Report of Investigation of Recycling and other Management Methods for Solar Panels, and Recommendations by the New Jersey Solar Panel Commission

Date of Report: November 29, 2023

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Executive Summary

To address the impacts of climate change, New Jersey has developed legislative and policy action (including the New Jersey Global Warming Response Act and Energy Master Plan) to strengthen its renewable energy sector. Solar power, a renewable source of energy that converts energy from the sun into power by way of solar panels, also known as photovoltaic (PV) modules, plays a crucial role in meeting the state's goals of substantially reducing greenhouse gas emissions and lessening the impacts of climate change. Despite its small size, New Jersey is 8th in the nation for cumulative installed solar PV capacity, with over 4.4 gigawatts installed from over 174,000 individual installations. The Solar Act of 2021 directed the Board of Public Utilities (BPU) to double the growth of the existing solar program and incent up to 3,750 MW of solar generation by 2026, as well as incentives for community solar facilities, and grid supply solar facilities.

While solar panel systems currently require a substantial initial investment, the current trends point towards a steady lowering of costs due to advances in technology and incentives such as tax credits. Lowered costs, along with the goals, initiatives, and actions outlined in the New Jersey Global Warming Response Act and Energy Master Plan, will allow more people to utilize the benefits of this renewable energy source, and increase both the demand for solar power, as well as the numbers of spent solar panels to be managed at the end of their useful life. Due to the longevity of these devices, there is seemingly no immediate concern around the management of large quantities of end-of-life (EOL) solar panels. However, it is forecasted that in New Jersey between the years 2025 and 2040, EOL solar panel or photovoltaic module accumulation will grow nearly thirty-fold. There are no existing mandates, policies, or guidelines that specifically address management of EOL solar panels in the State of New Jersey. As an example, PSE&G, New Jersey's biggest utility company, ships EOL solar panels to out of state hazardous waste landfills, at a substantial cost and with no recovery of the valuable heavy metals contained within the panels. Accordingly, in 2019 Governor Murphy signed P.L. 2019, c. 215, into law, establishing the New Jersey Solar Panel Recycling Commission (Commission).

The Commission was established to study and investigate options for recycling and other end-of-life management options for photovoltaic and other solar energy generation structures. This report details the Commission's associated research, including challenges and recommendations for solar panel recycling and end-of-life management, in New Jersey.

The challenges include:

- If not conducted properly, disassembly and processing of EOL solar panels may compromise encapsulation and expose cell/wire/solder material in modules (including the metals) to leaching into the environment. Additionally, processing technology – including chemical and thermal treatments - to recover precious metals and prevent leaching of lead and other metals could prove costly and/or harmful to the environment.
- Price increases due to fees (deposits, advanced recovery fees (ARFs), or Extended Producer Responsibility (EPR) fees), may dampen demand for solar panel modules.

- High cost and difficulty associated with processing of the polymer adhesive.

The recommendations are based on two main goals:

Goal 1: Recycling (processing) EOL solar panels and sending components to legitimate and verifiable end-markets:

- Recommendation 1.1 - Construction of new Solar Panel Recycling Centers.
- Recommendation 1.2 -Management of PV modules as Universal Waste at existing facilities, includes Advanced Recovery Fee (ARF) per panel, at the time of purchase by consumers or Extended Producer Responsibility (EPR) model.

Goal 2: Extended use and reuse of solar panels:

- Recommendation 2.1 - Continued use of solar panels beyond nominal or arbitrarily determined life span.
- Recommendation 2.2 - Reuse of solar panels by shipping the panels to both domestic and international areas with fewer financial resources and lower accessibility to new solar panels.

Pursuant to P.L. 2019, c. 215, the Commission will submit this report, its findings, and conclusions along with recommendations for legislative, administrative, or private sector actions, to the Governor and Legislature.

Acknowledgements

The Commission gratefully acknowledges input from the following individuals:

(1) Tommy McGuire, President of Echo Environmental, for providing information concerning what it would take to set up and operate a solar panel recycling facility in New Jersey.

(2) Judith Andrejko, Esq., New Jersey Department of Environmental Protection (NJDEP) Regulatory Officer, for providing information concerning the rule making process required to implement the Commission's recommendations.

(3) Karen Drozdiak, Director, ESG & Sustainability, First Solar, for providing information on management of EOL thin-film solar panels, as well as general insights provided throughout this Report.

(4) Karen Kloo, NJDEP Bureau Chief and Solar Panel Commission Chair until retirement.

Background

Governor Phil Murphy signed Public Law 2019, chapter 215 (P.L. 2019, c. 215) into effect on November 7, 2019. P.L. 2019, c. 215 mandated the formation of the "New Jersey Solar Panel Recycling Commission" ("Commission").

The Commission was established to:

- Investigate opportunities for recycling and other end-of-life (EOL) management methods for photovoltaic and other solar generation structures, and
- Develop recommendations for legislative, administrative, or private sector.

Pursuant to P.L. 2019, c. 215, the Commission consists of nine voting members including the New Jersey Department of Environmental Protection (NJDEP) Commissioner (or designee), and the Department of Community Affairs Commissioner (or designee). The Commission also included seven (7) members appointed by the Governor. These members included: Two citizens from the State's business community with knowledge, expertise and/or experience in recycling and management of consumer electronics as Class D materials, one representative of a non-profit organization with a record of promoting recycling in the state, two members who are currently employed in the solar panel industry, and two members of the state's academic community with expertise in recycling issues.

Council Members included:

- Nicholas Nader, Commissioner Designee, and technical/support staff Daniel Clark and Ashia McRae
  - NJ Department of Environmental Protection.

- James Entwistle, President and Founder - Newtech Recycling, Inc., Class D Recycling Center for consumer electronics located in Franklin Township, Somerset County.

- David A Thompson, Corporate Environmental Director - Panasonic Corporation of North America.

- Joseph Ferrante, Jr., Attorney at Law - Member of the Association of New Jersey Recyclers.

- Lyle K. Rawlings, President and Founder - Advance Solar Products.

- Christopher Gulics, Manager Environmental Strategy - PSEG.

- Dr. Dunbar P. Birnie, III, Professor - Department of Materials Science - Rutgers University.

- Dr. Stephanie Lee, Associate Professor, Department of Chemistry - New York University.

- Sean Thompson, Vice Chair, Director of General Planning Services - New Jersey Department of Community Affairs.

Commission meetings were held monthly from March 22, 2021 to April 4, 2022, and September 12, October 31, and November 21, 2022.

Section I: Components and Function of Solar Panel Modules

Solar panels are comprised of photovoltaic (PV) cells made of semiconductors that generate electricity when exposed to sunlight. These semiconductors absorb sunlight, which in turn causes electrons (negatively charged particles) to flow through the semiconductor to generate direct electric current. This process is known as the photovoltaic effect. The current subsequently flows through an inverter, which converts the direct current (DC) to alternating current (AC) for residential and commercial use.

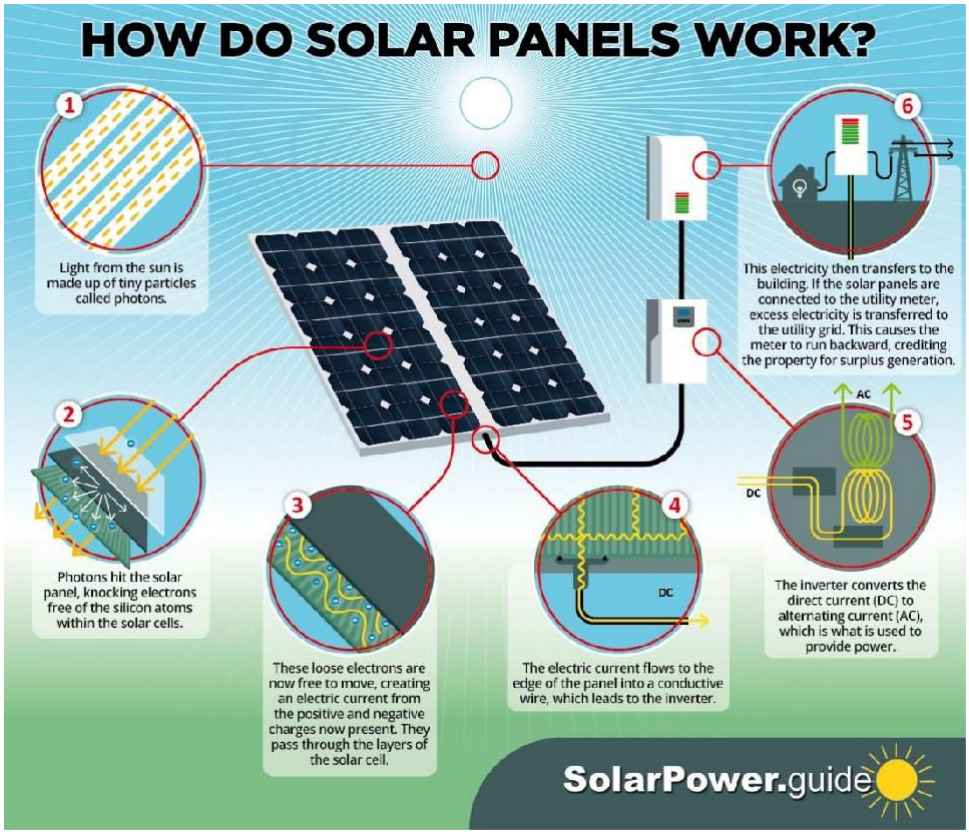


Image from Solarpowerguide.com

As of the writing of this report, over 99% of solar panels currently in operation in New Jersey are crystalline -silicon- panels (silicon), with a small fraction consisting of thin-film panels (cadmium telluride or CdTe).

As of January 2022, there are 91,404 CdTe modules installed in New Jersey, representing only about 0.2% of the solar power capacity installed in the State. All of the CdTe modules were manufactured by First Solar, a US manufacturer founded in Ohio (see page 32 of this Report). The CdTe modules are installed in 23 projects, by 6 installers. Consequently, and for the most part, this report concerns itself with silicon panels.

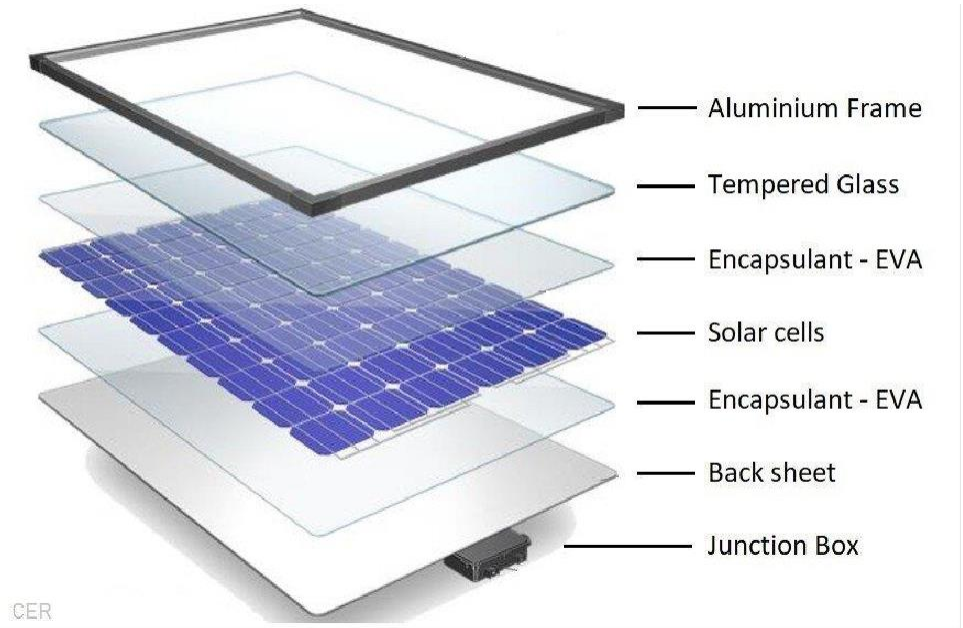


Image from cleanenergyreview.info

Silicon solar panels are typically composed of the following components:

- Glass – 76%
- Polymer (EVA or similar) – 10%
- Aluminum – 8%
- Silicon – 5%
- Copper 1%
- Trace amounts of silver, tin, and lead

Silicon solar panels carry a 25-to-30-year performance warranty but typically function beyond that time frame. Given the fact that solar panels are installed outdoors and exposed to the elements, manufacturers of solar panels must utilize the most advanced feasible technology for encapsulation. The encapsulating materials must be robust, durable, and resistant to moisture, gases such as oxygen, freeze-thaw cycles, and mechanical damage. Because the circulation of water or moisture into and out of the module would degrade the integrity of the panel, PVs are constructed with waterproof laminate. Further, there is no edge exposure to the environment for cells or interconnecting wires; PV modules have a border consisting only of glass and encapsulation, generally about 0.5” to 1.5” in width, around the perimeter of the laminate. This enhances the useful lifetime of the module and is a safety feature reducing the chance of electric shock and fire. Thus, essentially no leaching is possible at the edges of the laminate in unbroken modules, and the same is true of the front and back surfaces.

Section II: Data

The NJ Board of Public Utilities (BPU) keeps detailed records of all grid-connected solar projects in the state and provides these data for public analysis at the NJ Clean Energy website[1].

As of October 31st, 2021 there were over 148,494 solar installations in the state. Figure 1 (below) provides the historical record of installation scaled by cumulative capacity in each category. This represents the range of ages and types that are installed and may experience degradation and eventual replacement resulting in a need for disposal or recycling.

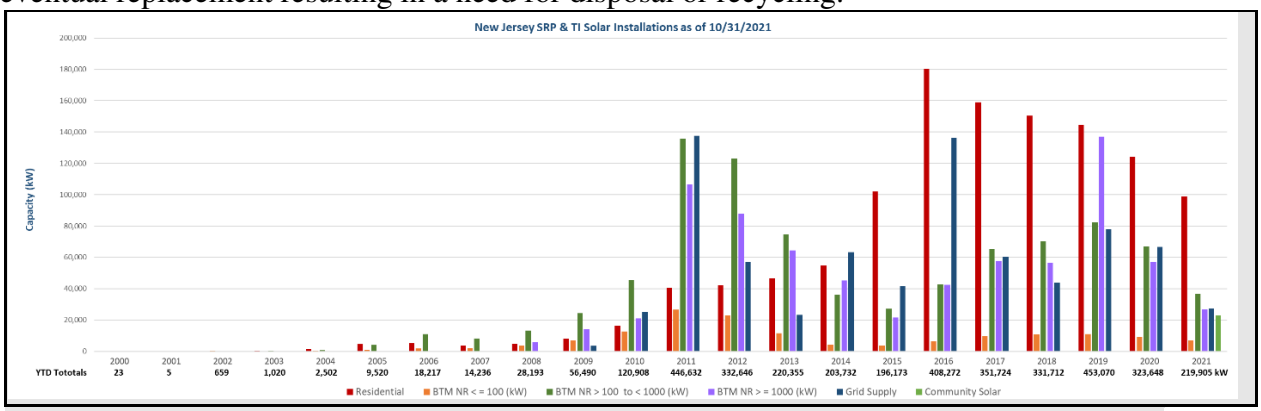


Figure 1. Historical record of solar installations in NJ as contained in the October 2021 NJ BPU report. Non-residential behind-the-meter (BTM NR) categories are broken down by array size. Community solar only started to be permitted in 2021.

Using the BPU database the Commission was able to make well-informed estimates of the lifespan and disposal schedule for the prior installations. Determining these estimates enabled the Commission to project into the future, based on likely trends in the state's goals under the NJ Energy Master Plan.

Figure 2 (below) shows an estimated end-of-life annual replacement projection typical of current solar modules and practice. In year one the failure rate of solar panels, which would necessitate replacement, could be ~1%, but with product quality and warranty the nominal annual failure rate after that will be only 0.5% and rising to 1% after 10 years. Beyond 20 years the Commission expects failure rates to rise as many modules may reach their warranted lifetime. There are spikes (representing decommissioning of solar panels) at 15, 20, and 25 years to quantify some expected re-powering of existing arrays with more modern, higher efficiency equipment, which might be more likely to happen at end of power-purchase agreement contract termination or renegotiation points[2]. An exception to the estimates of the lifespan and disposal schedule is that of modules damaged by inclement weather, accidents, or vandalism which may be expected when, for example, modules are installed on utility poles or are otherwise accessible.

[1] https://njcleanenergy.com/renewable-energy/project-activity-reports/solar-activity-report-archive

[2] Reliability data and industry experience provided by Lyle Rawlings representing the Mid-Atlantic Solar and Storage Industries Association (MASSIA). These estimates are based on industry experience; there is no existing data available.

By applying this end-of-life projection to the existing NJ installed and projected capacity, it is possible to estimate solar panel recycling quantities into the future. Figure 3 (below) shows how that aging histogram has been merged with the BPU's annual capacity and installation data. The earlier installations are already nearing ages of gradually higher replacement rates. The columns to the right show projections using the aging histogram for what capacity (in kW) might be expected to be replaced in future years. Column totals for future years' replacement out to 2040 are graphed in Figure 2. As mentioned above, Figure 4 shows ongoing low-level decommissioning over time, with spikes at 15, 20, and 25 years, and a gradual decline after that point.

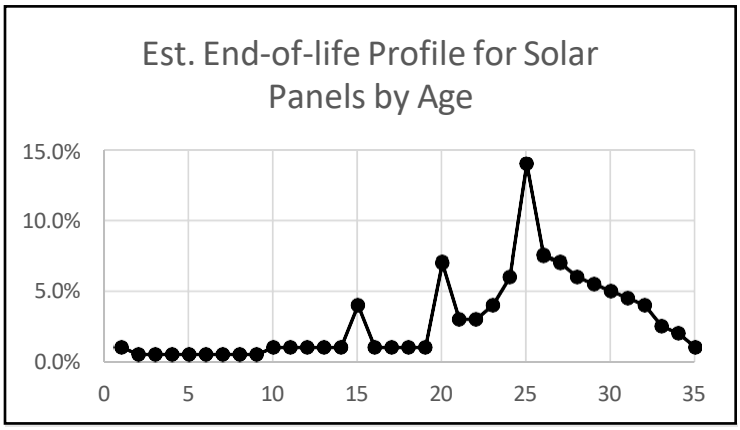


Figure 2: Estimated timeline for decommissioning of solar panels through 35 years of use.

END-OF-LIFE MODULE FLOW IN KILOWATTS										
	INCENTIVE PROGRAM					Year ---------- >				
VINTAGE YEAR	CORE/REIP	SREC	TREC	SREC-II	Total	2022	2023	2024	2025	2026
2000		23			23	1	0.92	1.37	3.20	1.72
2001	19	5			24	1	0.16	0.21	0.32	0.74
2002	258	659			917	64	27	27	37	55
2003	2,613	1,020			3,632	54	254	109	109	145
2004	5,422	2,502			7,925	119	119	555	238	238
2005	12,788	9,526			22,314	223	335	335	1,562	669
2006	20,214	18,227			38,441	384	384	577	577	2,691
2007	11,332	14,236			25,567	767	256	256	384	384
2008	10,262	28,193			38,455	192	1,154	385	385	577
2009	27,606	56,490			84,096	420	420	2,523	841	841
2010	23,731	120,908			144,639	723	723	723	4,339	1,446
2011	1,152	446,693			447,845	2,239	2,239	2,239	2,239	13,435
2012		333,251			333,251	1,666	1,666	1,666	1,666	1,666
2013		220,355			220,355	551	1,102	1,102	1,102	1,102
2014		203,732			203,732	509	509	1,019	1,019	1,019
2015		196,173			196,173	490	490	490	981	981
2016		408,227	45		408,272	1,021	1,021	1,021	1,021	2,041

2017		351,656	68		351,724	879	879	879	879	879
2018		330,560	1,152		331,712	829	829	829	829	829
2019		449,844	3,226		453,070	1,133	1,133	1,133	1,133	1,133
2020		140,455	180,996		321,451	804	804	804	804	804
2021		277	155,006	200,000	355,283	1,776	888	888	888	888
2022				407,000	407,000		2,035	1,018	1,018	1,018
2023				720,000	720,000			3,600	1,800	1,800
2024				757,000	757,000				3,785	1,893
2025				799,000	799,000					3,995

Figure 3. Partial view of spreadsheet predicting failure rates applied to existing and future solar installations in NJ. The first three columns apply to solar panels that were installed during the successive incentive programs and column 4 shows projected installed capacities (in kW) into future years.

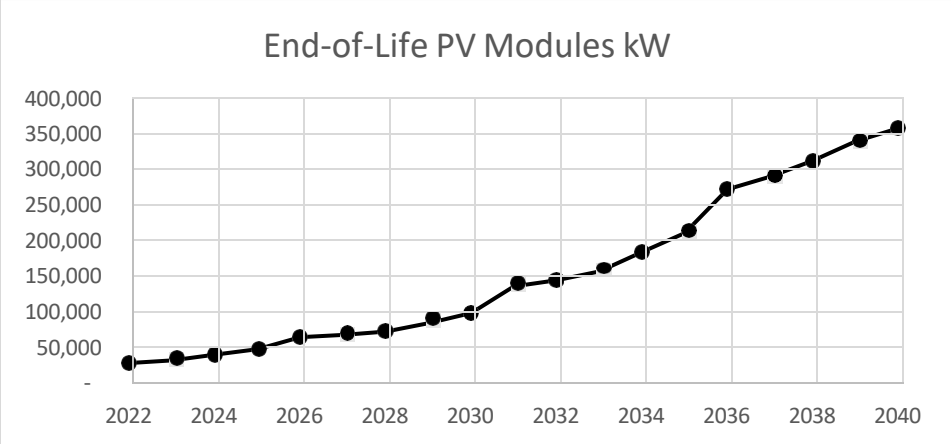


Figure 4. Cumulative predicted solar panel replacements (in kW) for NJ's current and projected future installation.

Mid-Atlantic Solar & Storage Industries Association (MSSIA) forecasted the flows of end-of-life modules through 2040 using the following:

1. Data regarding past installations published by the Board of Public Utilities (BPU).
2. Plans for future installations from the Energy Master Plan, including the Integrated Energy Plan, and program goals and plans adopted by BPU.
3. PV module specification data.
4. Industry experience regarding how module sizes and power ratings changed over time.
5. Assumptions regarding percent of modules that will reach end-of-life for various causes and purposes by number of years of service from 1 through 35, with the simplifying assumption that 100% of modules reach end-of-life by year 35.

The flows of end-of-life modules were calculated by number of modules, by volume, by weight, and by total power rating for each year through 2040. Selected results are shown below in Figure 5.

Year	Cumulative end-of-life modules		
	No. of Modules	**Volume (cy)**	**Weight (tons)**
2025	**306,900**	**4,700**	**7,700**
2030	**1,267,600**	**19,600**	**32,100**
2035	3,582,000	55,600	91,400
2040	7,980,900	125,300	206,800

Figure 5. Estimated New Jersey End-of-Life PV Module Accumulation forecasted through 2040. While this weight starts out relatively low, it will grow almost thirty-fold between 2025 and 2040.

Section III: Who Owns the Panels?

The market for solar power can be broadly grouped into "utility-scale" and "distributed generation" installations. Utility-scale projects are large capacity projects designed to sell electricity into the grid. These projects are owned either by the utility itself or by an independent power producer that has contracted to sell all the power produced by the project to the utility. Distributed generation projects, on the other hand, are generally intended to satisfy all or a portion of the energy needs of the owner or occupant of the property where the equipment is installed. For example, a rooftop system that generates electricity for consumption on the property could be considered a distributed generation project.

For purposes of this analysis, it is assumed that the breakdown of ownership of the solar power projects has remained at a fairly constant ratio over the years. This means that about one-third of the solar panels are owned directly by the property owner and two-thirds are third-party ownership (for both utility-scale or distributed generation projects).

Property owners with access to credit can apply for a loan from a bank to finance the acquisition of solar panels. Accordingly, the solar generating system is owned directly by the property owner. The benefits of this approach include the ability to claim tax benefits accruing to an equipment owner and the standing to deal directly with the utility in establishing the power purchase arrangements. However, direct ownership may not be a good option for many entities interested in acquiring solar generating capacity. Those interested in acquiring solar generating capacity may not have a sufficiently high credit rating or collateral to qualify for financing or may not have sufficient taxable income to benefit from the various tax incentives available including investment tax credits. In these cases, entities that cannot benefit from tax advantages available to solar equipment owners can benefit from entering into other tax saving arrangements where gains may be accrued by a third-party owner. Hence, power purchase agreements and solar leases can help distributed generation installations obtain the benefits of cheaper solar energy without substantial upfront costs. This is thought to be a factor in the popularity of solar leases and power purchase agreement among distributed energy installations. This also helps to explain why the vast majority of commercial installations are financed through third-party ownership structures.

As of early 2021, in New Jersey, direct ownership by the property owner represented thirty-eight (38%) percent of installed solar power capacity at 39,723 installations with a total capacity of

1,164,211 KW. Ownership by third-party investors represented sixty-two (62%) percent of installed solar power capacity at 98,389 installations with a total capacity of 1,734,908 KW.

While ownership of an installation, to some degree, will account for the responsibility for end-of-life disposal of the solar panels, actual responsibility can be negotiated as part of an installation contract for both end-of-life events as well as other events that may cause panels to be removed from the property for disposal. The following is a sample of events that require allocation of responsibility between lessor and lessee in cases of third-party financing of solar power installations:

- Lessor arranges for system repair and maintenance;
- At the end of the initial lease term, system is removed;
- At the end of the initial lease term, system is repowered and upgraded;
- At the end of the initial lease term, system may be purchased;
- At the end of the initial lease term, lease may be renewed;
- If ownership of property changes, successor may assume lease;
- If ownership of property changes, owner may prepay lease balance;
- If ownership of property changes, owner may move system to new location;
- Damage to system insured by lessor is responsibility of lessor, unless the lessee is grossly negligent;
- Lessor contractors repair, remove, replace system throughout lease term;
- Lessor may assign, sell, or transfer system and lease without lessee's consent;
- Assignee takes on all of lessors' obligations; or
- Foreclosure by mortgagee, lease may be terminated, and system removed.

Section IV: What Are the Challenges?

Legislation and policies such as the New Jersey Global Warming Response Act, and Energy Master Plan, along with the ever-increasing trend to switch to renewable sources of energy such as solar energy, will continue to increase the number of EOL solar panels to be managed in an environmentally sound manner. While there are no immediate concerns over the management of large quantities of EOL solar panels, it is the Commission's conclusion that the lack of a comprehensive approach to do so would prove problematic in the future.

As indicated in Section I of this report, the major component of a solar panel is glass. Although glass is a recyclable material, its intrinsic value after recovery will be low. In addition, labor costs associated with the removal and separation of solar panel components may further lower the value of the commodity. Consequently, disassembly and recycling of EOL solar panels is unlikely to be a profitable operation and may require funding sources, such as a per module fee on all future installations.

Challenges expressed by Commission members include the following:

- Unless further processing such as "high-value recycling" (see Appendix A, Additional Sources of Information) of raw material is conducted to recover the potentially harmful metals (e.g., lead, cadmium, and selenium), and recover rare materials (e.g., silver, tellurium, and indium), disassembly and processing of EOL solar panels may compromise encapsulation (discussed in Section I) and result in cell/wire/solder material in modules (including the metals) to be released into the environment. Breaking encapsulation in this manner would dramatically increase the environmental exposure to potential toxicants. Processing technology – including chemical and thermal treatments - to recover precious metals and prevent leaching of lead and other metals may be costly at this time, and result in environmental exposure to lead and other toxicants.

- Price increases due to fees (deposits, advanced recovery fees (ARF), or Extended Producer Responsibility (EPR) fees), may dampen demand for solar panel modules, which would be contrary to the Energy Master Plan goals and other state policies designed to promote renewable energy production.

- The highest revenue generation for solar panel recycling would be to process all components of the panel separately, but removal of the polymer adhesive is difficult from both a cost and processing perspective.

Section V: Current and Developing Recycling Technologies

Current Recycling Facilities in the US

Thus far, solar panel recycling has primarily been undertaken by glass and electronics waste recyclers. Certain aspects of glass and electronic waste recycling are readily applicable to solar panels, which are ~70% glass. A major distinction, however, is that solar panels must withstand years to decades of outdoor weather conditions. To this end, solar panels are encased in protective polymer adhesive layers that are extremely difficult to remove, by design. Encased within the polymer adhesive are the glass supports, silicon cells, and metallic connections.

As of late 2022, the Solar Energy Industries Association (SEIA) has five solar panel recycling partners: Cascade Eco Minerals, Echo Environmental, First Solar, Green Century Recycling, and ERI.[1] Below are brief summaries of US companies engaged in solar panel recycling, plus the recycling process used, if available.

(1) Cascade Eco Minerals https://www.cascadeecominerals.com/

- Locations: Waxahachie, Texas; Lawrenceburg, Kentucky; Upper Sandusky, Ohio; Yuma, Arizona; Natrona Heights, Pennsylvania; Hardeeville, South Carolina; Portland, Oregon

- Recycling process: Remineralize glass from solar panels into roadbead, paint fillers, fiberglass, bottles, etc. Other materials are transferred to recycling partners. Laminated parts are separated by a proprietary process.[2]

(2) Echo Environmental https://echoenvironmental.com/
- Locations: 166,000 square foot recycling and reuse facility in Carrollton, Texas
- Recycling process: Removal of aluminum frames and wires. Panels are then shredded, and a milling process is used to separate glass for fiberglass insulation and reflective paint. Metals-bearing materials are mixed with other electronic waste and smelted.[3]

(3) First Solar https://www.firstsolar.com/en/Solutions/Recycling
- Location: Recycling of First Solar CdTe panels in Perrysburg, Ohio[4]
- Recycling process: Panels are shredded to break module into large pieces, and then a hammermill is used to crush glass to 4-5mm pieces. Acid and peroxide treatments to remove semiconductor films are performed prior to separation of glass from metal rich materials.
- High-value recycling process provides closed-loop semiconductor.
- The only US manufacturer of solar panels with in-house recycling capabilities.

(4) Green Century Recycling https://greencenturyonline.net/
- Location: Portland, Oregon
- Recycles electronic waste

(5) Electronics Recyclers International[5] https://eridirect.com/
- Locations: Fresno, California. Facilities for panel shredding are planned for Indiana and Massachusetts
- Recycling process: After removal of the junction box, the entire panel is shredded and shipped to glass recyclers.

Other US facilities, not partnered with SEIA, include:

(6) We Recycle Solar https://werecyclesolar.com/
- Location: Phoenix, Arizona
- Recycling process: Removes the aluminum frame and wiring and shreds the panels. The shredded mix then undergoes secondary chemical processing, electrolysis, and additional processes to separate the metals, silicon, and glass for shipments to downstream processors.[6]

(7) Dynamic Lifecycle Innovations https://thinkdynamic.com/
- Location: Onalaska, Wisconsin
- Recycling process: Dismantles and shreds solar panels.[7]

(8) Cleanlites Recycling https://cleanlites.com/

- Location: Cincinnati, Ohio. Other facilities in South Carolina, Michigan and Minnesota
- Recycling process: Solar panels are dismantled; aluminum, iron copper and steel from frame sent downstream; glass sent downstream; silver and copper recovered from panel; silica loaded into reactor furnaces for "flux."[8]
- Is a member of SEIA according to a 2019 brochure but is not listed on SEIA website.

(9) Desktop Disposal (www.desktopdisposal.com) http://www.desktopdisposal.com/

- Location: Irving, Texas
- Electronics recycling company serving contiguous US.

What are the current recycling technologies?

In the US, solar panel recycling efforts have primarily been undertaken by electronics recycling companies. Typical recycling processes involve removing the aluminum frame and junction box, then shredding the remaining panel, which is comprised of glass, silicon, silver, copper, and aluminum.[9] Silicon is generally shredded along with the glass support.[11] These components are embedded in ethylene vinyl acetate (EVA), a protective polymer adhesive. In some recycling processes, chemical and thermal treatments of the shredded panels are applied to extract metal components. Glass and silicon waste can be recycled as low-quality glass fillers. However, upgrading recycling processes to recover higher-purity silicon may increase the value significantly.

What are the limits/constraints of current recycling technology? Status of separation technologies and costs.

A 2019 report funded by the US National Science Foundation,[10] suggests that materials recovered from commercial silicon solar panel recycling were estimated to generate a revenue of $3/panel, based on the recovery of glass at a price of $0.06/kg, aluminum ($0.95/kg), and copper ($5.00/kg) whereas the cost of recycling is $25/panel for a standard 60-cell aluminum back-surface field (BSF) panel. This estimate does not consider the cost of decommissioning and shipping of panels to recycling plants.

What other technologies are under development?

Improved separation technologies have been under development, including selective recovery. Selective recovery of silicon from panels could increase the resale price to $5.52/kg for second-grade solar silicon in which the emitter and back-surface field have been removed.[10] These latter layers are heavily doped and decrease the silicon quality.[11] Such recovery will require gentle processing methods to remove the EVA binder such that the silicon wafer (the building block of solar panels) can be separated from the glass support without being damaged. Chemical and

thermal treatments have been under development to separate silicon and EVA, thus allowing for recovery of silicon.

- Chemical Treatment. Trichloroethylene[12] and ortho-dichlorobenzene[13] have been demonstrated to dissolve EVA in PV modules. These methods can effectively remove EVA but generate liquid chemical waste and can require additional energy (e.g., heat and ultrasonication).

- Thermal Treatment. Studies have demonstrated that EVA can be burned out of solar panels during thermal treatment at 400º Celsius or higher.[14,15,16] After thermal decomposition of EVA, one study found that the recovered silicon wafer could be reused in solar cells with comparable solar cell conversion efficiencies to untreated cells.[17] NCP Incorporated, a Japanese-based company, developed a method to use a sharp blade heated to 300 ºC to separate silicon from glass. This company sells automated equipment for solar panel recycling using this technology.[18]

  The Commission is however skeptical of claims that silicon wafers would survive the process of chemical or thermal separation in a functional state, and thereafter be reused in solar panel manufacturing. Currently, silicon wafers used in solar manufacturing have a thickness of 160 micromeres or about 0.006 inches. The industry trend is to reduce this thickness to produce more wafers from the same silicon crystal ingot, and thereby lower the manufacturing costs for solar panel.

- Pyrolysis. This process involves heating the panels in the absence of oxygen to break down the EVA layer.[19, 20] One recent study found that heating solar modules to 500 ºC for 1 hour in a nitrogen environment could effectively remove 99 wt% of EVA. This method has been implemented in a solar panel recycling pilot plant in Germany.[21]

Section VI: Current Management Practices in New Jersey

While subject to other solid or hazardous waste regulations, there are currently no regulations, official policies, or guidelines specifically for recycling or reusing EOL solar panels in the State of New Jersey. In other words, New Jersey has very limited knowledge of how such panels are reused or recycled at this time. The Commission's endeavor is to rectify this situation.

It is known that PSE&G, New Jersey's biggest utilities company, ships its damaged or otherwise non-functional modules to out of state hazardous waste landfill(s), at substantial cost. Also, some independent operators may take it upon themselves to collect and transport EOL panels to out of state facilities. Anecdotal evidence suggests that some panels are being disposed of in New Jersey's solid waste landfills.

Section VII: Current Management Methods by other US States

California

California began regulating EOL PV panels as Universal Waste (UW) on January 1, 2021. This program is administered under the CA Department of Toxic Substances Control (DTSC). Under the program:

- UW handlers may handle, treat, or dispose of EOL panels and must file a notification for each of these activities.
- UW handlers that accept more than 100kg/200 lbs. from offsite, or who generate over 5,000kg/10,000 lbs. of PV modules, are also required to submit an annual report to DTSC.
- Authorized treatment activities under UW PV modules regulations allow UW handlers to conduct removal, dismantling, and processing treatment activities if these authorized treatment activities do not involve the use any heat or chemicals (including water).

Generators/UW handlers are expected to contact solar panel manufacturers to obtain information on the contents of PV panels, their toxicity. Additionally, DTSC assumes that older generations of solar panels are hazardous. However, California assumes all EOL solar panels to be UW, unless such panels are determined to be non-hazardous, based on testing/manufacturer's information. The first full year of implementation was the 2021 calendar year, and the reporting deadline for this program was in February 2022. As of this writing, CA DTSC has not yet released a public report on the program. Essentially at this point, it is too early to assess how California's approach has impacted the solar panel industry and whether it may be considered a success.

Washington State

In 2017, the Washington Legislature passed Senate Solar Incentives Job Bill 5939 (codified as RCW 70A.510), amended with ESHB 2645, then delayed by the 2021 Legislature for two years by HB 1393, to allow for analysis and quantification of the potential future product and waste stream.[1] One portion of the bill created Chapter 70.355 RCW (Photovoltaic Module Stewardship and Takeback Program), which requires manufacturers of solar panels, also known as photovoltaic or "PV" modules, to provide the public a convenient and environmentally sound way to recycle all modules at no cost to their owners. The manufacturers must also meet specific recycling standards. The program, which had its first full year of implementation in 2021 includes both residential solar panels as well as large-scale utility projects, like solar farms. As of 2021 all solar manufacturers with sales in Washington will be required to participate in the stewardship program's takeback and recycling mandates, as well as submit annual recycling reports to the Department of Ecology.[2]

As of 2020, there were a total of 264 MW installed in Washington State, representing 0.26% of the total installed capacity in the US. The Solar Energy Industry Association (SEIA) expects the state to install an additional 834 MW of solar modules in the next five years, an increase consistent with the national increase in solar deployment. According to available data, 42 manufacturers have sold into Washington State since 1999, with the 2018 and 2019 market dominated by three companies: Itek Energy (no longer manufacturing in, or selling into the state), Hanwha Q-cells,

and Silfab Solar. The majority of installations are small-scale rooftop systems under 1 MW and were supported by subsidies from the state. Those subsidies have since been terminated for new installations.[3]

Illinois

The Illinois Sustainable Technology Center (ISTC), at the University of Illinois Urbana-Champaign, launched a Solar Panel Recycling Initiative in 2017 in response to the Illinois Future Jobs Act of 2016 and the growing projections of decommissioned PV in the state. The Illinois Future Jobs Act requires the state to increase installed PV capacity to approximately 2,700 MW by 2030—up from 87 MW in 2018 (Holm and Martin 2018). As part of the Solar Panel Recycling Initiative, ISTC in conjunction with the Illinois Environmental Protection Agency, formed a PV EOL management stakeholder working group. The working group includes a diverse set of stakeholders that hopes to identify barriers to PV module recycling and to develop policy, technical, and economic solutions that may enable environmentally sustainable EOL PV management decisions and the recovery of valuable resources in Illinois (ISTC 2019).

North Carolina

On July 19, 2019, the Governor of North Carolina signed House Bill (HB) 329 directing the North Carolina State's Environmental Management Commission to, among other things, develop regulations for decommissioning utility-scale solar and wind energy projects and management of end-of-life photovoltaic modules, energy storage system batteries, and other equipment deriving from such projects. The legislation required the commission to establish a stakeholder involvement process by September 2019 and set a deadline of January 1, 2022, to adopt new rules. On November 20, 2020, the North Carolina Department of Environmental Quality (DEQ) and the Environmental Management Commission issued a draft report for a 25-day review and comment period, which ended on December 14, 2020. Subsequently, on January 1, 2021, the final report was issued and approved by the EMC at its meeting on January 14, 2021.

Key findings and recommendations of this report:

- EOL PV modules will require TCLP testing to be considered non-hazardous and the North Carolina DEQ has asked ASTM to adopt a sample preparation method for this procedure.
- The waste hierarchy of waste reduction, reuse, and recycling prior to disposal applies to EOL PV modules, and only non-functioning PV modules should legally be considered EOL. Every effort should be made to reduce, reuse, and recycle PV modules. Reuse, refurbishment, and recycling are all environmentally preferable management options, and are largely economically advantageous.
- However, recycling opportunities are limited and costly, but costs should come down as more PV modules reach EOL. This is predicted to happen, to a greater extent, around 2030.
- More infrastructure would be needed for the collection and transport of EOL PV modules.
- North Carolina does not currently recommend a manufacturer stewardship program but is still considering it for the future.

Section VIII: International Approaches to EOL Solar Panel Management

European Union (EU)

EU uses a specific approach to Extended Producer Responsibility (EPR) that focuses on the responsibility of the "producer" placing electrical and electronic equipment (EEE) on the market. EU's WEEE Directive defines "producer" in a manner that applies not only to original equipment manufacturers (OEM), but also to importers, distributors, and E-commerce platforms selling directly to consumers. This means the cost for managing an EOL solar panel is the responsibility of the party that placed (sold) the panel on the EU market.

WEEE Directive 2012/19/EU was published on 24 July 2012 and as an EU Directive, it must be transposed into each EU member state's national legislation.

The Directive:

- Requires all EOL solar panels to be collected and processed.
- Prohibits landfilling of EOL panels.
- Establishes Producer Compliance Schemes (PCS) intended to help EEE producers to fulfill EOL obligations by providing data collection, and legal and administrative infrastructure.
- Each EU member state has a slightly different approach to PCS, aligned with its own individual recycling/waste management infrastructure and national administrative law.

As nonprofit organizations, Producer Compliance Schemes levy fees solely to cover operating and treatment costs, not for profit. This fee is included in the sale price of EEE and passed on to the end-consumer, who bears no further financial responsibility.

The EU Commission mandated the European Standardization Organization (CENELEC) to develop supplementary standards for the collection, transport, and treatment of waste for all products covered by the WEEE Directive. The standards specific to PV panel collection and treatment (EN50625-2-4 and TS50625-3-5) include technical requirements aimed at preventing pollution and improper disposal, minimizing emissions, promoting increased material recycling and high-value recovery operations, and impeding PV waste shipments to facilities that fail to comply with standard environmental and health and safety requirements.

Japan

Like the US, Japan does not have specific regulations for end-of-life PV modules. Therefore, disposal is treated under a general regulatory framework for waste management, known as the Waste Management and Public Cleansing Act. The regulation defines the wastes covered, requirements for industrial waste generator and handler responsibilities, and other factors related to industrial waste management aspects, including landfill disposal. Together, the Japanese Ministry of Economy, Trade and Industry (METI) and the Ministry of Environment (MOE) have examined, studied, and released assessments as to the handling of end-of-life renewable energy

equipment that includes PV equipment including modules, solar water heaters, and wind turbines. In June 2015, they published a roadmap to promote the processes for collection, recycling, and equipment treatment. The roadmap identifies necessary process and infrastructure development, including equipment development for the promotion of design of low-cost recycling technology R&D, environmentally conscious PV equipment designs, process guidelines for optimally dismantling, transportation and logistics, and treatment (mechanical, chemical, etc.), and communication to the public-at-large and to solar energy consumers. As the roadmap identifies several pathways for development, the Commission expects that the roadmap will lead to further consideration of processes, requirements, and other national policies as achievements are made and new information is uncovered throughout its progress well into 2035.

China

As in the US and Japan, China does not currently have specific regulations for end-of-life PV modules. According to the 2016 report from the International Renewable Energy Agency (IRENA), China has established related technology research under the National High-tech R&D Program for PV Recycling and Safety Disposal Research, covered under the Twelfth 5-Year Plan, which includes milestones and recommendations for policy, process, and technology R&D and promulgates the examination of the need for special laws and regulations. The policy provisions may include end-of-life PV panel recycling, targets for recycling rates and the creation of necessary financial frameworks. Regarding technology and R&D, the recommendations focus on the development of high-efficiency, low-cost and low-energy-consumption recycling technologies and design recommendations for c-Si and thin-film PV panels. These considerations also include recommendations for on-site recovery of PV equipment intended for recycling.

South Korea

Like the other Asian countries, South Korea does not have specific regulations covering the end-of-life management of waste PV modules. However, a 2015 report of "energy information and policy support projects" from the Ministry of Trade, Industry and Energy (MOTIE) recommended the exploration of a draft regulations potentially mandating the reporting of PV waste disposal. It was recommended that the potential requirements be added to the existing "Act on the Promotion of the Development, Use and Diffusion of New and Renewable Energy" to encourage PV recycling, including R&D on new PV module recycling equipment.

Recommendations

The Commission's recommendations are based on two main goals:

Goal 1: Recycling (processing) EOL solar panels and sending components thereof to legitimate and verifiable end-markets, with the eventual goal of recycling 100% of the components. Directly correlated to this concept is reduction and ultimately elimination of disposal of EOL solar panels and components thereof.

Recommendations for recycling EOL solar panels are divided in two possible pathways that could be implemented individually or in conjunction with each other:

- Recommendation 1.1 - Construction of new PV solar panels Recycling Centers.
- Recommendation 1.2 - Manage PV solar panels as Universal Waste at existing facilities.

Goal 2: Extended use and reuse of solar panels.

Recommendations for extended use of solar panels are also divided in two pathways that could also be implemented independently or in conjunction with one another:

- Recommendation 2.1 - Continued use of solar panels beyond nominal or arbitrarily determined life span.
- Recommendation 2.2 - Reuse of solar panels by shipping the panels to both domestic and international areas with fewer financial resources and lower accessibility to new solar panels.

Goal 1 Recycling

Recommendation 1.1 - Encourage and Incentivize Construction of New Solar Panel Recycling Centers in New Jersey

As detailed in Section V. of this document, there are currently several companies in other states engaged in solar panel recycling operations, reportedly with great success.

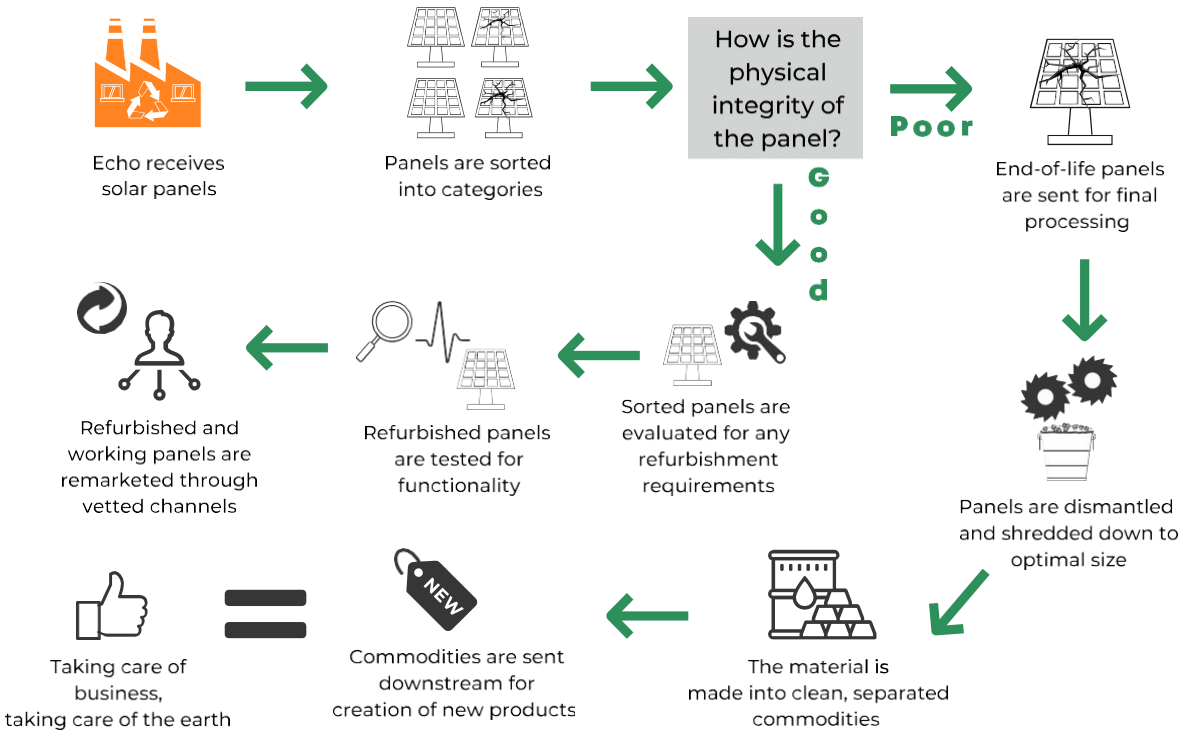
One common characteristic among these companies is their years of experience in automobile glass recycling and/or precious metals recovery operations. The technical knowledge, skilled labor, tools and technologies, and precision acquired over the years by such companies have proven significantly valuable when applied to solar panels recycling operations.

To illustrate what operations to recycle EOL solar panels may entail, the Commission presents as an example, Echo Environmental located in Carrollton, Texas:

Echo Environmental
2101 W Belt Line Road

Carrollton, TX 75006
https://echoenvironmental.com/solar-panel-recycling/

As depicted in the flow chart below, panels received at Echo Environmental are initially evaluated based on physical conditions to determine whether they can be refurbished or should be processed. Panels that undergo refurbishment are tested for functionality and remarketed. The remaining panels are processed, and materials generated are shipped out as products to downstream markets. According to Echo Environmental, no components of panels processed at this site are sent for disposal at a landfill. For example, there are established end-markets for glass (home insulation) and metals (smelters) generated by the EOL solar panel processing.



The above-described operations meet the recommendations of the Commission:

- Extended use of panels is achieved through refurbishing and remarketing.
- Recycling of components of solar panels is maximized.
- Landfilling of EOL solar panels (and their components) is minimized/eliminated.

The following subsections will discuss the possible tools available for implementing Recommendation 1.1.

1.1(a) **What Economic Incentives May Be Offered to Solar Panel Recyclers?**

To avoid additional costs associated with out-of-state disposal, the State of New Jersey will need a means of recycling solar panels. Based on estimates of solar panel decommissioning rates, it would be ideal for New Jersey to have an established solar panel recycling infrastructure in place by 2025 and no later than 2030. Economic incentives are recommended and will likely be required to attract businesses, that conduct solar panel recycling, to the State of New Jersey from other states accustomed to fewer environmental regulations or lower taxes.

Recommendations for economic incentives that may be offered by the State of New Jersey include:

(1) Infrastructure:10-year tax abatement on building (recycling center).
(2) Off-set the cost of equipment: shredders, hammermill, balers, and forklifts.
(3) Performance rebates for creating new jobs within the community.
(4) Sustainable workforce and easily accessible interstate system, public transportation, and air/shipping ports.
(5) Further analysis of opportunities to incentivize siting of recycling facilities on brownfields sites and offset start up costs.
(6) Methods to ensure equitable distribution of potential economic incentives

1.1(b) **Regulatory Approach**

With regards to the regulatory aspect of such operations, the Commission recommends the following:

(1) In an effort to encourage siting of a potential solar recycling facility in New Jersey, state and local regulatory requirements should be streamlined to be minimally burdensome to the extent possible, while still meeting all regulatory obligations and ensuring equitable siting decisions to avoid impacts to members of overburdened communities.

(2) Amend the scope of the New Jersey Solid Waste regulation, at N.J.A.C. 7:26-1.1, to exempt EOL solar panels that are recycled, from these regulations (see Section 1.2).

(3) The NJDEP - Division of Sustainable Waste Management should keep records on all incoming EOL solar panels and end-markets for same, and conduct periodic (e.g., quarterly) inspections of the facility. The Division of Air Quality would issue permits for equipment used for such operations, as deemed necessary.

Summary of Recommendation 1.1

The Commission recommends that the State of New Jersey (NJ Economic Development Authority) should communicate with established US-based solar panel recycling facilities (as outlined above) to determine under what conditions they would construct and operate a solar panel recycling facility in the state. A description of the existing solar panel recycling facilities in the US is provided in Section V. of this Report.

The timeline from construction to operation of a solar panel recycling facility is estimated to be approximately one year. This estimate is based on information drawn from the Commission's discussion with Echo Environmental. It also assumes that all permitting and other requirements are in order, and incentives and infrastructure support is provided by the State of New Jersey.

Upfront, an agreement to have an out of state company construct and operate a solar panel recycling facility in New Jersey would require substantial economic and regulatory incentives and/or concessions on the part of the state. It may also take time to implement. Nevertheless, such agreement offers major advantages which would make this an attractive and practical option because:

- As outlined in Section 1.1 above, operations of such facility would meet all the stated recommendations of the Commission concerning the management of EOL solar panels: minimize/eliminate landfill disposal, maximize recycling of components, and extend the life of solar panels through refurbishment.
- Once the operations commence, NJDEP would have effective oversight of such operations, without dedicating a great amount of its resources to this task.
- The facility should determine a per module fee for managing EOL solar panels based on market conditions.
    - Noting that transportation constitutes a significant portion of the overall costs for managing EOL panels, having a recycling facility in New Jersey would significantly lower these costs.

To implement Recommendation 1.1 the Commission recommends that NJDEP amend the New Jersey Solid Waste rules, and specifically N.J.A.C. 7:26-1.1(a), to exempt EOL solar panels from such regulations.

Recommendation 1.2 - Management of EOL Solar Panels as Class D (Universal Waste)

The other option studied by the Commission was to recycle EOL solar panels through the existing network of Class D (Universal Waste/UW) facilities. There are currently nine (9) Class D recycling centers in New Jersey that are authorized to receive, store, process, or transfer universal waste, through General Approvals (GA) issued by NJDEP.

1.2(a) **What is the Universal Waste Rule (UWR)?**

- Adopted by the United States Environmental Protection Agency (USEPA) in 1994, Universal Waste is a specific designation that allows for alternative management options for specific waste streams that would otherwise be considered hazardous waste under the Resource Conservation and Recovery Act (RCRA).
- UWR may be found under 40 CFR Part 273 and lists batteries, mercury containing devices, pesticides, and some lamps (e.g., fluorescent) as Universal Waste (UW). Each State may choose to adopt additional waste streams as UW.
- New Jersey adopted its UWR under N.J.A.C. 7:26A-7 *et. seq*. (Recycling Regulations) and includes additional waste streams, namely consumer electronics, and oil-based finishes.

- Universal Wastes may be recycled or reused rather than disposed of or treated as Hazardous Waste. Managing these materials as Universal Waste rather than Hazardous Waste poses significantly less risk to public health and the environment. Furthermore, the cost of managing these materials as Universal Waste is considerably lower than Hazardous Waste.

1.2(b) **Designation of EOL Solar Panels As UW**

In order to designate EOL solar panels as UW, NJDEP must evaluate the suitability of a UW designation, including potential environmental and socio-economic impacts. and undertake the process to amend the New Jersey Recycling Regulations, and specifically N.J.A.C. 7:26A-7 (Standards for Management of Class D Universal Waste).

1.2(c) **How to Implement Managing EOL Solar Panels as UW**

- Establish a network of collection centers (depots) to receive EOL solar panels. Existing Class D (UW) recycling centers may qualify as depots. To begin with, select and designate three (3) regional depots, strategically located in south, central, and north New Jersey. Should there be interest on behalf of additional Class D facilities to participate in such operations, additional depots may be designated, depending on market conditions and at NJDEP's discretion.
- Depots must have adequate capacities and offer pick-up services to industrial, commercial, and residential clients.
- Depots are required to be Responsible Recycler (R2)[1] certified by Sustainable Electronics Recycling International (SERI)[2].
- Each depot will act as an EOL solar panel transfer facility to a designated downstream processing facility. However, aluminum frames and junction boxes may be removed by the operator to offset operation costs.
- Class D (UW) recycling centers are currently responsible for downstream processing of electronics they accept. Similarly with solar panels, it will be the depot's responsibility to ensure that panels are properly processed by designated downstream facilities.
- Establish a technology-neutral advanced recovery fee (ARF) per panel, at the time of purchase by consumers.
- Establish an Extended Producer Responsibility (EPR) in which recyclers would be able to bill PV panel producers for each panel recycled.
- NJDEP, along with NJ Department of the Treasury, would implement a method/structure to collect and manage fees.
- Implement a landfill ban on disposal of EOL solar panels in New Jersey.
- UW handlers will not be part of the above-described EOL solar panel management operations. The Commission believes that limiting such operations to Class D recycling centers only, would make the program more manageable. At NJDEP's discretion, UW handlers may be added to the program in the future, should demand for services exceed the capacity of the Class D recycling centers.
- Each depot may be used to store panels with encapsulation intact, on a temporary basis.

1.2 (d) **Advanced Recovery Fee Structure or Extended Producer Responsibility**

Suggestions concerning this topic were put forward by the Commission members, as described below:

- To develop the ARF, NJDEP, BPU, or other appropriate entity would conduct a cost study to estimate and project the cost of managing EOL panels by specific calendar years, e.g., 2025, 2030, 2035, and 2040. Fees would be imposed on manufacturers and distributors and gradually phased in, corresponding to those 5-year intervals.
- Develop an Extended Producer Responsibility Program for solar panels by which manufacturers and importers bear a degree of responsibility for the cost of managing EOL solar panels.

Alternatively, the above steps may be avoided by considering a pay as you go approach by which Class D recycling centers will set the cost of managing EOL solar panels based on operating costs and market conditions. According to the National Renewable Energy Laboratory (NREL), recycling a solar panel in the US can cost $15-45. Owners of EOL solar panels would bear the costs associated with the collection, transportation, and recycling of the EOL solar panels. The pay as you go approach has been successfully incorporated by many of the existing solar panel recycling facilities referenced in Section V. of this Report.

Summary of Recommendation 1.2

As detailed in Section 1.2 above, the Commission's recommendation is to designate and manage solar panels as universal waste, subject to the New Jersey Recycling Regulations https://www.state.nj.us/dep/dshw/resource/rules_docs/26%20CHAPTER%201.pdf.

Compared to Recommendation 1.1, the main advantage of this approach is the existing infrastructure already in place, i.e., universal waste recycling centers that may be utilized as transfer facilities for these panels. In other words, there is no need for a significant upfront investment. Furthermore, the necessary regulatory framework (Recycling Regulations) is also in place and would only require revisions to include solar panels. The Class D General Approvals issued to these recycling centers would have to be modified to authorize receipt, storage, and transfer of EOL solar panels. However, this modification of Class D General Approvals should be initiated by NJDEP, and all application fees required for these modifications should be waived by NJDEP. The proposed ban on disposal of solar panels in landfills would require legislative action.

On the downside, the fact remains that less than two (2) years into California's EOL solar panels management, there is simply not enough data to accurately assess the success/failure of managing these panels as UW. In other words, there is no proven record of success when it comes to Recommendation 1.2.

Another point of concern is that California DTSC, the agency tasked with overseeing solar panel recycling, does not have any information concerning downstream end-users. No explanation was provided by DTSC as to why no end-user information is available. The Commission can only speculate that tracking information, specifically concerning out of state end-users may be difficult or not practical. It would also be logical to assume that some components of the panels may end up in landfills.

Finally, unless the pay as you go approach is chosen, this recommendation would require NJDEP, BPU, or other appropriate entity to collect, manage, and distribute the ARF or oversee the EPR program. The management of these funds would require significant resources, including planning and staff hours. As previously mentioned, such fee would also increase the upfront cost of solar panels.

A likely scenario for management of EOL solar panels as Class D (UW) would be as follows:

- Class D Recycling Center receives and stores EOL solar panels.
- The recycling center conducts minimal processing by removing the aluminum frame and the junction box from each panel.
- Panels are subsequently shipped by the recycling center to an established recycling facility such as those described in Section V. of this Report.

To implement Recommendation 1.2, the Commission recommends that NJDEP amend the New Jersey Recycling rules, and specifically N.J.A.C. 7:26A-7, to include EOL solar panels as universal waste. At the same time, the Commission recommends legislation to explicitly ban disposal of EOL solar panels in New Jersey landfills. Based on the tipping fees charged by solid waste landfills in New Jersey, the ballpark figure is about $100 per ton. The estimated weight of a typical solar panel is in the 40-50 lb. range. Therefore, the tipping fee per solar panel would be in the $2-2.5 range. It should be noted that tipping fees in many other states (e.g., Ohio, Michigan, etc.) are significantly less than those in NJ.

The relatively low cost of disposal at landfill vs. recycling, preservation of landfill space, and protection of human health and the environment are the bases for the proposal by the Commission to ban disposal of EOL panels in landfills.

The Commission recommends an expedited process, to the greatest extent possible, to amend the above reference rules and suggests that:

- This report has identified the need for rule making.
- This report may serve as conceptual briefing for the NJDEP Commissioner.
- The Commission members represent a diverse background from business, industry, academia, and government. The Commission believes this background makes it unnecessary to hold stakeholder meetings, typically required for the rule making process.

Goal 2 Extended Use and Reuse of Solar Panels

According to the Solar Energy Industries Association's most recent Market Insight Report, as of the end of 2021 New Jersey ranked 20th among US states in the annual capacity of solar energy installations. Cumulatively, New Jersey has over 4.4 GW (gigawatts) of solar installed to date. At present, during spring and fall days with clear skies over the state, the proportion of the state's power being generated by in-state solar systems, from 11:00 AM to 3:00 PM, can reach over 30%.

Solar modules installed in New Jersey, as elsewhere, are expected to have a very long service life of 30 to 40 years or more. In fact, investors in PV systems typically analyze their investments for

an internal rate of return over a 25 to 35-year service life. Virtually all PV modules that are sold in the US have 25 year or 30-year warranties that guarantee more than 80% of rated power output at the end of the warranty. However, a small number of PV modules may reach the end of their service life earlier due to shipping breakage, accidental breakage either during installation or during service, or defects.

Additionally, the owners or site hosts of some solar projects may choose to re-power those projects with new modules, especially if the power output of those facilities degrades faster than expected.

Recommendation 2.1 - Extended Operation of Solar Panels

The Commission recommends that the State of New Jersey encourage and/or mandate extended use of solar panels. As noted above, a typical solar panel retains somewhere around 80% of its output at the end of its nominal lifetime (25-30 years).

Additionally, the Commission recommends that the State of New Jersey discourage and/or disincentivize early re-powering (replacement) of existing panels that perform at high efficiencies (80% or more) for beneficiaries of state incentive programs. As described in Section II of this report, and as depicted on Figure 1, repowering of solar projects will likely result in significant spikes in the number of module installations at 10-, 15-, and 25-year intervals.

The Commission also recommends that New Jersey should establish regulations, along with incentives and disincentives, financial, regulatory, or other as appropriate, to promote extended use of solar panels (80% < efficiency) and prevent replacement of same.

Finally, the Commission recommends requiring sellers/installers to inform clients in writing (via standardized form), at the time of sale/installation, that solar panels continue to operate at high efficiencies beyond their nominal lifetime. Clients will be required to acknowledge having been advised as such by signing the form.

Recommendation 2.2 - Reuse of Solar Panels

The Commission recommends reusing EOL solar panels that are still functional at high efficiencies (% threshold to be determined) within the US as well as collaborating with organizations identified below to assess appropriate opportunities for reuse outside of the US.

SolarRecycle.org is a non-profit organization with the stated mission of promoting sustainable disposal of end-of-life solar equipment by facilitating engagement with donation recipients, secondary markets, and recycling vendors. The organization's website provides a link for donation of equipment to other non-profit organizations that promote domestic and international reuse of functioning solar equipment: https://www.solarrecycle.org/general-9

The Commission's other proposals concerning the reuse of EOL solar panels are discussed below.

2.2(a) **Domestic Reuse**

One idea proposed by the Commission is to conduct outreach to charitable organizations, such as Habitat for Humanity, to reuse and re-install solar panels in their affordable housing projects. If the Commission received positive feedback from such organizations on this idea, then the Commission would evaluate and determine the logistics for such operations, including but not limited to:

- Who is responsible for testing and assessing the suitability, transportation of panels designated for potential reuse and costs of disposal - Current residential/commercial owners, the charitable organization, or an independent third party?
- Should the State of New Jersey exercise some oversight of such operations, or allow interested parties to make the arrangements?
- How to keep track of and ensure that reused panels are properly managed, when no longer functional in a few years.

In practical terms, domestic reuse of older modules with lower efficiencies may not be an attractive option, given the fact that the cost of new modules has been steadily decreasing.

2.2(b) **Overseas Reuse**

During its research and investigation, the Commission came across companies and organizations that export used electronics to countries in Africa and Latin America, with the stated goal of fair trade and responsible recycling.

One such entity is the World Reuse, Repair and Recycle Association (WR3A). The WR3A is a business consortium of used electronics recycling professionals, academics, and environmental activists operating in the US and overseas.

The Commission recommends reaching out to WR3A, or the individual electronics recyclers that make up this consortium, to develop a well-managed operation to ship used solar panels overseas.

Given the experience of these electronics recyclers, such operation would have many advantages, including but not limited to:

- The logistics already in place may be deployed to facilitate testing, evaluation, and shipping of used solar panels overseas.
- The operations would require minimum oversight by the State.

The State of New Jersey may incentivize the process of shipping used solar panels overseas by providing designated solar panel collection sites or depots, preferably located near the Ports of Elizabeth or Newark. Should New Jersey choose to manage EOL solar panels as universal waste, as described in Recommendation 1.2 of this report, the designated UW depots may be utilized for that purpose. In effect, overseas destinations for EOL solar panels would serve as end-markets for UW facilities.

A major concern of this recommendation is what will happen to panels sent overseas, once they are no longer functional. New Jersey will not be able to exercise any oversight on how such panels

may be disposed of or handled. It is imperative to receive guarantees from WR3A that at the end of their useful lives New Jersey's solar panels are not abandoned in place or handled in a manner that is not protective of the environment and human health. The cost of final disposition of the panels must also be considered, as the value of these panels must exceed the cost disposal for these schemes to be successful.

Another option worthy of consideration is for the State of New Jersey to reach out to international institutions such as the World Bank, and/or the International Monetary Fund to evaluate the possibility of cooperation/joint venture to ship EOL solar panels to developing countries. The World Bank has ongoing projects in India and African countries to generate electricity through solar panels. More information can be found at the following locations:

https://www.worldbank.org/en/news/press-release/2022/06/28/world-bank-provides-165-million-to-support-renewable-energy-in-india-s-residential-sector
https://projects.worldbank.org/en/projects-operations/project-detail/P162580
https://www.imf.org/en/Publications/fandd/issues/2020/03/powering-Africa-with-solar-energy-sy

Commentary on EOL Responsibility and Thin-film Solar Panels

Peripheral to the above recommendations, and worth noting is that it would benefit all stakeholders (e.g., power companies, solar panel manufacturers, solar installers, PV recyclers, and residents) for the New Jersey Legislature to consider specifying that all installation contracts for solar power generating equipment provide a clear allocation of responsibility for events that result in the removal and disposal of solar power generating equipment. In this regard, the recent publication by the National Renewable Energy Lab (NREL) titled "Best Practices at the End of the Photovoltaic System Performance Period," reviews the issues to be addressed during contract negotiations between lessee and system owner with the understanding that it is not easy to predict the best solution at the end of the performance in 25 to 30 years. Among NREL's recommendations, is the use of financial instruments to allocate responsibilities during the decommissioning process, including the use of decommissioning trusts, escrow accounts, surety or performance bonds, and letters of credit. Each of these mechanisms could also cover the cost of retaining a third-party to perform the decommissioning activity when the activity involves disposal of the PV system.

Additionally, as mentioned in Section I of the Report, thin-film solar panels, all manufactured by First Solar, Inc., constitute a tiny fraction of all PV modules in New Jersey. First Solar specializes in recycling of thin-film modules that are manufactured by same. The recycling facility, located in Perrysburg, Ohio, has an established high value recycling process, including semiconductor recovery for use in new solar panels. In accordance with characterization testing Toxicity Characteristic Leaching Procedure (TCLP) of new and aged thin-film solar panels conducted by Arizona State University's Photovoltaic Reliability Laboratory, EOL solar panels manufactured by First Solar are characterized as non-hazardous waste.

Accordingly, the Commission suggests that EOL thin-film modules be shipped to the First Solar recycling facility or alternatively, to other companies listed in Section V. of this Report that may recycle such modules.

Conclusion

The Commission met regularly from March 2021 through November 2022, and consisted of NJDEP personnel, as well as stakeholders from the legal, energy, solar panel production, installation, and recycling sectors. While the Commission members were not wholly of one mind on how solar panels should be managed in New Jersey, consensus was reached on the following:

1. Large numbers of solar panels will be reaching end-of-life in New Jersey in the next five years. This number will only increase.

2. The matter of disposition is complicated by the fact that these panels may have one of several ownership schemes.

3. Since solar power is also part of the Energy Master Plan and other clean energy initiatives undertaken in NJ, management of solar panel waste should not discourage their use. These panels may contain some hazardous substances, and a clear management strategy should be in place. In addition to containing harmful and potentially harmful substances, these panels also contain materials that are or are potentially economically valuable.

4. This strategy should include a clear delineation of responsibility for panel disposition.

5. A disposal ban should be in place.

Two main potential mechanisms were identified as frameworks for management, both with their own challenges. The first is some form of EPR, advanced recovery fee, or deposit. The second is to manage solar panels as universal waste (or similar classification). In either case, further testing should be performed to identify the type and levels of toxicity of solar panels. Additionally, steps should be taken to encourage the prolonged life of solar panels where appropriate.

Further, since a major cost in both the solar panel industry and the recycling industry is transportation, the Commission identified opportunities for the state to provide tax or other incentives for the development of solar panel recycling facilities within the state. This would reduce the costs of solar panel recycling and could lead to the creation of jobs and economic activity. While certain components of solar panels are easy to recycle (economically), others are not currently recyclable in an economically feasible fashion. Investments in these recycling technologies could hasten the arrival of viable recycling options.

Any of the paths identified would likely require regulatory or legislative action. Doing so expediently would ensure that the necessary infrastructure is in place, as large numbers of panels reach end-of-life, so that they are not disposed of in a manner that negatively impacts human and environmental health in New Jersey.

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APPENDIX A: Additional Sources of Information

- International Renewable Energy Agency (IRENA) Report – June 2016 https://www.irena.org/publications/2016/Jun/End-of-life-management-Solar-Photovoltaic-Panels

  The report defines "high-value recycling" of EOL solar panels as:

  (1) Potentially harmful substances (e.g., lead, cadmium, selenium) will be removed and contained during treatment.
  (2) Rare materials (e.g., silver, tellurium, indium) will be recovered and made available for future use.
  (3) Materials with high embedded energy value (e.g., silicon, glass) will be recycled.
  (4) Recycling processes will consider the quality of recovered material (e.g., glass).

- Sampling Methods for Toxicity Testing of PV Modules for End-of-Life Decisions, Arizona State University – Photovoltaic Reliability Laboratory, 2021

New Standard Aids in Testing Toxicity of Photovoltaic Modules | NEWSROOM (astm.org)

https://ieeexplore.ieee.org/document/9518620

Appendix B: Acronyms

AC	alternating current
ATSM	Formerly American Society for Testing and Materials, now "ATSM International"
BPU	Board of Public Utilities
BTM	Behind the Meter
DC	direct current
DEP	Department of Environmental Protection
DEQ	Department of Environmental Quality (DEP-equivalent agency in some states)
DTSC	Department of Toxic Substances Control (a California agency)
EEE	Electrical and Electronic Equipment
EMC	Environmental Management Commission
EOL	end-of-life
EPR	Extended Producer Responsibility
ESG	Environmental, Social, and Governance
EU	European Union
EVA	ethylene vinyl acetate
KW	kilowatt
MSSIA	Mid-Atlantic Solar & Storage Association
NJ	New Jersey
NJDEP	New Jersey Department of Environmental Protection
PSE&G	Public Service Enterprise Group, a NJ energy company
PV	photovoltaic
R&D	Research and Development
SEIA	Solar Energy Industries Association
SP	Solar Panel(s)
TCLP	Toxic Characteristic Leaching Procedure
US	United States
UW	Universal Waste
UWR	Universal Waste Regulations
WEEE	Waste Electrical and Electronic Equipment