Looking Ahead at Solar Panel Recycling in Illinois

Nancy Holm & Jennifer Martin
September 6, 2018

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Image: University of Illinois

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Image: ISTC

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.

ISTC began its **Solar Panel Recycling Initiative** in 2017 as we saw a need to address this issue and it fits well with our mission.

Outline of Presentation:

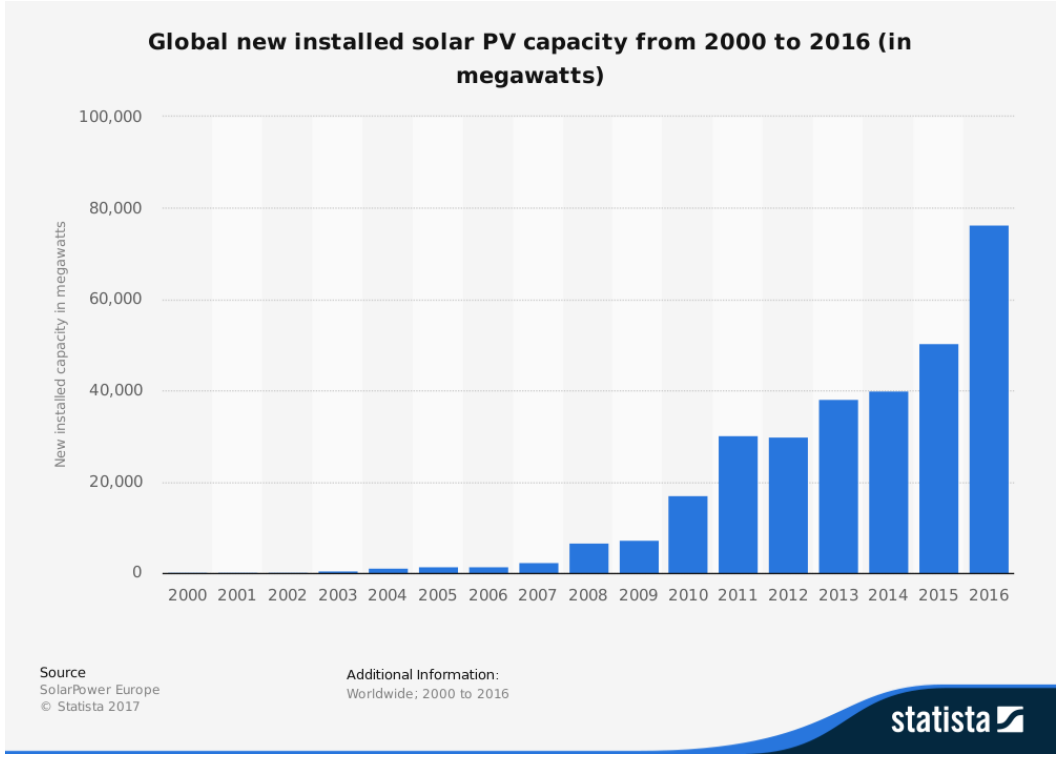
- **Why are we interested in solar panel recycling?**
- What are the most common recycling processes?
- What are the guidelines for solar panel disposal in Europe and the U.S.?
- What is status of solar panel recycling in the U.S.?
- What is the solar outlook in Illinois and next steps for solar recycling?

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.

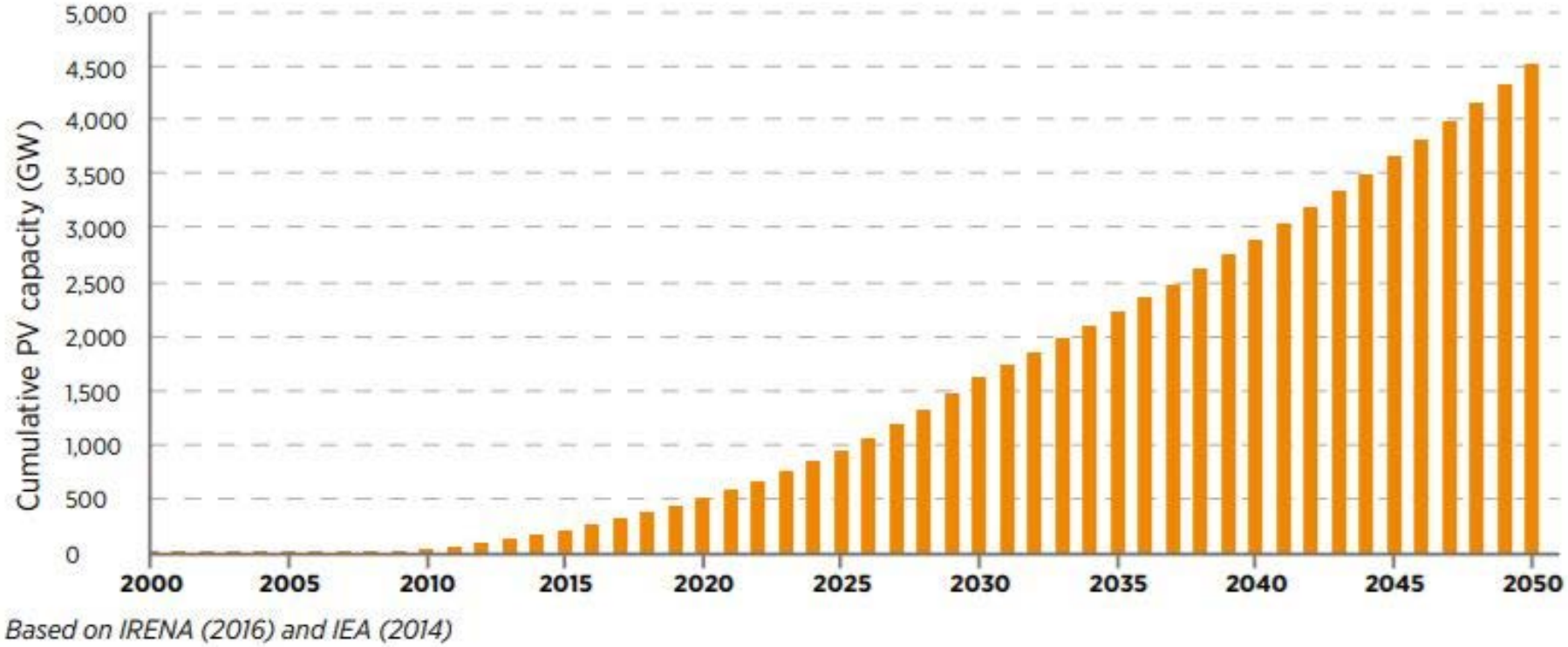
- U.S. has installed approximately
  175 million solar panels as of 2018.

- According to the Solar Energy Industries Association (SEIA), total installed U.S. solar capacity is expected to double in the next 5 years.



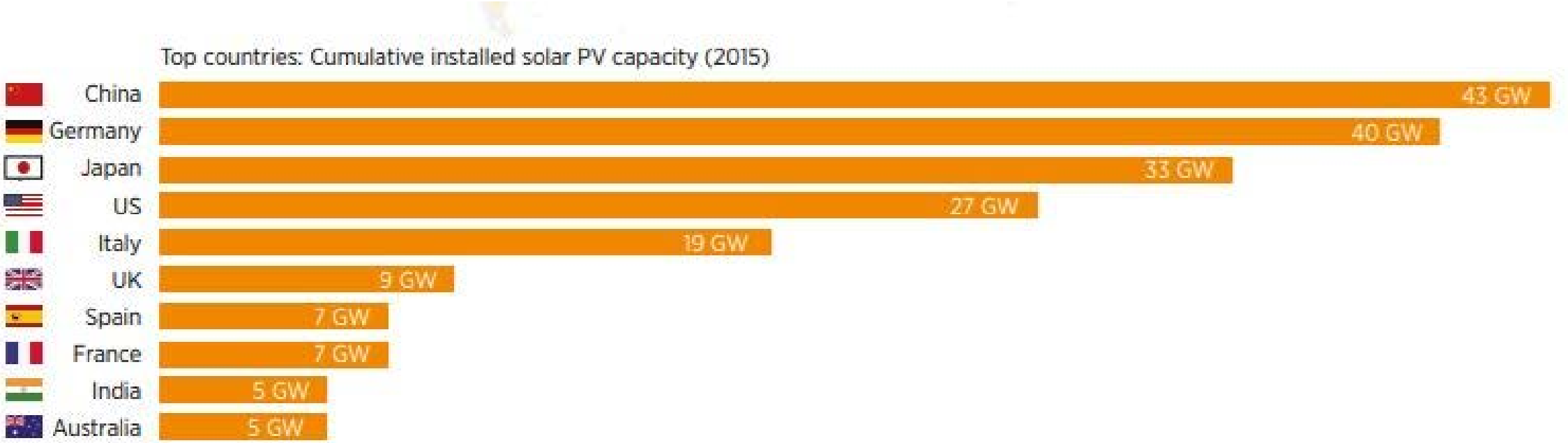
Source: Statista (2017) & NREL (2018)

Global installed solar (PV) capacity reached **222 gigawatts (GW) at the end of 2015** and is expected to rise further to **4,500 GW by 2050**.



Source: IRENA and IEA-PVPS (2016), "End-of-Life Management: Solar Photovoltaic Panels," International Renewable Energy Agency and International Energy Agency Photovoltaic Power Systems.

Cumulative installed solar PV capacity (2015)



Source: IRENA and IEA-PVPS (2016)

In the U.S. and IL

- In 2018, the U.S. has nearly 56 GW power installed (equivalent to the generating capacity of 50 commercial nuclear reactors).

- Illinois ranks **34th nationally** in Quarter 1 of 2018 with **87 MW** (was 40th in 2017).

- Growth projection of 1400 MW in IL in the next 5 years (**to rank 13th**).

Image: University of Illinois
Source: GMT Research & SEIA (2018), U.S. Solar Market Insight Q2

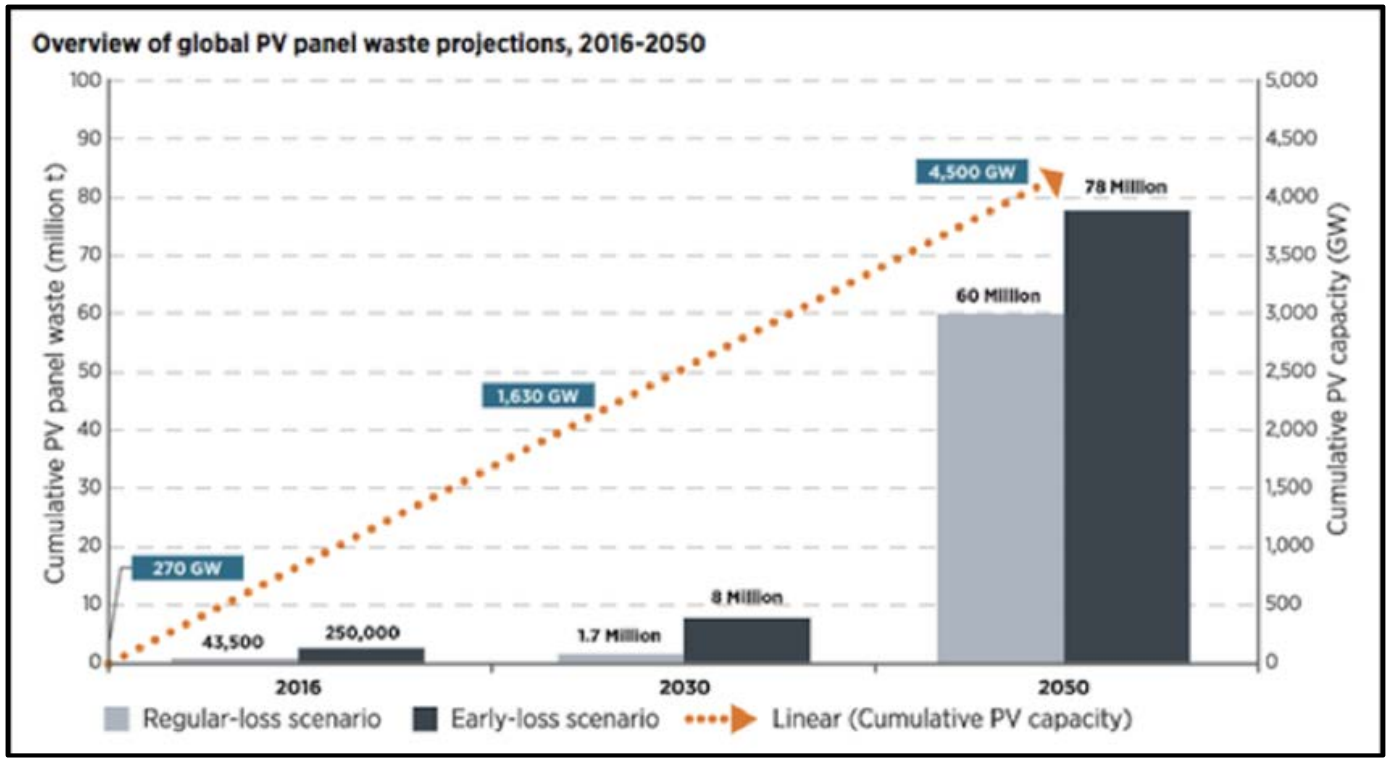
- As mentioned, by 2050, there will be very high cumulative deployment rates for solar - in China (1,731 GW), India (600 GW), the U.S. (600 GW), Japan (350 GW) and Germany (110 GW).
- As the global solar market, including the U.S. market, increases, so will the volume of decommissioned/damaged solar (PV) panels.
- At the end of 2016, cumulative global solar 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).

Source: 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 be 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: cleantechnica.com
Source: IRENA and IEA-PVPS (2016)

- However, given the design life of solar panels of 25-35 years, as well as early loss of modules, there will be **a huge surge in solar panel disposal in the 2020s and 2030s** since many were installed beginning in the 1990s and 2000s.
- By 2050, there will be **60 to 78 million cumulative metric tons of solar panel waste globally**, estimates the International Renewable Energy Agency (IRENA).



- 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.

Source: IRENA and IEA-PVPS (2016)

Therefore, we should not ignore the growing issue today and that is why we started our initiative to examine this imminent problem.

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

Image: 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 earth elements, e.g., gallium and indium.

Image: down2earthmaterials.ie

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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.

Dismantling of end of life modules in Belgium

Image: http://www.renewableenergyfocus.com
Source: http://earth911.com/eco-tech/recycle-solar-panels

Main Types of Solar Technology

The solar panel technology and its composition is important to consider 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

Source: IRENA and IEA-PVPS (2016)

Market Share of PV Panels by Technology Groups (2014-2030)

Technology		2014	2020	2030
Silicon-based (c-Si)	Monocrystalline	92%	73.3%	44.8%
	Poly- or multicrystalline			
	Ribbon			
	a-Si (amorph/micromorph)			
Thin-film based	Copper indium gallium (di)selenide (CIGS)	2%	5.2%	6.4%
	Cadmium telluride (CdTe)	5%	5.2%	4.7%
Other	Concentrating solar PV (CPV)	1%	1.2%	0.6%
	Organic PV/dye-sensitised cells (OPV)		5.8%	8.7%
	Crystalline silicon (advanced c-Si)		8.7%	25.6%
	CIGS alternatives, heavy metals (e.g. perovskite), advanced III-V		0.6%	9.3%

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

Source: IRENA and IEA-PVPS (2016)

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...

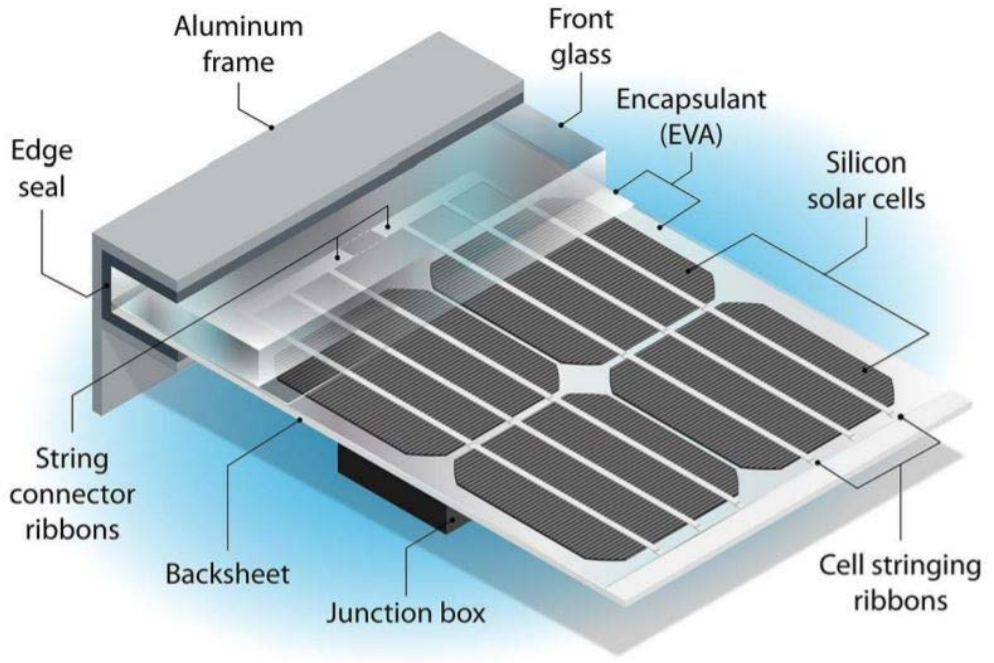


Image: EPRI (2018), “Program on Technology Innovation: Feasibility Study on Photovoltaic Module Recycling in the United States”

Source: 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.

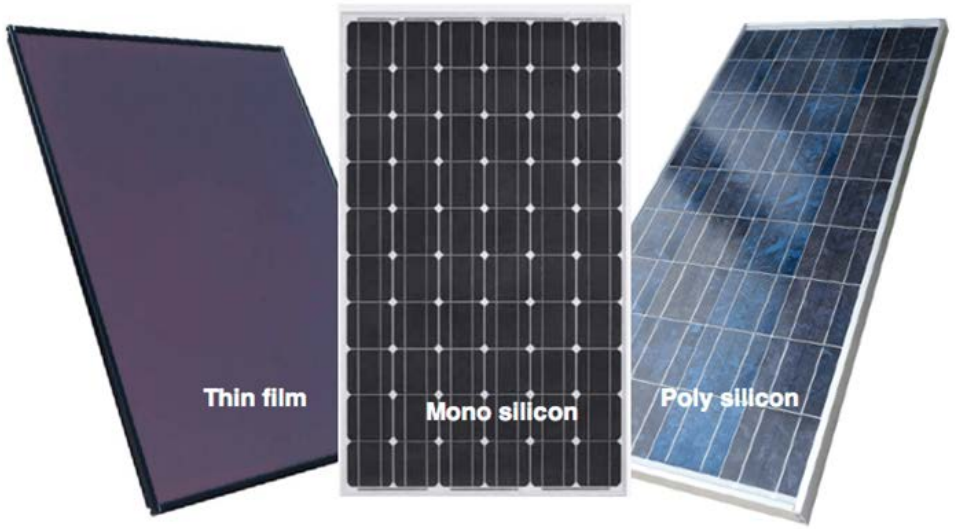


Image: www.cleanenegyreviews.org

Source: 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%.

Image: https://understandsolar.com/recycling-solar-panels-pv/
Source: http://www.pvcycle.org/

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.

The European Union is funding (as of 2018) a new pilot plant for solar panel recycling that could recycle up to 50,000 Si-based modules per year. The plant will use an energy-efficient pyrolysis process.

Image: www.recyclesolar.ie
Source: Pickerel (April 2, 2018), Solar Power World
Source: pv magazine international – 8.23.2018

Example of Percentage of Output Materials from Recyclers in Europe Study

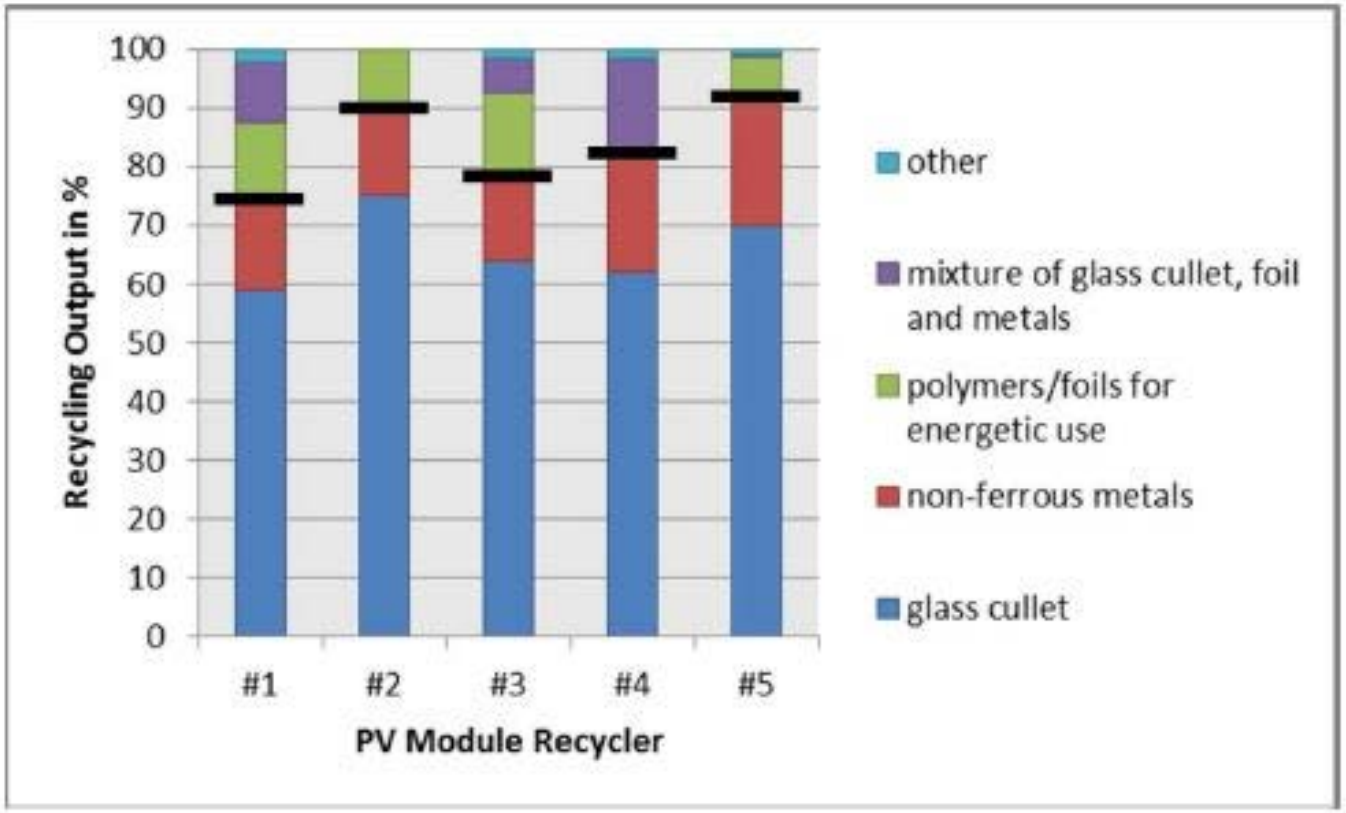
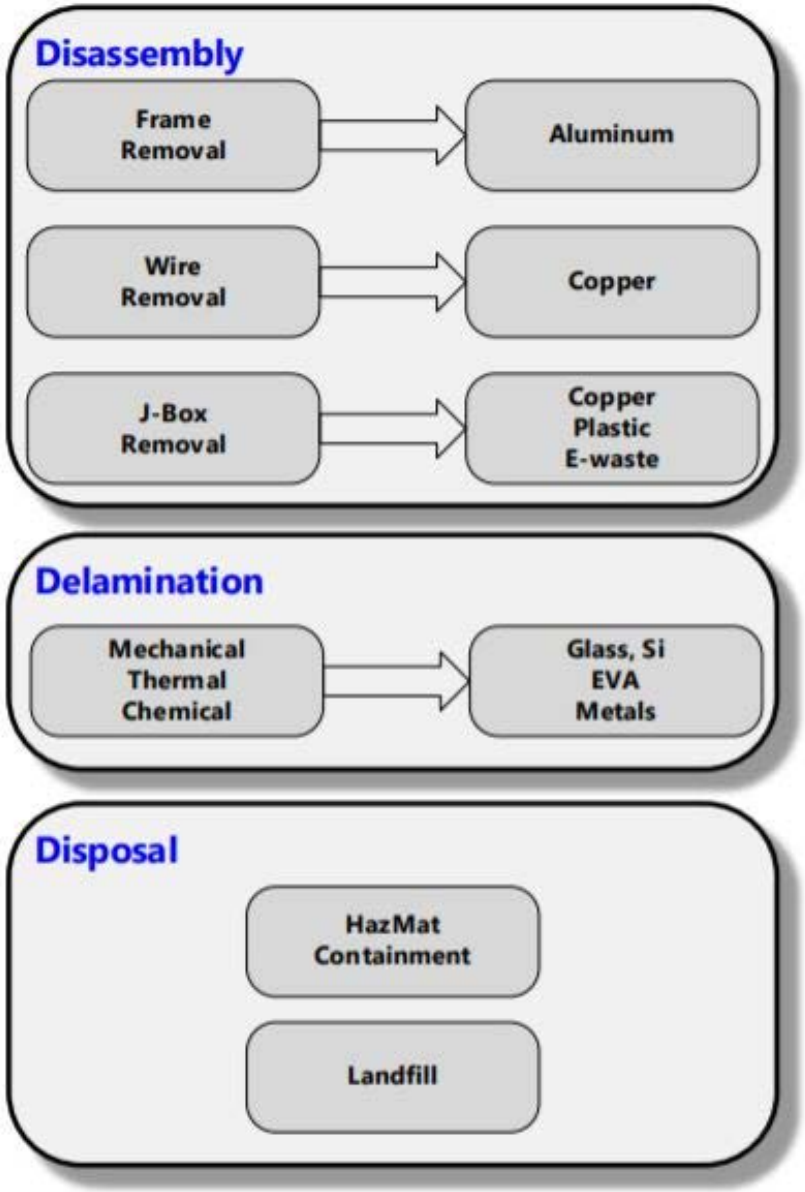


Image: EPRI (2017)," Program on Technology Innovation: Insights on Photovoltaic Recycling Processes in Europe, A Survey-Based Approach"

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.



Source: EPRI (2018)

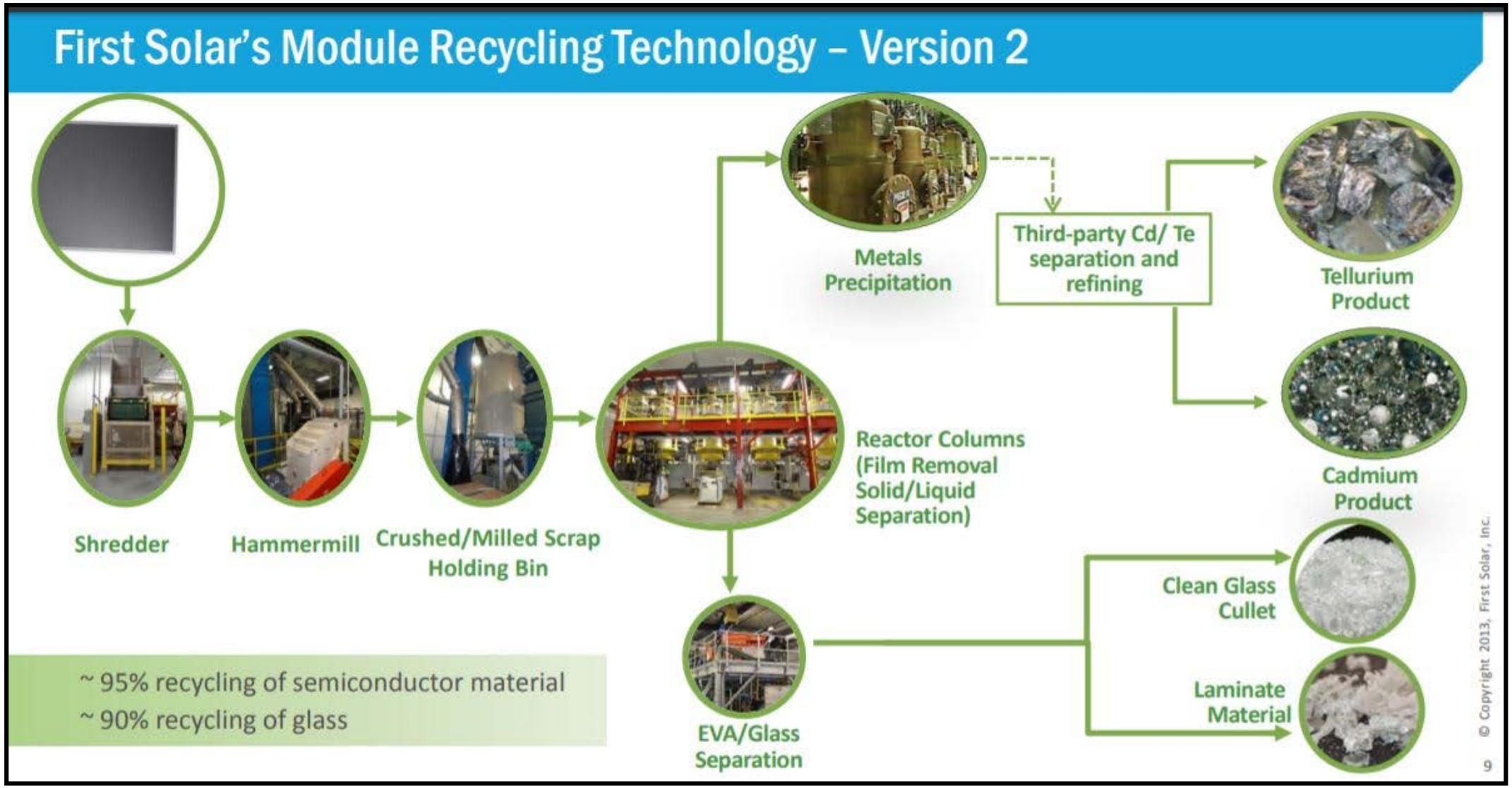


Image: First Solar (2013) – http://iea-pvps.org/fileadmin/dam/public/workshop/07_Andreas_WADE.pdf

Ensuring Sustainable Supply of Raw Materials through Recycling

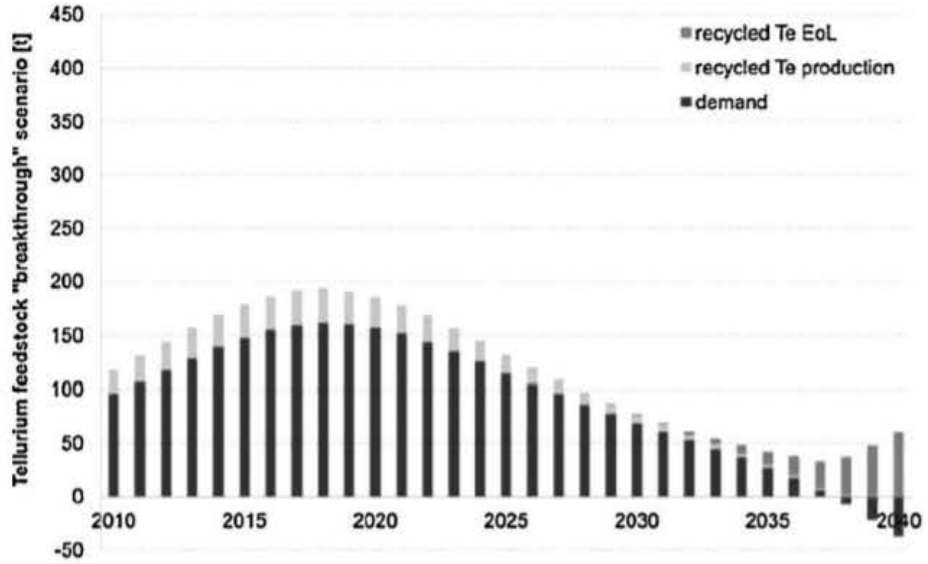


Fig. 8. Tellurium feedstock in the "breakthrough" scenario.

- Minimizing environmental impacts and maximizing resource recovery
- 10–50% of the Te needed for CdTe PV production could realistically come from EOL modules by 2040
- Material and conversion efficiency measures combined with recycling reduces tellurium demand per Watt peak
- "The CdTe-PV industry has the potential to fully rely on tellurium from recycled end-of-life modules by 2038"
  - — Improvements in material efficiency
  - — Scaling of efficient collection and recycling systems

M. Marwede and A. Reller, Future recycling flows of tellurium from cadmium telluride photovoltaic waste, Resources, Conservation, and Recycling 69 (2012) 35-49.

Image: First Solar (2013) – http://iea-pvps.org/fileadmin/dam/public/workshop/07_Andreas_WADE.pdf

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

Process	Value	Unit per m^2 module
Materials and Fuels		
Transport (20 tonne truck)	11.2	tonne-km
Recycling electricity	4.4	kWh
Sulfuric acid	0.083	kg
Deionized water	5.4	kg
Hydrogen peroxide (50% in water)	0.57	kg
Sodium hydroxide (50% in water)	0.10	kg
Emissions		
Cd emissions to air	5.89×10^{-9}	kg
Cd emissions to water	8.92×10^{-8}	kg
Waste to Treatment		
Disposal of plastics to municipal incineration	0.62	kg
Disposal of inert glass waste to inert waste landfill	0.13	kg

Sinha, P., M. Cossette, and J.-F. Ménard. 2012. End-of-life CdTe PV Recycling with Semiconductor Refining. Proceedings: 27th EU PVSEC, Frankfurt, Germany, pp. 4653 – 4656.

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Image: First Solar (2013) – http://iea-pvps.org/fileadmin/dam/public/workshop/07_Andreas_WADE.pdf

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

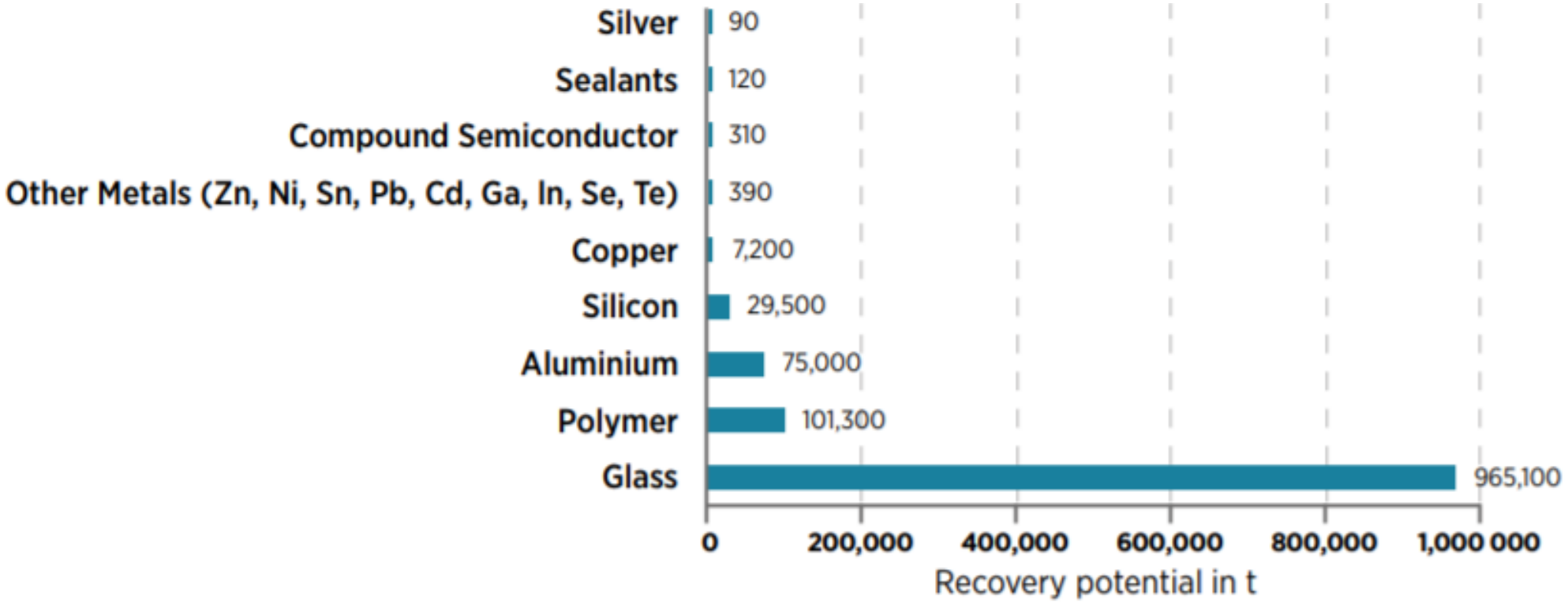
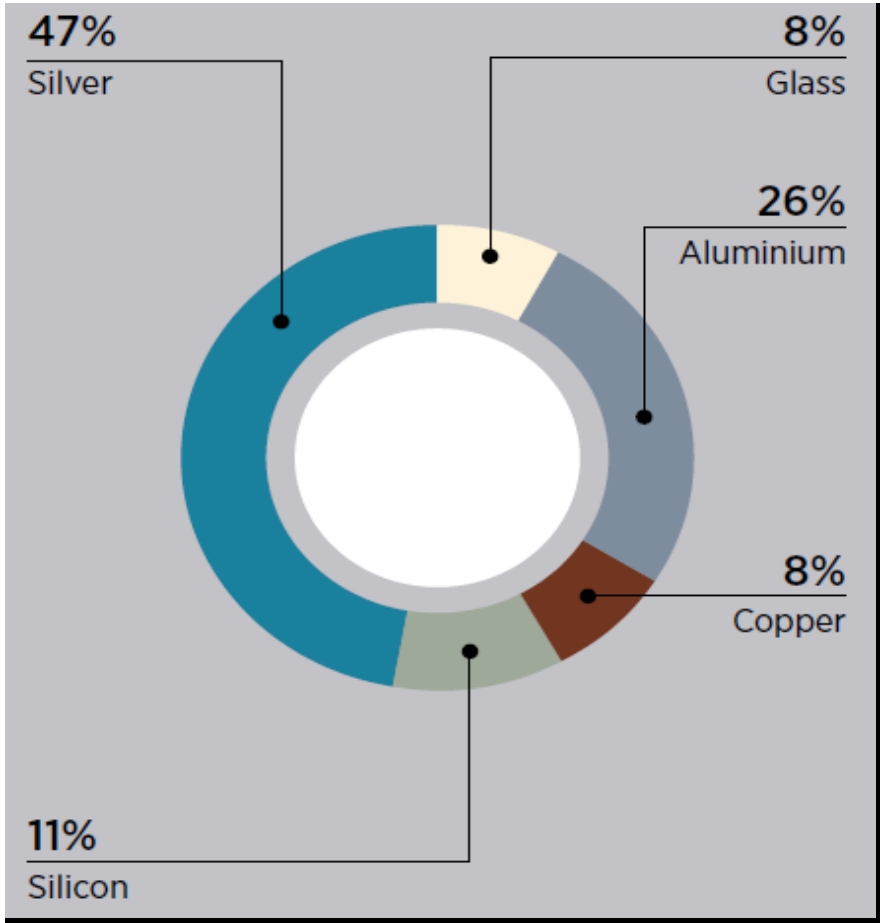


Image: IRENA and IEA-PVPS (2016)

Relative material value of a c-Si Panel

- Silver is the most valuable material per unit mass in the c-Si panel followed by aluminum.
- However, if less silver is used in panels to reduce manufacturing costs, that will decrease the value of the panels for recycling.

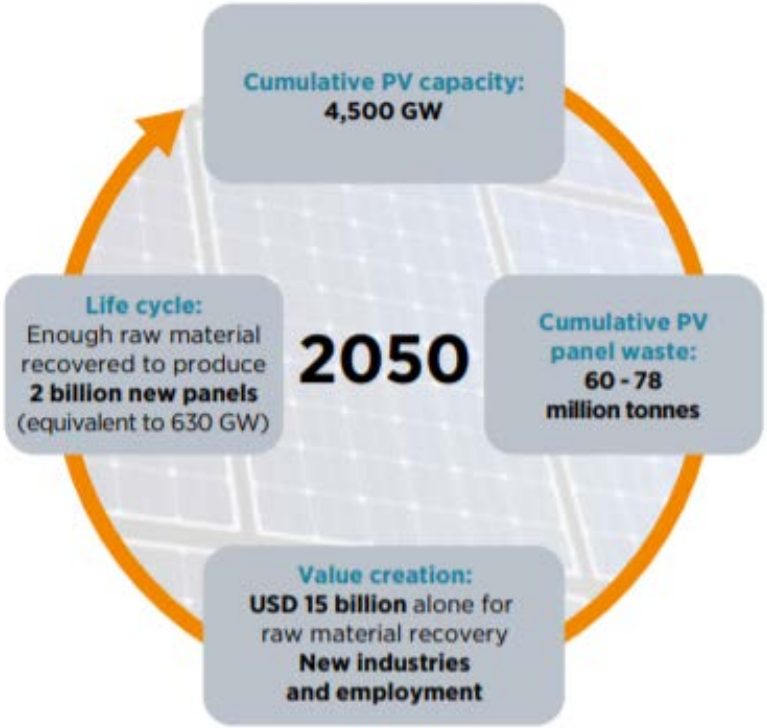


Relative material value of a c-Si Panel

Based on Raithel (2014)

Conclusions on Recycling Processes –

- 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 ($2 billion in U.S.) in recoverable value** by the year 2050.
- This recovered material will be enough to produce **2 billion new panels**.
- 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.



Source: IRENA and IEA-PVPS (2016)

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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 panel recycling guidelines in 2012.

- **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.

Source: http://www.solarwaste.eu/

PV Cycle is a non-for-profit member-based organization established in Europe.

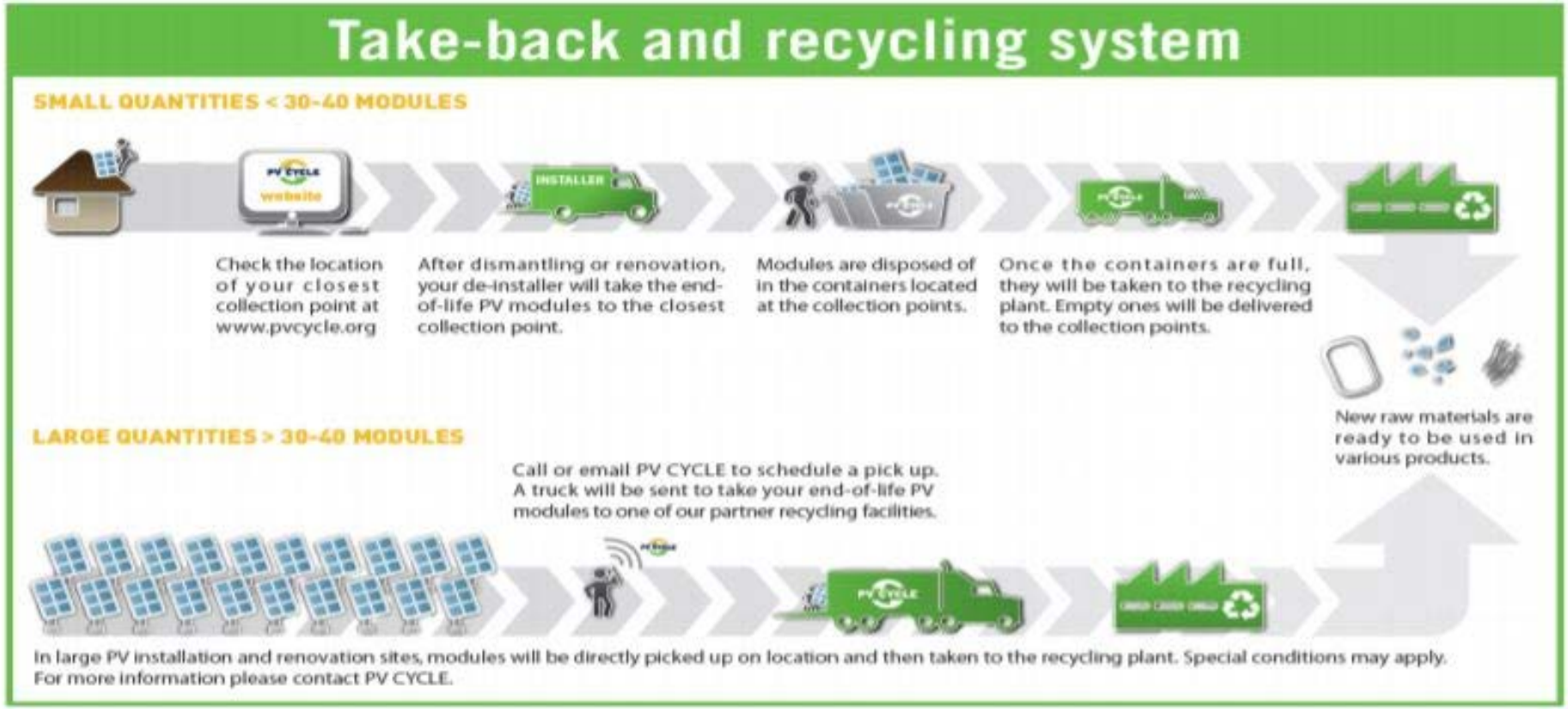

Image: www.pvcycle.org

Solar Panel Recycling Guidelines in the U.S.

- Many broken or damaged PV panels find their way to landfills rather than being recycled.
- End-of-life disposal of solar PV in the U.S. is governed by the Federal Resource Conservation and Recovery Act (RCRA), and state solid waste policies.
- To determine if hazardous waste or non-hazardous waste, panels are evaluated using Test Methods for Evaluating Solid Waste: Physical/Chemical Methods (SW-846).
- 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.

Source: EPRI (2018)

Solar Panel Recycling Guidelines in the U.S. (continued)

- 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.

Source: 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 encourages safe disposition of old panels.
- The California regulations will 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

- Senate Bill 2837B – "solar panel collection act" will require PV manufacturers to collect panels when they are taken out of use.

- The program would also require an educational component funded by manufacturers.

- **This Bill is still waiting on the State Assembly for approval before being delivered to the governor.**

Source: nysenate.gov (2018)

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U.S. Solar Panel Recycling

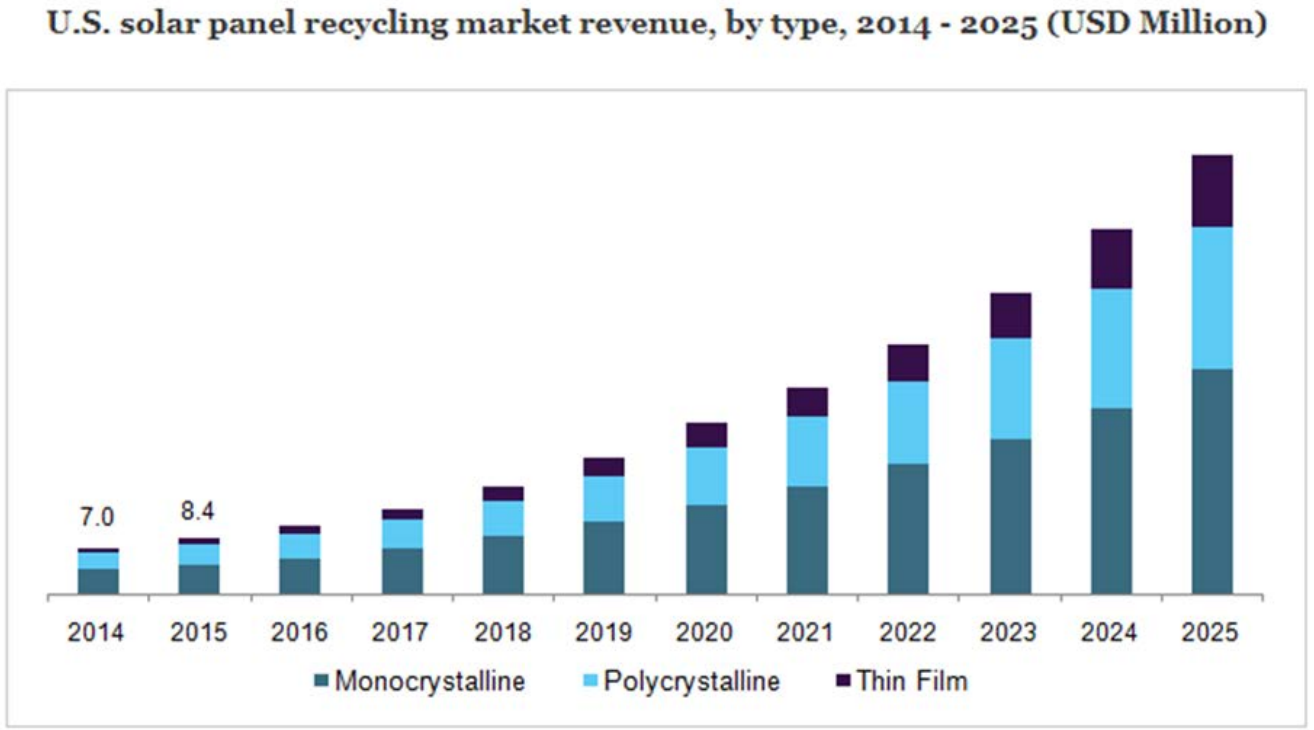
- Even without many federal and state level regulations, there are companies in the U.S. that are recycling PV modules.
- The value of materials reclaimed depends on the yield and purity of the output streams from the recycling process as well as the cost of collecting, transporting, and processing the panels. Making current recycling costs high.
- Some existing recycling facilities now process PV panels in batches using existing facilities designed for laminated glass, metal, and e-waste.

Source: IRENA (2016)
Image: www.greentechmedia.com

PV Recycler	Operations Locations	Established U.S. PV Recycling Details	Unique Details	Amount of PV Waste Recycled to Date
CLEANLITES RECYCLING	MI, MN, OH, SC www.cleanlites.com	Waste management & logistics established in 1994. PV recycling established in 2015.	Analyze, transport, & disassembly. Partners with downstream vendors for reintegration into products.	~900 metric tons
First Solar.	OH, AZ, TX, NJ, & CA www.firstsolar.com	Manufacturer of CdTe-panels. PV module recycling established in 2005.	Collection and recycling program is free and only for First Solar modules.	~48,000 metric tons
TEKOVERY	NY www.tekovery.com	PV module & cell recycling established in 2016.	Re-purpose, reuse, and recycle panels.	~272 metric tons
interco TRADING COMPANY Celebrating 20 Years	Madison, IL www.intercotradingco.com	Metals and electronics recycling established in 1996. Recycling PV established in 2012.	Metals & electronic recycling. Partners with downstream vendors to complete recycling services.	No public data available
RECYCLE PV	AZ www.recyclepv.solar.com	Modeled after PV Cycle program in Europe in 2007. U.S. Pilot program begins 2018.	Crystalline module recycling only. $15 customer fee to recycle per panel.	Still in its early stages in the U.S. No U.S. data to date

U.S. Solar Panel Recycling Market & Projections

- Solar PV deployment at a significant level started in the 1990s and the long life time of PV modules result in a relatively small waste stream today.
- The North America solar panel recycling market was valued at $11.2 million in 2016.
- The amount of recycled modules is projected to greatly rise after the year 2020.



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Sources: Life Cycle Assessment of Photovoltaic Module Recycling, Stolz & Frischknecht (2016), and 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 U.S. solar trade association. They are now **working to create a national network of recyclers** for SEIA business members.
- **New U.S. PV recyclers are starting to get established** as they see need starting to grow.

Image: Edie.net

PV Recyclers Needs Include:

- Solar manufacturers should clearly label their products with recycling options for consumers if the company does not take them back for recycling.
- Education for contractors installing and decommissioning solar.
- Establishing a single point of contact for solar customers to easily access for information on proper disposal at the end of their systems life.

Image: www.recyclesolar.co.uk

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Illinois Future Energy Jobs Act (FEJA)

FEJA, passed in 2016, fixes funding for Illinois' renewable energy law, and mandates that 25% of ComEd's and Ameren's power come from renewable sources, such as wind, solar and biofuels, by 2025.

This directs a budget from utility companies of more than $180 million annually for purchasing clean energy produced in Illinois.

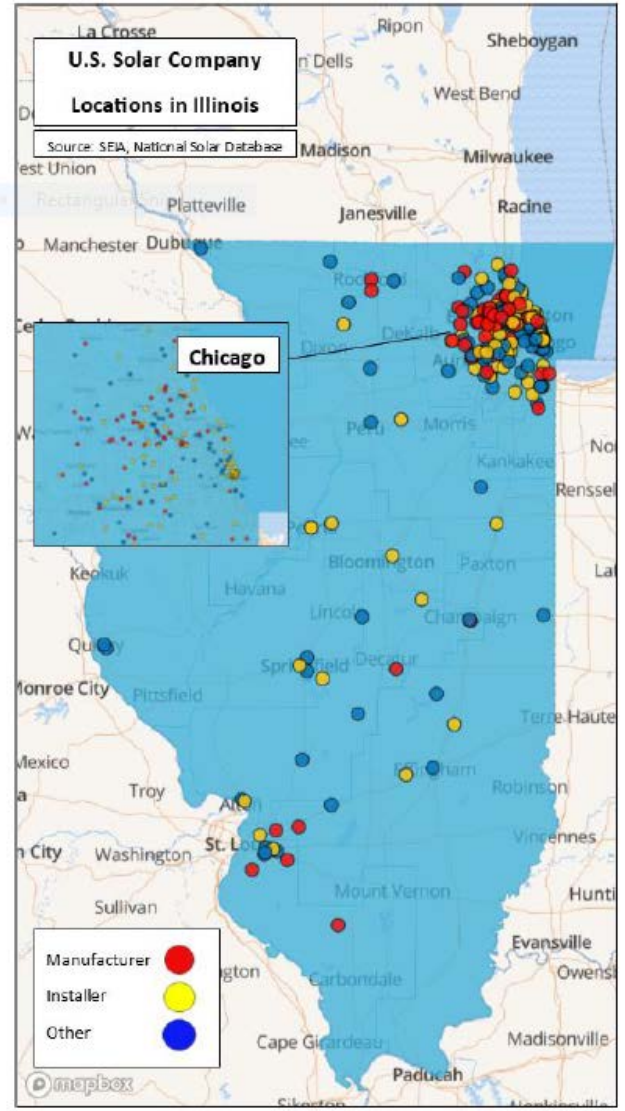
Through FEJA, it is estimated that this will require an additional 2,700 MW of NEW solar installed in Illinois by 2030.

This plan includes long-term funding for solar job training for low-income individuals, returning citizens, and those in the foster care system. This also includes funding for solar development for low-income residents.

Solar Companies in Illinois

There are currently over 300 solar companies in Illinois.

- 116 installers/developers
- 68 manufacturers
- 135 classified as other



Source & Image: Solar Energy Industries Association

Current Solar Installations in Illinois

- Most of the 87 MW of solar is currently installed is in populated areas of the state.
- Through FEJA, 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.

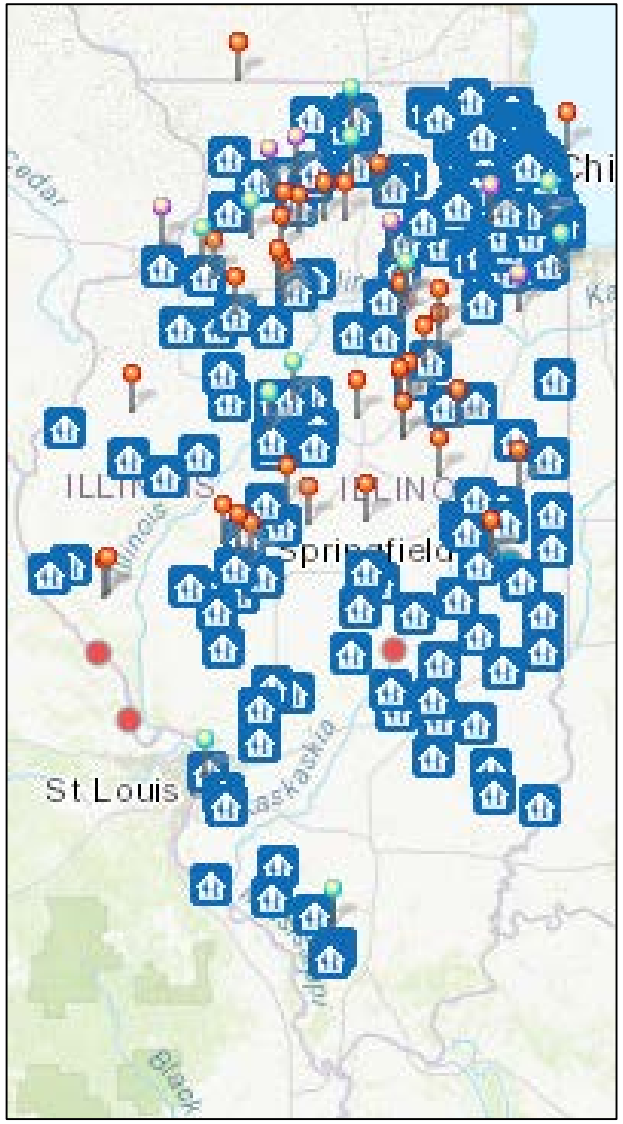
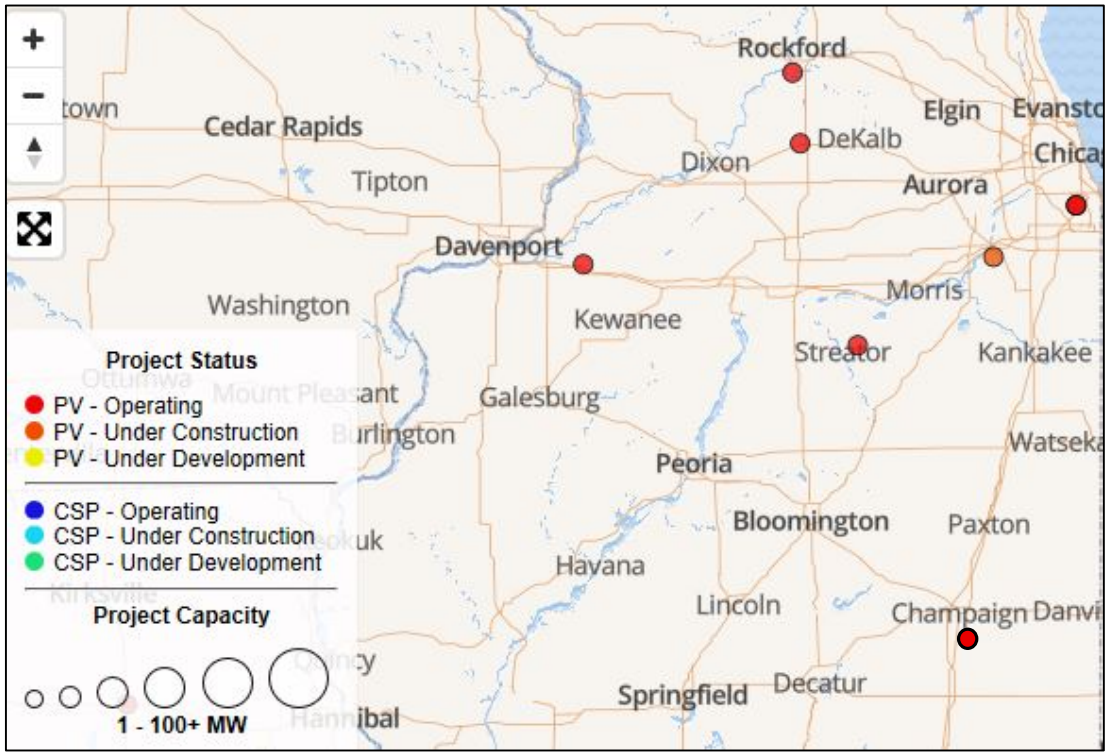


Image: www.e2.org
Source: Illinois Solar Energy Association

Large-Scale Solar Installations in Illinois



Source: Solar Energy Industries Association

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

Solar PV End-of-Life
FEJA Impacts in Illinois

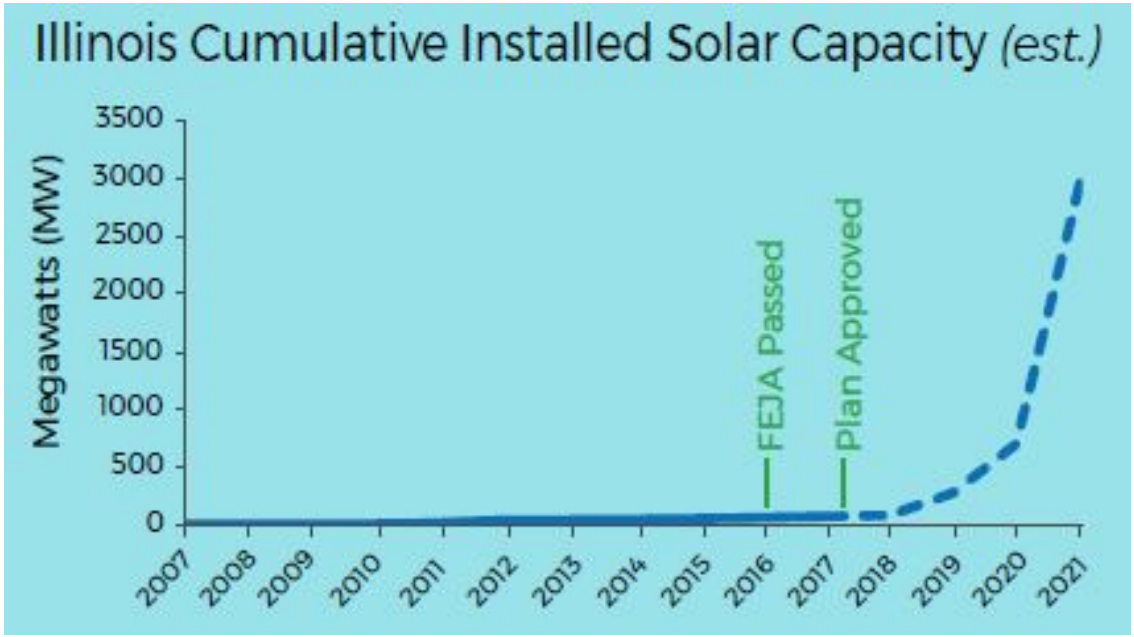


Image: Environmental Law and Policy Center

- Illinois currently has 87 MW installed solar in the state = **approximately 350,000 panels.**
- FEJA requires **approximately 11 million new PV panels to be installed by 2030.**
- Most modules range in weight from 35 lbs. to 50 lbs. = **approximately 192,500 – 275,000 U.S. Tons of installed modules in Illinois.**

End-of-life Options for Solar Panels in Illinois

- In order for a waste to be considered a hazardous waste, it must first meet the definition of solid waste. For the most part, this includes any material that you are discarding, but there are many exceptions. Solid waste is defined in the regulations at Part 721 in Section 721.102.

- It is the responsibility of all solid waste generators to determine whether their waste is hazardous or special waste in Illinois is under Title 35 Adm. Code 722.111 and 808.121. The procedure for this is called a "hazardous waste determination“.

Public Act 100-0598

Agricultural Impact Mitigation Agreement (AMIA)

- 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?

- Exploring **new methods** for maximizing material recovery.
- Working with **Illinois EPA, Solar Energy Industry Association**, and **the Illinois Solar Energy Association** to:
  - Collaborate on **outreach to create awareness** for communities and businesses.
  - Establish a **network of solar panel recyclers** in Illinois.
  - Examine **policies and regulations** to determine best practices.
- Working with training organizations to **create new jobs** in solar recycling.
- Working to develop a network for **repurposing old modules** that are still working properly.

Questions & Contact Information

Visit our website for more info:
https://go.illinois.edu/ISTCSolarPanelRecycling

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