Solar PV Recycling: Challenges and Approaches

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

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 global e-waste.

Source: IEA/IRENA, 2016
USA Expected As Second Largest PV Waste Volume: Challenge and Opportunity

Source: IEA/IRENA, 2016

- **China**: 20 million (13.5 million in regular-loss scenario, 6.5 million in early-loss scenario)
- **US**: 10 million
- **Japan**: 7.5 million (6.5 million in regular-loss scenario)
- **India**: 7.5 million (4.5 million in regular-loss scenario)
- **Germany**: 4.3 million (4.4 million in regular-loss scenario)

Total PV panel waste globally by 2050: 78 million tonnes

Source: IEA/IRENA, 2016
Manufacturing analysis led us to consider circular economy

End of Life (EOL)

Infrastructure supporting the circular supply chain
Growing PV Waste Source: Manufacturing Scrap


Source: Michael Woodhouse, NREL
PV R&D has set priority topics for material use reduction or substitution for different components commonly used in today’s PV panels.

Reusing modules (potentially preceded 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, but more development is needed.

Significant recovery potential for different material streams can be realized through *high-value recycling*.
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)

<table>
<thead>
<tr>
<th>Material</th>
<th>Recovery potential in mt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver</td>
<td>90</td>
</tr>
<tr>
<td>Sealants</td>
<td>120</td>
</tr>
<tr>
<td>Compound Semiconductor</td>
<td>310</td>
</tr>
<tr>
<td>Other Metals (Zn, Ni, Sn, Pb, Cd, Ga, In, Se, Te)</td>
<td>390</td>
</tr>
<tr>
<td>Copper</td>
<td>7,200</td>
</tr>
<tr>
<td>Silicon</td>
<td>29,500</td>
</tr>
<tr>
<td>Aluminium</td>
<td>75,000</td>
</tr>
<tr>
<td>Polymer</td>
<td>101,300</td>
</tr>
<tr>
<td>Glass</td>
<td>1,000,000</td>
</tr>
</tbody>
</table>

Source: IEA/IRENA, 2016

Relative material value of a c-Si Panel
Based on Raithel (2014)
Potential Value Creation and Circular Economy: A Whole New Waste Management Industry?

**Cumulative PV capacity:**

- **2030:** 1,600 GW
- **2050:** 4,500 GW

**Life cycle:**
- 2030: Enough raw material recovered to produce 60 million new panels (equivalent to 18 GW)
- 2050: Enough raw material recovered to produce 2 billion new panels (equivalent to 630 GW)

**Cumulative PV panel waste:**
- 2030: 1.7 - 8 million tonnes
- 2050: 60 - 78 million tonnes

**Cumulative Value Creation:**
- **2030:** USD 450 million alone for raw material recovery
- **2050:** USD 15 billion alone for raw material recovery

**Value Creation and Employment:**
- **2030:** $60 M for USA
- **2050:** $2 B for USA

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.

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

Historic and expected silver consumption per Wp

Source: IEA/IRENA, 2016
New Study Goal, Context and Focus

- **Circular Economy**: A circular economy is an alternative to a traditional linear economy (make, use, dispose) in which we keep resources in use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life.

- **Project Goal**: To elucidate drivers for sustainable manufacturing and circular economy through a series of project phases that can inform sustainable manufacturing strategy and develop analytical and technical capability.

  - Enhanced material efficiency strategies can potentially save 5-9% of total energy consumption, but these strategies are not widely implemented or integrated to-date.

  - Approaches to collect, sort, extract, and process materials from end-of-life products are not always cost-effective, the recovered materials often are of lower quality/purity than that required to manufacture the same product, and the circular supply chains are often not well developed or integrated.

A collaboration between DOE EERE Strategic Priorities & Impact Analysis, the Advanced Manufacturing Office, the Solar Energy Technologies Office, and other DOE partners
Thank you!