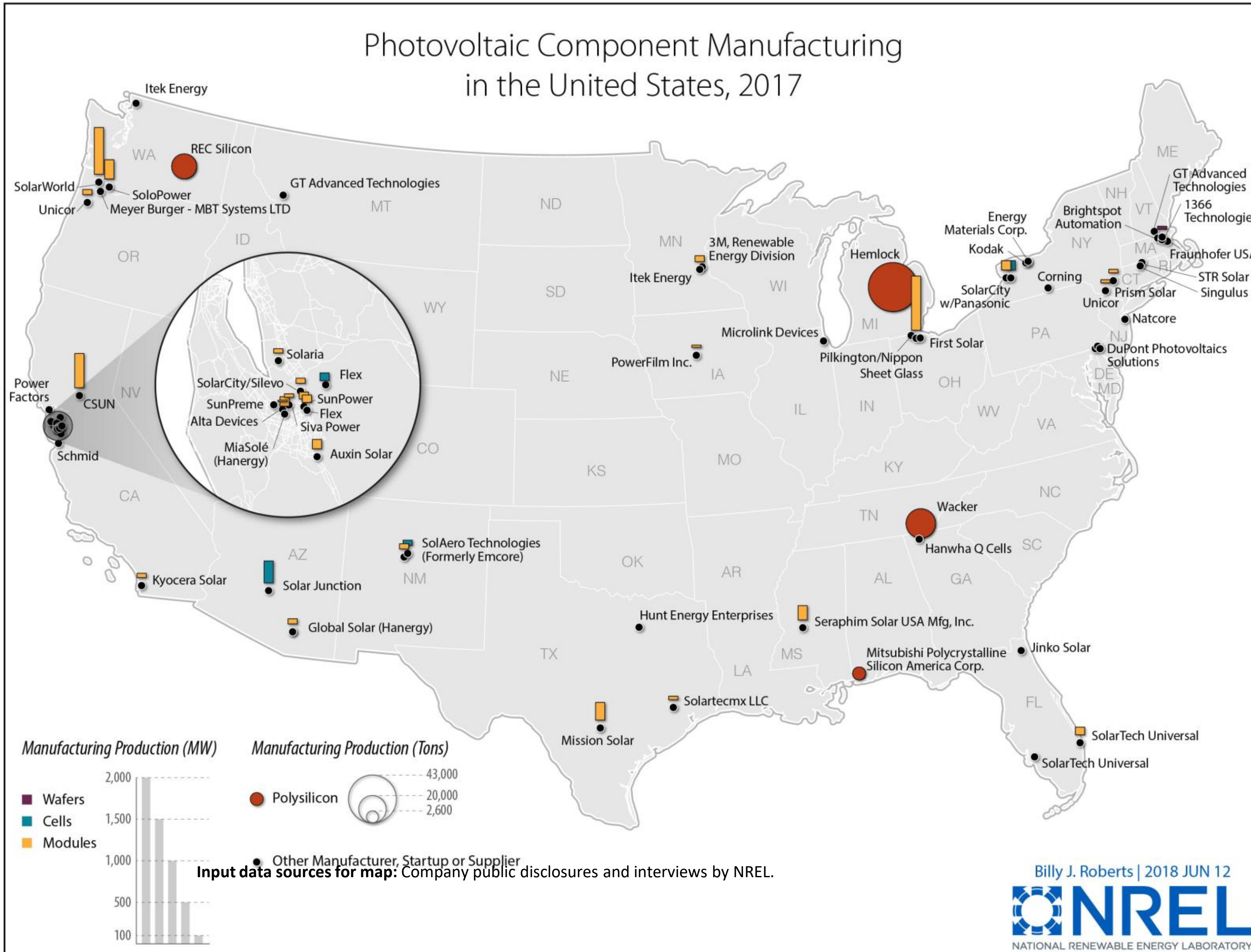
Historic and expected silver consumption per Wp

Based on: Perez-Santalla, M. (2013), Silver Use: Changes & Outlook,

Source: IEA/IRENA, 2016

Growing PV Waste Source: Manufacturing Scrap

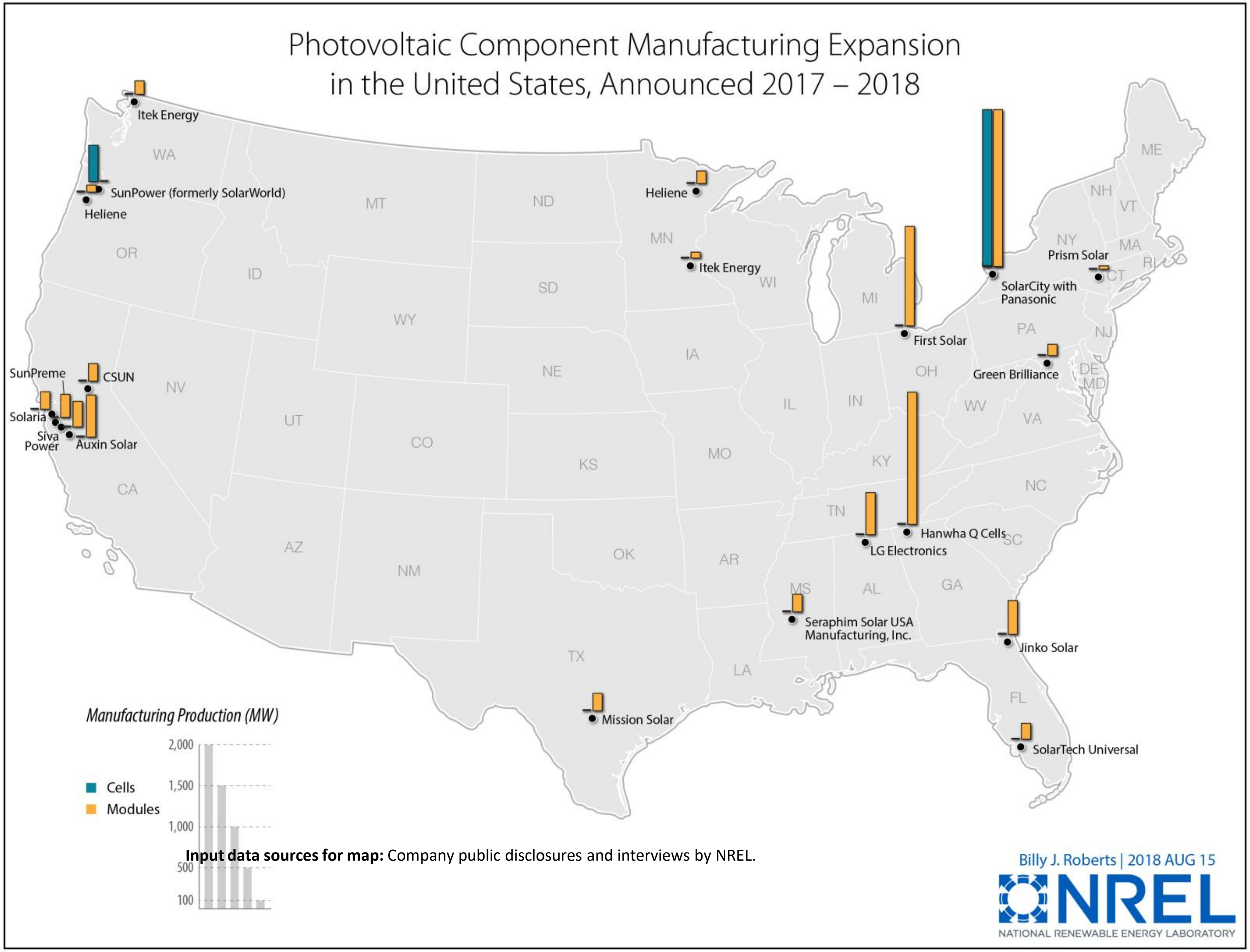
2017 Polysilicon, Wafer, Cell, and Module Capacities. Startup Companies, Materials, and Equipment Suppliers Locations.



Input data sources for map: Company public disclosures and interviews by NREL.

Source: Michael Woodhouse, NREL

New Capacity Announcements Made in 2017 and 2018



Input data sources for map: Company public disclosures and interviews by NREL.

Source: Michael Woodhouse, NREL

A Market Pull for Recycling?
New Sustainability Leadership Standard for PV Modules

- "NSF 457" – Sustainability Leadership Standard for PV Module Manufacturing (ANSI standard, published December 2017)
  - Comprehensive framework for the establishment of product sustainability performance criteria and corporate performance metrics that exemplify sustainability leadership in the market with third party verification
  - Aims to enable easier specification of high sustainability performance in large purchase contracts of PV modules, alleviating individual purchasers from the arduous and complex task of defining sustainability performance for PV modules
    - Potentially adopted by Green Electronics Council as a new category within the successful EPEAT registry
  - Three tiers of performance: Bronze, Silver, Gold
    - Based on the principle that only leaders – those in the top third of the market – are expected to qualify to the standard at the Bronze level at the date of publication of the standard
    - Very few will qualify for Silver and Gold

Sustainability Performance Categories

- Substance Management
- Manufacturing Chemicals
- Preferable Materials
- Design for Recycling
- Product Packaging
- Responsible End of Life Management
- Water Use
- Energy Management
- Life Cycle Assessment
- Corporate Environmental Performance
- Corporate Social Performance
- Conflict Mineral Sourcing

(ANSI) NSF 457 Scope

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Energy Use and Materials Flows of Current PV Module Recycling Processes in Europe

Introduction and Purpose

- PV module recycling is required in Europe under WEEE regulations
- Few environmental assessments have been published on PV module recycling technologies
- The purpose of this study was to collect energy and material flows (life cycle inventory) for currently operating recycling facilities in Europe that are treating PV modules in order to better understand the process design and support life cycle assessment of their environmental impacts

Approach

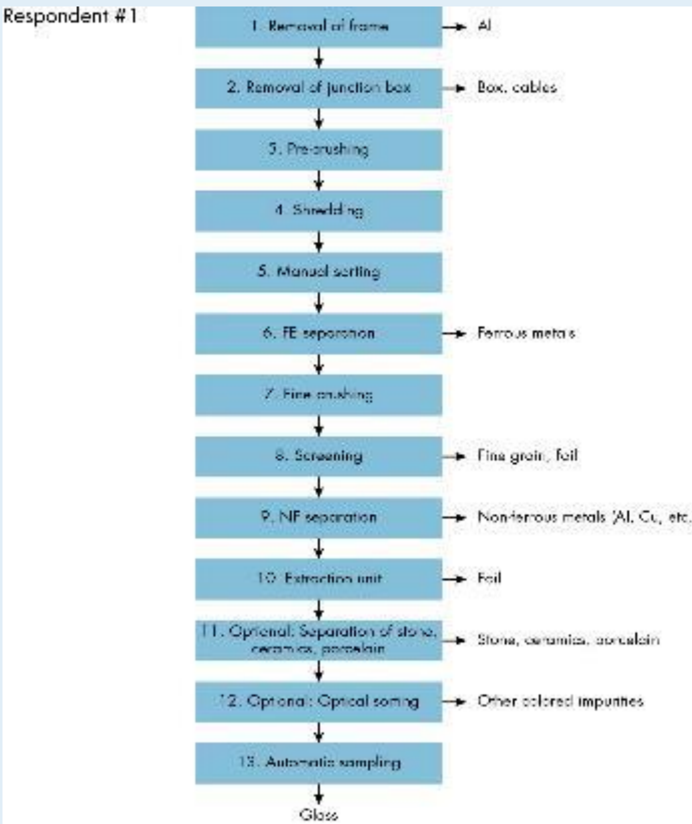
- Survey of known recyclers in Europe
  - 9 surveys sent
  - 5 returned

Respondent	Company	Country	Process	Type of Recycler	PV Volume (t/yr)
#1	Anonymous	Germany	Mechanical	Glass	1,200
#2	Exner Trenntechnik GmbH	Germany	Mechanical	Metal	100-250
#3	Maltha	Belgium	Mechanical	Glass	1,000
#4	Nike	Italy	Mechanical	Glass	600
#5	Sasil S.r.l.	Italy	Combination of mechanical, thermal, and chemical	Prototype PV recycling system	(1 t/hr tests)

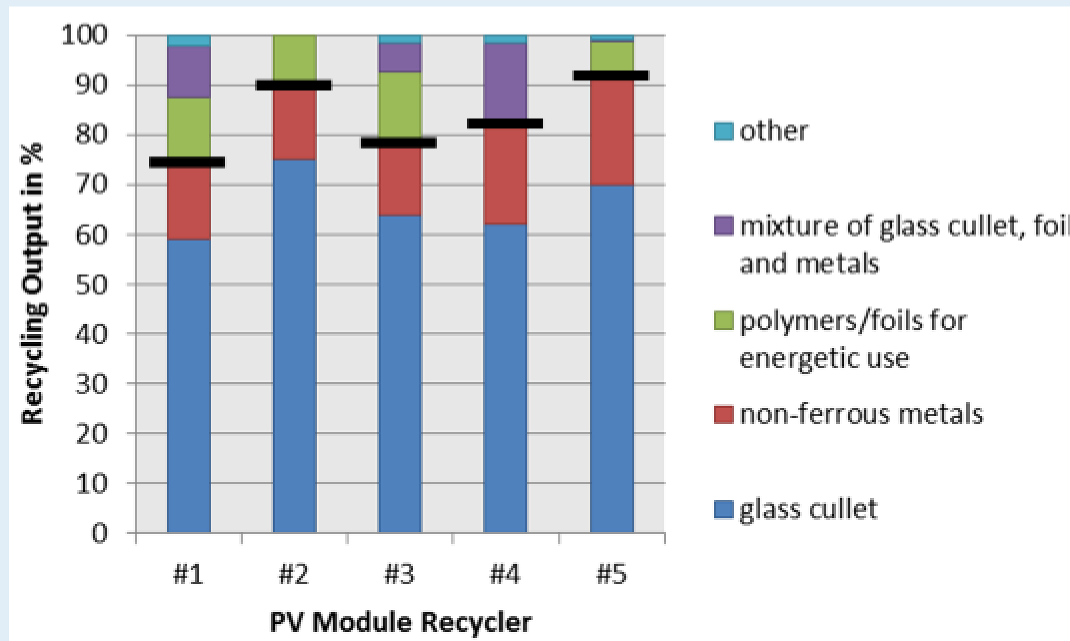
Citation: *Wambach K, Heath G, Libby C. 2018. Life Cycle Inventory of Current Photovoltaic Module Recycling Processes in Europe. IEA-PVPS Task 12 Report T12-12:2017. ISBN 978-3-906042-67-1.*

Synthesis

- Electricity is main energy source for recycling operations, with all but one using 50-100 kWh per tonne of module input
- Higher material recovery rate can be achieved with greater input energy - Respondent #2 used more electricity for a more intense mechanical process; whereas Respondent #5 additionally used thermal energy.



Example of a PV-module recycling process performed as a batch run in a laminated-glass recycling plant, which is considered the reference process of this study since it sets a cost benchmark for PV module recycling in Europe today.



Fraction of recycling output (percent of total output mass) by material category for each of the five respondents. (Polymers are included in mixture for respondent #4.) The bold black lines indicate the total material recovery rate of the process.

End-of-Life Management of Photovoltaic Panels: Trends in PV Module Recycling Technologies

Introduction

- When a product cannot be repaired or reused, recycling is the next best option.
- In the case of PV modules, recycling has become an important emerging topic and various development and research activities have been conducted.
- The purpose of this study was to provide an international survey of trends related to the development of PV module recycling technology.

Approach

1. Patent analysis
    - Database used: online WIPS (worldwide intellectual property service) covering Jan. 6, 1976 – Dec. 9, 2016.
    - Countries covered: EP, DE, FR, GB, US, CN, JP, KR, and the PCT
2. Overview of technology R&D
    - Survey of literature published by firms implementing R&D projects.

Citation: *K. Komoto, J.-S. Lee, J. Zhang, D. Ravikumar, P. Sinha, A. Wade, G. Heath, 2018, End-of-Life Management of Photovoltaic Panels: Trends in PV Module Recycling Technologies, IEA PVPS Task 12, International Energy Agency Power Systems Programme, Report IEA-PVPS T12-10:2018.*

Patent Analysis

- **Procedure**

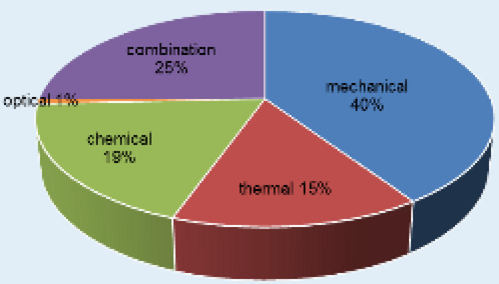
Initial search → 6,465 patents → Screening → 178 patents* → analysis (based on targeted components, processing method, and recovered materials)

*directly related to PV recycling

- **Analysis results**

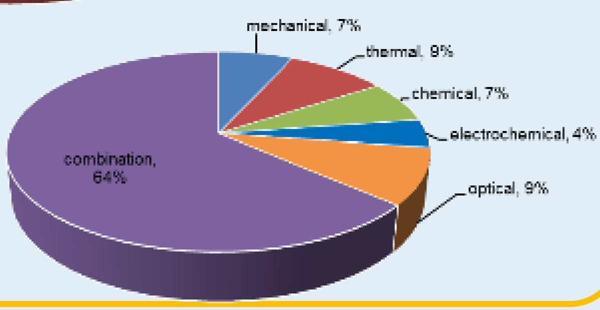
c-Si – 128 patents
- 45% focusing on module separation
- Mechanical method for 40%
- Many patents for recovery of components, not for recovery of individual materials.

Thin-film compound – 44 patents
- High value recycling recovers higher fraction of the mass
- Combination method for 64%
- Total recycling from module separation to material recovery.



c-Si

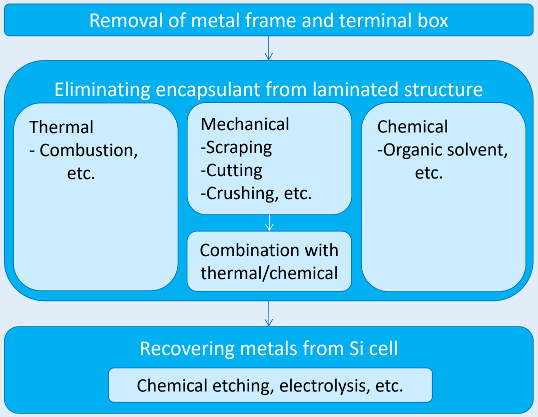
Thin-film compound



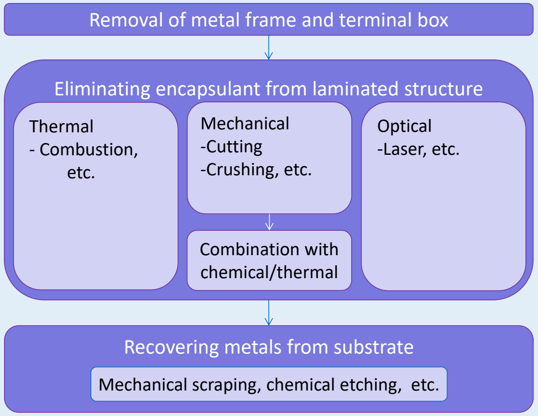
Overview of Technology R&D

Delamination is a key recycling step:

c-Si
- Separation and recovery of glass, Si cells, and other metals
- Thermal, mechanical and chemical approaches can be used.



Thin-film compound
- Recovery of cover and substrate glass with the semiconductor layer
- Thermal, mechanical and optical approaches can be used.



PVPS

Environmental 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 Environmental Assessment (LCA)

- Life cycle inventories
  - c-Si PV module recycling based on average of current European recyclers (3 glass recyclers, 1 metal recycler – data from Task 12 LCI report)
  - CdTe PV module recycling by First Solar
- Tested two life cycle inventory modelling approaches: Cut-off / End-of-life
- Followed recognized international procedures for life cycle assessment (LCA)

PVPS

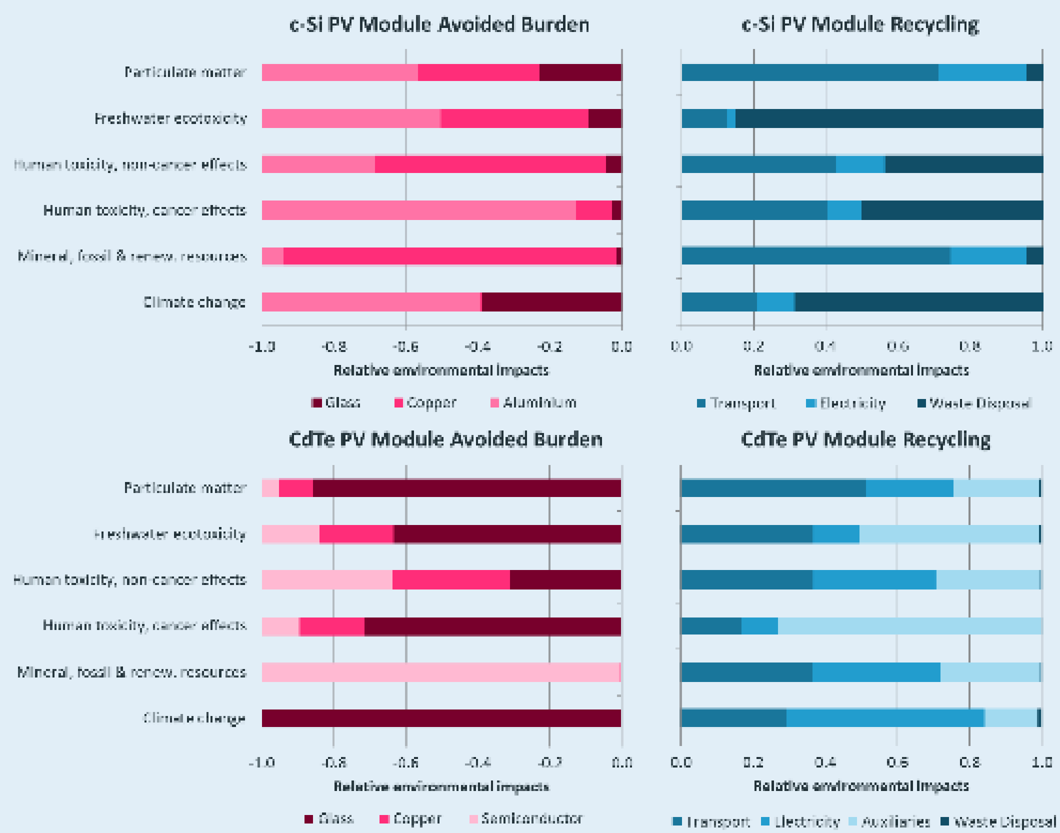
Citation: *P. Stolz, R. Frischknecht, K. Wambach, P. Sinha, G. Heath, 2018, Life Cycle Assessment of Current Photovoltaic Module Recycling, IEA PVPS Task 12, International Energy Agency Power Systems Programme, Report IEA-PVPS T12-13:2018.*

Environmental impacts of end of life of PV modules (cut-off approach)

- Current generation recycling 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 (end-of-life approach)

- 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.



Information Gaps States Could Help to Fill

- Market size: how much PV module waste is being generated?
  - This is a very basic information gap critical to enabling investment in recycling infrastructure and industrial R&D.
    - Manufacturing off-spec
    - Warranty issues
    - Other failures – transport, installation, field operation (e.g., extreme weather)
- Current recycling costs are high relative to landfilling or other options
  - R&D and industrial experience is needed to reduce cost, increase material recovery rates, increase purity and decrease contamination
- Analysis of recycling policy design options for cost (owner and administrator), recovery rates, compliance rates, environmental benefits, etc.
  - Collection systems through treatment and disposal
  - Also limitations and challenges given current codes, standards, regulations

Thank you!

Garvin.Heath@nrel.gov

IEA PVPS Task 12:
http://iea-pvps.org/index.php?id=60

Thank you for attending our webinar

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Upcoming Webinar

Community Solar Program Design and Implementation for Low-and Moderate-Income Customers

Thursday, August 30, 1-2pm ET

Guest speakers from NREL will discuss their new report, which reviews existing and emerging LMI community solar programs, discusses key questions related to program design, outlines how states can leverage incentives and finance structures to lower the cost of LMI community solar, and examines marketing and outreach considerations.

Read more and register at www.cesa.org/webinars