Solar Panel Recycling
Prairie Research Institute at University of IL – Urbana-Champaign

- One of the largest institutes on campus
- Over 900 staff members
- Comprised of 5 divisions
  - IL State Archeological Survey
  - IL State Geological Survey
  - IL State Natural History Survey
  - IL State Water Survey
  - IL Sustainable Technology Center
ISTC’s Mission is to encourage and assist citizens, businesses, and government agencies to prevent pollution, conserve natural resources, and reduce waste to protect human health and the environment of Illinois and beyond.

We integrate applied research, technical assistance, and information services to advance efforts in the areas of pollution prevention; water and energy conservation; and materials recycling and beneficial reuse.
Outline of Presentation:

• Why are we interested in solar panel recycling?
• What are the most common recycling processes?
• What are the guidelines for solar panel disposal in Europe and the U.S.?
• What is status of solar panel recycling in the U.S.?
• What is the solar outlook in Illinois and next steps for solar recycling?
Why are we interested in Solar Panel Recycling?

• Solar power is now the fastest-growing energy source. An estimated 500,000 solar panels were installed globally every day in 2015.
Global installed PV capacity reached **222 gigawatts (GW)** at the end of **2015** and is expected to rise further to **4,500 GW by 2050**.

Cumulative installed solar PV capacity (2015)

Top countries: Cumulative installed solar PV capacity (2015)

- China: 43 GW
- Germany: 40 GW
- Japan: 33 GW
- US: 27 GW
- Italy: 19 GW
- UK: 9 GW
- Spain: 7 GW
- France: 7 GW
- India: 5 GW
- Australia: 5 GW

From IRENA and IEA-PVPS (2016)
In the U.S.

- In 2018, there are now 1.75 million solar installations (total of 55.9 GW power).
- Illinois ranks 35th nationally in 2018 with 86 MW (was 42nd in 2017).
- Growth projection of 1400 MW in IL in the next 5 years (to rank 13th).

Information from https://www.seia.org/state-solar-policy/illinois-solar
• As mentioned, by 2050, there will be very high cumulative deployment rates for solar - in China (1,731 GW), India (600 GW), the U.S. (600 GW), Japan (350 GW) and Germany (110 GW).

• As the global solar market, including the U.S. market, increases, so will the volume of decommissioned/damaged solar (PV) panels.

• At the end of 2016, cumulative global PV waste streams was expected to have reached 43,500-250,000 metric tons. That is 0.1%-0.6% of the cumulative mass of all installed panels (4 million metric tons).

Information from IRENA and IEA-PVPS (2016)
The so-called early-loss shelf life category of solar panels is estimated to contribute more than 80.0% share to the solar panel recycling market in 2017.

Early loss is due to factors such as damage during transit or installation, or exposure to harsh weather conditions.

Also there can PV materials recycled from fallout from the manufacturing process.

0.05% of installed panels fail annually.

0.05% of panels fail before leaving manufacturer per year.

2% of panels are broken in production per year.

Image from cleantechnica.com
Information from IRENA and IEA-PVPS (2016)
• However, given the design life of solar panels of 25-30 years, as efficiencies decrease, there will be a huge surge in solar panel disposal in the 2020s and 2030s.

• By 2050, there will be **60 to 78 million cumulative metric tons of solar panel waste globally**, estimates the International Renewable Energy Agency (IRENA).

![Overview of global PV panel waste projections, 2016-2050](image)

- Regular-loss: Assumes a 30-year lifetime for solar panels, with no early attrition;
- Early-loss: Takes account of “infant”, “mid-life” and “wear-out” failures before the 30-year lifespan.

Information and figure from IRENA and IEA-PVPS (2016)
Therefore, we should not ignore the growing issue today.

It’s time to plan for solar panel recycling in the United States By Kelly Pickerel
April 2, 2018 - Solar Power World

Image from rueters.com/Jean-Paul Pelissier
• This is a **looming waste management issue**.

• However, many countries, including the U.S., do not have a strong recycling infrastructure in place as of now for solar panels.

• **Panels should be properly recycled otherwise:**
  
  ➢ Heavy metals in the panels such as cadmium and lead, or other toxic compounds could leach into the environment.

  ➢ Valuable resources (e.g., silver) will end up in landfills.

  ➢ Finite resources in the panels that are slowly being depleted will be lost, such as rare elements, e.g., gallium and indium.
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Solar Panel Recycling Processes

- Complex task because panels contain many different types of materials –
  - metals, e.g., lead, copper, gallium, cadmium
  - aluminum frame
  - silicon solar cells
  - synthetic material that encapsulates the silicon

- The various materials need to be separated to be properly recycled.

- Undamaged solar cells that have lost efficiency can often be recovered and reused in new products.

Main Types of Solar Technology

Important to consider the solar panel technology and its composition when recycling.

• Crystalline silicon (c-Si) PV is the oldest PV technology and currently dominates the market with around 92% of market share. Multicrystalline silicon panels have a 55% and monocrystalline silicon panels a 45% share of c-Si technology, respectively.

• The two thin-film PV panel technologies make up 7% of the PV market, 2% for CIGS panels, and 5% for CdTe panels
## Market Share of PV Panels by Technology Groups (2014-2030)

<table>
<thead>
<tr>
<th>Technology</th>
<th>2014</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon-based (c-Si)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monocrystalline</td>
<td>92%</td>
<td>73.3%</td>
<td>44.8%</td>
</tr>
<tr>
<td>Poly- or multicrystalline</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ribbon</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a-Si (amorph/micromorph)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thin-film based</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper indium gallium (di)selenide (CIGS)</td>
<td>2%</td>
<td>5.2%</td>
<td>6.4%</td>
</tr>
<tr>
<td>Cadmium telluride (CdTe)</td>
<td>5%</td>
<td>5.2%</td>
<td>4.7%</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concentrating solar PV (CPV)</td>
<td></td>
<td>1.2%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Organic PV/dye-sensitised cells (OPV)</td>
<td></td>
<td>5.8%</td>
<td>8.7%</td>
</tr>
<tr>
<td>Crystalline silicon (advanced c-Si)</td>
<td></td>
<td>8.7%</td>
<td>25.6%</td>
</tr>
<tr>
<td>CIGS alternatives, heavy metals (e.g. perovskite), advanced III-V</td>
<td>0.6%</td>
<td>9.3%</td>
<td></td>
</tr>
</tbody>
</table>

Based on Fraunhofer Institute for Solar Energy Systems (ISE) (2014), Lux Research (2013) and author research
Composition of Solar Panel Modules

- c-Si modules contained about 76% glass, 10% polymer (encapsulant and backsheet), 8% aluminum (mostly the frame), 5% silicon, 1% copper and less than 0.1% of silver, tin and lead.

- As new technologies are adopted, the percentage of glass is expected to increase while aluminum and polymers will decrease, most likely because of dual-glass bifacial designs and frameless models...


Information from IRENA and IEA-PVPS (2016)
Composition of Solar Panel Modules

• CIGS thin-film modules are composed of 89% glass, 7% aluminum and 4% polymers. The small percentages of semiconductors and other metals include copper, indium, gallium, and selenium.

• CdTe thin-film is about 97% glass and 3% polymer, with other metals including nickel, zinc, tin, and cadmium telluride.

Image from www.cleanenegyreviews.org
Information from IRENA and IEA-PVPS (2016)
The fact that it is possible, even today, to recycle virtually all of a solar panel is not widely known. New products can be made of the recycled glass, aluminum, copper, and plastic.

- Some recycling companies have achieved a **96% recovery rate** for silicon-based solar panels.
- The remaining 4% is utilized in an energy recovery process, using a waste-to-energy technology.
- Non-silicon-based solar panels can have a recovery rate of up to **97%**.

Information from [http://www.pvcycle.org/](http://www.pvcycle.org/)
Image from [https://understandsolar.com/recycling-solar-panels-pv/](https://understandsolar.com/recycling-solar-panels-pv/)
The Electric Power Research Institute (EPRI, 2017) found that most solar panel recycling in Europe happens at **glass recyclers**.

Panels are crushed or shredded and then glass and metals are separated. Other chemical and thermal processes may be used to recover high-value material like silver or copper.

Information from Pickerel (April 2, 2018), Solar Power World
Image from www.recyclesolar.ie
Example of Percentage of Output Materials from Recyclers in Europe Study

U.S. Generic Solar Panel Recycling Steps

- The disassembly process consists of removing the frame, wires, and junction box, sometimes after coarse-crushing of the modules.
- Then the sandwich is delaminated to recover glass, silicon (Si), EVA, and other metals.
- Any hazardous materials can be contained, and non-hazardous waste can be disposed of in a landfill or incinerated.

From EPRI (2018)
First Solar’s Module Recycling Technology – Version 2

- Shredder
- Hammermill
- Crushed/Milled Scrap Holding Bin
- Reactor Columns (Film Removal Solid/Liquid Separation)
- Metals Precipitation
- Third-party Cd/Te separation and refining
- Tellurium Product
- Cadmium Product
- Clean Glass Cullet
- Laminate Material

~ 95% recycling of semiconductor material
~ 90% recycling of glass

Image from First Solar (2013) –
The Future of PV Recycling

- 3rd generation continuous process recycling
  - More efficient 7/24 operations
  - 30 tons/day capacity
  - Higher quality USM
  - Targeting costs below hazardous waste disposal by 2015

- 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

Image from First Solar (2013) –
Life Cycle Benefits of CdTe PV Module Recycling

- Recycling requires energy and materials
  - This increases the life cycle environmental impact of CdTe PV
- Recycling produces products (copper, glass, CdTe)
  - This displaces primary sources of these products
  - This is counted as environmental credit
- The credits are greater than the impacts
  - The net impact is beneficial

<table>
<thead>
<tr>
<th>Process</th>
<th>Value</th>
<th>Unit per</th>
<th>m²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Materials and Fuels</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport (20 tonne truck)</td>
<td>11.2</td>
<td>tonne-km</td>
<td></td>
</tr>
<tr>
<td>Recycling electricity</td>
<td>4.4</td>
<td>kWh</td>
<td></td>
</tr>
<tr>
<td>Sulfuric acid</td>
<td>0.083</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Deionized water</td>
<td>5.4</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Hydrogen peroxide (50% in water)</td>
<td>0.57</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Sodium hydroxide (50% in water)</td>
<td>0.10</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td><strong>Emissions</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cd emissions to air</td>
<td>5.89×10⁻⁶</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Cd emissions to water</td>
<td>8.92×10⁻⁶</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td><strong>Waste to Treatment</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disposal of plastics to municipal incineration</td>
<td>0.62</td>
<td>kg</td>
<td></td>
</tr>
<tr>
<td>Disposal of inert glass waste to inert waste landfill</td>
<td>0.13</td>
<td>kg</td>
<td></td>
</tr>
</tbody>
</table>

End-of-life Recovery Potential under Regular-Loss Scenario to 2030 (in metric tons)

Image from IRENA and IEA-PVPS (2016)
• Recycling and repurposing has both a great environmental and economic benefit.

• The 2016 study by IRENA estimates the recyclable materials in old solar modules will be worth $15 billion in recoverable value by the year 2050.

• By weight, this PV recycling number is based on 60 - 78 million metric tons of PV materials.

• IRENA predicts solar panel recycling and repurposing of old panels can help spawn new industries and will create new green job opportunities.
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Solar Panel Disposal Guidelines in Europe

• The European Union’s Waste of Electrical and Electronic Equipment (WEEE) directive has guidelines on how solar panels are to be disposed.

• Established PV panels in 2012 and has undergone revisions since.

• Extended-producer-responsibility principle is at its core. Producers are liable for the costs of collection, treatment and monitoring. They must inform buyers that the panels have to be disposed of in dedicated collection facilities and should not be mixed with general waste, and that take back and recycling are free.
PV Cycle is a non-for-profit member-based organization, first established in Europe.
Solar Panel Recycling Guidelines in the U.S.

• With no dedicated national program or requirements for recycling, many broken or damaged PV panels find their way to landfills.

• End-of-life disposal of solar products in the U.S. is governed by the Federal Resource Conservation and Recovery Act (RCRA), and state policies that govern solid waste.

• To determine if hazardous waste or non-hazardous waste, panels can be evaluated using Test Methods for Evaluating Solid Waste: Physical/Chemical Methods, also known as SW-846.
Solar Panel Recycling Guidelines in the U.S. (continued)

• Solar panel wastes can include heavy metals such as silver, copper, lead, arsenic, cadmium, and selenium that at certain levels may be classified as hazardous wastes.

• Having no federal regulations for recycling, some states such as Washington, California, and New York are working on their own recycling policies and disposal regulations.

• Other states require solar systems of a certain size to have decommissioning plans (e.g. VT, NB, NH, OK, LA, HW, NY, and IL) to restore the land to its original condition.

• Having regulations for universal PV module recycling may accelerate recycling in the U.S. as it has done in Europe.

Information from EPRI (2018)
Washington State

• In July 2017, Washington became the first state to pass a solar stewardship bill (ESSB 5939), requiring manufacturers selling solar products into the state to have end-of-life recycling programs for their own products.

• Manufacturers that do not provide a recycling program or outline will not be able to sell solar modules into the state after Jan. 1, 2021.

• Regional takeback locations will be set up to accept solar panels at no cost to the system owner, and the state may charge manufacturers for the program. Final plans are still being decided.
California

- California SB 489 passed in 2015 and encourages safe disposition of old panels.

- The California regulations – yet to be finalized – would designate end-of-life solar panels as universal waste, a type of hazardous waste that is widely used in homes and businesses (like TVs or batteries).

- By California law, universal waste cannot be trashed or landfilled, but no guidelines are given on the proper way to recycle solar panels. Until the new regulations are adopted, hazardous waste solar panels must be managed as hazardous wastes and not as universal wastes.
New York State

• New York is in the process of creating a law that will allow the Department of Environmental Conservation (DEC) to work with solar panel manufacturers to create a program to help with the collection, transportation, recycling, and disposal of used solar panels.

• The program would also have an educational component and would be funded by the manufacturers. (nysenate.gov, 2018)
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U.S. Solar Panel Recycling

- As mentioned, regulations/requirements for recycling are absent at the federal and state level, for most states.
- Some recycling facilities now process PV panels in batches using existing facilities designed for laminated glass, metal, and e-waste.
- The value of materials reclaimed depends on the yield and purity of the output streams from the recycling process.
- The economics of recycling also involve the cost of collecting, transporting, and processing the panels.
- First Solar is the only panel manufacturer that offers recycling for their customers.
- Even without many federal and state level regulations, there are companies in the U.S. that are recycling PV modules.

Information from IRENA (2016)
Solar Panel Recycling Companies in the U.S.

- Recycling solar panels since 2012 (Madison, IL).
- Provides metals and electronic recycling services for panels.
- Partners with multiple downstream vendors to recycle the rest of the module.
- Recycles panels from across North America, the Caribbean, and Hawaii.
Solar Panel Recycling Companies in the U.S.

First Solar

www.firstsolar.com

• PV thin film (CdTe-panels) manufacturer formed in 1999 (OH, AZ, TX, NJ, & CA).
• PV recycling for their thin film panels established in 2005.
• Panel collection and recycling program is free & unconditional.
• Prefunded by estimated collection and recycling costs.
• Panels are labeled with information for the owner on how to return for free.
• Plans to include scalable to accommodate future high volumes.
• ~48,000 metric tons recycled to date.
Solar Panel Recycling Companies in the U.S.

- PV recycling since around 2015.
- Transports post-consumer material nationwide to their recycling facilities and partner with downstream vendors based on waste classification needs.
- Approaching zero waste.
- As of 2018, Cleanlites has recycled around 2 million pounds or approximately 900 metric tons of solar PV panels.

www.cleanlites.com
Solar Panel Recycling Companies in the U.S.

ECS

www.ecsrefining.com

• 100% Solar PV processing/recycling since around 2008 (CA, OH, OR, TX).
• Works with multiple equipment manufacturers and PV technologies.
• Works with all state and federal regulations.
Recycling solar panels and PV cells since 2016 (NY).

Most panels received are damaged from extreme weather or during installation.

Re-purpose, reuse, or recycle panels.

Clients share in the recovery value on qualified opportunities.

Have processed a little more than 15,000 panels (which is about 272 metric tons).
Solar Panel Recycling Companies in the U.S.

RECYCLE PV  www.recyclepv.solar.com

• The program is still in its early stages in the U.S.
• Will partner to offer a comprehensive nationwide PV recycling program with: Solar CowboyZ™, PV CYCLE™ and RINOVASOL™.
• Modeled after successful PV Recycle program in Europe.
• Membership is offered to solar panel manufacturers, installers, distributors, utilities, solar system owners, developers and solar finance companies who have an ongoing need to recycle solar panels.
• A fee-structure is charged to recycle solar panels that have broken glass or major structural damage.
• Thin Film and non-crystalline panels are not currently part of the Recycle PV program.
U.S. Solar Panel Recycling Market Projections

- Solar installations began to really surge in the mid-2000’s, so PV recycling in the U.S. has just begun to take place over the last decade.

- The North America solar panel recycling market was valued at $11.2 million in 2016.

- This is projected to increase dramatically over the next decade and beyond.

Information and Image from https://www.grandviewresearch.com/industry-analysis/solar-panel-recycling-market
What is Being Done in the U.S. to Encourage Recycling?

• Solar Energy Industries Association (SEIA) is the national trade association for the U.S. solar industry and is working to create a national network of recyclers. Right now the network is only for SEIA members.

• New recyclers are starting to get established as they see need starting to grow.

• Also current solar recycling companies have suggested ideas to help build awareness of recycling.
Ideas from Recyclers Include:

- Asking solar manufacturers to clearly label their products with recycling options for consumers if the company does not take them back for recycling.
- Giving recycling information to contractors receiving and treating the end-of-life panels.
- Establishing central telephone number and/or internet address on products for questions on disposal.

Image www.recyclesolar.co.uk
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Solar Companies in Illinois

According to Solar Energy Industries Association:

• There are currently about 327 solar companies in Illinois.
  • 116 installers/developers
  • 68 manufacturers
  • 135 classified as other

* Only 1 solar panel recycler in Illinois – Interco.
* First Solar also will take back their panels to recycle.
Current Solar Installations in Illinois

• Approximately 86MW solar currently installed in Illinois.

• Most of the solar currently installed is in populated areas of the state and these areas will see the most distributed generation (DG) growth.

• Community solar and utility scale solar projects are projected to be installed in rural areas where there is more access to land and distribution lines.

• Larger scale installations are predicted to be installed west of Chicago, and in the central and southern areas of the state.
Large Scale Solar Installations in Illinois

2009 Exelon Solar Chicago, LLC (9 MW)
Chicago, IL

2012 Grand Ridge Solar Farm (20MW)
Marseilles, IL

2012 Rockford Solar Farm (3.06MW)
Rockford, IL

2014 North Nine Street (.3MW)
Rochelle, IL

2015 Town of Genesco (1.2MW)
Genesco, IL

2015 University of Illinois (4.6MW)
Champaign, IL

2017 IKEA Rooftop (2MW)
Joliet, IL

*1 MW = Powers an average of 164 homes
New Illinois Solar Development
Future Energy Jobs Act (FEJA)

FEJA will increase Illinois’ solar capacity from about 86 MW currently to about 2,700 MW by 2030.

However, with these new FEJA requirements for increased solar installations across the state, there will also be a critical need to ensure that PV panels are properly disposed through recycling and/or repurposing efforts.
• Illinois currently has 86 MW installed solar in the state = approximately 350,000 panels.

• FEJA requires approximately 10,800,000 new PV panels to be installed by 2030.

• This means that by 2030 there will be around 11 million PV panels in Illinois.

• Modules range in weight from 35 lbs. to 50 lbs. = approximately 192,500 – 275,000 U.S. Tons of installed modules in Illinois.
This Act requires solar developers to enter into an agreement with the Illinois Department of Agriculture prior to construction of a commercial solar facility on agricultural land.

AIMA is intended to ensure that the decommissioning of a commercial solar energy facility is done in conformance with the Department's standard agricultural impact mitigation agreement.

Applies to all ground mounted solar project larger than 500kW located on agricultural land.

Standard AIMA provisions contemplate: decommissioning plans and security, drain tile repair, indemnification of participating landowners, electrical cabling depth, topsoil removal, weed control, soil compaction amongst other things.
What is ISTC’s Solar Panel Recycling Initiative doing in IL?

- Helping to brainstorm ideas and facilitate discussions with state and federal organizations interested in solar (e.g. Illinois Solar Energy Association and the Solar Energy Industries Association), installers, manufacturers, and national recyclers about how to establish a network of solar panel recyclers in Illinois.

- Examining policies and regulations to determine best practices for IL to ensure proper recycling of solar panels at end-of-life to avoid landfill disposal.


- Collaborating on outreach to create awareness for communities and businesses.

- Working with community colleges and other organizations to create jobs and training in the solar panel recycling industry.
Questions & Contact Information

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