

# Planning for Solar PV End-of-Life Options



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**I ILLINOIS**

Illinois Sustainable Technology Center

PRAIRIE RESEARCH INSTITUTE

Image: University of Illinois

# Prairie Research Institute at the University of Illinois – Urbana-Champaign

PRI is the home of the state's five scientific surveys, which collectively have served the state for more than 165 years.

- IL State Archeological Survey IL
- State Geological Survey
- IL State Natural History Survey
- IL State Water Survey
- **IL Sustainable Technology Center (ISTC)**



Image: University of Illinois

# Prairie Research Institute at the University of Illinois – Urbana-Champaign



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.

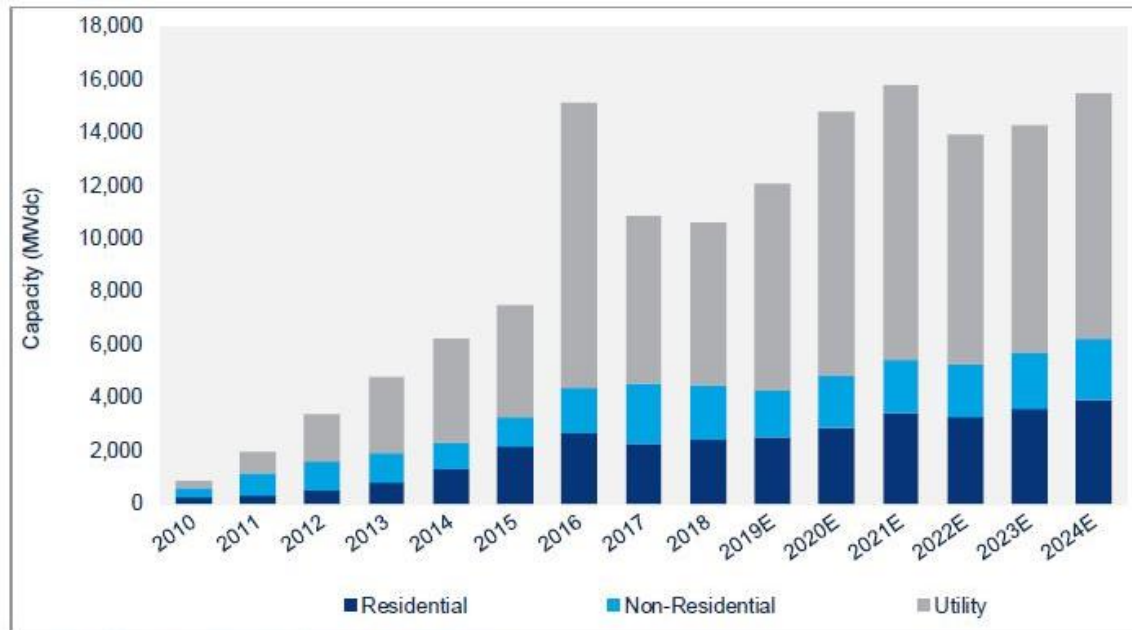
ISTC began its **Solar PV Module Recycling Initiative** in 2017 as we saw a need to address this issue after the passing of the 2016 Illinois Future Energy Jobs Act.



# Outline of Presentation:

- **Why prepare options NOW for PV End-of-Life?**
- What are the current PV End-of-Life options in Europe and the U.S.?
- What are the most common PV recycling processes?
- What is Illinois doing to address PV recycling?

# Why prepare NOW for PV End-of-Life options?

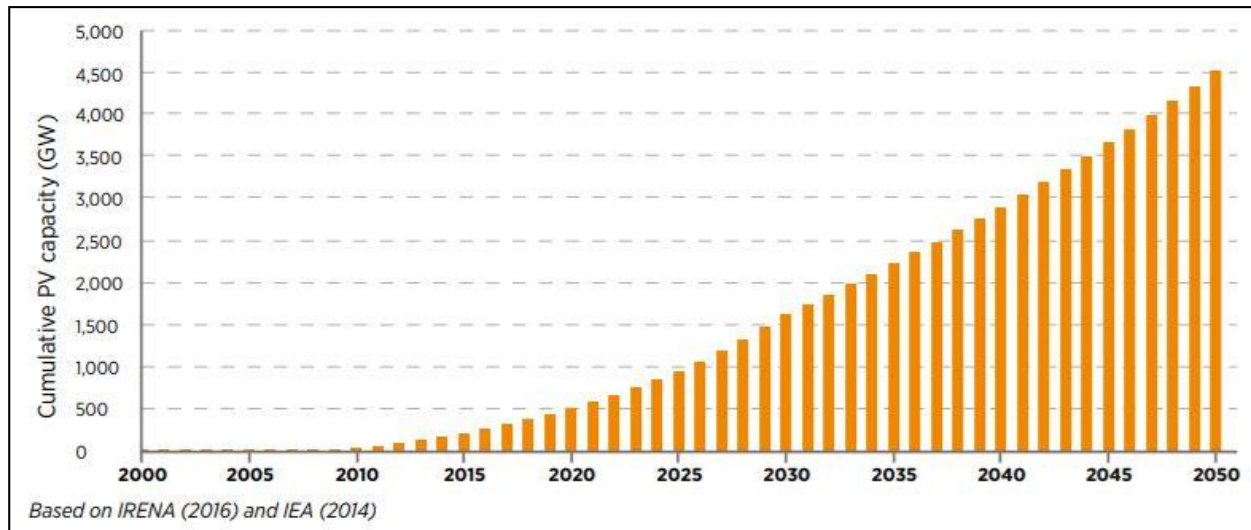


- Solar power is now the fastest-growing energy source. An estimated **800 thousand modules were installed globally every day** in 2018.
- As of March 2019, the U.S. has nearly 64.2 GW power installed, approximately = **257 million solar modules**.
- According to the Solar Energy Industries Association (SEIA), total installed U.S. PV capacity is expected to more than **double** over the next five years.

Sources: Wood Mackenzie Power & Renewables & NREL (2018);

<https://www.pv-tech.org/news/global-solar-pv-installations-reach-109gw-in-2018-bnef>

# Why prepare NOW for PV End-of-Life options?



- Global installed PV capacity is expected to rise to **4,500 GW by 2050**.
- As the global solar market increases, so will the volume of decommissioned/damaged PV modules.
- At the end of 2016, cumulative **global solar waste** streams was expected to have reached **43,500-250,000 metric tons**.

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

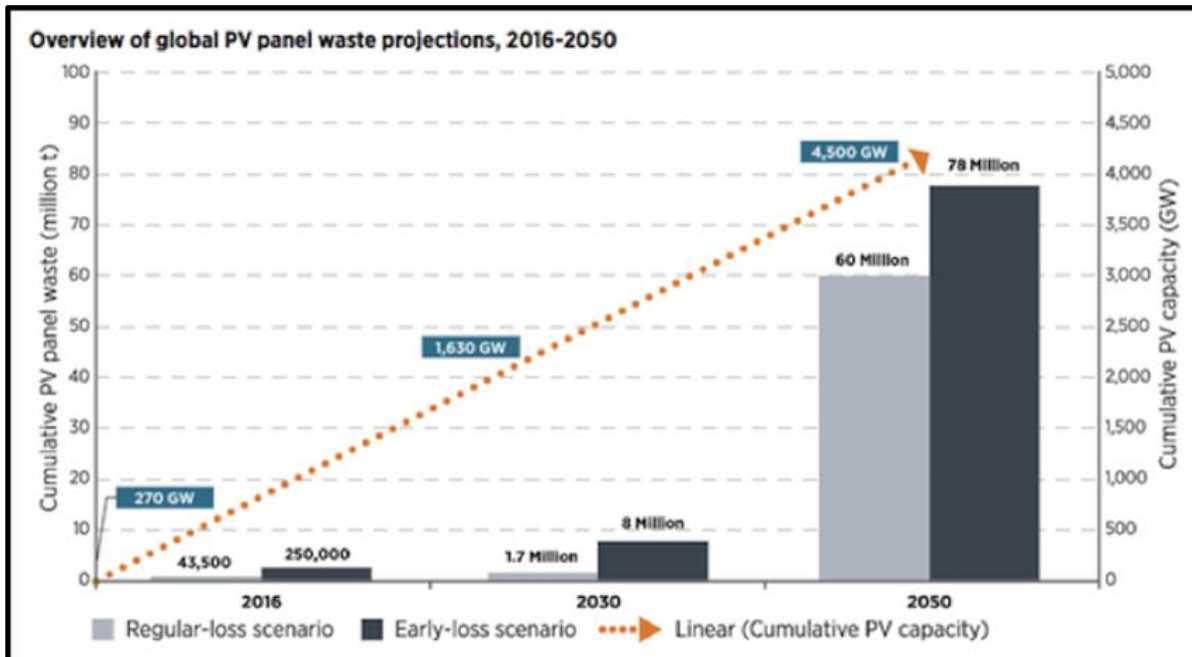
# Why prepare NOW for PV End-of-Life options?

- The so-called **early-loss shelf life category** of solar modules is estimated to contribute more than 80.0% share to the solar module 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 modules fail annually.
- 0.05% of modules fail before leaving manufacturer per year.
- 2% of modules are broken in production per year.



Image: University of Illinois  
Source: IRENA and IEA-PVPS (2016)

# Why prepare NOW for PV End-of-Life Options?



## Regular-loss

Assumes a 30-year lifetime for solar modules

## Early-loss

Accounts for “infant”, “mid-life” & “wear-out” failures before 30 years

- Given the design life of solar modules of 25-35 years and early loss data, there will be **a huge surge in solar module disposal in the 2020s and 2030s.**
- By 2050, there will be **60 to 78 million cumulative metric tons of solar module waste globally**, estimates the International Renewable Energy Agency (IRENA).

Source: IRENA and IEA-PVPS (2016)



# It's time to plan for solar PV recycling in the United States

April 2, 2018 - Solar Power World



Image: Puerto Rico Solar Farm, forbes.com

# Why prepare NOW for PV End-of-Life options?

- This is a **looming waste management issue**.
- However, many countries, including the U.S., do not have a strong PV recycling infrastructure in place as of now for solar modules.
- **Modules should be properly recycled.**
  - Toxic compounds could leach into the environment if they are landfilled.
  - Valuable resources (e.g., silver) will end up in landfills.
  - Finite resources in the modules that are slowly being depleted will be lost, such as rare elements, e.g., gallium and indium.



Image: [down2earthmaterials.ie](http://down2earthmaterials.ie)



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- What is Illinois doing to address PV recycling?

# PV Disposal Guidelines in Europe



EUROPEAN UNION



- The **European Union's Waste of Electrical and Electronic Equipment (WEEE) directive** has guidelines on how solar modules are to be disposed.
- Established PV module recycling guidelines in 2012.
- **Extended-producer-responsibility principle** is at its core. Producers are liable for the costs of collection, treatment and monitoring. Modules are required to be disposed of in dedicated collection facilities and should not be mixed with general waste.
- Take back and recycling is free for consumers.

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

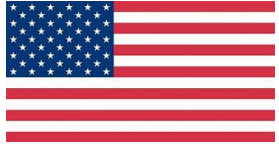


# PV Waste Guidelines in the U.S.



- Many broken or damaged PV modules find their way to landfills rather than being recycled.
- 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, modules are evaluated using Test Methods for Evaluating Solid Waste: Physical/Chemical Methods (SW-846).
- Some solar module wastes can include heavy metals such as silver, copper, lead, arsenic, cadmium, and selenium that may be classified as hazardous wastes.

Source: EPRI (2018)



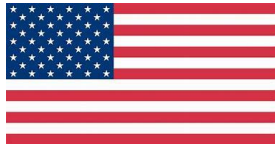
# State Policies Related to End-of-Life PV

## Enacted legislation:

California (2015): Formerly classified as Hazardous Waste, the California Department of Toxic Substances Control (DTSC) now plans to add end-of-life photovoltaic (PV) modules to the State Universal Waste regulations. This will encourage proper waste disposal, reduce waste abandonment, and increase cost savings for PV module waste generators.

Washington State (2017): Manufacturers are responsible for creation and on-going maintenance costs of waste module collection system and recycling; working with installers in Washington to develop an industry-proposed draft/comments due by the end of June.

Source: SEIA, May 2019



# State Policies Related to End-of-Life PV

## Proposed legislation in 2019:

NJ: A4011 would **require the owner of solar and photovoltaic energy generation facilities and structures to remove and recycle** the facility and structures and any related equipment or infrastructure after the termination of their use.

NY: S942 would enact the "solar modules collection act" to **require manufacturers of solar modules to collect** such modules when they are taken out of use.

Source: SEIA, May 2019



# State Policies Related to End-of-Life PV

## Proposed legislation in 2019:

NC: Two bills in the state legislature seek to **address fringe concerns related to solar modules toxicity** by implementing requirements similar to 2017 Washington state recycling requirements.

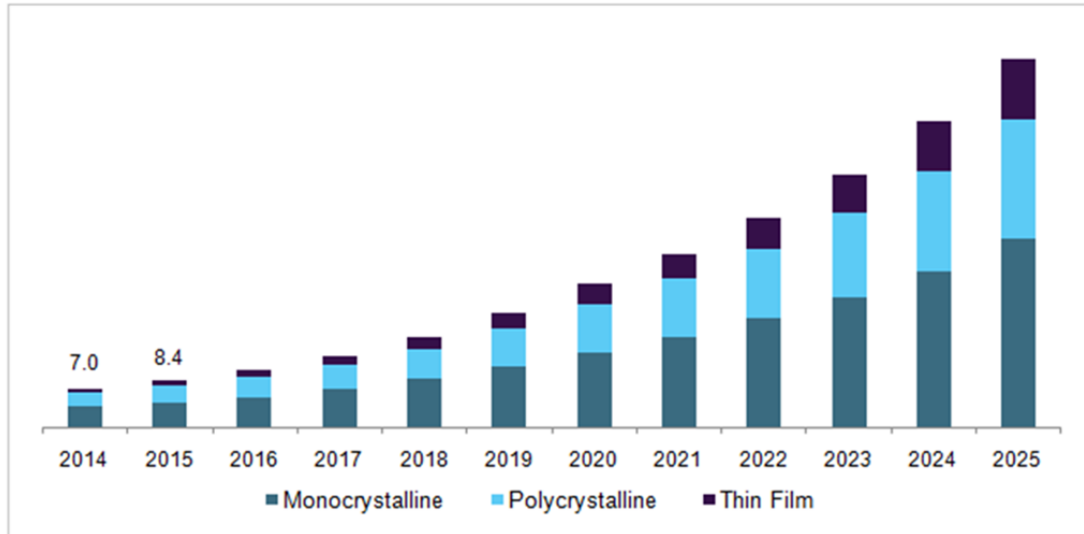
MD: HB0125 would establish a **solar PV recycling fee to be paid by installers** beginning October 1, 2019; and require 20% of the first sale price of each renewable energy credit sold to be deposited into a Solar Photovoltaic Recycling Fund.

Source: SEIA, May 2019



# U.S. PV Recycling Market

U.S. solar panel recycling market revenue, by type, 2014 - 2025 (USD Million)



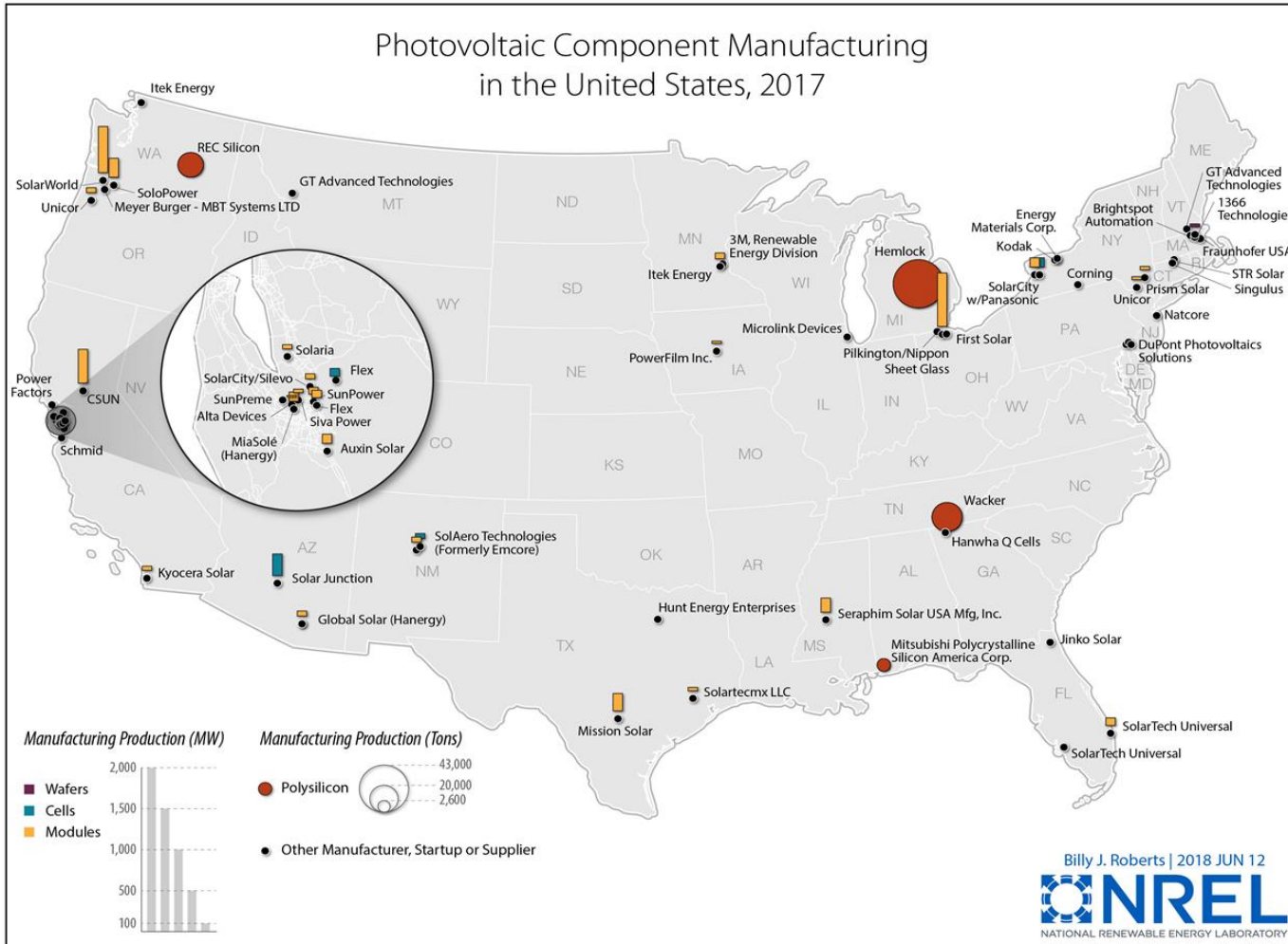
- Solar PV deployment at a significant level started in the 1990s and the long life time of PV modules result in a relatively small waste stream today.

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

- The amount of recycled modules is **projected to greatly rise after the year 2020**.

Sources: Life Cycle Assessment of Photovoltaic Module Recycling, Stolz & Frischknecht (2016), and <https://www.grandviewresearch.com/industry-analysis/solar-panel-recycling-market>.

# Where is the waste coming from?



- Manufacturing scrap
- Warranty-related
- Broken during logistics or handling
- Extreme weather events
- Technology upgrades



# PV Recycling Program

## Member-based program

- Evaluate service capabilities
- Downstream capabilities
- Anyone can use these recyclers

## Evaluate and develop recyclers

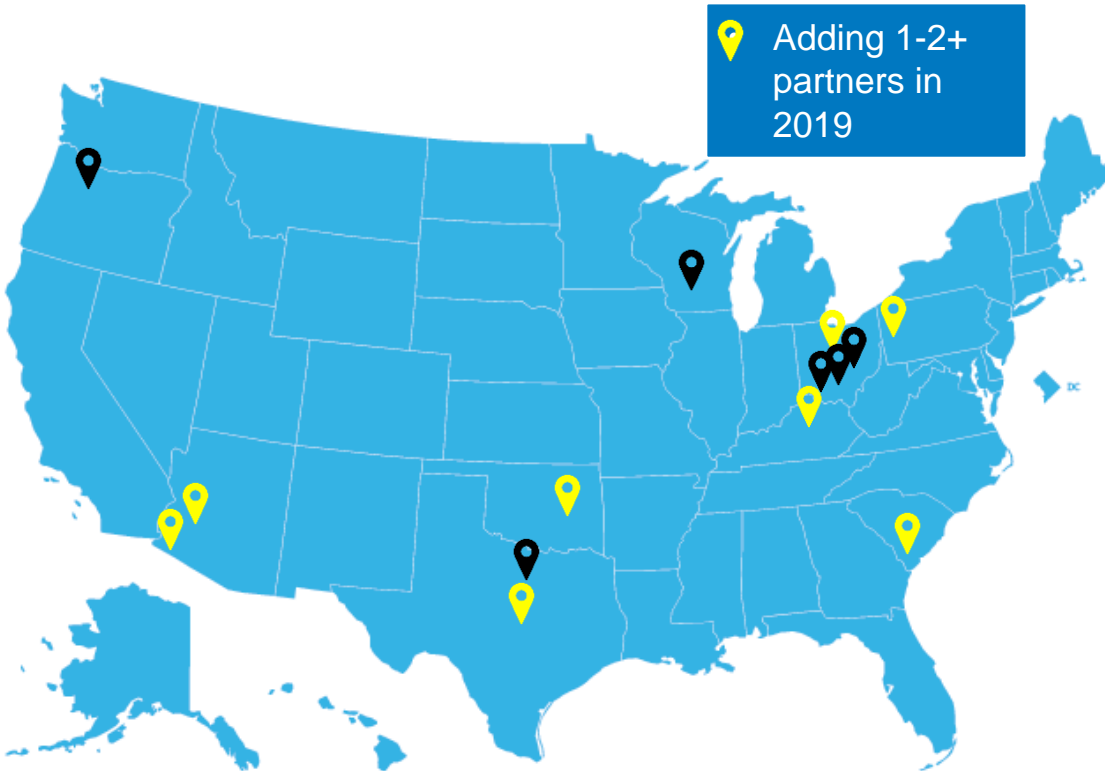
- Members help develop process
- Members help with technology
- Site visit, samples

## Collect data

- Weight and volume (est. annually)
- Recovered materials (modeled)



# Recycling Partners



Onalaska, WI



[www.seia.org](http://www.seia.org)



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- **What are the most common PV recycling processes?**
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# Solar PV Recycling Processes

- Complex task because modules 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>

# Market Share of PV Modules 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 PV Modules

- **c-Si modules** contain 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.
- **IGS 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.

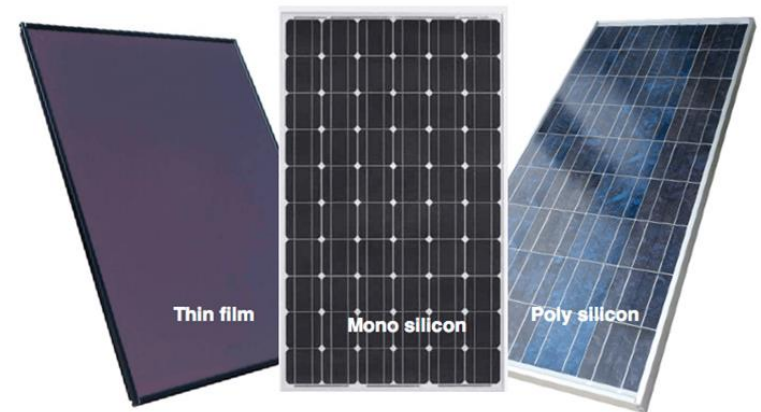


Image: [www.cleanenergyreviews.org](http://www.cleanenergyreviews.org)  
Source: IRENA and IEA-PVPS (2016)



# PV Recycling – Resource Recovery

The fact that it is possible, even today, to recycle virtually all of a solar module 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 modules.
- The remaining 4% is utilized in an energy recovery process, using a waste-to-energy technology.
- Non-silicon-based solar modules can have a **recovery rate of up to 97%**.



Image:

<https://understandsolar.com/recycling-solar-panels-pv/>

Source: <http://www.pvcycle.org/>



# PV Recycling

The Electric Power Research Institute (EPRI, 2017) found that most solar module recycling in Europe happens at **glass recyclers**.

Modules 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 modules recycling that could recycle **up to 50,000 Si-based modules** per year. The plant will use an energy-efficient pyrolysis process.



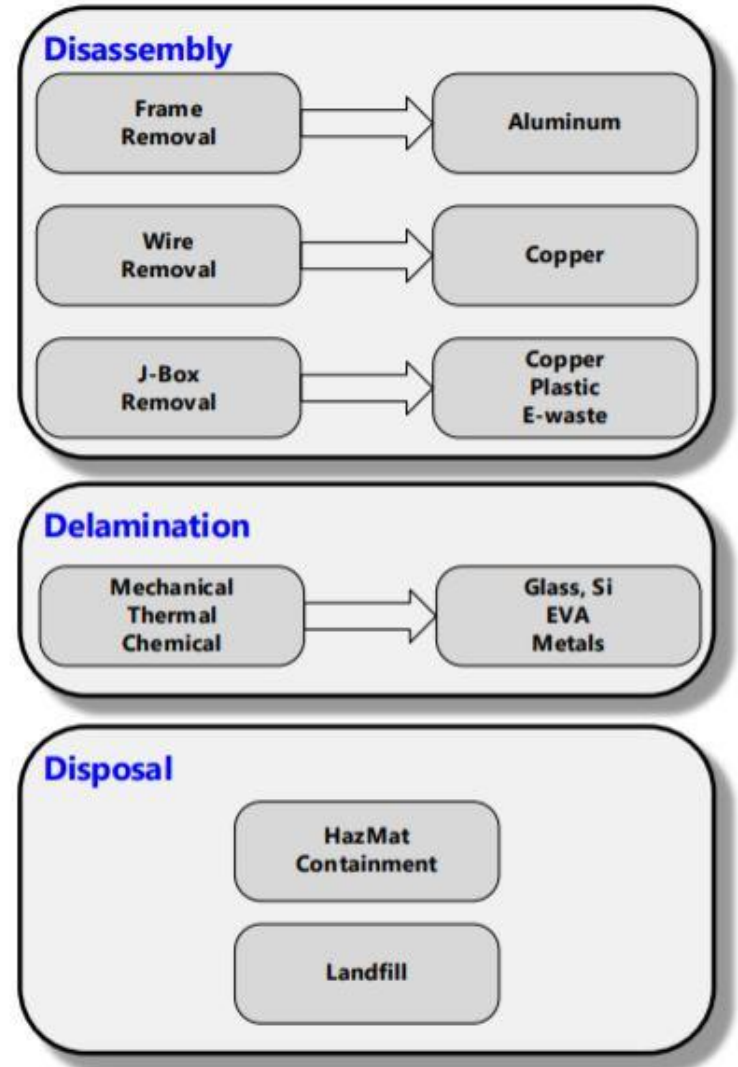
Image: [www.recyclesolar.ie](http://www.recyclesolar.ie)

Source: Pickerel (April 2, 2018), Solar Power World

Source: pv magazine international – 8.23.2018

# U.S. Generic PV c-Si 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.



# First Solar PV Recycling Steps

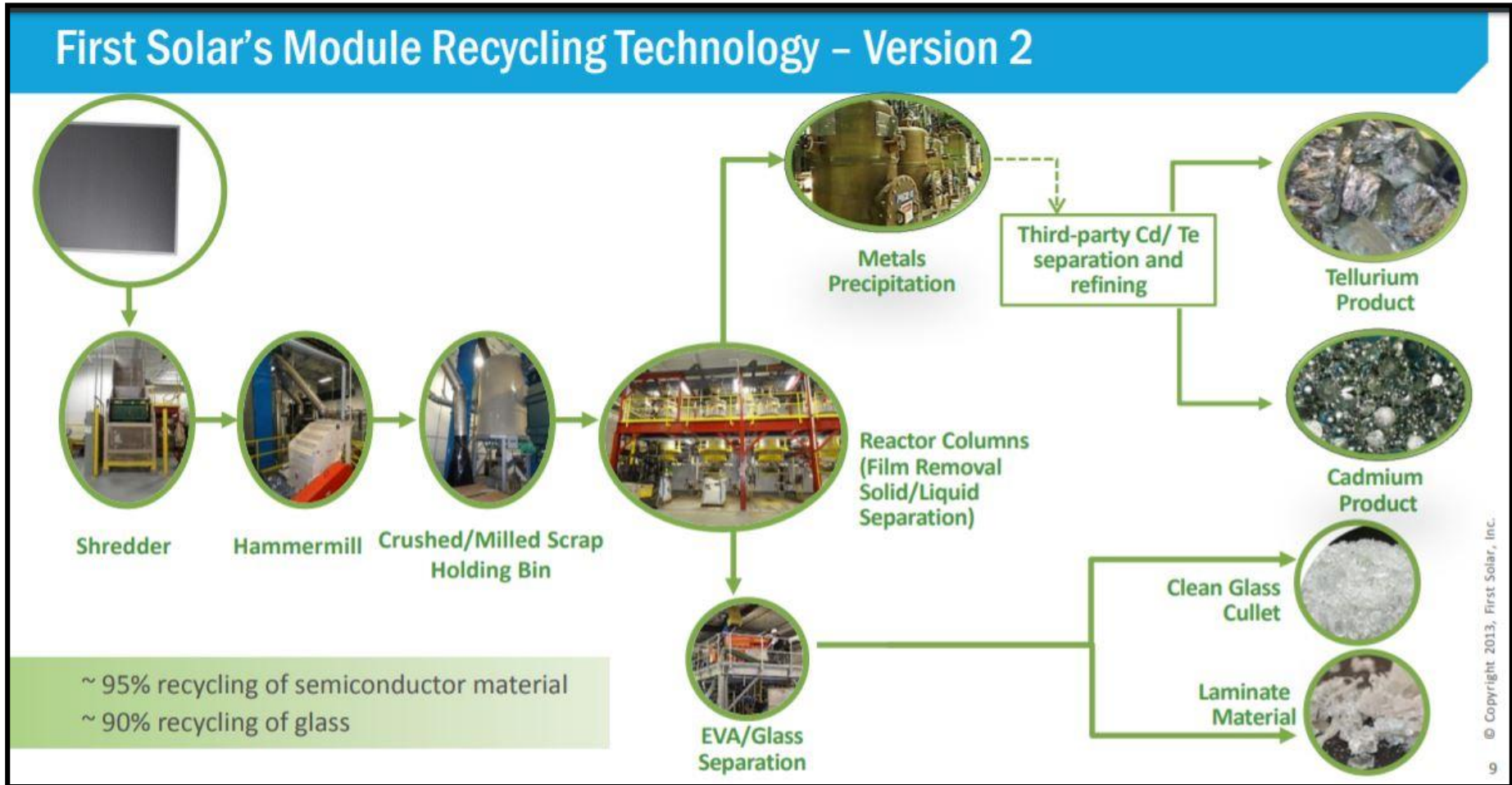


Image: First Solar (2013) – [http://iea-pvps.org/fileadmin/dam/public/workshop/07\\_Andreas\\_WADE.pdf](http://iea-pvps.org/fileadmin/dam/public/workshop/07_Andreas_WADE.pdf)

# First Solar's CdTe PV Life Cycle Benefits

## Ensuring Sustainable Supply of Raw Materials through Recycling

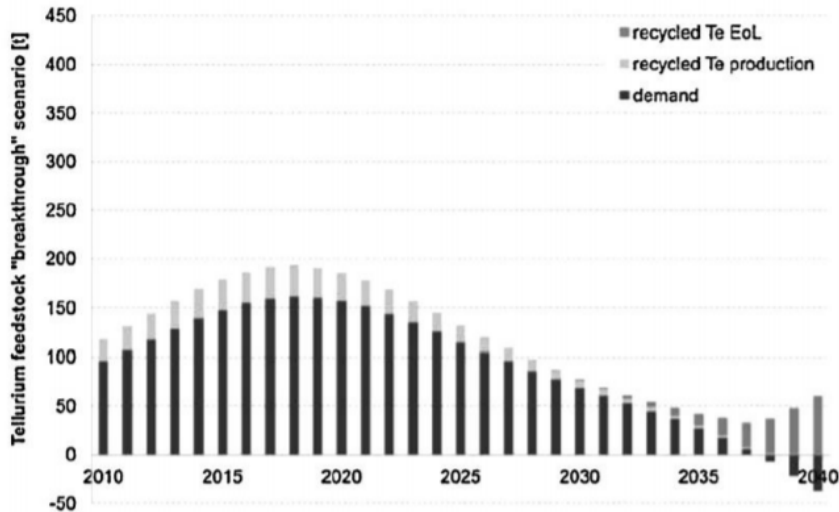


Fig. 8. Tellurium feedstock in the "breakthrough" scenario.

- 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

Source: First Solar (2013) –

[http://iea-pvps.org/fileadmin/dam/public/workshop/07\\_Andreas\\_WADE.pdf](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)

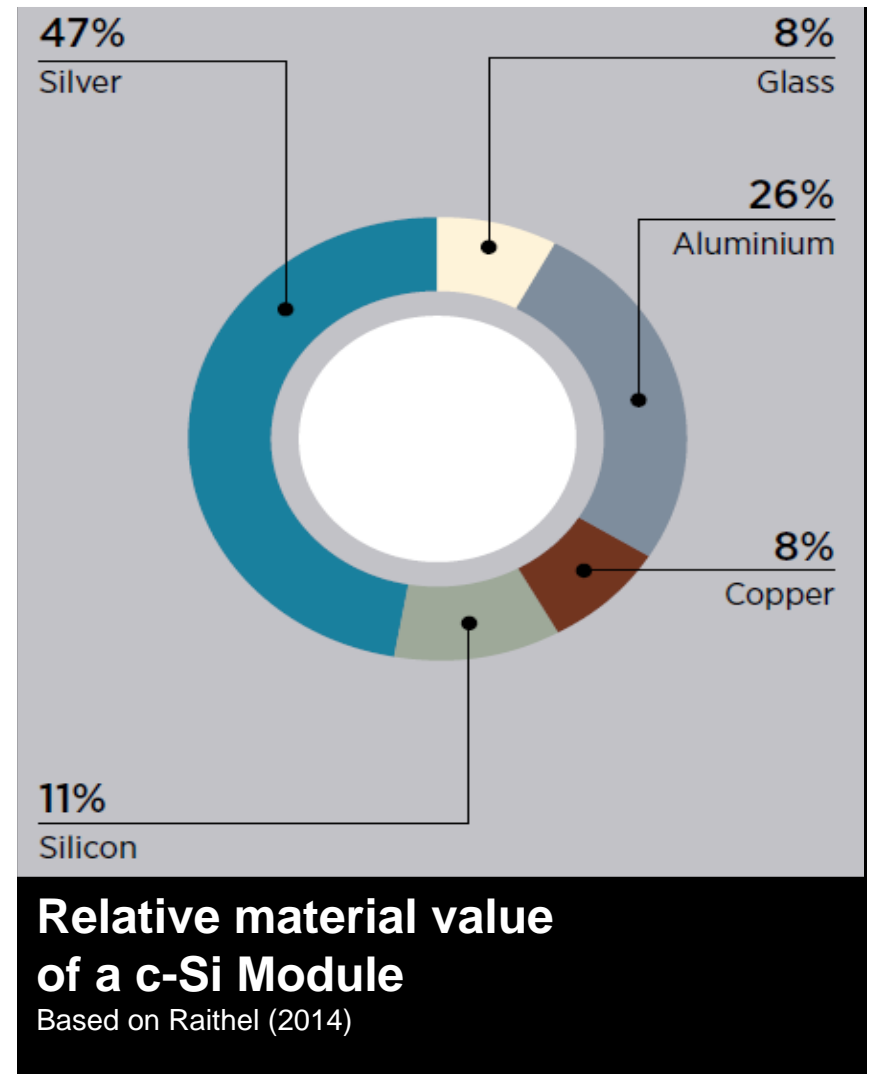


Image: IRENA and IEA-PVPS (2016)



# Relative Material Value of a c-Si Module

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



# Conclusion on PV Recycling Processes

- Recycling and repurposing has both a great **environmental and economic benefit**.
- By weight, based on 60 - 78 million metric tons of PV materials.
- Worth \$15 billion (\$2 billion in U.S.) in recoverable value by the year 2050.
- Enough to produce **2 billion new modules**.
- Solar modules recycling and repurposing of old modules can help spawn new industries and will create new green job opportunities.

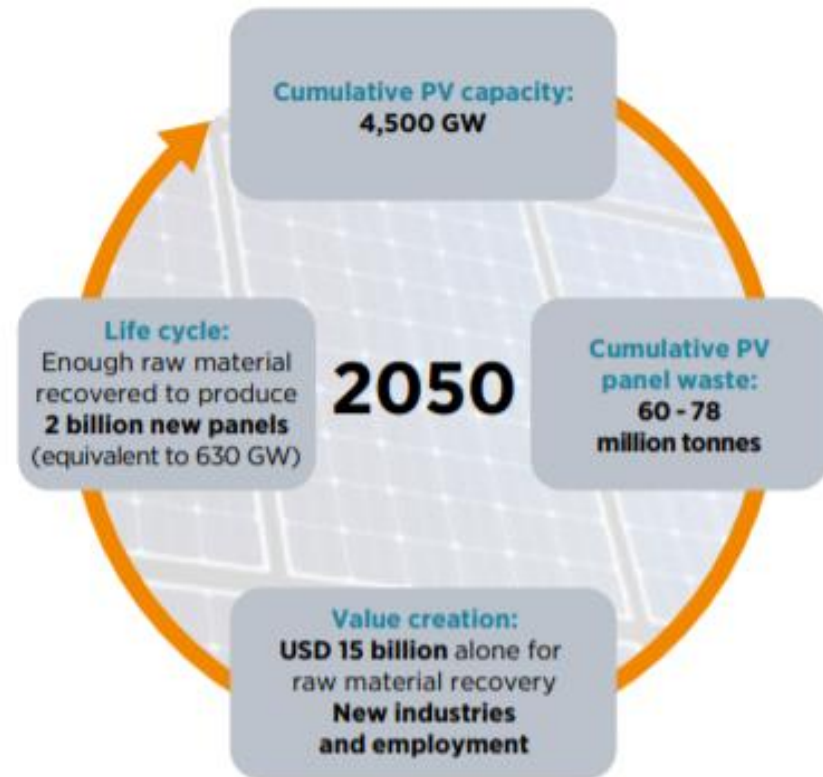


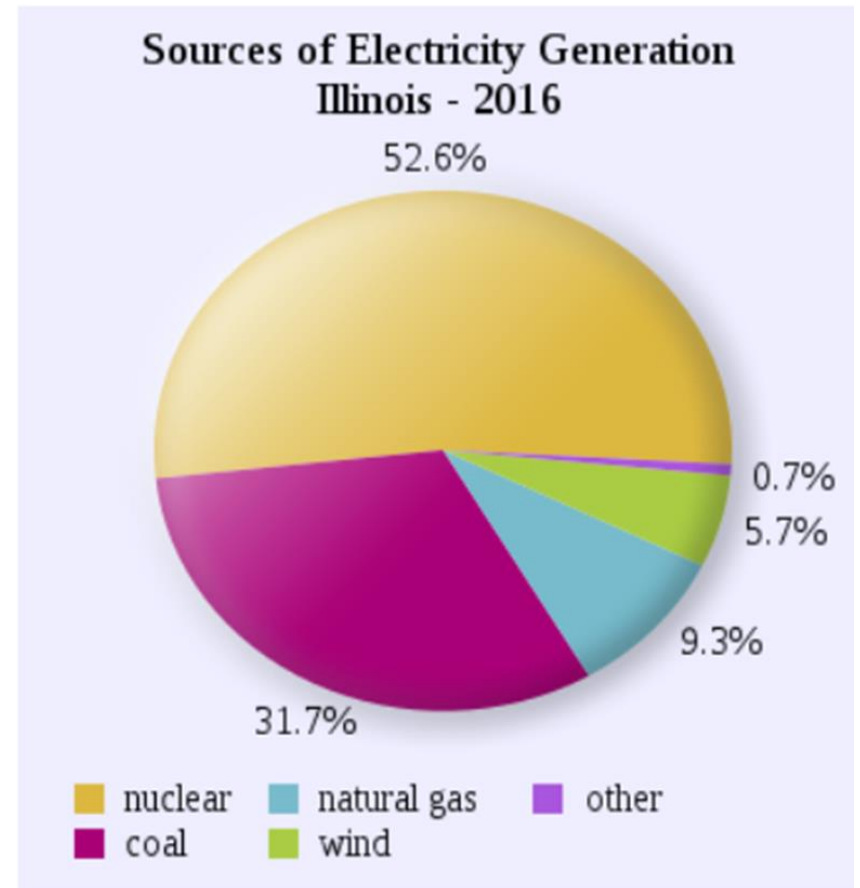
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# Illinois RPS Future Energy Jobs Act (FEJA)

- FEJA requires a goal of 25% energy generation to be from “renewable sources” by 2025.
- As of April 2019, there is ~108.5 MW of solar installed in Illinois.
- FEJA will increase this solar capacity in Illinois an additional ~2,500 MW by 2030.



Source: US Energy Information Administration, 2017

# FEJA's RPS Goals

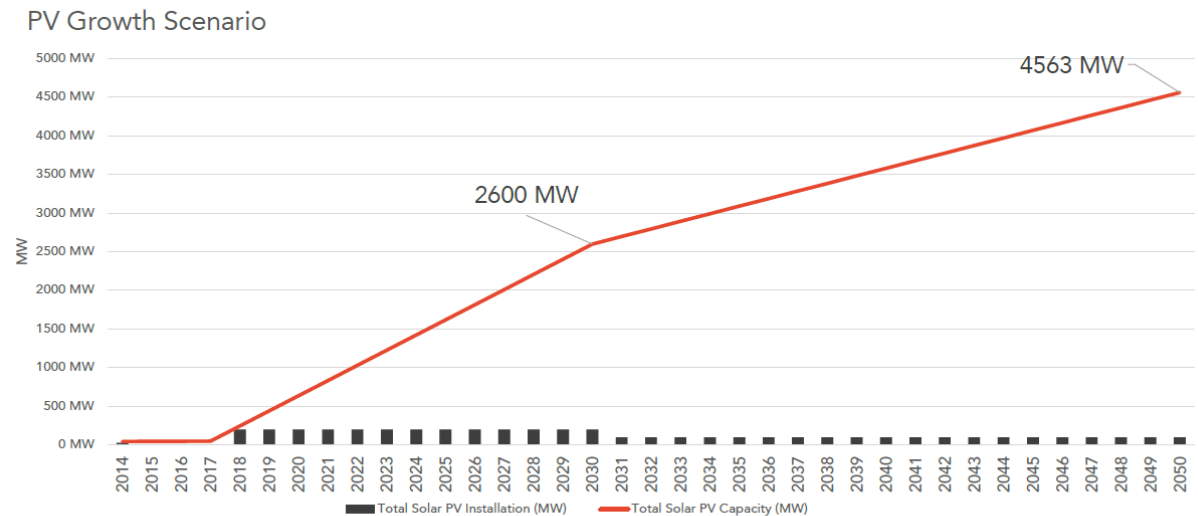
## Future Impacts on Waste Streams

- Many broken or damaged PV modules in Illinois currently are not recycled and end up in landfills.
- Illinois has ~108.5 MW of solar installed now = **~374,000 modules**

### PV Growth for Illinois 2050

Based on FEJA goals to reach 2600 MW by 2030 and projected out to 2050

- FEJA goals = **~9 million more PV modules** installed by 2030
- **200,000 U.S. Tons** of PV modules installed by 2030

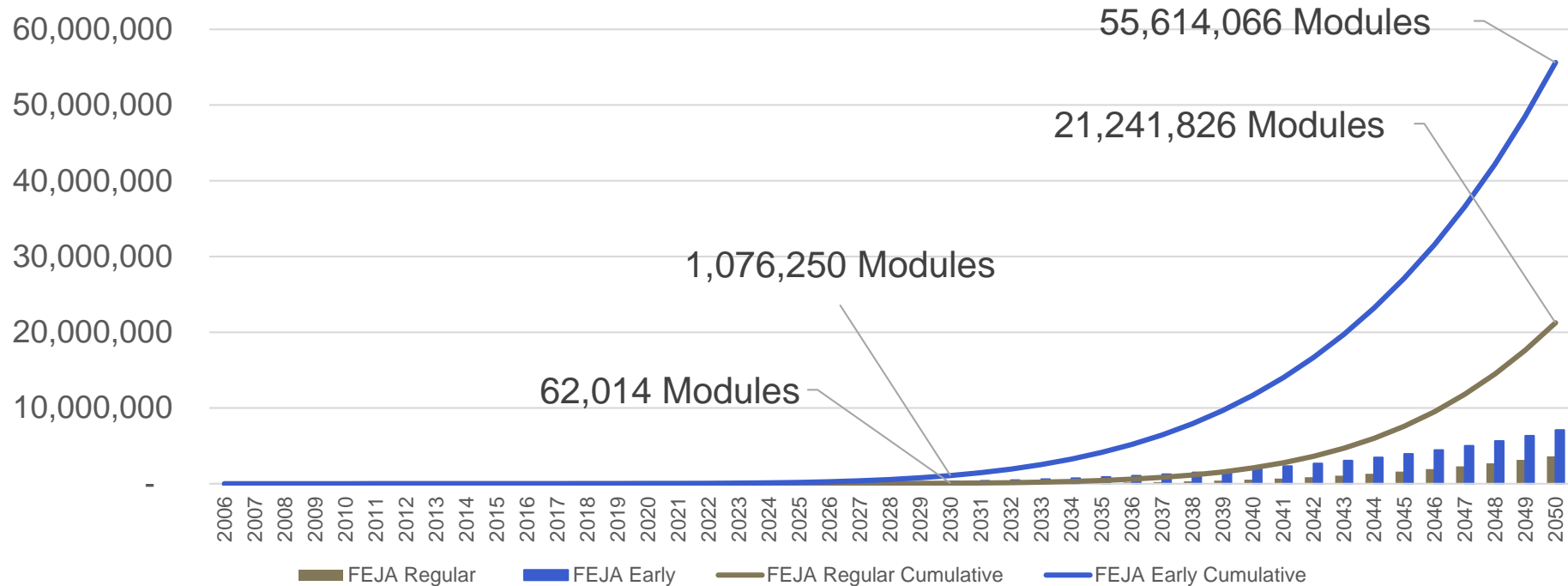


DRAFT: Solar PV Panel End of Life Projections for Illinois



# PV End-of-Life Projections for Illinois

## EOL PV Modules



Source: ISTC. Based on IRENA and IEA's waste model in [End-of-Life Management: Solar Photovoltaic Panels](#) & IL FEJA goals

# Illinois Solid Waste Current Regulations

- PV waste that is **intended for disposal** must:
  - Comply with Illinois' adaptation of **Resource Conservation Recovery Act (RCRA)** for onsite storage of the equipment
  - Procure a **permitted authorized special waste hauler**
- Aside from water or air permits, **recycling is not regulated** in Illinois.
- **Agriculture Impact Mitigation Agreement (AIMA)**  
Ensures that farmland with solar projects on it is restored to its pre-construction use. This includes all ground-mounted solar projects larger than 500kW.



Image: University of Illinois

# Challenges for Creating a Sustainable PV Recycling Program in Illinois

- Ensuring policy/interventions do not impact solar deployment. Requirements of a program must not overburden one industry stakeholder or consumer.
- Funding mechanisms are necessary to handle waste responsibly. Costs necessary to consider:
  - Repowering & lifetime estimation impacts on fees
  - Responsibilities of manufacturers & developers and the impacts on consumers
  - Infrastructure & collection logistics
  - Program administration
- Protection of funding sweeps for a long-term EOL PV program



# Strategies for Creating a PV Circular Economy in Illinois

- **Early engagement of key stakeholders**

IL EPA, NREL, SEIA, ISEA, US EPA, installers, manufacturers, distributors, recyclers, Illinois Department of Economic Opportunity, Illinois Environmental Council, and energy market consultants

- ❖ Establishing a PV recycling & repurposing network in Illinois
- ❖ Economic impacts and fee structure options
- ❖ Impacts of policies, regulations, and a landfill ban

- **Preparing opportunities for a diverse workforce**

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