PV Recycling Policies and Technology

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Why Does High-Value PV Recycling Matter?

- **Crucial for managing large future PV waste volumes**
  - Over 137 GW PV installed worldwide today
- **All PV technologies require responsible EOL management**
  - Environmentally sensitive materials are common in the industry (Pb, Cd, Se compounds...)
- **Provides socio-economic and environmental benefits**
  - Minimizes life cycle impacts
  - Reclaims valuable (Te, In, Ag) and energy-intensive (Si) materials
  - Creates jobs (EU estimates 20,000 jobs by 2050)
  - Inclusion of PV in the EU WEEE Directive is expected to yield recoverable values of ~ 17.5 billion EUR by 2050

### Material content of current PV technologies

<table>
<thead>
<tr>
<th>Material</th>
<th>Crystalline Silicon Modules</th>
<th><strong>α-Si</strong></th>
<th><strong>CdTe</strong></th>
<th><strong>CIS/CIGS</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td>74%</td>
<td>86%</td>
<td>95%</td>
<td>84%</td>
</tr>
<tr>
<td>Aluminium</td>
<td>10%*</td>
<td>&lt;1%</td>
<td>&lt;1%</td>
<td>12%</td>
</tr>
<tr>
<td>Other components (including rare metals)</td>
<td>16%</td>
<td>14%</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>Other key materials (representing over 1% of composition)</td>
<td>EVA, Tedlar backing film, silicon, adhesive</td>
<td>Polyol, MDI</td>
<td>EVA</td>
<td>EVA</td>
</tr>
<tr>
<td>Rare metals included</td>
<td>Silver</td>
<td>Indium, Germanium</td>
<td>Indium, Gallium</td>
<td></td>
</tr>
<tr>
<td>Presence of Cadmium (Cd) and Lead (Pb)</td>
<td>Pb</td>
<td>Cd</td>
<td>Cd</td>
<td></td>
</tr>
</tbody>
</table>

* Represents the frame, which is primarily aluminium

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Recycling and resource recovery

- In addition to future waste problem, PV will need large quantities of raw materials to sustain a rapidly growing industry
- Recycling can contribute to resource recovery
Motivation for the workshop

- PV Life Cycle Management & Recycling reached next level of maturity (regulatory framework under WEEE / development of technical minimum standards)
- Global annual deployment levels go beyond the 10 GW scale and will undoubtetly continue growing – this adds more than 1 000 000 tons to the material flow equation which will cycle back at End-of-Life of these installations
- Questions of recycling friendly design, innovative reuse and re-powering schemes arise and get more importance in the life cycle management approaches
- Learning curve for PV recycling technologies progresses – what are the trends

EU PVSEC workshop - Highlights

- Insight into recent recycling technology developments in Japan and China
- Update on the regulatory situation in Europe with regard to the WEEE transposition and the inclusion of photovoltaic panels in the scope
- Announcement of the development of a minimum treatment standard for the recycling of PV modules through the CENELEC TC111X WG4
- Announcement of a best practice policy paper of IRENA with a special focus on non-OECD countries
- Update on expected recycling volumes on a European and Global Perspective
- Presentation of new technology approaches to delamination of end-of-life PV modules which enable cost-effective high value glass recycling
- Insights into the European Union CU-PV project, with focus on recycling friendly design of future PV modules

Key Technical Challenges to Recycling

- Delamination
  - Efficient encapsulant (EVA) removal
- Collection reverse logistics
  - Waste classification
  - Inter-country transport
- High value recycling
  - Need PV-specific recycling standards
  - Recover energy intensive, economically valuable, and environmentally sensitive materials as well as bulk materials

Exhibit 1: Photovoltaic Module Recycling Value Chain

Source: First Solar
First Solar’s Module Recycling Process

Total annual recycling capacity of ~26,000 MT

+ 90% Recycling of semiconductor material
~ 90% Recycling of glass

Shredder → Hammermill → Crushed/Milled Scrap Holding Bin → Metals Precipitation → Reactor Columns (Film Removal Solid/Liquid Separation) → EVA/Glass Separation → Third-party Cd/Te Separation and Refining → Tellurium Product → Cadmium Product → Clean Glass Cullet → Laminate Material
First Solar Product Development Approach

• Strive for continuous improvement of our technologies while ensuring recyclability
  — Recyclability is fully integrated in module design
  — Product development budget allocates funds for recycling process upgrades
  — Technology improvement projects are tracked through Change Management System (CMS)
  — Module improvement projects require timely implementation of recycling process upgrades

Ensuring the recyclability of our products is integral to our R&D process.
The Future of First Solar Recycling – In-situ recycling with mobile facilities

- 3rd generation continuous process recycling
  - More efficient 7/24 operations
  - 30 tons/day capacity
  - Higher quality USM
  - Targeting costs below hazardous waste disposal cost

- Recycling facilities will be smaller and mobile by 2027
  - In-country recycling will minimize transportation costs

- 4th generation high volume recycling
  - 350 tons/day capacity for large markets
## Alternative Delamination Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Applied on</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic solvents [1,2]</td>
<td>Crystalline Silicon</td>
<td>1. Does not require thermal or mechanical processes</td>
<td>1. Batch process and increased time.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2. EVA swells and cracks semiconductor layer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. Complete removal of EVA requires heating with Ar gas for 1 hr.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Automation reduces labor costs and safety issues</td>
<td>2. Energy intensive (16049 MJ/m2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Clean glass</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Clean glass</td>
<td>2. Works only when carrier glass is intact</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. Increased time</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4. Contamination with abrasives</td>
</tr>
<tr>
<td>Tenside chemistry [3]</td>
<td>CIGS</td>
<td>1. Does not require thermal or mechanical processes</td>
<td>1. Process is area dependent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Does not require thermal or mechanical processes</td>
<td>2. Energy intensive</td>
</tr>
</tbody>
</table>

Physical method of PV module recycling

- Artificial dismantling
- Crush
- Grind under -197°C
- Physical separation
  - Mixed power of Si, Ag, Al, etc.
  - Back sheet
  - EVA

Thermal method of PV module recycling

- PV modules
  - Research of dismantling
  - Research of TGA
- Artificial dismantling
  - Tube furnace heat treatment experiments
  - Dissolve in Organic solvent
  - Silicon cell
  - Tempered glass
- Recycling Al
- Recycling Ag
- Recycling Si
NEDO, Japan

Source: provided from NEDO/FAIS

CU-PV Project – Recycling Friendly Design

- Use thermoplastics as encapsulant (melts, easier to separate)
- Use release layers (intermediate layers with specific properties)
- Use no encapsulant (e.g. the Nice module concept)
- Use different kind of sealants in the Al-frame (easier to remove from module)
EU WEEE Directive and PV

- Collection targets – a staggered approach has been taken by the regulator, defining collection targets from 45% of WEEE collected based on EEE put on the market, going up to 65% and finally converging into an 85% collection quote, based on WEEE arising.

- Recovery targets – a staggered approach from 75% recovery / 65% recycling up to 85% recovery / 85% recycling.

- These recovery quotas will be accompanied by minimum treatment requirements and technical treatment standards and specifications for specific equipment, such as PV Panels. This will enable implementation of high value recycling processes which go beyond the legal requirements.

- Financing
  - For business to consumer (B2C) and dual use equipment, the financing requirements for the producers who put equipment on the market require a form of pre-funding, which can be fulfilled either individually or jointly (joint liability scheme with last man standing insurance).
  - For business to business (B2B) equipment, the Directive foresees that the business partners should contractually fix the financing of collection and recycling at end-of-life.
Joint and several liability system

Producers

Distributing costs according to Market share to registered producers, which are obliged to pay for the running system ("Pay-as-you-go")

Register & Report POM figures

Clearing House

Putting product X on the market (POM)

Streamlining of feed-in tariffs

Collection of EoL Products

B2C Public collection systems

B2B Industry collection systems

Recovery and Recycling

Joint Financing Guarantee + last man standing insurance
Producer Definition

• A Producer is any natural or legal person who is established in an EU country and
  — manufactures and sells under his own name or trademark in this country (MANUFACTURER)
  — resells products produced by other suppliers (except where the brand of the original manufacturer
    appears on the product) within this country’s territory under his own name or trademark
    (DISTRIBUTOR / RESELLER)
  — places products from a third country or from another Member State on this market (IMPORTER)
  — sells by means of distance communication directly to private households or to users other than
    private households in this country, and is established in another Member State or in a third country
    (INTERNET / DISTANCE SALES)

• Any person or company falling under one of these cases has the legal obligation to ensure the take-
  back and recycling – which includes the related financing, reporting and administration - of their
discarded product.
High Value Recycling Standards - Background

• European Commission mandated the European Standardisation Organisations to develop standards for the treatment of waste electrical and electronic equipment (M/518 issued on 24 January 2013)

• The recast WEEE Directive stipulates the development of specific WEEE collection and treatment standards and identifies photovoltaic panels as one of the equipment categories which should be investigated for specific rules

• EPIA and PV CYCLE took the lead to initiate a new work item proposal (NWIP) for the development of a supplement standard and technical specification

• The NWIP has been accepted by the National Committees represented in the Technical Committee 111X in July 2014
High Value Recycling Standards - Scope

- TS 50625-6 - Collection, Logistics & Treatment requirements for WEEE – Part 6: Specific Requirements for the treatment of photovoltaic panels

- Scope: Definition of additional requirements to those defined in the general standard which aim to:
  - Achieve effective and efficient handling of PV panels at waste status to prevent pollution, minimize emissions and maximize recovery of fractions
  - Assure that quality, environmental, and health and safety limits are complied with during waste PV panel handling and proper documentation
  - Avoid release and/or dispersion of hazardous materials from treated PV panels and fractions to the environment
  - Identify criteria for determining end-of-waste status for PV panel fractions
Key Lessons Learned from EU WEEE

• All photovoltaic technologies require responsible end-of-life management. High value recycling is the preferred option to generate highest socio-economic benefits and mitigate potential environmental impacts.

• A voluntary approach failed due to the financial risks of free riders misusing the system, as well as due to a lack of enforceability.

• For equipment sold to private household users, pre-funding of collection and recycling is not cost-effective. Producer pay-as-you-go approaches combined with last man standing insurances / joint and several liability producer schemes with legislative framework conditions prove more efficient and viable.

• For equipment sold to business users, pre-funding of collection and recycling is also not cost-effective. The regulatory framework foreseen in recast WEEE Directive Article 13 mandates contractually assigning responsibility and costs between the producer and user, and will most likely prove most effective.

• Mass-based collection and recycling quotas need to be complemented by qualitative standards and technical specifications, taking into consideration recovery of material that is rare or has a high embedded energy, and containment of potentially harmful substances.

• High value recycling processes for all PV technologies have been developed and proven, including on an industrial scale. Further development and cost reduction will require consistent, mandatory regulations. Such regulations may generate substantial future socio-economic benefits.
Summary of Key Challenges for PV Recycling

• Efficient removal (delamination) of encapsulant (EVA) from PV modules

• Reducing transportation costs and logistics, for example with mobile recycling facilities (in situ recycling)

• Develop PV-specific resource recovery standards that promote high-value recycling (recovery of energy-intensive, economically valuable, and environmentally sensitive materials as well as bulk materials)

• Separate financing schemes for business to consumer and business to business recycling

• Transfer of best recycling practices from EU to other PV markets.

• All presentations of the EU PVSEC recycling parallel event can be downloaded here: