

Final Report on the Activities Conducted to Establish a Regulatory Program for the Management and Decommissioning of Renewable Energy Equipment

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Executive Summary

Pursuant to Section 2.(d) of S.L. 2019-132 (HB329/Renewable Energy Amends), the North Carolina Department of Environmental Quality (Department or DEQ) and the Environmental Management Commission (Commission), were directed to submit a joint final report with findings, including stakeholder input, to the Environmental Review Commission and the General Assembly, no later than January 1, 2021. This final report is the culmination of the Department's consideration of the nine matters set out in Section 2(a) of HB329 to inform the development of rules governing the management of end-of-life (EOL) photovoltaic (PV) modules and energy storage battery systems and the decommissioning of utility-scale solar projects and wind energy facilities ("renewable energy equipment"). The information presented herein is also informed by the active participation of more than 100 stakeholders representing the renewable energy industry, investor-owned utilities, local governments, materials recyclers, academia, not-for-profit organizations, and state agencies (Appendix A lists the organizations the participating stakeholders represented throughout the process).

On November 20, 2020, the Draft Final Report was distributed to the stakeholders and members of the Commission via email. The email requested feedback and comment on the Draft report no later than close of business on December 14, 2020, providing 25 days for review. On December 9, 2020, the Commission held a Special Meeting to take up several informational items that were not addressed during the November regular meeting, including an overview of the Draft Final Report, and DEQ staff were available to respond to questions posed by Commissioners. The Commission is scheduled to vote to adopt the Final Report at its meeting in January. A table compiling the substantive comments the Department received is included as Appendix E, and Appendix F includes the comments submitted in full by both Commissioners and stakeholders.

Each of the following nine sections respond in detail to each of the corresponding subsections of the Session Law. Each section begins with an overview of our findings and recommendations (if any) followed by a detailed summary of the research and data that supports the Department's findings.

Key Findings and Recommendations

Section 2(a)(1): Hazard Characterization of EOL Renewable Energy (RE) Equipment

EOL PV modules:

- Only end-of-life (EOL) PV modules – those modules that no longer serve the purpose for which they are intended – are evaluated in this report. Any module, panel, or associated equipment that is in operation and continues to serve the purpose for which it is intended is not considered a waste for purposes of this report.
- For purposes of waste characterization, which indicates waste management requirements, DEQ finds that EOL PV modules will require Toxicity Characteristic Leaching Procedure (TCLP) testing to be considered nonhazardous.
- The Department expects to advance rulemaking efforts to define EOL PV modules as universal waste in 2021.

- The Department has asked the American Society for Testing and Materials (ASTM) to adopt a sample preparation method in TCLP testing of PV module waste for representative and accurate waste characterization. If ASTM adopts such a standard and it is found to be acceptable by the U.S. EPA, the DEQ may initiate rulemaking to 15A NCAC 13A to incorporate this new procedure in North Carolina.

EOL Energy Storage System Batteries:

- The Department finds that some energy storage system batteries exhibit hazardous characteristics and that existing regulations for managing batteries characterized as such indeed apply to energy storage system batteries and further finds that the development of a specific regulatory program for storage batteries is not recommended at this time.

Section 2(a)(2): Preferred Methods to Responsibly Manage RE Equipment

- The Department finds that the waste management hierarchy – waste reduction at the source > recycling and reuse > municipal solid waste (MSW) landfill disposal – applies well to the EOL management of PV modules, energy storage system batteries, and other equipment used in utility-scale solar projects or wind energy facilities.
- Every effort should be made to reduce, reuse, and recycle these materials, to the extent practicable under law, prior to landfill disposal.

Section 2(a)(3): Costs and Benefits of EOL RE Equipment Management Methods

- Reuse/refurbishment and recycling markets for EOL renewable energy equipment in the U.S. are still developing and not fully established due to a limited supply of decommissioned equipment.
- Reuse, refurbishment, and recycling are all environmentally preferable management options.
- Reuse and refurbishment are largely economically advantageous.
- Recycling opportunities are limited and costly, however as more renewable energy equipment reaches EOL and is available for recycling, the recycling process is expected to improve with new technology and operational efficiency which should lead to reduced recycling costs.

As recycling technologies evolve and mature, the Department recommends the creation and maintenance of an on-line list of renewable energy equipment recyclers (both in- and out-of-state), modeled after the registration requirements set out in G.S. 130A-309.142 for facilities recovering or recycling electronics equipment.

Section 2(a)(4): Life-Cycle of RE Equipment Currently in Use in North Carolina

- The Department finds that the economically productive life-cycle for EOL PV modules averages 25 years, energy storage battery systems averages 10 years, and wind energy facilities averages 20 years.

- The Department also finds that the earliest scenario for EOL management appears to apply to those solar facilities installed around 2010, as they approach end of useful life – notwithstanding repowering – beginning in 2031.

Section 2(a)(5): Volume of RE Equipment in Use and Impacts on Landfill Capacity

- DEQ estimates that approximately 500,000 tons of PV modules are currently installed in the state and installations are projected to double in the next 5 years.
 - ***Site specific information and annual generation amounts reported to the Energy Information Administration (EIA) through Forms 860 and 923 contain a robust set of static and dynamic generator-specific data. The EIA considers grid-tied facilities with a combined alternating current nameplate capacity rating of 1MW or greater to be a utility-scale operation. DEQ has determined that additional site-specific information may be necessary to evaluate waste management options when existing facilities in North Carolina reach EOL between 2030 and 2045. DEQ recommends the development of minimum notification requirement for facilities 1MW capacity or greater to coincide with federal reporting threshold for utility-scale operation. This recommendation would require amendments to the statutes authorizing the Division of Waste Management to request facility installation information. Furthermore, this recommendation is expected to have a fiscal impact, whether through establishing fee authority in statute or direct appropriations, to provide the Division with the resources necessary for program implementation.***
 - ***To ensure adequate landfill capacity is available to dispose of EOL RE equipment, the Department recommends modeling the 10-year waste management planning required for generators of industrial waste pursuant to G.S. 130A-309.09D(c).***
- Conservatively, if all installed EOL PV modules were decommissioned and disposed of at the same time, that volume would account for less than 10% of the total tonnage disposed in North Carolina MSW landfills in FY2018-19.
- According to DWM experts, if every EOL PV module is disposed of in landfills, landfill capacities will not be negatively impacted.
- Fewer than 12MW of energy storage system batteries are installed statewide and because of their relative age, will not reach EOL for at least 10 years.
- Existing laws banning disposal of some batteries in landfills will result in limited landfilling of energy storage system batteries.
- One wind energy generation facility is in operation in North Carolina with an estimated date for decommissioning around 2037.
- Even if technology has not evolved to recycle the fiberglass blades at scale, DEQ predicts no strain on regional landfill capacity if all 4,400 tons of blades must be landfilled at EOL.

Section 2(a)(6): Survey of Other Jurisdictions' Regulatory Requirements

The Department's thorough survey and review of federal, state, and international approaches to management of EOL renewable energy equipment, decommissioning,

and financial assurance reveals many similarities across a patchwork of statutory, regulatory, and voluntary policies. With respect to energy storage system batteries, the Department supports the adoption of a federal regulatory program for EOL management for energy storage system batteries based on information and comments provided by stakeholders and industry experts who expressed concern about the development of a viable reuse and recycling market absent a federal strategy.

Section 2(a)(7): Is Financial Assurance Required to Ensure Proper Decommissioning

- The Department finds that there is a minimum 10-year time horizon for when the first significant tranche of PV modules may reach EOL, repowering efforts notwithstanding.
- The Department finds that existing local government regulatory structures for EOL management and decommissioning are in effect in the majority of the counties where utility-scale solar projects are installed.
 - ***At this time, mandated financial assurance requirements are not necessary to ensure proper decommissioning of utility-scale solar projects and DEQ recommends further study on the feasibility and advisability of establishing a statewide standard for financial assurance in five years.***
 - *DEQ recommends the future study involve stakeholders and participation by the North Carolina Utilities Commission to evaluate the feasibility of tying such financial instruments to applications the Commission receives for new projects and methods for capturing financial assurance information for existing projects.*
 - *The future study should assess the historic and projected salvage value of EOL PV modules, incentives to reuse, repower, or recycle EOL PV modules, and the market forces necessary to drive the Department's preferred EOL management options.*

Section 2(a)(8): Infrastructure Needed to Collect and Transport EOL RE Equipment

Given the large volumes of PV modules and other equipment being removed from utility-scale renewable energy sites, transportation will likely be arranged directly to the EOL management facility. A network of collection and consolidation points would not be necessary to manage utility-scale PV modules, energy storage system batteries, and other equipment. The distance that the EOL equipment will need to be transported can vary greatly depending on the destination for EOL management, and the Department recommends that utility-scale renewable energy facilities anticipate and thoroughly evaluate the cost of collection and transportation as part of decommissioning planning.

Section 2(a)(9): Advisability of Establishing a Manufacturer Stewardship Program

- The Department finds that a manufacturer stewardship program for the recycling of EOL PV modules is not advisable at this time due to a variety of considerations including the lack of a strong recycling market, current limited need, and the fact that there is no other state with a mature stewardship program to benchmark.

- Existing rules for the management of solid and hazardous waste provide an adequate framework for proper recycling and disposal of PV modules.
- The Department recommends studying this management option in the future.

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I. HB329 Section 2.(a)(1)

Whether or not any PV modules, energy storage system batteries, or the constituent materials thereof, or other equipment used in utility-scale solar projects or wind energy facilities, exhibit any of the characteristics of hazardous waste identified in 40 C.F.R. Part 261, or under rules adopted pursuant to G.S. 130A-294(c), or whether or not any such equipment is properly characterized as solid waste under State and federal law.

- **PV modules:** To be clear, only end-of-life (EOL) PV modules – those modules that no longer serve the purpose for which they are intended – are evaluated in this report. Any module, panel, or associated equipment that is in operation and continues to serve the purpose for which it is intended is not considered a waste for purposes of this report. The waste characterization of EOL PV modules is assessed under existing RCRA regulations (40 CFR 262.11). Consistent with these regulations, the Department finds that EOL PV module waste may be identified as either nonhazardous or hazardous waste following the proper testing.
 - (1) As set out in Title 40 C.F.R, Part 261, PV waste subjected to a toxicity characteristic leaching procedure (TCLP) test and found to be nonhazardous, may be managed as solid waste and disposed of in accordance with 15A NCAC 13B (Solid Waste Management rules);
 - (2) For PV waste subjected to the TCLP test that meets the criteria for hazardous waste must be managed in accordance with Article 9 of N.C.G.S.130A and 15A NCAC 13A;
 - (3) To facilitate the handling and treatment of PV waste, DEQ, in consultation with the U.S. Environmental Protection Agency (EPA), will begin the rulemaking to define EOL PV modules that are deemed to be hazardous waste as *universal waste* to provide:
 - a. a facilitated path for encouragement of recycling of PV waste,
 - b. regulatory clarity to owners as to responsible recycling options and,
 - c. elimination of the need to conduct TCLP testing on PV waste unless so elected by the waste generator or other stakeholder to show a nonhazardous categorization.
- With respect to PV modules, the Department has asked the American Society for Testing and Materials (ASTM) to develop a sample preparation procedure for use in TCLP testing of PV modules for representative and accurate waste characterization. If ASTM develops and adopts such a standard and it is deemed acceptable by the U.S. EPA, the Department will initiate rulemaking to incorporate the new standard in 15A NCAC 13A (Hazardous Waste Management rules).
- **Energy storage system batteries:** The Department finds that some energy storage system batteries exhibit hazardous characteristics and that existing regulations for managing batteries characterized as such indeed apply to energy storage system batteries. Therefore, the Department finds that Title 40, C.F.R., Part 273 appropriately addresses the Universal Waste requirements for batteries and the development of a specific regulatory program for storage batteries is not recommended at this time.

- **Wind energy facilities:** Although there are challenges with EOL management of wind turbines, particularly the wind turbine blades, DEQ found no evidence to suggest that turbine components contain one or more characteristics of hazardous waste. Furthermore, no states specifically classify wind turbines or their composite materials as hazardous waste. Some associated equipment like electrical panels, generators, motors, cabling, and wiring can be directed into specific waste streams as appropriate. At this time, the Department suggests that existing rules for relevant waste streams (such as for batteries, electronics waste, solid waste, etc.) are sufficient to manage the EOL equipment used in wind energy generation facilities.

An Overview of Hazardous Waste Management in North Carolina

Hazardous waste requirements can apply to the waste itself, the site handling the waste, and to the hazardous waste handler. Any site generating hazardous waste (including but not limited to waste PV modules, energy storage system batteries, and waste from wind energy facilities) must meet any applicable hazardous waste generator requirements. Any site that stores, treats, and/or disposes of hazardous waste must be permitted and is subject to specific state laws and rules. The transportation of hazardous waste is also subject to specific requirements.

Universal waste (a subset of the hazardous waste rules that presently apply only to some energy storage system batteries) requirements apply to the waste itself, the site handling the waste, and to the universal waste handler. Any site that handles universal waste must meet applicable universal waste handler (either small or large) requirements. Any site that recycles or disposes of universal waste is considered a universal waste destination facility and must meet specific requirements which are similar to the treatment, storage, and disposal of hazardous waste. The transportation of universal waste is also subject to specific requirements. If universal waste is mismanaged, the more stringent hazardous waste rules reattach to both the waste and the facility responsible for its mismanagement.

North Carolina is authorized by the U.S. EPA to implement the State Hazardous Waste Program in lieu of the federal program under Resource Conservation and Recovery Act (RCRA). North Carolina General Statute (N.C.G.S.) 130A-294(c) provides the statutory authority for the Hazardous Waste Section in the Division of Waste Management (DWM) to implement the Hazardous Waste Rules in North Carolina. State laws relevant to the Hazardous Waste Section are codified at N.C.G.S. 130A-290 through 130A-310.12. The Hazardous Waste Management Rules are promulgated in the Administrative Code at 15A NCAC 13A. Federal hazardous waste regulations (40 CFR 260 through 279) are incorporated by reference in the NCAC and additional state requirements (those that are more stringent than the federal regulations) are set out in the NCAC. Most of the state laws mandated in the General Statutes are promulgated as rules in the NCAC; however, there are requirements relevant to the North Carolina Hazardous Waste Management Program for which rules have not yet been made in 15A NCAC 13A. For this reason, both the General Statutes and the Administrative Code should be reviewed to ensure compliance with the hazardous waste management requirements. North Carolina's hazardous waste laws and rules are available online at: <https://deq.nc.gov/about/divisions/waste-management/hw/rules>.

Appendix B is a detailed summary of management requirements for waste based on whether they are characterized as non-hazardous, hazardous, or universal wastes.

Appendix C compares hazardous waste and universal waste regulatory requirements.

Photovoltaic Modules

Monocrystalline, polycrystalline, and thin film photovoltaic modules may contain trace amounts of material characterized as hazardous at specific composition levels, and in which case may test above the regulatory limits presented in Table 1, in 40 CFR 261.24, relevant to the TCLP. Crystalline silicon solar panels are the predominant type of module technology installed and 90% of their mass by weight is composed of glass, polymer, and aluminum. Crystalline silicon solar panels may also contain traces of copper, zinc, silver, tin, and lead.¹ However, crystalline silicon modules generally test below the regulatory thresholds following the TCLP test.² Cadmium-telluride (CdTe) modules are the most common thin film technology and in addition to the ultra-thin semiconductor layer of CdTe, may also possess toxic materials containing traces of copper, zinc, tin and other metals. Approximately 98% of a CdTe panel's mass is composed of glass, polymer, and aluminum.³ CdTe panels are only considered hazardous waste if the modules have cadmium or other toxins classified substances greater than or equal to the regulatory levels following the TCLP test. CdTe modules waste generally tests below the regulatory thresholds following the TCLP test.⁴ Photovoltaic modules that contain hazardous materials pose minimal risks to the environment and human health during normal operation. In the case of module breakage during operation or landfill disposal, risk assessment of utility-scale PV systems with EPA leaching and fate and transport methods found potential impacts to be below EPA human health screening levels.^{5,6} However, if a module containing toxic materials is broken, the module may leach toxic contaminants into the environment.⁷

Using this information, content informed by research for this report, and data shared from the participating stakeholders, the Department recommends the following approach to making hazardous waste determinations for EOL PV modules. Key points from research and data used to make the determinations below can be found in DEQ and stakeholder presentations as well as other documents, which are included or referenced throughout the Final Report and in the associated Appendices.

Guidance for Hazard Characteristic Determination

¹ Weckend, Stephanie, et al. "End-of-Life Management: Solar Photovoltaic Panels," International Renewable Energy Agency and International Energy Agency Photovoltaic Power Systems. 2016.

² Cleveland, Tommy. Health and Safety Impacts of Solar Photovoltaics. NC Clean Technology Center, 2017.

³ Weckend, Stephanie, et al. "End-of-Life Management: Solar Photovoltaic Panels," International Renewable Energy Agency and International Energy Agency Photovoltaic Power Systems. 2016.

⁴ Cleveland, Tommy. Health and Safety Impacts of Solar Photovoltaics. NC Clean Technology Center, 2017.

⁵ P. Sinha, G. Heath, A. Wade, K. Komoto, 2019, "Human health risk assessment methods for PV, Part 2: Breakage risks, International Energy Agency (IEA) PVPS Task 12, Report T12-15:2019. ISBN 978-3-906042-87-9."

⁶ P. Sinha, G. Heath, A. Wade, K. Komoto, 2019, "Human health risk assessment methods for PV, Part 3: Module disposal risks, International Energy Agency (IEA) PVPS Task 12, Report T12-16:2020. ISBN 978-3-906042-96-1."

⁷ Sinha, Parikhit, and Andreas Wade. "Assessment of Leaching Tests for Evaluating Potential Environmental Impacts of Photovoltaic Module Field Breakage." 2015.

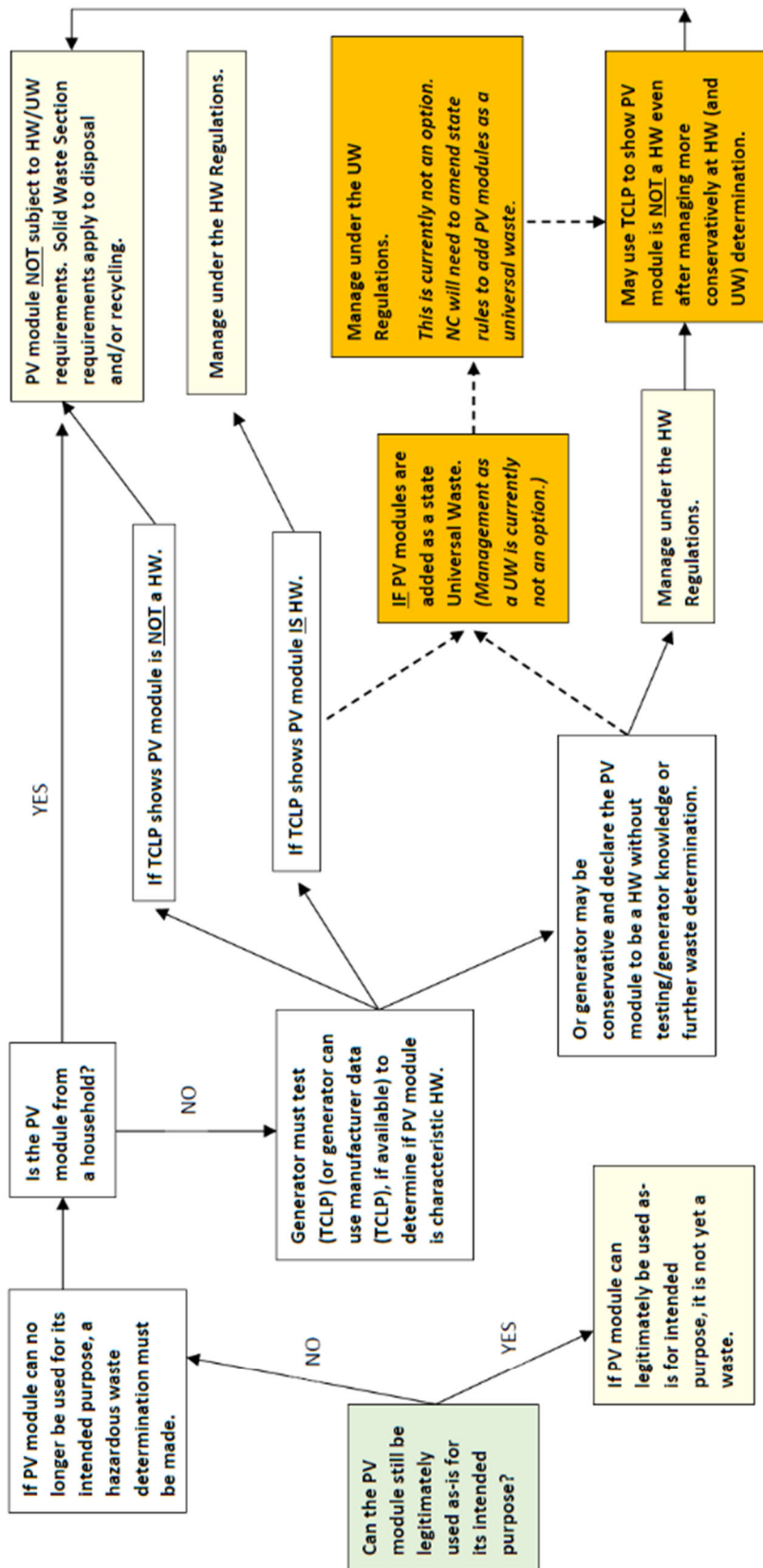
Following several internal discussions, staff in the Hazardous Waste Section of the Division of Waste Management (DWM) created a guidance document for making a hazardous waste determination for PV modules. The guidance document consists of a flow chart depicting different management options depending on the resulting TCLP waste characterization for the tested PV module waste. The flow chart includes the Department's recommendation to add PV module waste to the Universal Waste category. If TCLP test results show constituents above toxicity thresholds or if the PV waste is declared by the waste generator to be a hazardous waste without having conducted a TCLP test, then that PV waste could be managed as either hazardous waste or universal waste, according to RCRA rules. If the TCLP test shows constituent materials are below the toxicity thresholds, then the PV waste will not be subject to either hazardous or universal waste requirements.

The document was presented to stakeholders at the June 3, 2020 meeting, during which stakeholders generally agreed that the process for a hazardous waste determination for PV waste was consistent with the existing RCRA rules. There were several questions from stakeholders concerning which parts of PV modules are subject to TCLP testing when making a waste determination. As a result, Hazardous Waste Section staff also recommended draft language to accompany the HB329 definition of a PV module and clarified which components of PV modules are subject to TCLP analysis for purposes of either making a waste determination or for appropriate waste management. The proposed language clarifies that PV modules that comprise a solar panel, including, but not limited to the glass, encapsulant, solar cells, polymer backing and other components that cannot be readily detached from the panel shall be evaluated/managed. Components that are not integrated into the PV module such as brackets, braces, supports, wiring, inverters, and batteries should be evaluated and managed separately from the PV module. The flow chart and recommended draft language can be found on the next page.

Hazardous Waste Determination for Photovoltaic Modules Flowchart

The below flow chart provides a basic overview of the general steps to make a hazardous waste determination on photovoltaic modules* (PV modules)/solar panels. For ease of explanation, this is an abbreviated version of the full waste determination described at 40 CFR 262.11. The following assumptions were applied to the flowchart: PV modules typically are not ignitable, corrosive or reactive so the only hazardous waste characteristic (as described in 40 CFR 261 subpart C) evaluated in the flow chart is toxicity (through a Toxicity Characteristic Leaching Procedure (TCLP)); PV modules are not a listed hazardous waste (under 40 CFR 261 subpart D) in North Carolina; and the only exclusion (described in 40 CFR 261.4) that applies to the PV modules is the household hazardous waste exclusion. **PV modules are not currently a universal waste in North Carolina so rulemaking needs to occur before they could be managed as a universal waste.**

HW = Hazardous Waste; UW = Universal Waste



"Photovoltaic module" means the smallest nondivisible, environmentally protected assembly of photovoltaic cells or other photovoltaic collector technology and ancillary parts intended to generate electrical power under sunlight, except that "photovoltaic module" does not include a photovoltaic cell that is part of a consumer electronic device for which it provides electricity needed to make the consumer electronic device function. "Photovoltaic module" includes interconnections, terminals, and protective devices such as diodes that: (i) are installed on, connected to, or integral with buildings or (ii) are used as components of freestanding, off-grid, power generation systems, such as for powering water pumping stations, electric vehicle charging stations, fencing, street and signage lights, and other commercial or agricultural purposes. (Session Law 2019-132)

Proposed addition to definition for photovoltaic module:

For the purposes of making a waste determination and/or waste management, the photovoltaic module or combination of photovoltaic modules that comprise a solar panel, including but not limited to the glass, encapsulant, solar cells, polymer backing and other components that cannot be readily detached from the panel shall be evaluated/managed. Components that are not integrated in the PV module/solar panel such as brackets, braces, supports, wiring, inverters, and batteries should be evaluated/managed separately from the PV module.

TCLP Test Method

One issue that garnered much discussion among Department staff as well as the participating stakeholders was the advisability of applying the standard TCLP test for hazardous determinations on EOL PV waste. Recall that a TCLP test is performed when a waste may contain toxic elements and the test characterizes whether the waste is hazardous or non-hazardous. The test is used on a host of different wastes, including construction material, paint, electronics, furniture, and PV modules. However, the TCLP methodology does not include guidance for sampling from PV modules and variability in parameters such as sample size, sample location, and method of sample extraction can affect testing results. For example, the TCLP methodology requires a photovoltaic module to be reduced in size by crushing, cutting, or grinding to a maximum size of 9.5mm,⁸ but does not require a minimum size. As a result, laboratories that perform TCLP testing may reduce the sample size to the maximum allowable 9.5mm or may instead grind samples to micron levels.⁹ Inconsistencies across these parameters and the variability in TCLP processes between laboratories can and has produced significantly different TCLP results for the same PV module.¹⁰ Several stakeholders reiterated their concerns during meetings regarding variability in parameters that can lead to inconsistencies in TCLP results. It should be noted however, that these issues are not unique to PV modules, but for any waste as the TCLP method is not specific to any one product.

Because of these inconsistencies and variabilities as well as the concerns articulated by stakeholders, Department staff queried the American Society for Testing and Materials (ASTM) in mid-2020 about the development of sampling guidelines specific for waste PV modules in preparation for the TCLP test method. DEQ shared with ASTM the issues revealed following the conduct of a literature review and discussions with the participating stakeholders. As a result of these discussions, ASTM committee members agreed to support the development of an already proposed sample preparation guidance document to reduce the discrepancies that may arise in preparing samples for the TCLP test method as applied to testing PV modules designated as waste.

One of the ASTM committee members is the director of the Arizona State University (ASU) Photovoltaic Reliability Laboratory, Dr. Govindasamy Tamizhmani. Dr. Tamizhmani and colleagues published a proposed standard operating procedure (SOP) for unbiased and repeatable sampling methodology to prepare test samples of PV modules which would be subjected to perform TCLP toxicity testing of PV modules. ASTM committee members agreed to support the publication of this procedure as a standard for TCLP sampling methodology for PV modules. Most recently, the ASU Photovoltaic Reliability Laboratory modified the proposed SOP into the ASTM template, which will be submitted to the ASTM subcommittee and main committee ballot for approval. If approved, the new test sampling method standard would be published around mid-2021. To provide regulatory consistency,

⁸ Method 1311, Revision 0, July 1992, Toxicity Characterization Leaching Procedure, EPA publication SW-846.

⁹ Leslie, Joswin. "Dependence of Toxicity Test Results on Sample Removal Methods of Photovoltaic Modules." Arizona State University, Arizona State University, 2018. ASU Digital Repository.

¹⁰ *Ibid.*

the Department recommends considering adoption of this new this test sampling method standard through rulemaking once it is published. The ASTM methods and standards relevant to hazardous waste are listed in 40 CFR 260.11 and are incorporated by reference in 15A NCAC 13A .0101(e). If EPA does approve the new ASTM test sampling method as an industry standard, but does not update its regulations to include the new published TCLP ASTM standard the test sampling method, North Carolina should amend the state regulatory rules to include the approved test sample preparation method as the new standard.

Rulemaking to Clarify Requirements Pertaining to EOL PV Modules

The rules established under the North Carolina Administrative Code (NCAC) Title 15A, Chapter 13, Subchapter A incorporate by reference the federal regulations and describe any additional state requirements for the management of hazardous waste in North Carolina. 15A NCAC 13A .0106 references 40 CFR 261 as the regulations governing identification and listing of hazardous wastes in North Carolina. Further, 40 CFR 261.24 provides that a solid waste exhibits the characteristic of toxicity if the TCLP test method results in a contaminant equal to or above the thresholds listed in the subpart.¹¹ Presently, North Carolina hazardous waste rules do not specifically list any requirements pertaining to waste PV modules designated as waste. However, wastes (including EOL PV modules designated as waste) that exhibit one or more characteristics of hazardous waste must be managed as a hazardous waste when no longer used for their intended purpose. It is DEQ's recommendation, that based on the limited specificity that currently exists to address EOL PV modules, the Administrative Code governing Hazardous Waste Management (15A NCAC 13A) should be evaluated, and possibly amended to include information, definitions, and any additional testing requirements for making a hazardous waste determination regarding PV modules designated as waste not in conflict with the 40 CFR 261 requirements.

As of the date of this report, California is the only state that has "[designated] end-of-life photovoltaic modules that are identified as hazardous waste as a universal waste and subjects those modules to universal waste management."¹² California's Department of Toxic Substances Control (DTSC) was authorized and directed to develop regulatory language for PV modules designated as waste to be managed under Universal Waste regulations through California Senate Bill 489. In recent amendments to the California Code of Regulations, Title 22, Division 4.5, Chapters 10, 11, and 23, PV modules designated as waste and that are characterized as hazardous according to RCRA rules, due to the characteristic of toxicity are subject to the newly approved California state universal waste regulations, effective January 1, 2021. Any PV modules that do not exhibit a characteristic of hazardous waste, exhibit any characteristic of hazardous waste other than toxicity, are not yet wastes, or are destined for recycling would not be subject to the universal waste regulations.¹³ However, until the new universal waste regulations are

¹¹ 40 CFR 261.24

¹² CA Senate Bill SB 489: https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160SB489

¹³ 22 CCR § 66260-66273

implemented in 2021, PV modules designated as waste that exhibit the characteristic of toxicity must be managed as hazardous wastes in California.

Finally, in order to effectuate the proposed off-ramp from a default hazardous waste characterization for EOL PV modules designated as waste contemplated in the flowchart referenced above, DEQ staff recommend rulemaking to add PV modules designated as waste that exceeds the threshold for classification as nonhazardous (or solid) waste to the state Universal Waste Rules. As of the date of this report, DWM has been in communication with U.S. EPA examining this proposal. The universal waste program is a subset of hazardous waste rules that requires less stringent regulations for certain waste streams. PV modules designated as waste are appropriate candidates for universal waste rules and fit the common characteristics typically present in universal wastes: wastes generated in significant volumes and in a wide variety of settings, which can lead to difficulties implementing a management program to handle those wastes.¹⁴ In addition, PV modules are comprised of compounds and compositions unique to a manufacturer where some PV modules, when deemed waste might present toxic characteristics greater than regulatory thresholds. However, the risks of handling and transporting PV modules designated as waste that exceed toxicity thresholds is low compared to other hazardous wastes. As a result, the Department proposes adding EOL PV modules designated as waste as a new waste category under state universal waste rules. Such a proposal would necessitate rulemaking to the Commission and the Rules Review Commission (RRC) for approval in 2021. To provide more regulatory clarity and flexibility, the Department may also petition the U.S. EPA to add PV modules as universal waste under federal regulation.

Energy Storage System Batteries

Lead-acid, nickel-cadmium, lithium-ion, and flow batteries are used in energy storage systems.¹⁵ Neither hazardous waste rules nor North Carolina law set out requirements pertaining to management of EOL energy storage system batteries. However, batteries that contain at least one hazardous characteristic must be managed in accordance with the North Carolina hazardous waste rules or may be managed as universal waste.¹⁶ A discussion of the most commonly used batteries in energy storage systems in descending order follows.

Lithium-Ion Batteries

The majority of energy storage systems throughout the United States that are one megawatt (MW) or greater in capacity are comprised of lithium-ion batteries.¹⁷ The composition of lithium-ion batteries includes a cathode, anode, separator, and electrolyte. The materials used for these components are known to present flammable and toxic characteristics and have the potential to release toxic elements into the environment if not

¹⁴ 40 CFR 273.81

¹⁵ "U.S. Battery Storage Market Trends." U.S. Energy Information Administration, 2018.

¹⁶ 40 CFR § 273 (adopted by reference in 15A NCAC 13A .0119)

¹⁷ "U.S. Battery Storage Market Trends." U.S. Energy Information Administration, 2018.

properly managed.^{18,19} Under federal regulations, a lithium-ion battery is classified as hazardous waste if it exhibits one or more of the following characteristics: ignitability, corrosivity, reactivity, or toxicity. Presently, North Carolina does not have any additional information in state rules specifically pertaining to the characterization of lithium-ion batteries. If a lithium-ion battery is determined to not contain any of these characteristics, it is not subject to existing hazardous waste (or universal waste) rules. As with all hazardous wastes, it is the generator's responsibility to determine whether or not a battery is classified as hazardous.²⁰

Lead-Acid Batteries

Lead-acid batteries are the oldest energy storage system technology.²¹ A typical lead-acid battery is composed of lead (either metal or lead oxide paste), plastic, sulfuric acid, electrolyte, and other components such as antimony, arsenic, and cadmium.²² Lead-acid batteries are subject to hazardous waste or universal waste regulations if disposed due to the lead.²³ In North Carolina, it is illegal to dispose of a lead-acid battery in a landfill, incinerator, or any waste-to-energy facility.²⁴ At the federal level, the Resource Conservation and Recovery Act (RCRA) regulates lead-acid batteries unless managed under universal waste or are reclaimed pursuant to 40 CFR 266 Subpart G.²⁵

Nickel-Cadmium Batteries

Nickel-cadmium batteries are also used in energy storage systems.²⁶ The components of typical nickel-cadmium batteries include nickel hydroxide, cobalt hydroxide, cadmium hydroxide, iron oxide, and potassium hydroxide.²⁷ Cadmium is used as the battery's power source. Because cadmium is a hazardous metal, these batteries must be properly managed and disposed of in accordance with hazardous waste requirements.²⁸ Nickel-cadmium batteries are subject to RCRA unless managed under universal waste regulations. North Carolina does not have regulations for this type of battery technology.

To reiterate, lithium-ion batteries are used in the majority of battery energy storage projects and represent the fastest growing energy storage technology under development. However,

¹⁸ Mishra, Amit, et al. "Electrode Materials for Lithium-Ion Batteries." *Materials Science for Energy Technologies*, vol. 1, no. 2, Dec. 2018, pp. 182–187.

¹⁹ Winslow, Kevin, et al. "A Review on the Growing Concern and Potential Management Strategies of Waste Lithium-Ion Batteries." *Resources, Conservation, and Recycling*, vol. 129, Feb. 2018, pp. 263–277.

²⁰ "Questions about the Disposal of Lead-Contaminated Items | Hazardous Waste Treatment, Storage & Disposal." *Wastes- Hazardous Waste- Treatment, Storage & Disposal (TSD)*, Environmental Protection Agency.

²¹ "U.S. Battery Storage Market Trends." U.S. Energy Information Administration, 2018.

²² CEC. *Environmentally Sound Management of Spent Lead-acid Batteries in North America: Technical Guidelines*. Montreal, Canada: Commission for Environmental Cooperation, 2016, 92 pp.

²³ "Wastes - Hazardous Waste - Universal Wastes." *U.S. EPA*.

²⁴ N.C.G.S. §130A-309.71

²⁵ "Wastes - Hazardous Waste - Universal Wastes." *U.S. EPA*.

²⁶ "U.S. Battery Storage Market Trends." U.S. Energy Information Administration, 2018.

²⁷ SAFETY DATA SHEET Nickel Cadmium Batteries. Storage Battery Systems, LLC.

²⁸ 42 U.S.C. §14322

there are several challenges facing end-of-life management of this battery technology. Currently, the U.S. lacks efficient and wide scale lithium-ion battery collection infrastructure, regulations and financial incentives for recycling, standards for reusing and recycling, and a structured secondary market for large scale batteries. It is unclear which of the foregoing challenges contribute to the vacuum of regulations governing EOL management of lithium-ion batteries, despite the potentially flammable and toxic characteristics of these batteries. Since few lithium-ion battery storage systems have been decommissioned in the U.S., recycling remains a relatively new industry and untested option. There is a need for a stable recycling market and further development to improve the recycling process. In the future, advancements towards a mature lithium-ion battery recycling industry will drive clear regulatory frameworks and best practices.²⁹

Until such time, existing laws and regulations for managing batteries characterized as hazardous waste will continue to also apply to batteries used in energy storage systems. Because the existing regulatory structures address EOL management of energy storage system batteries, the Department does not recommend rulemaking and the creation of a regulatory program at this time. To that end, the Department does recommend revisiting approaches to EOL management of energy storage system batteries in five years to allow the application of these energy systems and accompanying EOL markets to evolve.

Wind Energy Facilities

Currently, the Amazon Wind Farm U.S. East is the only utility-scale wind farm installed and operating in North Carolina. The project is located in Perquimans and Pasquotank counties. The Amazon Wind Farm's 2MW Gamesa G114 models are comprised of a tower, rotor, generator, gearbox, and three fiberglass reinforced blades with epoxy or polyester resin.^{30,31} There are 104 turbines currently installed at the facility that are expected to reach EOL in approximately 2037. Although there are challenges with EOL management of wind turbines, there is no evidence to suggest that turbine components contain one or more characteristics of hazardous waste. Extensive research revealed that no states classify wind turbines or associated equipment into a specific waste stream or categorize wind turbine components as hazardous waste. The Department determined that existing waste management rules are sufficient to manage EOL equipment used in wind generation facilities and do not require modifications.

²⁹ Chupka, Marc. "End of Life Management of Lithium-Ion Energy Storage Systems." U.S. Energy Storage Association, 22 April 2020.

³⁰ SG 2.6-114 Onshore Wind Turbines." Siemens Gamesa Renewable Energy.

³¹ Mundt, Jennifer. "Wind Energy and Equipment in North Carolina." PowerPoint Presentation. 2020.

II. HB329 Section 2.(a)(2)

Preferred methods to responsibly manage end-of-life photovoltaic modules, energy storage system batteries, or the constituent materials thereof, or other equipment used in utility-scale solar projects or wind energy facilities, including the extent to which such equipment may be:

- a. Reused, if not damaged or in need of repair, for a similar purpose.*
- b. Refurbished, if not substantially damaged, and reused for a similar purpose.*
- c. Recycled with recovery of materials for similar or other purposes.*
- d. Safely disposed of in construction and demolition or municipal solid waste landfills for material that does not exhibit any of the characteristics of hazardous waste under State or federal law.*
- e. Safely disposed of in accordance with State and federal requirements governing hazardous waste for materials that exhibit any of the characteristics of hazardous waste under State or federal law.*

- **PV modules:** The Department finds that the waste management hierarchy applies well to the EOL management of PV modules. The Department's preferred method of management is to first reduce the hazardous and waste constituents in the manufacture of PV modules that will result in reduced quantities of hazardous and nonhazardous materials necessitating EOL management. After waste reduction at the source, DEQ recommends the following management methods in order of preference: that EOL PV modules are reused if not in need of repair, refurbished according to industry safety and reliability standards, recycled if reuse and refurbishment are not feasible, and lastly, disposed of in a municipal solid waste (MSW) landfill or hazardous waste treatment disposal facility, as appropriate.
- **Energy storage system batteries:** Based on research conducted and an understanding of the current market forces, in addition to encouraging the industry to reduce hazardous constituents in manufacturing, the Department recommends that EOL energy storage system batteries are recycled to the extent practicable and allowed by law.
- **Wind energy facilities:** With the exception of the blade, the constituents and components of wind energy facilities (WEF) are largely recyclable. The Department recommends both reuse and repowering of WEF equipment when possible followed by recycling. The Department recommends revisiting methods to dispose of blades in five years to allow recycling technologies and applications to mature.

Waste Management Hierarchy

As with most materials that have served their intended purpose, a set of options exist for EOL management that are dependent upon circumstances such as location, material composition, and condition. North Carolina General Statute 130A-309.04 provides that "it is the policy of the State to promote methods of solid waste management that are alternatives to disposal in landfills" and there is an "established ... hierarchy of methods of managing solid waste, in descending order of preference."

1. Waste reduction at the source;
2. Recycling and reuse;

3. Composting;
4. Incineration with energy recovery;
5. Incineration without energy recovery; and
6. Disposal in landfills.

The following sections discuss applicable EOL management options for PV modules, energy storage system batteries, and wind energy facilities in order of preferred method.

Photovoltaic Modules

Waste Reduction at the Source

The Department recommends that waste reduction at the source (the top of the state's listed hierarchy for solid waste management) be considered for PV modules. The industry has already improved technology and manufacturing practices to use less hazardous materials like lead, cadmium, and selenium and less precious materials such as silver and silicon which reduces the potential loss of valuable materials at EOL.³² Continued progress to reduce the amount of hazardous constituents will likewise reduce risks to human health and the environment at EOL.

In December 2017, a new NSF International Standard/American National Standard was established to improve sustainability of PV modules through the manufacturing process and supply chain. The standard, NSF/ANSI 457 Sustainability Leadership Standard for Photovoltaic Modules and Photovoltaic Inverters, provides a suite of product and performance criteria to identify sustainability leadership in the market. Goals include the reduction of hazardous and toxic substances, design for recycling, improvements in sustainable packaging, reduced energy and water use, and performance of a life-cycle assessment. The standard also recommends that manufacturers provide a nationwide take-back service to recycle their own PV modules.³³ The most recent update to the standard was made in 2019, and it has been incorporated as the criteria for modules and inverters to meet in order to be certified under the Electronic Product Environmental Assessment Tool (EPEAT) ecolabel.³⁴ Purchasing PV modules with less hazardous waste constituents and supporting the EPEAT criteria contributes to waste reduction at the top of the hierarchy and should be encouraged.

Refurbishment and Reuse

According to the International Renewable Energy Agency (IRENA), the reuse of PV modules is the preferred method for EOL management. If modules are damaged during installation or transit, or if they fail before the end of their expected lifetime, they may be covered by warranty or insurance and be returned to the manufacturer or a service partner for inspection and repair. The repaired modules may be suitable for return and use by the original owner or could be sold as replacements.³⁵

³² Weckend, Stephanie, et al. "End-of-Life Management: Solar Photovoltaic Panels," International Renewable Energy Agency and International Energy Agency Photovoltaic Power Systems. 2016.

³³ Sustainability Leadership Standard for Photovoltaic Modules and Photovoltaic Inverters. NSF/ANSI 457-2019. NSF International.

³⁴ "Timing of Criteria Implementation." *Green Electronics Council*.

³⁵ Weckend, Stephanie, et al. "End-of-Life Management: Solar Photovoltaic Panels," International Renewable Energy Agency and International Energy Agency Photovoltaic Power Systems. 2016.

When modules are removed in large scale, either for replacement with newer technology or because they have met the anticipated service life, many may still be operational but operating with lower efficiency. While these may not perform to the standards of the original owner, a second owner may be interested in purchasing them at a reduced cost.³⁶

Before the PV modules can be reused, they are subject to quality tests and other inspections to check the integrity and safety of the modules. Following inspection, and refurbishment if needed, used modules can be sold at a reduced market price or donated in the United States or abroad. Reused and resold PV modules can be installed in many applications such as charitable projects, off-grid, or grid-connected projects as long as they meet the appropriate building codes and safety standards.³⁷ A modest market is beginning to emerge with a few online platforms for the sale of second-generation panels. As more PV modules begin to come out of service, the reuse and refurbishment market is expected to grow.³⁸

Recycling

If a PV module is not suitable for refurbishment or reuse, it becomes a waste and a determination must be made as to whether or not the PV module waste is considered hazardous. If the PV module designated as waste is not characterized as hazardous, it can go to any recycler. However, if PV module waste exceeds the threshold identified for nonhazardous characterization, it should go to a recycler that is designated and permitted as an authorized hazardous waste treatment facility if the module is destined for recycling instead of disposal.

Recycling options for EOL PV modules can be divided into two categories, low-value and high-value recycling. Low-value recycling typically involves shredding the PV module and extracting materials that are easily accessible, primarily metals and sometimes plastics and glass. Glass makes up more than 70% of a PV module by weight; and although easy to extract, requires additional processing to remove impurities such as metal and adhesives before it is pure enough to sell as a valuable commodity. Low-value recycling can be achieved by existing facilities with large shredding machines that typically handle other large electronics or scrap metals and automobiles. While this method diverts portions of a PV module from landfill disposal, it does not recover precious metals and more valuable materials such as silicon, silver, or copper.³⁹

High-value recycling extracts materials of higher purity or quality that can deliver greater value for reuse, such as silver and semiconductor materials. The process is more energy and labor intensive and therefore has a higher overall cost. With current technology, the value of recovered materials does not cover the cost to process and extract those materials, so recyclers charge a fee to manage the materials.⁴⁰ High-value recycling is

³⁶ IEA 2018, End-of-Life Management of Photovoltaic Panels: Trends in PV Module Recycling Technologies.

³⁷ "SEIA National PV Recycling Program." *Solar Energy Industries Association*.

³⁸ Weckend, Stephanie, et al. "End-of-Life Management: Solar Photovoltaic Panels," International Renewable Energy Agency and International Energy Agency Photovoltaic Power Systems. 2016.

³⁹ Deng, Rong, et al. "A techno-economic review of silicon photovoltaic module recycling." *Renewable and Sustainable Energy Reviews*, vol. 109, July 2019, pp. 532-550.

⁴⁰ EPRI 2018, Solar PV Module End Of Life: Options And Knowledge Gaps For Utility-Scale Plants.

preferred over low-value recycling because even though it is more energy intensive, the process achieves a higher diversion and recovers environmentally-sensitive, valuable, and energy-intensive materials.⁴¹

A high-value PV module recycling process follows a number of steps:

- 1 – The aluminum frame, junction box, other electronics equipment, and cables are removed. These components are easily recycled through existing metal and electronics recycling markets.
- 2 – The laminated layers of the panel are then separated so that glass and plastic can be separate from the silicon cells (c-Si panels) or semiconductor materials (thin film panels). This process is performed using mechanical, thermal, or chemical treatment:
 - Mechanical processes shred the panel into pieces to be further sorted by hand and machinery.
 - Thermal processes burn off the encapsulant and send the resulting gas though a scrubber.
 - Chemical processes remove the encapsulant using a chemical bath, producing a waste product as a result.
- 3 – Valuable metals and silicon can be harvested and recycled.⁴²

Figure 2-1 illustrates the general process of PV module recycling.⁴³

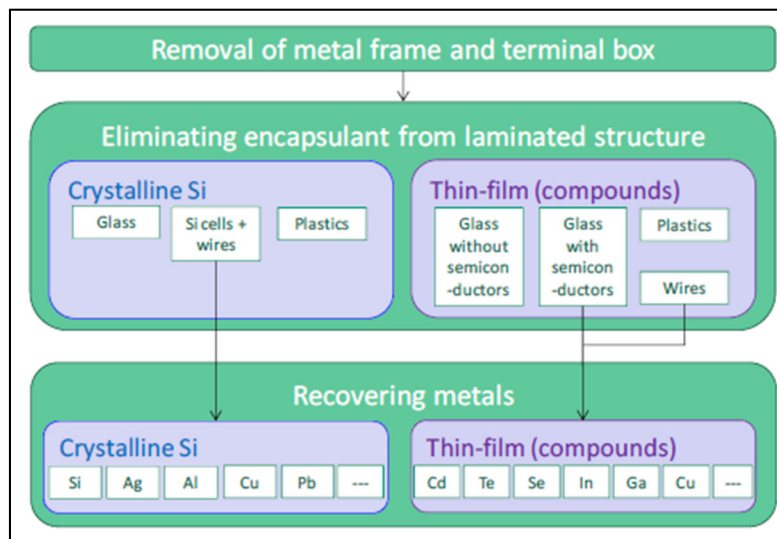


Figure 2-1 Separation Process for PV Module Recycling

In North Carolina, there are presently no high-value PV module recycling facilities. One electronics recycler located in Creedmoor, Metech Recycling, can accept PV modules;

⁴¹ Weckend, Stephanie, et al. "End-of-Life Management: Solar Photovoltaic Panels," International Renewable Energy Agency and International Energy Agency Photovoltaic Power Systems. 2016.

⁴² Buehler, Colby. "Solar Energy's Secret – Hazardous Waste: The Case for a National Recycling Framework," AICHE.

⁴³ IEA 2018, End-of-Life Management of Photovoltaic Panels: Trends in PV Module Recycling Technologies.

although, they are transported to the company's California facility for processing and recycling. A handful of companies can accept PV modules for low-value recycling on a case-by-case basis. The development of PV recycling facilities and technology in the state and across the United States has been slow to progress because high volumes of EOL modules that would make investment worthwhile have not yet materialized.⁴⁴ DEQ intends to maintain a publicly-accessible list of PV module recycling facilities that will be kept up-to-date in consultation with recyclers and industry organizations including the Solar Energy Industries Association, the North Carolina Sustainable Energy Association, and the North Carolina Clean Energy Business Alliance.

As utility-scale decommissioning projects generate large quantities of EOL PV modules, more recyclers may invest in technology and equipment to manage this waste stream provided they can rely on a steady stream of material for recycling as opposed to landfill disposal. Incentives, such as grant funding for recycling businesses, could encourage more investment and development. Incentives could also encourage greater incorporation of recycled content into new PV modules, which is part of the required and optional criteria for the EPEAT ecolabel.

Other recycling opportunities exist outside North Carolina. The Solar Energy Industries Association (SEIA) has a PV recycling working group with more than 75 members and recycling partners throughout the country.⁴⁵ The members of this working group are committed to responsible EOL management and improving the recycling process for the solar industry. Cleanlites Recycling and Dynamic Lifecycle Innovations have a presence in nearby states of South Carolina and Tennessee, respectively. However, neither company recycles PV modules at those nearby facilities. Cleanlites recycles PV modules at its Ohio facility while Dynamic recycles PV modules at its Wisconsin facility.^{46,47} Therefore, North Carolina PV module owners utilizing these companies would need to factor in the cost of transportation. SEIA is continuing to form new partners throughout the country to help expand PV module recycling capabilities. Many current members offer takeback programs for their products.⁴⁸

First Solar, a manufacturer of thin film cadmium telluride (CdTe) panels, offers take-back and recycling of its own PV modules and has a recycling facility in Ohio. The modules are sent for high-value recycling to recover valuable and environmentally-sensitive materials, such as tellurium and cadmium.⁴⁹ First Solar's high-value recycling process recovers more than 90% of the semiconductor material for reuse in new solar modules and 90% of the glass for use in new glass container products.

⁴⁴ "Solar Pv Module End Of Life: Options And Knowledge Gaps For Utility-Scale Plants." *EPRI*, 2018.

⁴⁵ Butler, Evelyn. PV End-of-Life Management. December 2019, PowerPoint Presentation.

⁴⁶ Cleanlites Recycling. Personal communication, Sept. 2020.

⁴⁷ Dynamic Lifecycle. Personal communication, Oct. 2020.

⁴⁸ "SEIA National PV Recycling Program." *Solar Energy Industries Association*

⁴⁹ Sinha, Parikh. "High Value Recycling." PowerPoint Presentation. 2019.

In both the United States and Europe, almost all c-Si module recycling is performed by facilities that specialize in another waste stream, commonly metals, glass, or electronics. These recyclers process PV modules in discrete batches on a periodic basis due to low volumes and usually rely on mechanical processing.⁵⁰ In 2018, Veolia opened the first facility dedicated to c-Si PV recycling in southern France. In its first operating year, the plant was expected to process 1,800 metric tons of PV module, with a projected increase in capacity over time to 4,000 metric tons per year. As more dedicated PV module recycling facilities emerge, process improvements are expected to lead to more efficient recovery and reduced recycling costs.⁵¹ Most recyclers focus on c-Si modules since they are most common. Notably, the majority (70 to 95%) of all modules are comprised of glass which is the lowest value material. Figure 2-2 shows the relative value of each material that can be extracted for recycling from a c-Si module.⁵²

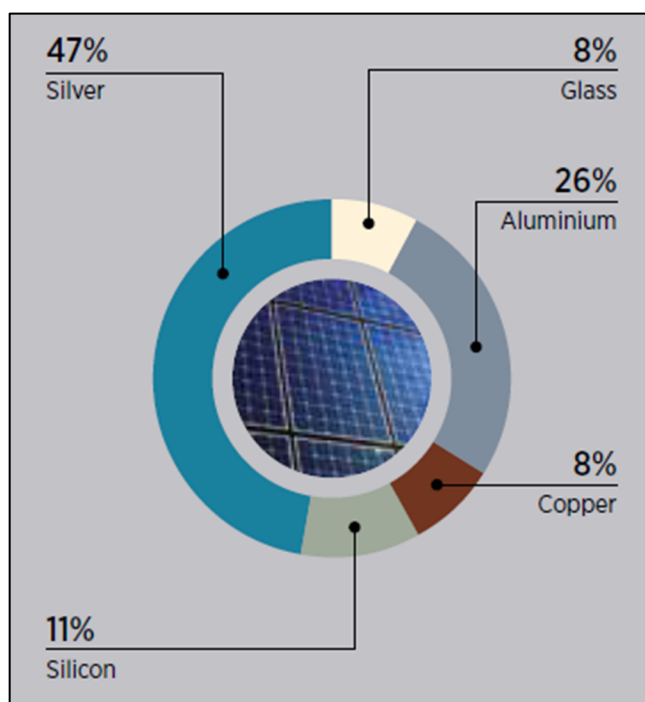


Figure 2-2. Relative Value of Materials Extracted from c-Si Modules

Recycling copper indium gallium selenide modules is not discussed in detail in this section because they account for only 2% of the installed modules in North Carolina. CdTe modules make up 18% of installed modules and c-Si make up 74%, with the remaining 6% unknown.⁵³ Most PV recyclers specialize in one type of panel, either c-Si or thin film, due to compositional differences between the two. Figure 2-3 shows the compositional makeup of

⁵⁰ "Solar Pv Module End Of Life: Options And Knowledge Gaps For Utility-Scale Plants." *EPRI*, 2018.

⁵¹ *Ibid.*

⁵² Weckend, Stephanie, et al. "End-of-Life Management: Solar Photovoltaic Panels," International Renewable Energy Agency and International Energy Agency Photovoltaic Power Systems. 2016.

⁵³ NCDEQ. *NC Solar Facility Data*. NC Department of Environmental Quality, Microsoft Excel, 2020.

different types of PV modules as percent by weight.⁵⁴

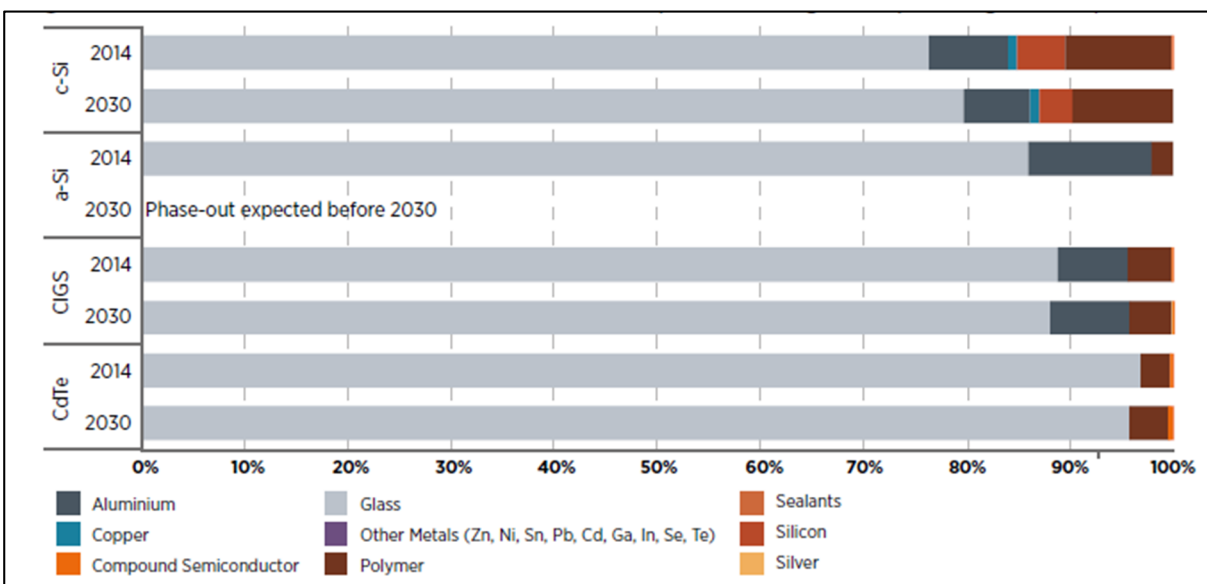


Figure 2-3. Compositional Makeup of PV Modules as Percent by Weight

Disposal of Non-Hazardous PV Modules

If a PV module is not suitable for refurbishment or reuse, it becomes a waste and a determination must be made as to whether or not the waste is considered hazardous. If the PV module designated as waste is deemed non-hazardous, it can go to any recycler or to a municipal solid waste (MSW) landfill. If a PV module is characterized as non-hazardous waste following a TCLP test, it is subject to the state's solid waste management rules and can be disposed in a MSW landfill or in an industrial landfill (monofil) designed for this particular waste. Municipal Solid Waste landfill disposal is the least preferred EOL management option for PV modules. As discussed in Section 2(a)(3), it is important to note that the positive health and environmental impacts of reduced emissions from PV systems as compared to fossil fuel combustion more than offset the risks or effects of landfilling. A PV module designated as waste should not be disposed into a construction and demolition (C&D) landfill. The decommissioning of solar facilities is not considered demolition and therefore waste, if not characterized as hazardous, would be managed as solid waste but not construction and demolition debris. Furthermore, the majority of C&D landfills are unlined and not subject to the same environmental control standards as MSW landfills.

During this study, DWM and Division of Environmental Assistance and Customer Service (DEACS) staff considered the positives and negatives of establishing a ban on MSW landfill disposal for non-hazardous PV modules and windmill blades, some of which are listed below:

Positives of a landfill ban

⁵⁴ Weckend, Stephanie, et al. "End-of-Life Management: Solar Photovoltaic Panels," International Renewable Energy Agency and International Energy Agency Photovoltaic Power Systems. 2016.

- + Recycling facilities would receive ample supply of product.
- + Amount of waste disposed in landfills would be reduced.
- + Landfills would be relieved of handling large bulky items, such as windmill blades and PV modules, which are operationally challenging to manage.

Negatives of a landfill ban

- Recycling markets in North Carolina and nearby states for EOL PV modules are not yet developed. A landfill ban could prematurely force material into an underdeveloped recycling marketplace that may become flooded with material or result in the stockpiling of equipment due to a lack of reasonably economic recycling options. Disposal may be the best short-term EOL management solution.
- Facility owners, local governments, and the solar industry would have to recycle materials at significant cost.
- A landfill ban may inhibit the growth of solar and wind energy production which could result in continuing use of fossil fuels.
- In limited instances, such as catastrophic events (e.g. fire, hurricane) where high amounts of other debris are interspersed with PV waste, it is not possible to recycle, reuse or refurbish damaged PV modules

Disposal of Hazardous PV Modules

If a PV module designated as waste is deemed hazardous as a result of characterization from the TCLP test, the PV module designated as waste must be recycled, stored, treated, and disposed in accordance with state and federal regulations for hazardous waste. In this case, a PV module designated as hazardous waste may go to a hazardous waste landfill. As previously discussed in Section 2(a)(1), DEQ staff recommends rulemaking to add PV modules designated as waste to the state universal waste rules. If the state adopts PV modules under North Carolina's universal waste rules, those products can be managed by universal waste handlers, but would still need to be recycled, stored, treated, or disposed at a permitted or interim status hazardous waste treatment, storage, and disposal facility (TSDF). Alternatively, the PV modules designated as waste may be recycled at a universal waste destination facility which is either subject to all the same requirements as a hazardous waste TSDF or if the universal waste is not stored, there are less stringent requirements for the management of the universal waste. If hazardous waste PV modules are recycled as a universal waste, a current limitation is that the destination facility must be located in North Carolina or in a state that has adopted universal waste rules for PV modules. Any hazardous PV modules managed out of state (in a state or transported through a state that has not adopted PV modules as a universal waste) must be managed as a hazardous waste.

Designating PV modules as universal waste could reduce disposal costs and be an efficient EOL management option. Since universal waste rules can alleviate transportation difficulties (currently only when transported in state), recycling centers would be able to

more efficiently process bulk shipments of PV modules designated as waste, rather than just a few.

Energy Storage System Batteries

The proper EOL management for energy storage system batteries largely depends on the type of battery used. As previously discussed in Section 2(a)(1), energy storage system batteries include lithium-ion, nickel-cadmium, and lead-acid batteries. Lithium-ion batteries represent over 80% of energy capacity of battery storage systems greater than 1MW but represent a relatively new market for recycling.⁵⁵

Lithium-Ion Batteries

There is not an established process to refurbish lithium-ion batteries for a second life. The market and performance of second-life batteries needs to be lucrative to make refurbishment an appealing option. Presently second-life battery system applications in the United States are limited. In addition, a battery will eventually reach the end of its productive life and no longer be able to support a secondary application. As a result, recycling is the preferred way to manage used lithium-ion batteries. However, recycling these batteries from large stationary sources can be difficult since it is a new industry. Currently, recycling lithium-ion batteries is challenging because of a lack of programs in place and their different chemistry make-ups.⁵⁶

Call2Recycle is the only lithium-ion battery processor in the United States, but several other companies can collect or recycle lithium-ion batteries nationwide.⁵⁷ Umicore has a dedicated process for recycling rechargeable batteries and is able to treat all types of lithium-ion batteries.⁵⁸ Umicore's facility in Hoboken, Belgium focuses on recycling lithium-ion batteries. Its process collects and recovers nickel, copper, cobalt, and rare earth elements. In September 2020, Li-Cycle Incorporated announced plans to construct its first U.S. battery recycling facility in New York. Construction is slated to begin in 2021, and the Canada-based company will recycle lithium-ion batteries used in energy storage, electric vehicles, and electronic devices.⁵⁹ Additional developments to advance the recycling process of lithium-ion batteries are underway. This will create new commercial opportunities, regulatory frameworks, and best practices for EOL management of lithium-ion battery storage systems.⁶⁰

Landfilling a lithium-ion battery is an EOL management option if the battery is considered non-hazardous. If the battery is deemed non-hazardous, it can go to any recycler or to a MSW landfill. However, there are several states with landfill bans for lithium-ion batteries, which is further discussed in Section 2(a)(6). It is possible for lithium-ion batteries to contain the hazardous characteristics of ignitability and toxicity. If they do, those batteries would be

⁵⁵ "U.S. Battery Storage Market Trends." U.S. Energy Information Administration, 2018.

⁵⁶ Chupka, Marc. "End of Life Management of Lithium-Ion Energy Storage Systems." U.S. Energy Storage Association, 22 April 2020.

⁵⁷ Smith, Carl. Market Trends and Considerations for End of Life and Recycling of Lithium-Ion Batteries. Jan. 2020, PowerPoint Presentation.

⁵⁸ Caffarey, Mark. Introducing Umicore. April 2020, PowerPoint Presentation.

⁵⁹ NY Press Release 2020, "Governor Cuomo Announces Canadian Firm Li-Cycle to Build \$175 Million Lithium-Ion Battery Recycling Hub in Monroe County." 2020.

⁶⁰ Chupka, Marc. "End of Life Management of Lithium-Ion Energy Storage Systems." U.S. Energy Storage Association, 22 April 2020.

subject to hazardous waste regulations and could be managed under the universal waste rules when recycled.

Lead-Acid and Nickel-Cadmium Batteries

Lead-acid and nickel-cadmium batteries are subject to RCRA hazardous waste regulations and may be managed under universal waste regulations if disposed due to the properties of lead and cadmium in their composition.^{61,62} According to G.S. 130A-309.70, it is illegal in North Carolina to dispose of a lead-acid battery in a landfill, incinerator, or any waste-to-energy facility. Existing laws and regulations do not appear to exclude lead-acid batteries used in energy storage systems. The preferred method to manage EOL lead-acid and nickel-cadmium energy storage system batteries is to recycle. Lead is the most efficiently recycled commodity metal; and as a result, 99% of lead-batteries in the United States are recycled.⁶³ While recycling options are readily available and cost-efficient, lead-acid batteries must be handled carefully as lead and sulfuric acid are highly toxic and can pose a risk to human health.⁶⁴ Nickel-cadmium batteries are also highly recyclable.⁶⁵

Other Equipment Used in Renewable Energy Facilities

Ancillary equipment that may be used in renewable energy facilities include mounting structures, electrical and transmission/distribution components, and associated site infrastructure improvements.

Other Utility-Scale Solar Project Equipment

Utility scale solar arrays include four main systems, the PV modules, mounting and racking structures, electrical components, and general site infrastructure. The system components that support PV modules are generally non-hazardous waste streams that have existing outlets for recycling and proper disposal. The mounting and racking structures are made of steel and aluminum which can be easily recycled by existing scrap metal recyclers. Steel and aluminum are valuable metals that will provide revenue to the generator although market values, like most recyclable commodities, fluctuate over time.⁶⁶

Electrical equipment may include wiring, inverters, transformers or other electronic components. None of this electronic equipment is banned from landfill disposal (N.C.G.S. 130A-309.130 through 309.142); however, DEQ recommends that it be reused, resold, or recycled to the maximum extent possible before considering landfill disposal. Some electronic components may provide revenue depending on the makeup of materials and presence of high-value metals. The wiring can be managed by existing electronics recyclers and some scrap metal recyclers. Inverters can be managed by existing electronics recyclers. Many inverters are compliant with the Restriction of Hazardous Substances (RoHS) which is required in Europe. RoHS ensures inverters do not include toxic materials such as lead, mercury, and cadmium. Older transformers may include

⁶¹ "Evaluation of Three RCRA Regulations Designed to Foster Increased Recycling." *Environmental Protection Agency*, 30 November 2004.

⁶² 40 CFR 273.2

⁶³ May, Geoffrey, et al. "Lead batteries for utility energy storage: A review" *Journal of Energy Storage*, Science Direct, Feb 2018.

⁶⁴ "BU-703: Health Concerns with Batteries." Battery University.

⁶⁵ "Collection and Recycling of Nickel-Cadmium (NiCd) Batteries." *International Cadmium Association*.

⁶⁶ Sandler, Simon. "Solar & Storage Waste Classification Overview." November 2019, PowerPoint Presentation

polychlorinated biphenyls (PCBs) which must be managed as hazardous waste. New transformers use non-toxic oils for cooling and do not contain PCBs. Transformers should be disposed of or recycled using existing outlets that appropriately manage or recycle the cooling oils (both hazardous and non-hazardous). Any other electrical equipment may contain valuable metals and may be managed by existing electronics recyclers.⁶⁷

General facility site improvements may include fencing, access roads, concrete pads, etc. All of these materials have existing outlets for recycling or proper disposal. Components should be reused or recycled to the maximum extent possible or disposed of in MSW or construction and demolition debris landfills.

Other Energy Storage System Equipment

Energy storage system components, such as containers, electrical components, and HVAC thermal management systems are typically reused or recycled. However, decommissioning entire energy storage systems is completed manually and requires a significant amount of time and expenses.⁶⁸

Wind Energy Equipment

Currently, there is not an established recycling system or feasible recycling process for wind turbines.⁶⁹ However, the tower, gear box, and generator components on wind turbines are recyclable.⁷⁰ In comparison, processing the wind turbine blades for repurposing is an energy intensive process due to the size of the blades and cost of equipment needed.⁷¹ An alternative for the blades is reusing them for repowering projects.⁷² Landfilling blades is currently the most cost-effective disposal option in the United States and most EOL wind turbine blades are landfilled. However, this is not the Department's preferred method of management as the blades are highly resistant to heat, sunlight, and moisture due to their composition. Degradation in a landfill would take hundreds of years. Currently, the cost effectiveness of disposing wind turbine blades in landfills makes it difficult for alternative EOL methods to compete.⁷³

Global Fiberglass Solutions (GFS), which began operation in Texas in 2019, is the first U.S. company to recycle wind turbine blades into products. GFS collects and transports EOL wind turbine blades to a processing facility. The blades are processed into small manufacturing-grade pellets and are sold to customers for their own manufacturing needs. Construction and automotive industries are developing product interest and subcontracting

⁶⁷ Ibid.

⁶⁸ Westlake, B., et al. "Recycling and Disposal of Battery Based Grid Energy Storage Systems." Electric Power Research Institute, December 2017.

⁶⁹ Hoefer, Michael. "Wind Turbine Blade Recycling: An Economic Decision Framework." Iowa State University, 2015.

⁷⁰ "Research note outline on recycling wind turbines blades." *The European Wind Energy Association*.

⁷¹ Ramirez-Tejeda, Katerin, et al. "Unsustainable Wind Turbine Blade Disposal Practices in the United States." *NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy*, vol. 26, no. 4, 2016, pp. 581–598.

⁷² Lawson J. "Repowering gives new life to old wind sites." *Renewable Energy World*, Jun. 2013.

⁷³ Ramirez-Tejeda, Katerin, et al. "Unsustainable Wind Turbine Blade Disposal Practices in the United States." *NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy*, vol. 26, no. 4, 2016, pp. 581–598.

agreements with GFS and the company is in the process of opening an Iowa facility by the end of 2020.^{74,75}

Recently, GE Renewable Energy signed an agreement with Veolia North America to recycle onshore blades that are removed during repowering efforts. Veolia will process the blades at its facility in Missouri by using a cement kiln co-processing technology. Approximately 90% of the blade material will be repurposed through this process. Repurposing wind turbine blades will replace the need for raw materials in cement manufacturing. This new opportunity will create a circular economy for the blade's composite materials and will be quickly deployed in the country.⁷⁶

⁷⁴ "Global Fiberglass Solutions Becomes the First US Based Company to Commercially Recycle Wind Turbine Blades into Viable Products." *Cision PRWeb*, Jan. 2019.

⁷⁵ Uhlenhuth, Karen. "Wind turbine blade recycler trying to fit the pieces together at Iowa factory." *Energy News Network*, Feb. 2020.

⁷⁶ "GE Renewable Energy Announces US Blade Recycling Contract with Veolia." *Waste360*, Dec. 10. 2020.

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Economic and environmental costs and benefits associated with each method identified in subdivision (2) of this section to manage end-of-life photovoltaic modules, energy storage system batteries, or the constituent materials thereof, and other equipment used in utility-scale solar projects or wind energy facilities.

The Department researched and evaluated the economic and environmental costs and benefits associated with the EOL management methods described in the previous section. In brief, reuse, refurbishment, and recycling markets for EOL renewable energy equipment are still developing and not fully established in the United States due to a limited supply of decommissioned equipment. Reuse, refurbishment, and recycling are environmentally preferable management options. While reuse/refurbishment is environmentally advantageous for PV modules, recycling opportunities for PV modules, energy storage system batteries and wind turbine blades are limited and costly. As more renewable energy equipment reaches EOL and becomes available for recycling, the recycling process is expected to improve with new technology and operational efficiency which should lead to reduced recycling costs. Until these technologies mature to achieve cost parity across applications, the cheapest, readily available EOL management option at this time for certain EOL renewable energy equipment is landfill disposal.

Photovoltaic Modules

In 2018, the Electric Power Research Institute (EPRI) published its first conceptual cost estimate for decommissioning a 11-MWAC c-Si PV plant. The cost estimate assumed decommissioning activities would have taken place in December 2017 and that PV modules would be disposed of in a MSW landfill. The overall cost of decommissioning was shown to be \$83/kW, which represents 4.8% of the system’s installed cost of \$1,727/kW. The value for the scrap metal was factored into the calculation, which decreased the overall decommissioning cost by approximately 25%. The cost for transportation and disposal at a MSW landfill accounted for approximately 10% of the total decommissioning cost. Figure 3-1 below shows a breakdown of cost elements.⁷⁷

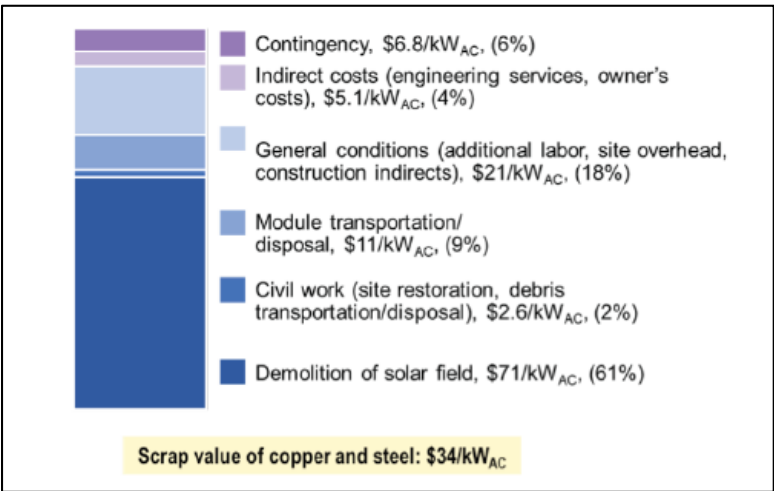


Figure 3-1. Decommissioning Cost Breakdown for PV Facility Assuming Modules Are Landfilled

⁷⁷ “PV Plant Decommissioning Salvage Value Conceptual Cost Estimate.” EPRI, 2018.

Alternative EOL management options such as selling or donating PV modules into secondary markets versus paying to recycle modules or dispose of modules as hazardous waste will change the estimate. Furthermore, without a mature market to drive recycling of EOL modules, approximate costs can only be estimated at this time.

Refurbishment and Reuse

Benefits

As the preferred waste management strategy, reuse extends the service life and thereby increases the lifetime electricity production of a PV module using the same amount of extracted materials and embodied energy from the original manufacturing process.⁷⁸ Even if refurbishment or replacement parts are necessary to maintain overall functionality, additional electricity output will be achieved with far fewer environmental impacts as compared to the manufacturing of a new PV module. Extending the use of existing PV modules to maximize output reduces the need to produce more new panels.

Owners of PV modules that can be reused or refurbished will likely be incentivized to pursue this management strategy as a potential revenue source if the modules are sold, or a claim a tax credit if modules are donated. By extending the useful life of a PV module, the owner does not have to manage waste materials. Therefore, all EOL management decisions and associated costs are transferred to the new owner or recipient.

Costs

Although a potential revenue source, there are costs associated with preparing PV modules for reuse or resale. Each module must be inspected, tested, and possibly certified for safety and performance before it can be donated or resold.⁷⁹ In addition, modules must be carefully dismantled and transported to ensure they remain intact and undamaged. This careful handling leads to increased labor and transportation costs as compared to recycling or disposal.

For the recipient or buyer of a used PV module, there are potential challenges to consider. Even when purchased at a discounted cost, reused modules may not provide as much economic value to new owners compared to new modules because of their shorter lifetime and lower efficiency. Used PV modules may not come with a warranty or guarantee; and due to the age of the module, it may be difficult to find and source replacement parts or components for older modules.⁸⁰

While extending the life of older modules helps reduce the need to extract resources for the manufacturing of new modules, older PV modules may contain more potentially hazardous constituents. The amounts of cadmium and tellurium have declined by more than 90% by weight as compared to early market CdTe modules with advances in manufacturing to reduce production costs and minimize semiconductor materials. Older silicon modules are

⁷⁸ Heath, Garvin A., et al. "Research and Development Priorities for Silicon Photovoltaic Module Recycling to Support a Circular Economy." *Nature Energy*, vol. 5, no. 7, 2020, pp. 502–510.

⁷⁹ Ibid.

⁸⁰ Ibid.

also likely to contain more lead used in soldering and therefore may be more likely to exceed TCLP test standards.⁸¹ If shipped internationally, the burden of waste management is shifted to the receiving country which may have less stringent waste regulations and fewer protections for human health and the environment. Additionally, the transport of modules to international and overseas markets will result in higher transportation costs and a larger greenhouse gas footprint.

Photovoltaic Modules Recycling

Benefits

The process of recycling recovers materials from PV modules to be used in the manufacturing of new PV modules or other products. This reduces the amount of new, or virgin, materials that need to be harvested for the manufacturing of new products. It also allows for the recovery of valuable metals such as silver, copper, and aluminum which would otherwise be lost to landfill disposal. This is particularly important for materials with limited supply and/or global trade constraints, such as tellurium, gallium, and indium which are commonly used in thin film modules.⁸² The International Renewable Energy Agency (IRENA) and the International Energy Agency Photovoltaic Power Systems (IEA-PVPS) estimate that the value of materials recovered from end-of-life PV modules worldwide could exceed \$15 billion by 2050 and these materials could be used to produce 2 billion new modules (about 630 GW of new capacity).⁸³ While materials of value can be recovered from EOL PV modules, it is important to note that modules are difficult to recycle because they are designed to be durable and long-lasting. Separation and extraction of materials is energy intensive and the cost to extract these materials currently exceeds their value. Despite the cost, the decision to landfill PV modules means that these materials will be lost and cannot be recovered for economic use. Although the energy required to recycle PV modules contributes to a higher cost, the climate change impacts due to energy consumption from the recycling process are less than 5% of the climate impacts associated with the manufacturing of new PV modules, as discussed in the costs section below.⁸⁴

The recycling of PV modules is still an emerging technology, with most modules processed in batches at facilities designed to manage other material streams such as electronics, metals, or glass. As more modules reach EOL and become available for recycling, the recycling process is expected to improve with new technology and operational efficiency which should lead to reduced recycling costs.⁸⁵ Manufacturers can contribute to improved cost-effectiveness by designing new modules with recyclability in mind to make dismantling and recovery of high-value materials easier. As previously discussed in Section 2(a)(1), the new NSF/ANSI 457 standard and EPEAT certification requires manufacturers to offer a national take-back and recycling service for their products which will incentivize design for

⁸¹ Solar PV Module End Of Life: Options And Knowledge Gaps For Utility-Scale Plants. *EPRI*, 2018.

⁸² Sustainable Materials Management (SMM) Web Academy Webinar: Shining the Light on Solar Panel Recycling - A Status Update. *EPA*, 2019.

⁸³ Weckend, Stephanie, et al. "End-of-Life Management: Solar Photovoltaic Panels," International Renewable Energy Agency and International Energy Agency Photovoltaic Power Systems. 2016.

⁸⁴ P. Stolz, R. Frischknecht, K. Wambach, P. Sinha, G. Heath, 2017, Life Cycle Assessment of Current Photovoltaic Module Recycling, IEA PVPS Task 12, International Energy Agency Power Systems Programme, Report IEA-PVPS T12- 13:2018.

⁸⁵ Solar PV Module End Of Life: Options And Knowledge Gaps For Utility-Scale Plants. *EPRI*, 2018.

recyclability in the manufacturing process.⁸⁶ The incentivization of recycled content in the EPEAT label award criteria for new PV modules is expected to generate market pull for high value recycling and secondary resources. As demand for recycling increases, recyclers will invest in new facilities or additional processing lines leading to the creation of new jobs.

Manufacturers have already made progress to improve the environmental footprint and reduce toxic materials in PV modules. Beginning in 1999, lead-free solder was introduced to the market, and as of 2016, more than half of PV module manufacturers are using lead-free solder.⁸⁷ Manufacturers can also use recovered materials from recycled panels to lessen the environmental footprint of new panels. In particular, energy and emissions savings can be realized when recycled materials replace raw semiconductor materials that require energy-intensive pretreatment to achieve required purity levels.⁸⁸

The International Energy Agency (IEA) conducted an environmental life cycle assessment of PV module recycling that was released in 2018. The life cycle assessment addressed six indicators: (i) particulate matter; (ii) freshwater ecotoxicity; (iii) human toxicity non-cancer effects; (iv) human toxicity cancer effects; (v) mineral, fossil fuel, and renewable resource depletion; and (vi) climate change. Results from the IEA lifecycle assessment showed that recycling c-Si PV modules results in net environmental benefits in all six indicators with the highest potential benefit in the mineral, fossil fuel, and renewable resource depletion category. For this indicator, the potential benefits are 54 times higher than the impacts caused by recycling. The recycling of CdTe PV modules was shown to have a net benefit in five of the six indicators. Potential benefits in the renewable resource depletion category are 750 times higher than the impacts caused by the recycling. The only category that did not show a net environmental benefit is human toxicity cancer effects. The avoided environmental burdens by recovered materials do not outweigh the human toxicity cancer effects caused by the recycling efforts due to the use of hydrogen peroxide in the recycling process.⁸⁹

Costs

As discussed above, PV module recycling comes at a charge because the cost to recycle PV modules far exceeds the revenue of recovered materials. Low-value recycling is more cost-competitive with landfill disposal but the process only recovers metal, plastic, and sometimes glass. It is common for glass, which makes up more than 70% of the panel by weight, to be landfilled, along with remaining encapsulated valuable and raw metals.

Costs for high-value recycling of c-Si modules have been reported in the United States in the range of \$25 to \$30 per module. This cost for recycling does not include transportation

⁸⁶ Sustainability Leadership Standard for Photovoltaic Modules and Photovoltaic Inverters. NSF/ANSI 457-2019. NSF International.

⁸⁷ Fthenakis, Vasilis. "Chapter IV-1-A - Overview of Potential Hazards." *McEvoy's Handbook of Photovoltaics*, 2018, pp. 1195–1212.

⁸⁸ P. Stolz, R. Frischknecht, K. Wambach, P. Sinha, G. Heath, 2017, Life Cycle Assessment of Current Photovoltaic Module Recycling, IEA PVPS Task 12, International Energy Agency Power Systems Programme, Report IEA-PVPS T12- 13:2018.

⁸⁹ Ibid.

costs to the recycling facility.⁹⁰ Assuming a c-Si PV module weighs an average of 40 pounds, the recycling cost equates to \$0.625 per pound. This is compared to an average cost of \$0.021 per pound to landfill materials in North Carolina in FY2018-19.⁹¹ Due to the low amounts of PV module waste, there is no financial incentive to establish recycling facilities in the United States that are dedicated to PV modules, which is needed to reduce recycling costs.

The recycling process itself is energy intensive, especially for separating and achieving purity rates for particular materials such as silicon.⁹² Even so, the climate change impacts due to energy consumption associated with recycling are only 1.1% relative to product manufacturing for c-Si PV modules and 4.8% relative to product manufacturing for CdTe PV modules.⁹³

After initial processing to separate layers, resultant material streams may need to be re-tested for hazardous constituents (e.g., glass that becomes mixed with lead solder that was used in older modules). Ethyl vinyl acetate (EVA), which is used as an encapsulant, cannot currently be recycled. Current recycling processes dissolve the encapsulant into a waste solution or evaporate it to be released as an emission. Research is underway to determine if EVA can be recycled or if modules could be manufactured without the encapsulant but cost-effective and durable solutions have not yet been identified.⁹⁴

Photovoltaic Modules Disposal – MSW Landfill

Benefits

While reuse, refurbishment, and recycling are the preferred waste management options for PV modules, MSW landfill disposal is a safe and acceptable alternative that does not present risks to human health or the environment for non-hazardous PV modules. As discussed in Section 2(a)(2), non-hazardous PV modules can be disposed of in MSW landfills, all of which are lined in North Carolina – but should not be disposed of in an unlined C&D landfill.

Although disposal of all non-hazardous PV modules would be into only lined MSW landfills in North Carolina, DEQ evaluated an IEA study of the risks associated with disposing PV modules in a non-sanitary (unlined) landfill. The IEA study found that PV modules disposed of in this manner are unlikely to negatively affect human health. Lead from c-Si modules had exposure-point concentrations less than one-tenth of the EPA risk-based screening levels in soil, air, and water. Cadmium and selenium from other module types

⁹⁰ Heath, Garvin A., et al. "Research and Development Priorities for Silicon Photovoltaic Module Recycling to Support a Circular Economy." *Nature Energy*, vol. 5, no. 7, 2020, pp. 502–510.

⁹¹ DEQ 2020, FY2018-19 Consolidated Waste Management Report.

⁹² Solar PV Module End Of Life: Options And Knowledge Gaps For Utility-Scale Plants. *EPRI*, 2018.

⁹³ P. Stolz, R. Frischknecht, K. Wambach, P. Sinha, G. Heath, 2017, Life Cycle Assessment of Current Photovoltaic Module Recycling, IEA PVPS Task 12, International Energy Agency Power Systems Programme, Report IEA-PVPS T12- 13:2018.

⁹⁴ Heath, Garvin A., et al. "Research and Development Priorities for Silicon Photovoltaic Module Recycling to Support a Circular Economy." *Nature Energy*, vol. 5, no. 7, 2020, pp. 502–510.

were found to be several orders of magnitude below EPA cancer risks and non-cancer hazard screening thresholds.⁹⁵

Landfill disposal offers a relatively cheap and cost-effective EOL management option for PV modules provided they are not characterized as hazardous waste. The average MSW landfill tipping fee in North Carolina in FY2018-19 was \$42.60 per ton, or \$0.0213 per pound.^{96,97}

Costs

In order to dispose of PV modules in a MSW landfill, waste generators must provide a waste determination to illustrate that the PV modules are not hazardous waste. Making such a determination will require TCLP testing, which presents a cost to the PV module owner.

Disposal of non-hazardous PV modules in MSW landfills will increase the state's disposal tonnages in future years. Industry leaders estimate that only 10% of EOL modules are currently recycled in the United States, and the rest are either sent to landfills or exported overseas.⁹⁸ As provided in Section 2(a)(5), forecasts for future PV module waste generation, conservatively assuming it is all destined for MSW landfill disposal, do not present concerns about landfill capacity in North Carolina. To that point, landfill operators are authorized to reject certain waste streams or adjust tipping fees, especially for materials that are large or difficult to manage. Therefore, PV module waste generators may incur additional costs to comply with landfill operator requirements.

Finally, as discussed in previous sections, the raw materials, including precious metals contained in PV modules, will not be recovered in a landfill disposal scenario. Not only will their economic value never be realized, but the embodied energy from the extraction and production will be lost. This will require continued extraction of raw materials for the production of new PV modules.

Photovoltaic Modules Disposal – Hazardous Waste Treatment or Disposal Benefits

PV modules characterized as hazardous waste must be managed in accordance with RCRA in order to protect human health and the environment.

Costs

Hazardous waste disposal is costly. A survey of hazardous waste operators estimated tipping fees to be \$175 per ton and higher for accepting bulk quantities of PV modules. This value factored in a minimum tonnage requirement but does not include the additional costs associated with manifesting and transporting hazardous waste. One operator reported a

⁹⁵ P. Sinha, G. Heath, A. Wade, K. Komoto, 2019, Human health risk assessment methods for PV, Part 3: Module disposal risks, International Energy Agency (IEA) PVPS Task 12, Report T12-16:2020. ISBN 978-3-906042-96-1.

⁹⁶ "Tipping Fee" means cost per ton of waste at the MSW landfills when weighed at the facilities' scale house.

⁹⁷ DEQ 2020, FY2018-19 Consolidated Waste Management Report.

⁹⁸ Stone, Maddie. "Solar Panels Are Starting to Die. What Will We Do with the Megatons of Toxic Trash?" *Grist*, 13 August 2020.

charge of \$500 to \$600 per unit to accept and treat a small batch of PV modules that contained high lead levels.⁹⁹

Similar to landfill disposal, hazardous waste treatment or disposal will not allow for the recovery of valuable material to be recirculated into beneficial use.

Energy Storage System Batteries

As previously presented in Section 2(a)(1), energy storage system batteries come in different types: lithium-ion batteries, lead-acid batteries, and nickel-cadmium batteries. The oldest type are lead-acid batteries, and now lithium-ion batteries represent over 80 percent of energy capacity of battery storage systems greater than 1MW.¹⁰⁰ The preferred management strategy, reusing the battery storage systems if they can be reliably refurbished, can extend their life and result in less cost for buying new batteries or harvesting precious metals. Unfortunately, at this time, there is no established process for reuse or refurbishment of lithium-ion batteries. The market and performance of batteries in their second life must be promising to make refurbishment an option.¹⁰¹ It is a relatively new idea to refurbish battery storage systems and it is only beginning to gain traction, especially in the reuse of electric vehicle (EV) batteries for new capacities.

Energy Storage System Batteries Recycling

Benefits

Despite lithium-ion batteries being relatively new to the recycling market,¹⁰² energy storage system battery recycling has many potential economic benefits. It is currently the preferred method for managing lithium-ion batteries at EOL. There are many valuable recoverable elements, including: cobalt, nickel, lithium, and manganese. There have been significant developments in advancing the recycling of these batteries.¹⁰³

Lead-acid batteries are highly recyclable. Lead is one of the most efficiently recycled metals – 99% of lead-acid batteries are recycled in the United States cost effectively.¹⁰⁴ Recycling lead-acid batteries is profitable because recycled lead can easily be made into new batteries (Steward 2019). Nickel-cadmium batteries are also highly recyclable.¹⁰⁵

Battery recycling can supply the United States with a significant amount of raw materials for battery manufacturing.¹⁰⁶ Proper recycling of energy storage system batteries also prevents

⁹⁹ Solar PV Module End Of Life: Options And Knowledge Gaps For Utility-Scale Plants. EPRI, 2018.

¹⁰⁰ "U.S. Battery Storage Market Trends." U.S. Energy Information Administration, 2018.

¹⁰¹ Ibid.

¹⁰² Ibid.

¹⁰³ Chupka, Marc. "End of Life Management of Lithium-Ion Energy Storage Systems." U.S. Energy Storage Association, 22 April 2020.

¹⁰⁴ Torabi, Farschad, and Pouria, Ahmadi. Simulation of Battery Systems: Fundamentals and Applications. Academic Press, 2020, Google Books.

¹⁰⁵ "Collection and Recycling of Nickel-Cadmium (NiCd) Batteries." Cadmium, International Cadmium Association.

¹⁰⁶ Mann, Margaret. "Battery Recycling Supply Chain Analysis." NREL, presentation, Jun. 2019.

potentially hazardous constituents from landfill disposal and has lower environmental impacts when compared to mining virgin materials from the earth.¹⁰⁷

Costs

Recycling lithium-ion batteries presents a challenge because of the lack of recyclers available who can accept or manage the batteries and their different chemistry make ups.¹⁰⁸ The Electric Power Research Institute estimated costs for lithium-ion battery recycling to range from \$1.00 to \$2.50 per pound depending on chemistry makeup, based on 2015 market information and pricing.¹⁰⁹

Lead-acid batteries must be handled carefully to prevent negative environmental and health effects because of the highly toxic constituent materials including lead and sulfuric acid.¹¹⁰ A typical lead-acid battery is composed of lead (metal or lead oxide paste), plastic, sulfuric acid, electrolyte, and other components such as antimony, arsenic, and cadmium.¹¹¹ Lead-acid batteries are subject to hazardous or universal waste regulations if disposed due to the lead present in its composition.¹¹² In North Carolina, it is illegal to dispose of a lead-acid battery in a landfill, incinerator, or any waste-to-energy facility.¹¹³ The regulation does not include a definition of lead-acid battery that would exempt lead-acid batteries used in energy storage systems.

Energy Storage System Batteries Disposal

Benefits

There are limited or unknown benefits to landfill disposal of energy storage system batteries, if lawful. Proper disposal of nickel cadmium and lithium-ion batteries, if recycling is not an option, is the preferred management option to avoid accumulation and storage of EOL batteries.

Costs

Many energy storage system batteries contain hazardous constituents and lead-acid batteries in particular are banned from landfill disposal in North Carolina. Some other states have a landfill ban on lithium-ion batteries.

Federal hazardous waste and universal waste regulations apply to lithium-ion batteries only if they exhibit one or more of the hazardous waste characteristics. If a lithium-ion battery is

¹⁰⁷ Steward, Darlene, et al. "Economics and Challenges of Li-Ion Battery Recycling from End-of-Life Vehicles." Science Direct, NREL, 2019.

¹⁰⁸ Smith, Carl. Market Trends and Considerations for End of Life and Recycling of Lithium-Ion. Batteries. January 2020, PowerPoint Presentation.

¹⁰⁹ Westlake, B., et al. "Recycling and Disposal of Battery Based Grid Energy Storage Systems." Electric Power Research Institute, December 2017.

¹¹⁰ Torabi, Farschad, and Pouria, Ahmadi. Simulation of Battery Systems: Fundamentals and Applications. Academic Press, 2020, Google Books.

¹¹¹ CEC. Environmentally Sound Management of Spent Lead-acid Batteries in North America: Technical Guidelines. Montreal, Canada: Commission for Environmental Cooperation, 2016, 92 pp.

¹¹² "Wastes - Hazardous Waste - Universal Wastes." U.S. EPA.

¹¹³ N.C.G.S. §130A-309.71

determined to not contain any of these characteristics, it is not subject to hazardous waste or universal waste rules. It is the generator's responsibility to determine whether or not a battery is characterized as hazardous.¹¹⁴ In the event that an energy storage system battery is deemed non-hazardous, MSW landfill disposal is an inexpensive option. Although the disposal cost would be set by the MSW landfill operator, the average costs of waste disposal in North Carolina is currently \$42.60 per ton. Additionally, for lithium-ion batteries, the current materials mining production is limited and has the potential to create availability constraints and pricing issues. Disposal could increase the scarcity of lithium or other rare earth elements.¹¹⁵

Wind Energy Facilities

Wind Energy Equipment Reuse

Benefits

Reusing or repowering provides a second life application for wind turbines with some economic and environmental advantages. In terms of economic benefits, repowering could allow for streamlined development of wind energy facilities because operations have been previously permitted and sited, requiring less investment than would be needed to finance new greenfield wind energy projects.¹¹⁶ The environmental benefit of reusing wind components or repowering turbines is that it reduces both the need for producing new materials and wastes generated.

Costs

The total expenditures required for wind energy facilities may offset some of the economic benefits.¹¹⁷ In addition, there is a greater possibility of wind components failing as a result of reuse.¹¹⁸

Wind Energy Equipment Recycling

Benefits

Currently, the small amount of the components as well as the level of purity make the economic benefit of recycling wind blades difficult to value.¹¹⁹ However, as more wind turbines are decommissioned in the next decade across the country, the amount of composite material will be more widely available to make recycling a feasible option. The composite material derived from recycling can be used in other industries and gives turbines a second application rather than accumulating in a landfill.

As discussed in Section 2(a)(2), Veolia will be collecting and processing blades from GE Renewable Energy to produce raw materials for the cement industry. Quantis U.S.

¹¹⁴ "Questions about the Disposal of Lead-Contaminated Items | Hazardous Waste Treatment, Storage & Disposal." Wastes- Hazardous Waste- Treatment, Storage & Disposal (TSD), Environmental Protection Agency.

¹¹⁵ Steward, Darlene, et al. "Economics and Challenges of Li-Ion Battery Recycling from End-of-Life Vehicles." Science Direct, NREL, 2019.

¹¹⁶ Lantz, Eric, et al. "Wind Power Project Repowering: Financial Feasibility, Decision Drivers, and Supply Chain Effects." *National Renewable Energy Laboratory*, Dec. 2013.

¹¹⁷ Ibid.

¹¹⁸ "Repowering Wind Turbines Adds Generating Capacity at Existing Sites." *U.S. Energy Information Administration*, Nov. 2017.

¹¹⁹ "Research note outline on recycling wind turbines blades." *The European Wind Energy Association*.

conducted an environmental impact analysis for blade recycling by cement kiln co-processing and found that it produces a positive net benefit in all categories. Wind turbine blade recycling creates a 27% net reduction in carbon dioxide emissions and a 13% reduction in water consumption when compared to standard cement manufacturing.¹²⁰

Costs

Due to the lack of a recycling system and an efficient recycling process,¹²¹ the economic costs of recycling wind turbines outweigh the benefits at this time. Primarily, the capital investments as well as the labor necessary make recycling an expensive EOL management option. In addition, the energy intensive process of recycling wind turbine blades results in a small amount of total recyclable composite material.¹²² The recycling processes for wind turbine blades can emit hazardous gases and chemicals and/or produce dust emissions which may result in costs for pollution controls, monitoring, and possibly environmental cleanup.¹²³

Wind Energy Equipment Disposal

Costs

As the least preferred EOL management method, landfilling wind energy equipment has several disadvantages. The wind turbine blades are massive structures that take up valuable space that could prematurely fill a small landfill. Although landfill capacity is not an issue in North Carolina, it can present a problem for some local government owned/operated landfills that are required to provide disposal to industries within their jurisdictions. Obtaining a permit modification to increase landfill space or the need to open a transfer facility can incur additional expenses. In addition, disposing wind turbine blades in a landfill comes with the opportunity cost of the unrecovered materials.¹²⁴ Finally, degradation of wind turbine blades in a landfill may take hundreds of years due to the strength and resiliency of the structures. In a landfill, the blades would also contribute to methane emissions and release of volatile organic compounds.¹²⁵ A landfill operator may be required to continue post-closure monitoring and care for added decades, thereby incurring years of additional disposal management costs.

¹²⁰ "GE Renewable Energy Announces US Blade Recycling Contract with Veolia." Waste360, Dec. 10. 2020.

¹²¹ Ramirez-Tejeda, Katerin, et al. "Unsustainable Wind Turbine Blade Disposal Practices in the United States." *NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy*, vol. 26, no. 4, 2016, pp. 581–598.

¹²² "Research note outline on recycling wind turbines blades." *The European Wind Energy Association*.

¹²³ Ramirez-Tejeda, Katerin, et al. "Unsustainable Wind Turbine Blade Disposal Practices in the United States." *NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy*, vol. 26, no. 4, 2016, pp. 581–598.

¹²⁴ Stella, Christina. "Unfurling The Waste Problem Caused By Wind Energy." *NPR*, 10 Sept. 2019.

¹²⁵ Ramirez-Tejeda, Katerin, et al. "Unsustainable Wind Turbine Blade Disposal Practices in the United States." *NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy*, vol. 26, no. 4, 2016, pp. 581–598.

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The data-based expected economically productive life cycle of various types of photovoltaic modules, wind turbines, and energy storage system batteries currently in use in the State.

In summary, the Department finds that the economically product life cycle for the three studied forms of renewable energy equipment averages 20 years. The earliest scenario for EOL management appears to apply to those solar facilities installed around 2010, as they approach end of useful life – notwithstanding repowering – beginning in 2031.

Photovoltaic Modules¹²⁶

It is estimated that there are 601 solar facilities in North Carolina with nameplate generation capacities greater than 1MW. The majority of the utility-scale solar facilities in North Carolina have lifespan data available with estimated life cycles spanning 25 to 40 years. For those facilities that reported a lifespan with a range of years, the Department assigned the lowest value in the range as a conservative estimate for reporting and EOL management purposes. For those facilities for which lifespan data is not available, DEQ assigned 25 years as the lifespan because 25 years is the most commonly reported length of time covered by manufacturer warranties.

The Department was able to collect information on the types of solar panels installed for 577 of the 601 facilities. Crystalline silicon (c-Si) panels accounted for 504 of the 577 facilities with solar panel technology information available. There are approximately 62 facilities with cadmium-telluride (CdTe) panels, and only 11 facilities with copper indium gallium selenide panels installed (CIGS). The average lifespan of the three PV module technologies was collected from the 577 North Carolina facilities and is summarized in Table 4-1.

Panel Type	# of Facilities	Average Lifespan of Panels
CdTe	62	24 years
CIGS	11	28 years
c-Si	504	24 years

Table 4-1. Detail on Solar Panels Installed in North Carolina

Based on the Department's research and the aforementioned assumptions, it is estimated that:

- Of the 601 solar facilities in North Carolina, almost half of the facilities will be decommissioned between the years 2036 and 2040.
- A quarter of the 601 solar facilities will be decommissioned between the years 2031 and 2035.
- Approximately one fifth of solar facilities will reach EOL between 2041 and 2045.

Figure 4.1 depicts the breakdown of facilities by estimated year of decommissioning.

¹²⁶ NCDEQ. *NC Solar Facility Data*. NC Department of Environmental Quality, Microsoft Excel, 2020.

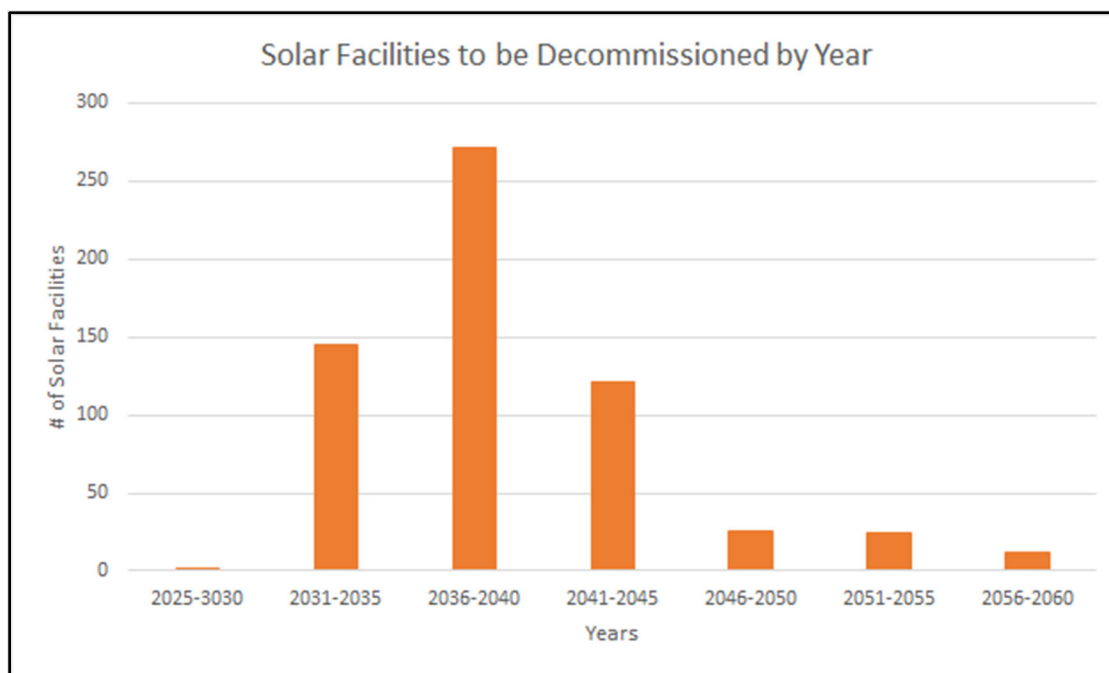


Figure 4-1. Solar Facilities Projected Decommissioning by Year

Energy Storage System Batteries^{127,128}

The lifespan of lithium-ion energy storage system batteries is influenced by the cycling depth of discharge, which is the fraction of the energy capacity that can be depleted during a charge-discharge cycle. This battery technology may lose energy storage capacity more rapidly over time depending on the depth of discharge; however, it is estimated that the lifespan of lithium-ion batteries ranges from 10 to 15 years. Similarly, nickel cadmium (NiCd) batteries have an estimated lifespan of 10 to 15 years. However, NiCd batteries are not as widely used as lithium-ion batteries because they are an early form of energy storage system technology.

In comparison, lead-acid batteries are one of the oldest energy storage technologies and represent a smaller portion of large scale energy storage systems. Lead-acid battery technologies that are used for energy storage projects typically have a lifespan of 15 to 30 years.

Although flow batteries are a relatively new energy storage system technology and currently represent a very small proportion of large-scale battery storage deployment, these batteries are an emerging option for energy storage. Vanadium redox flow batteries are estimated to have a lifespan of 10 to 15 years. However, maintenance or refurbishment can extend the battery life to 20 years or more.

¹²⁷ Carnegie, Rachel, et al. "Utility Scale Energy Storage Systems." *State Utility Forecasting Group (Purdue University)*, Jun. 2013.

¹²⁸ U.S. Battery Storage Market Trends." U.S. Energy Information Administration, May 2018.

Wind Energy Facilities

The Amazon Wind Farm U.S. East is comprised of 104 2MW Gamesa G114 models. Although there is no data available for the lifespan of this model, the Department conservatively estimates that the wind turbines will need to be decommissioned in approximately 20 years.¹²⁹ The Amazon Wind farm went into operation in 2017. Therefore, the associated wind energy equipment is estimated to reach EOL in 2037.

¹²⁹ "Repowering Wind Turbines Adds Generating Capacity at Existing Sites." *U.S. Energy Information Administration*, 6 Nov. 2017.

V. HB329 Section 2.(a)(5)

The volume of photovoltaic modules, wind turbines, and energy storage system batteries currently in use in the State, and projections, based upon the data on life cycle identified in subdivision (2) of this section, on impacts that may be expected to the State's landfill capacity if landfill disposal is permitted for such equipment at end-of-life.

- **PV Modules:** With the second-highest number of solar installations in the country, North Carolina has a significant amount of PV energy infrastructure to manage when the solar and related equipment reach EOL. The Department analyzed and cross-referenced several data sets to create the most comprehensive accounting of solar facility installations available. Based on this analysis and associated calculations, DEQ estimates that approximately 500,000 tons of PV modules are currently installed in the state and installations are projected to double in the next 5 years. At a conservative 1,000,000 tons, EOL PV modules would account for less than 10% of the tonnage disposed in landfills relative to FY2018-19. Based on the forecasted life of these projects, the PV modules would reach EOL between 2035 to 2045. According to DWM experts, if all 1,000,000 tons of EOL PV modules are disposed of in landfills, landfill capacities will not be negatively impacted. This finding does not consider the Department's preferred options for EOL management – reuse and refurbishment and recycling – which as those methods mature and become more cost competitive will divert some of the projected waste stream from landfills.
- **Energy Storage System Batteries:** Presently fewer than 12MW of energy storage system batteries are installed statewide and because of their relative age, will not reach EOL for at least 10 years. The Department's preferred method for EOL management combined with existing laws banning disposal of some batteries in landfills will result in limited landfilling of energy storage system batteries.
- **Wind Energy Facilities:** One facility is in operation in North Carolina and no projects are pending the Department for permitting. As demonstrated in Section 2(a)(4), the estimated life-cycle for the Amazon Wind U.S. East facility is 20 years, meaning EOL equipment management will not be necessary until at least 2037. Most component parts of the turbines are can be reused or recycled while the technology to recycle the fiberglass blades has not yet developed to scale. The Department does not predict strains on regional landfill capacity if all 4,400 tons of blades must be landfilled.

Photovoltaic Modules¹³⁰

North Carolina solar facility data was collected and obtained from the North Carolina Utilities Commission (NCUC) Renewable Energy Facility Registration, the NC Renewable Energy Tracking System (NC RETS), and the U.S. Energy Information Administration (EIA). To ensure the accuracy of the data, these compiled facilities were also cross checked against a list of facilities provided by Department of Agriculture & Consumer Services. Each solar facility was also checked using GIS tools to determine if the solar panels were currently installed. Due to

¹³⁰ NCDEQ. *NC Solar Facility Data*. NC Department of Environmental Quality, Microsoft Excel, 2020.

the data available, information was compiled only for ground-mounted, grid-connected solar facilities with a capacity of 1MW or greater.

For generators with capacity less than 2MW, the NCUC requires submission of the Report of Proposed Construction according to Commission Rule R8-65. These projects do not undergo a regulatory approval process, but their information is collected through Form R865 and maintained in a database on an irregular basis.¹³¹ For generators with capacity greater than 2MW but less than 80MW, an Application for a Certificate of Public Convenience and Necessity according to Rule R8-64 applies. These facilities submit project specific data and information according to Form R864.¹³² Facilities greater than 80MW do not have a form but must comply with NCUC rule R8-63, which has requirements similar to R8-64. At the federal level, EIA requires all affected generators to submit Forms 860 and 923 containing static site-specific information and annual generation amounts, respectively.

The EIA considers grid-tied facilities with a combined alternating current nameplate capacity rating of 1MW or greater to be a utility-scale operation. Facilities meeting the minimum EIA criteria are required to annually report key generator-level information such as capacity, panel composition, addresses, utility sectors, and the operating year. This information provides a consistent baseline to account for ground-mounted utility-scale PV operations across multiple datasets to quantify potential waste products. The Department identified the EIA reporting format as the most comprehensive and dynamic database for extracting current and future facility level information. As such, the EIA's reporting threshold of 1MW is recommended as the applicable threshold for development of minimum notification requirements for facilities to comply with EOL management requirements.

Where available, the Department acquired information on the following parameters for these solar facilities, including facility location; number of PV modules; lifespan of equipment; and panel technology and associated information (if available). The Department made the following assumptions during the data collection process:

- If multiple operation dates were listed, the most recent date was used.
- If multiple panel counts were listed, the number from the form most recently filed was used.
- If a range was provided for the projected lifespan, the lower bound of the range was used.
- For facilities without lifespan data, 25 years was used since this is the most common reported length of manufacturer warranties.
- For facilities missing solar panel counts, an average of 5,068 panels per MW (as calculated by the Department) was used to estimate the number of panels installed.

¹³¹ **Report of Proposed Construction (RPC) – Commission Rule R8-65.** Pursuant to G.S. 62-110.1(g), any person who seeks to construct an electric generating facility in North Carolina, and is exempt from the requirement to obtain a certificate of public convenience and necessity, is required to file this form and a notice of completion of the construction of the facility.

¹³² **Application for a Certificate of Public Convenience and Necessity – Rule R8-64.** Pursuant to Commission Rule R8-64, this form is required for use in applying for a Certificate of Public Convenience and Necessity (CPCN) by a person, other than an electric public utility, who is an owner of a renewable energy facility that is participating in the Competitive Procurement of Renewable Energy Program established in G.S. 62-110.8, or by a person who is seeking the benefits of 16 U.S.C. 624-3 or G.S. 62-156 as a qualifying co-generator or a qualifying small power producer as defined in 16 U.S.C. 796(17) and (18), or as a small power producer as defined in G.S. 62-3(27a), except persons exempt from certification pursuant to G.S. 62-110.1(g).

- The type of PV module technology and nominal power output capacity was collected for facilities that reported this information. However, few facilities included information on the PV module manufacturer. DEQ collected the PV modules weights from manufacturer information, where available, and also compiled additional weights and capacities from other common PV module manufacturers. The output capacity for PV modules installed in facilities that reported this data ranged from 90W to over 400W, and the capacity affected the weight of the module. As a result, DEQ created four categories and averaged the PV module weight within each nominal power output capacity range. The four different weight classes are as follows:
 - 0 to 199 watts (W): 27.2 lbs
 - 200W to 299W: 48.3 lbs
 - 300W to 399W: 52.4 lbs
 - > 400W: 67.8 lbs
- Any facility without a reported PV module power output capacity was assigned to the 300W to 399W range as most common range for installed PV modules in North Carolina facilities. Accordingly, the Department assigned those modules the corresponding weight of 52.4 lbs.
- A facility is assumed to be in operation if it was included on one or more of the following: NC-RETS Project List, EIA-860 Facility List, Facility Data provided by the participating stakeholders, and Transmission Interconnection Data.

Using the latest data reported for 2019, there are approximately 601 solar facilities in North Carolina with capacities that are greater than or equal to 1MW. More than 240 of the facilities are greater than or equal to 5MW but less than 10MW (see Figure 5-1 below). DEQ could not confirm the location and/or existence of roughly 9 facilities; however, these unconfirmed solar facilities are included in the data collection to provide a conservative estimate of the volume of modules in the state.

In summary, the compiled data reveals that there are more than 4,000MW of solar energy and 23.3 million modules installed in North Carolina. Applying the weight assumptions discussed above, the current volume of solar modules is estimated at 500,000 metric tons. The average lifespan of the facilities in North Carolina is 24 years, with the reported estimates ranging from 20 years to 40 years. Since all of the solar facilities were installed within the past 12 years, about 8.5 million PV modules will be decommissioned between 2036-2040. Another 8.2 million will reach end-of-life in the following 5 years based on facility lifespan estimates (Figure 5-2). This equates to more than 70% of the current volume of PV modules, or 364,000 tons, that will be decommissioned in a period of approximately 10 years (Figure 5-3).

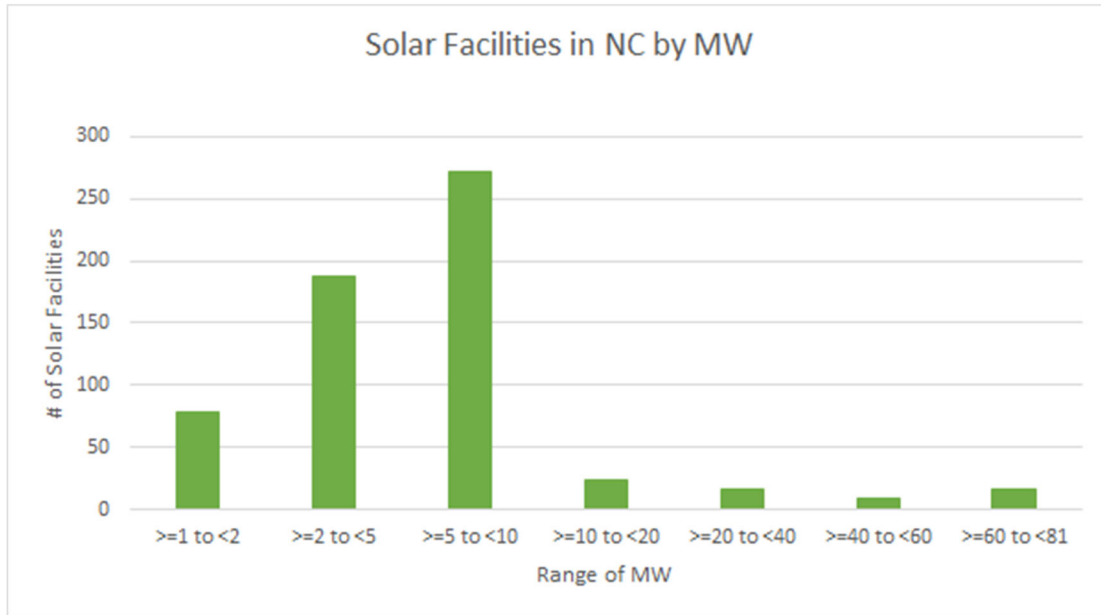


Figure 5-1. North Carolina Solar Facilities by Megawatt Capacity

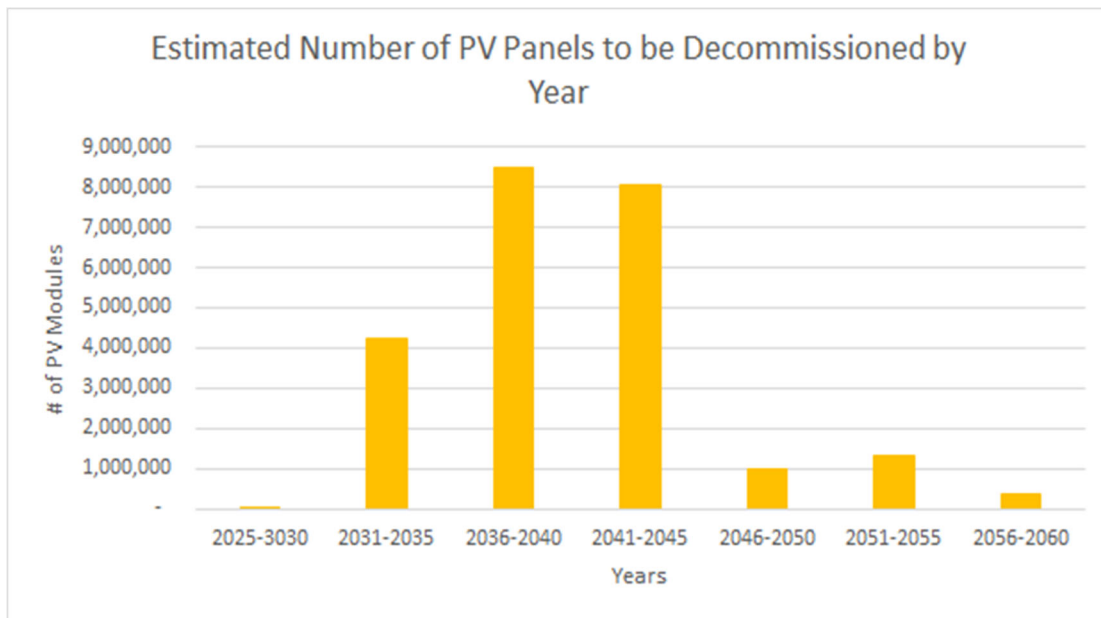


Figure 5-2. Estimated Number of PV Panels Decommissioned by Year

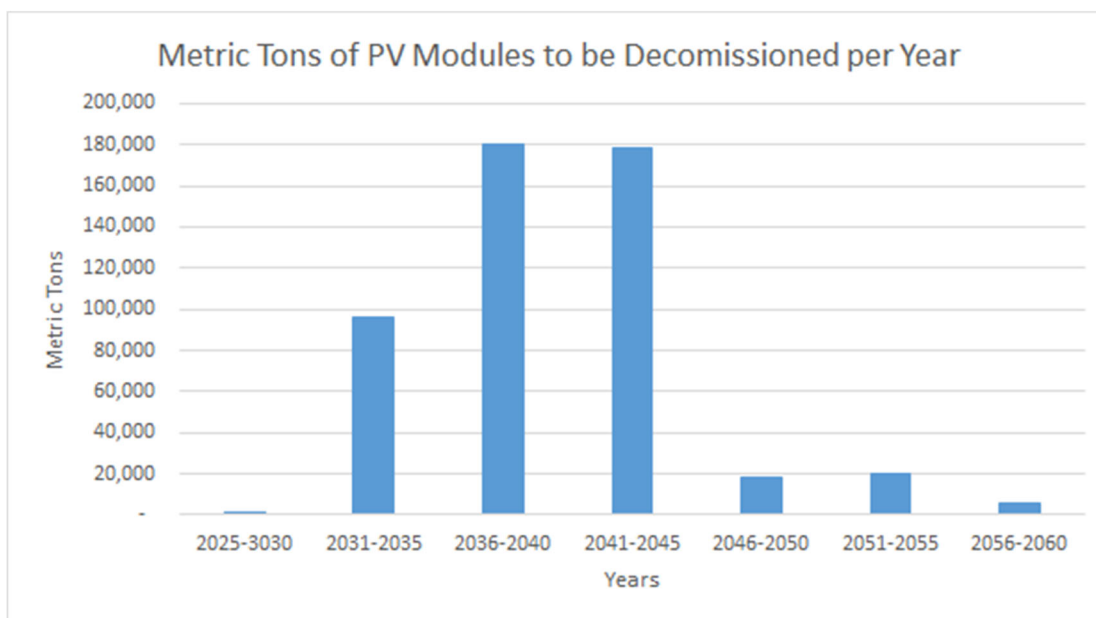


Figure 5-3. Estimate Metric Tons of PV Modules Decommissioned by Year

Industrial solid wastes, when shown to be non-hazardous, are currently disposed of in MSW landfills. Standards for MSW landfills consist of a design which includes engineered liners, closure cap systems, and leachate collection systems. Groundwater, surface water, leachate, and methane/landfill gas monitoring is required on at least a semi-annual basis to ensure that the environment is not compromised. Presently, and into the foreseeable future, there is capacity available to dispose of the projected EOL PV modules that are deemed non-hazardous in North Carolina's landfills.

The majority of the operational solar facilities are located in eastern North Carolina, primarily in the coastal plain. One-half of the tonnage that may be sent to either landfills or recycling facilities is located in just 15 of the 76 counties reporting solar facilities (See Figure 5-4).

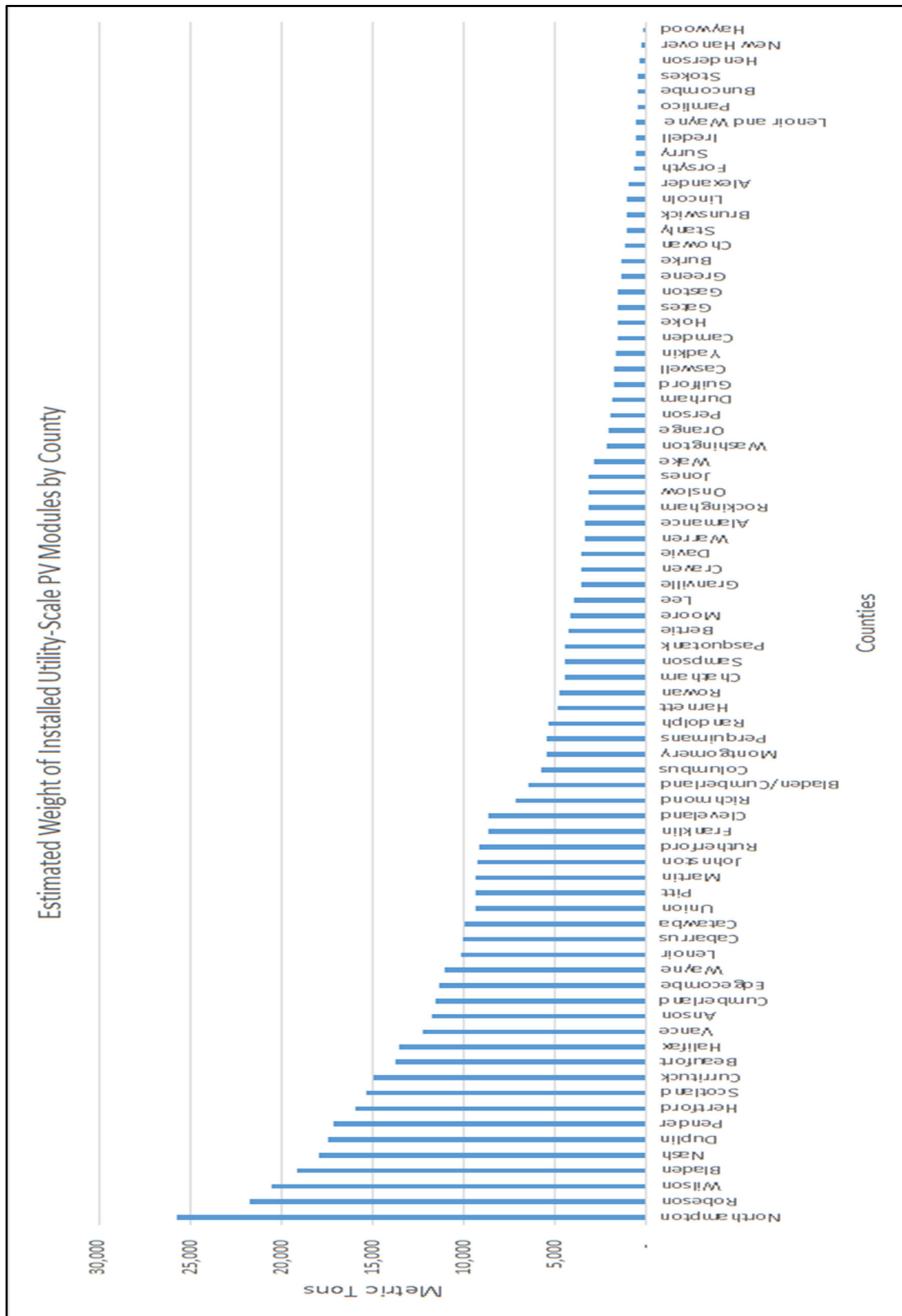


Figure 5-4. Estimated Weight of PV Modules by North Carolina County

The Department's analysis reveals that 500,000 tons of PV modules are presently installed in solar facilities across the state. In a worst-case scenario, if the entirety of present-day PV modules suddenly needed landfilling, the 500,000 tons of waste would still be dwarfed by the current year's disposal of 11,700,000 tons of waste (FY 2018-19). The capacity of landfills located in eastern North Carolina (see Figure 5-5)¹³³ will be barely impacted by a 4% increase in tonnage most likely spread out over years or even decades. While this evaluation accounts for only those materials currently installed in solar facilities, forecasts of an expanding solar industry in the state still do not raise concerns over available landfill capacity.

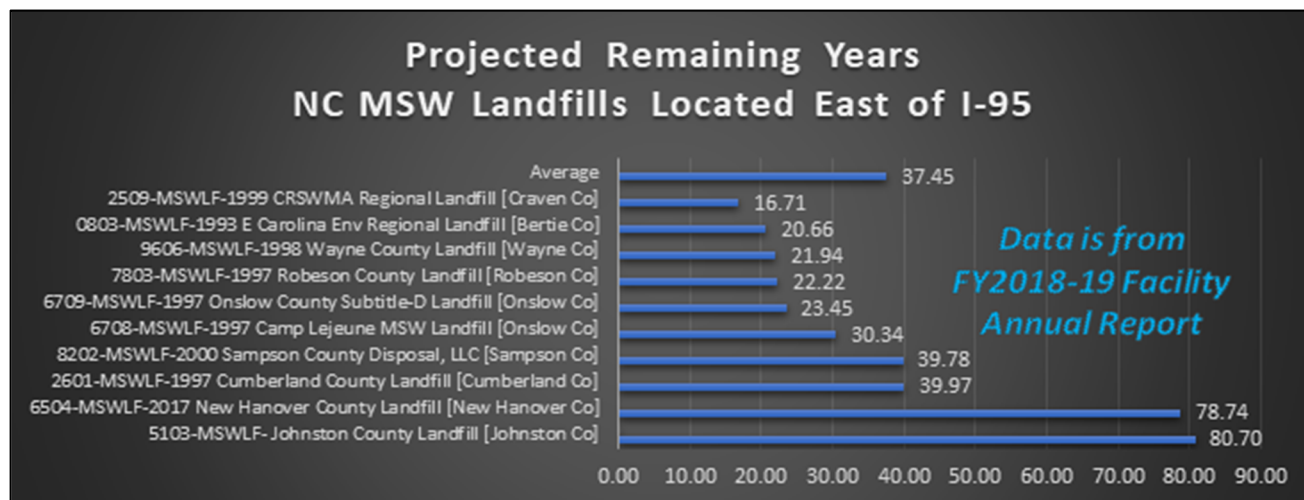


Figure 5-5. Projected Years Remaining for MSW Landfills in Eastern North Carolina

As previously mentioned, approximately 8.2 million PV modules, totaling to 182,000 tons of PV modules will need to be decommissioned between 2041 and 2045. In 2042, it is estimated that 73,000 tons of PV modules will be decommissioned, which is the largest predicted module waste volume in a single year according to facility data. The Department referred to other waste streams reported in 2018-2019 Solid Waste Management Report to compare to the largest volume of PV modules anticipated in 2042. The Division of Waste Management estimated in its Tonnage Annual Report that 76,000 tons of metal were collected by local governments during the 2018-2019. This waste stream is the most comparable to the largest volume of PV modules that will reach EOL in a given year (Figure 5-6).

¹³³ Consolidated Waste Management Report FY2018-19, DEQ, 2020.

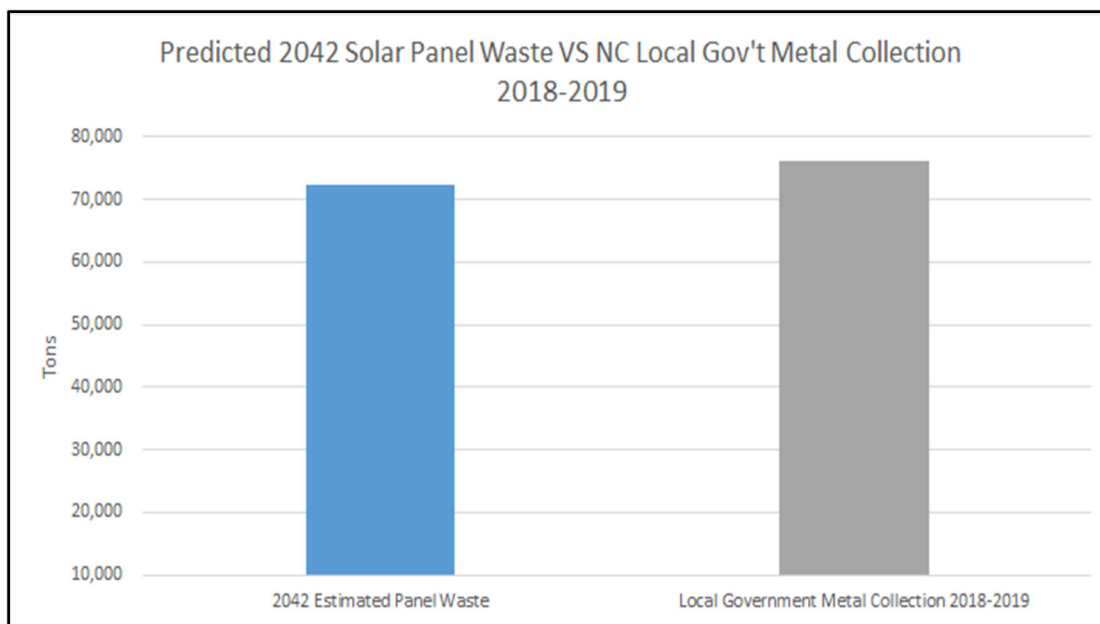


Figure 5-6. Predicted Solar PV Waste Compared to Local Government Metals Collection

Depending on the hazardous characterization of the PV modules as well as the feasibility of their reuse or recycling in the future, all of the modules may not be disposed of in landfills throughout North Carolina. The current volume of just under half a million metric tons of PV modules is significant. The Department articulated the preferred methods of EOL management landfill disposal as the last recommended option (See discussion in Section 2(a)(2)). Incentives for recycling compared to landfill disposal will become increasingly important in the future as the North Carolina Clean Energy Plan estimates an additional 4,000MW of solar capacity projected by 2025.

Energy Storage System Batteries

Currently, the state does not have a method for tracking energy storage systems, however, the Department estimates that there are approximately 11.3MW of battery energy storage systems currently installed in North Carolina with an additional 4MW in projects under development. According to the 2019 EIA Form 860 data, a 1MW energy storage project is installed on Ocracoke Island comprised of 10 Tesla Powerpacks.¹³⁴ A global database managed by the U.S. Department of Energy - Energy Storage Systems Program identifies several additional grid-tied battery energy storage projects in North Carolina totaling approximately 1.05MW. Recently, a 250kWh microgrid battery storage project was installed at Butler Farms in Lillington,¹³⁵ and another 4MW microgrid is under development in Madison County.¹³⁶ In

¹³⁴ Lambert, Fred. "Tesla completes another microgrid project with Powerpacks – powering an island in North Carolina." Electrek, Dec. 2016.

¹³⁵ Rubenoff, Sarah. "PowerSecure Provides Engineering, Procurement & Construction for Butler Farms Microgrid Upgrade." *Microgrid Knowledge*, Aug. 2019.

¹³⁶ "North Carolina regulators approve Duke Energy's innovative microgrid project in Madison County." Duke Energy, May 2019.

August 2020, Duke Energy commenced operation of a new 9MW lithium-ion Samsung battery energy storage system in Asheville.¹³⁷

Although the amount of non-hazardous energy storage system batteries currently in use by the state is not concerning if disposed of in landfills, the deployment of energy storage system batteries is expected to grow significantly. The 2018 Integrated Resource Plans (IRPs) for Duke Energy Carolinas and Duke Energy Progress indicate that a combined total 291MW of battery storage is expected to be installed by 2033.¹³⁸

As discussed in Section 2(a)(1), batteries often contain hazardous properties and cannot easily be disposed. There are no hazardous waste disposal facilities in North Carolina. As discussed in Sections 2(a)(2) and (4) transportation, treatment, or disposal of hazardous waste is expensive, making recycling options even more important.

Wind Energy Facilities

The Amazon Wind Farm U.S. East is the only utility-scale wind energy facility installed in North Carolina. The project consists of 104-2MW Gamesa G114 models.¹³⁹ As previously discussed in Section 2(a)(2), the main components of the wind turbine, including the tower, gear box, and other components are generally recyclable. However, each turbine is comprised of three fiberglass reinforced blades with epoxy or polyester resin,¹⁴⁰ materials that are not readily recyclable. Each blade weighs 14 tons¹⁴¹ (28,000 lbs) totaling approximately 4,400 tons of blades requiring decommissioning in a little less than 20 years. The energy intensity and challenges to recycling wind turbine blades makes landfilling the most cost-effective EOL management option in the United States. While the estimated volume of 4,400 tons of blades that will be decommissioned is significant, it is not a volume that will strain North Carolina landfill capacities. However, the tonnage will likely require distribution among larger local landfills if disposal remains the best EOL management option in two decades.

DEQ Recommendations for Section 2(a)(5)

I. Develop minimum notification requirements and authorize the Division of Waste Management to oversee, collect, and maintain records, and identify resources sufficient for program implementation that complements existing reporting for new and existing solar energy facilities and energy storage battery systems installed with a nameplate generation capacity of greater than or equal to 1MW.

Justification:

Because the recordkeeping and reporting for utility-scale solar facilities installed statewide does not include information sufficient for DEQ to responsibly monitor for EOL management, the Department recommends rulemaking for the development of minimum notification requirement for facilities 1MW capacity or greater. This recommendation would require amendments to the statutes authorizing the Division of Waste Management to request

¹³⁷ "Duke Energy begins operation of 9-MW energy storage site in Asheville, N.C." *Power Engineering*, Aug. 2020.

¹³⁸ "North Carolina Clean Energy Plan." *NCDEQ*, Oct. 2019.

¹³⁹ Mundt, Jennifer. "Wind Energy and Equipment in North Carolina." PowerPoint Presentation. 2020.

¹⁴⁰ SG 2.6-114 Onshore Wind Turbines." Siemens Gamesa Renewable Energy

¹⁴¹ Du Terroil, Jason. Personal communication, Oct. 2020.

minimum facility information. During rulemaking, the Department will identify the information and criteria for this proposed facility notification. In addition to the information documented on EIA Form 860, the following may be considered: the number and model of PV modules and batteries used; TCLP records, if any; estimated life-cycle; and other criteria that will assist DEQ in monitoring the potential waste generated by this industry in the future.

This recommendation is expected to have a fiscal impact, whether through establishing fee authority in statutes or direct appropriations, to provide the Division with resources necessary for program implementation.

II. To ensure adequate landfill capacity is available to dispose of EOL renewable energy equipment, the Department recommends modeling the 10-year waste management planning required for generators of industrial waste pursuant to G.S. 130A-309.09D(c).

The Division would obtain important information from the owner, responsible party, or operator regarding the estimated volume and timeline for the waste stream and allow for public and private MSW facility owners to plan for anticipated volumes of waste disposal by expanding, limiting, or adopting necessary fee structures, as appropriate.

VI. HB329 Section 2.(a)(6)

A survey of federal and other states' and countries' regulatory requirements relating to (i) management of end-of-life photovoltaic modules, energy storage system batteries, and other equipment used in utility-scale solar projects and wind energy projects, including identification of states' laws governing reuse, refurbishment, disposal, or recycling of such equipment, (ii) decommissioning of utility-scale solar projects and wind energy facilities, and (iii) financial assurance to be established by owners or operators of utility-scale solar projects and wind energy facilities to ensure responsible decommissioning.

The Department's thorough survey and review of federal, state, and international approaches to management of EOL renewable energy equipment, decommissioning, and financial assurance reveals many similarities across a patchwork of statutory, regulatory, and voluntary policies.

With respect to solar projects, several states, like North Carolina, are evaluating the best practices available to manage EOL PV modules and address decommissioning and financial assurance. Currently, one-third of the states have adopted decommissioning standards, half of which address financial assurance in some fashion. The European Union appears to have the most mature PV module EOL management program currently in place.

For batteries, the research reveals much the same. Notwithstanding applicability of federal law (RCRA), states do not have stringent requirements governing EOL management for energy storage system batteries. However, the ambiguity of how terms are defined leaves them open to interpretation as to the reach of the laws and regulations in those jurisdictions. The EU again appears to lead the world in implementing standards for the management of EOL batteries that apply to energy storage systems.

North Carolina has robust laws governing the EOL management of wind energy facilities that address financial assurance and decommissioning as do nearly half the states in the United States. Some of these states specify decommissioning and financial assurance requirements and a handful provide voluntary guidance. While there are no EOL management requirements set at the federal level for onshore wind energy facilities, regulations providing for proper decommissioning and financial assurance are promulgated for offshore wind projects in federal waters in the outer continental shelf. Countries in the EU vary in their regulatory approach to EOL wind energy facilities, though it appears France may have the most stringent requirements, including financial assurance of €50,000 (~\$59,000 in U.S. dollars) per wind turbine, of those reviewed pursuant to this Section.

Photovoltaic Modules

North Carolina

North Carolina does not have statewide regulatory requirements for decommissioning, managing EOL, or financial assurance for utility-scale solar energy facilities and PV modules. However, 56 counties in North Carolina have adopted local ordinances relating to decommissioning and/or financial assurance measures for solar energy facilities. Figure 7-1 identifying the counties with a decommissioning requirement can be found in Section 2(a)(7). A typical decommissioning ordinance requires the site to be decommissioned after no electricity is produced or after cessation of operations for a continuous period of time,

and usually involves the removal of all solar equipment and restoration of the entire property.

Many counties require that solar facility decommissioning plans include a decommissioning timeline, estimated decommissioning costs, anticipated methods for decommissioning, and plans for updating decommissioning plan in the future. In addition, 24 counties have adopted specific financial assurance requirements for solar facility decommissioning. The majority of these counties require a type of financial guarantee greater than or equal to the estimated decommissioning costs, with the estimated decommissioning costs re-evaluated on a regular basis. The highest financial assurance requirement established by one county is 150% of the estimated decommissioning cost of a solar facility. Some counties allow for the consideration of the potential salvage value in the estimated decommissioning costs for financial assurance. The ordinances authorize several different types of financial assurance instruments, such as a surety bond, certified check, irrevocable letter of credit, and a cash escrow. An additional six counties require decommissioning costs to be considered in the decommissioning plan but do not require a financial guarantee. Several counties' ordinances specify that decommissioning costs must be estimated by a third-party licensed engineer. Beaufort, Hertford, and Warren are the only counties that do not require a financial guarantee, but the ordinances explicitly provide that if the solar facility owner/operator is unable to pay for decommissioning costs, the decommissioning becomes the responsibility of the landowner.

Other States

North Carolina is not alone in its evaluation of the best management methods for EOL PV modules. Minnesota is engaged in a similar stakeholder process to research and develop PV module end-of-life regulations. The Minnesota Department of Commerce and the Minnesota Public Utilities Commission created a working group to review existing laws and decommissioning plans in order to make recommendations on decommissioning. As discussed in Section 2(a)(9), Washington was the first state to enact a PV module EOL management approach utilizing a manufacturer-based stewardship and takeback program. However, Washington recently postponed the effective date for submittals of the manufacturer-based stewardship plans, in part to further research applicability to all solar installed in the state, and to discuss implementation with stakeholders. As described in Section 2(a)(1), California has characterized EOL PV modules that exhibit the characteristic of toxicity as universal waste instead of hazardous waste. Additionally, some states have established best practices without statewide decommissioning mandates. Organizations in Georgia, Massachusetts, New York, and North Carolina, have developed guidance for local governments for solar facility decommissioning in the form of a model ordinance.

The 16 states with decommissioning regulations in place for solar facilities are listed in Table 6-1. The requirements for decommissioning vary from state to state. In Hawaii, the applicability of decommissioning regulations depends on the land classification, while in South Dakota decommissioning requirements apply to facilities greater than or equal to 100MW. Most states do not list specific requirements for inclusion in decommissioning plans, but some specifically require site restoration and an estimated cost of decommissioning. Seven states require financial assurance for future decommissioning of solar facilities. Many states do not specify the amount required; however, the amount must

be justifiable to the estimated decommissioning costs. The financial assurance can take various forms, including a bond, irrevocable letter of credit, or other financial instruments.

Based on our research and evaluation, it appears that the states of Washington and California have the most developed EOL management requirements for PV modules. A PV module stewardship and takeback program is detailed in Chapter 70A.510.010 in the Revised Code of Washington. The takeback and recycling system must be financed by the manufacturers and the manufacturer-based stewardship plans must be prepared and submitted to the Washington Department of Ecology by July 1, 2022, or within 30 days of the manufacturer’s first sale of a PV module into the state. Beginning April 1, 2024, the manufacturers must also submit an annual report that details the implementation of the stewardship plan as well as their progress towards PV module reuse and recycling achievement goals. A stewardship plan must describe how the manufacturers will finance the takeback and recycling system, provide adequate funding for management of PV modules designated as waste and destined for recycling, accept their own PV modules sold in or into the state, and provide locations to collect PV modules. After July 1, 2023, PV modules cannot be sold into the state of Washington unless that manufacturer has submitted a stewardship plan and received approval from the Department of Ecology.

As discussed in Section 2(a)(1), California recently amended Title 22, Division 4.5, Chapters 10, 11, and 23 of the Code of Regulations to include PV modules designated as waste and that exhibit the requisite characteristic of toxicity in the state’s universal waste program and subject to the newly developed regulations. Unless the PV modules are known by the waste generator to not exhibit a characteristic of hazardous waste, the waste PV modules will be managed as hazardous waste until the new regulations are implemented in January 2021.

California*	Hawaii*	Louisiana	Maine
Minnesota	Montana*	New Hampshire	New Jersey
North Dakota*	Ohio	Oregon	Rhode Island
South Dakota*	Vermont	Virginia*	Washington*

* denotes states with financial assurance requirements

Table 6-1. – States with Solar Decommissioning Regulations

International

Other countries have established regulations for the management of EOL PV modules. The European Union *Waste Electrical and Electronic Equipment (WEEE) Directive 2012/19/EU* provides a legislative framework for an extended producer responsibility (or manufacturer-responsible management) of PV modules. Although there is no blanket requirement for the preferred methods to manage EOL modules, the Directive regulates the collection, transport, and recycling of PV modules. Producers are responsible for establishing take-back programs. Individual EU countries have incorporated this Directive into national laws, where commonality between different nationwide regulations can be seen with producer responsibility to manage the waste.

For example, in Germany, *Das Elektro- und Elektronikgerätegesetz* (ElektroG) regulates how PV modules enter the market, recovery, and recycling of electrical and electronic

equipment. Producers are responsible for the EOL management of the products they sell and are required to take back and dispose of the waste at their own expense.

In France, *WEEE Law Le décret 2014-928* requires producers and importers of PV modules to plan and finance the collection and treatment of EOL PV modules. Under this law, a visible fee must be applied on all newly sold equipment to set aside mandatory funds for EOL management. Producers must register with an accredited take-back program or establish an individual system approved by the Ministry of Environment to put PV modules on the market.

As a final example, in Italy, *Attuazione della direttiva 2012/19/UE sui rifiuti di apparecchiature elettriche ed elettroniche* (RAEE) requires producers to plan and finance the collection and recycling of PV modules.

Energy Storage System Batteries

As previously noted, energy storage battery systems use various types of electrochemical storage technologies, including lithium-ion, lead-acid, and nickel-cadmium batteries. Depending on the chemistries, different types of batteries can release toxic elements into the environment if landfilled. Many also possess flammable characteristics that can present a hazard if improperly disposed. As a result, all states across the country have adopted EOL waste management regulations for batteries, with many laws employing broad verbiage that can be interpreted to include various electrochemical storage battery technologies. However, there are no states with laws that specifically regulate energy storage system batteries.

North Carolina

Neither hazardous waste rules nor state law specifically describe requirements pertaining to energy storage system batteries. However, batteries that are hazardous waste must be managed under either the state hazardous waste rules or the universal waste rules (40 CFR 273, adopted by reference at 15A NCAC 13A .0119). The hazardous waste rules set out requirements for reclaiming lead-acid batteries at Subpart G of 40 CFR 266, adopted by reference at 15A NCAC 13A .0111(c).

Other States

As discussed in Section 2(a)(1), lithium-ion batteries can be classified as hazardous waste if they exhibit ignitability, corrosivity, reactivity, or toxicity characteristics. Many states enacted statutes to minimize the disposal of battery technologies and several laws may be read to include lithium-ion batteries that are used in energy storage systems. Based on the Department's research, New York and California are the only states with regulations that explicitly apply to lithium-ion batteries. Both states list lithium-ion batteries and battery packs containing lithium-ion batteries in their respective regulatory definitions for rechargeable batteries and prohibit the disposal of rechargeable batteries as solid waste. These state's regulations also require all retailers and manufacturers to implement a system for the collection of lithium-ion batteries for reuse, recycling, or proper disposal.

Other states include regulations with definitions that can be interpreted broadly to apply to lithium-ion batteries by defining a battery as a device with electrochemical cells that is designed to receive, store, and deliver energy. The states with broad definitions include Massachusetts, Minnesota, Nebraska, Rhode Island, and Washington and also list

batteries in disposal restrictions or universal waste regulations. Connecticut's statute only addresses car batteries; however, some lithium-ion car batteries could be repurposed in energy storage systems. Therefore, these batteries would be subject to the state's lithium-ion waste management regulations. In Maryland, statutes apply to batteries weighing 25 pounds or less and can be interpreted to include lithium-ion battery storage systems if the battery packs are disassembled from the units prior to disposal and weigh less than this threshold.

A lead-acid battery is subject to RCRA regulations unless it is managed as a universal waste or reclaimed in accordance with Subpart G of 40 CFR 266. Subpart G exempts some lead-acid batteries from certain hazardous waste management requirements depending on the battery owner (generator, collector, transporter, importer, exporter) or if the lead-acid batteries will be reclaimed. Many states have written statutes to implement RCRA. As mentioned before, Massachusetts and Nebraska have broad definitions for batteries that can be interpreted to apply to lead-acid in addition to lithium-ion batteries. Table 6-2 lists the 40 states that have enacted statutes that either explicitly include lead-acid batteries or can be interpreted to apply to lead-acid batteries. In reviewing these laws, the Department assumed that if a state does not exclude storage batteries in a definition, or if it does not include a definition in the statute, a large stationary energy storage battery would be subject to regulation. Some states stipulate a maximum weight or a particular use for the lead-acid battery. For example, laws in Florida and Maryland apply to lead-acid energy storage system batteries if the battery packs are disassembled from the units prior to disposal and weigh less than or equal to 25 pounds. Illinois, Missouri, New Jersey, Oklahoma, and Rhode Island's statutes only apply to lead-acid batteries intended for vehicles. However, it is possible for EOL vehicle batteries to be safely repurposed in renewable energy storage systems.

Alabama	Hawaii	Maine	Missouri**	North Dakota	South Carolina	Virginia
Arkansas	Illinois**	Maryland*	Nebraska	Ohio	South Dakota	Washington
California	Indiana	Massachusetts	New Hampshire	Oklahoma**	Tennessee	West Virginia
Colorado	Iowa	Michigan	New Jersey**	Oregon	Texas	Wisconsin
Connecticut	Kentucky	Minnesota	New York	Pennsylvania	Utah	Wyoming
Florida*	Louisiana	Mississippi	North Carolina	Rhode Island**	Vermont	

* denotes states with regulatory battery weight limits of 25 lbs

** denotes states with regulations that only apply to vehicle batteries

Table 6.2 – States with Lead-Acid Battery Regulations

The components in NiCd batteries include nickel hydroxide, cobalt hydroxide, cadmium hydroxide, iron oxide, and potassium hydroxide. Since cadmium serves as the battery's power source, and is a hazardous metal, these types of batteries must be properly managed and disposed. A NiCd battery is subject to RCRA regulations unless it is managed as universal waste. Nickel-cadmium batteries are also designed for energy storage system and several states explicitly include NiCd batteries in their statutes. Seven

states enacted laws requiring proper disposal of this battery technology, including California, Florida (if battery weighs 25 pounds or less), Louisiana, Michigan, Minnesota, New York, and Vermont. As mentioned previously, there are several states with broad definitions for a battery that can be interpreted to apply to several different battery technologies, including NiCd.

The *Battery Council International* created a model ordinance which requires retailers to display written notice, accept used batteries, requires wholesalers/manufacturers to accept used batteries from retailers as purchased, and prohibits disposal of a battery in mixed MSW. A majority of states used the model ordinance as an outline for in the adoption of EOL battery waste management regulations. In addition, many laws specified where a battery retailer may deliver a battery, including a recycling facility, secondary lead smelter, or battery manufacturer. Several laws outlined retailers' take-back provisions and require accepting batteries at no cost from a consumer.

In terms of disposal, federal regulations prohibit landfilling lead-acid and NiCd batteries, and most states with EOL battery waste management regulations specify that no person can dispose of or attempt to dispose of these battery types in a landfill. Some states also provide that a landfill owner/operator cannot knowingly accept lead-acid batteries. A few states also detail that hazardous batteries cannot be disposed of off land, such as in marine waters.

From the research for this report, Alaska, Delaware, Kansas, Montana, and Nevada do not have regulations for managing EOL batteries. Approximately 16 states do not define what constitutes a battery in regulations; however, all of these states specified that the regulations applied at a minimum to lead-acid batteries. As a result, these regulations are assumed to apply to energy storage system applications of lead-acid batteries. There are no states with battery regulations that specifically excluded batteries used in energy storage systems; however, many laws specified that only vehicle batteries were subject to the regulations. These regulations were interpreted to include some energy storage system battery technologies since there is potential for vehicle batteries to be safely repurposed for energy storage systems following its assessment. Other states provided that only batteries of a maximum weight were subject to the regulation. These regulations were also presumed to include energy storage system batteries as the decommissioning of these systems generally require the disassembly of the battery packs from the units prior to disposal. After disassembly, the individual batteries may fall within regulatory thresholds.

International

In Europe, the 2006 Batteries Directive specifically lists measures to develop high level collection and recycling of batteries. The Directive applies to all batteries, including those used for PV modules and other renewable energy applications. In addition, producers and accumulators of batteries are responsible for the EOL management, including financing the costs of collecting, treating, and recycling. Currently, other regions do not have regulations in place specifically for EOL energy storage system batteries. Since the majority of deployed battery energy storage systems use lithium-ion battery technology, research was also conducted on the existence of regulations on EOL lithium-ion batteries.

Several countries in Asia have developed an efficient recycling process and infrastructure, while Europe is considered a few steps behind. A large number of lithium-ion battery storage systems are currently installed in China. China is mindful of the importance of recycling battery technologies and recently announced the country will develop regulations for the management of EV batteries. These regulations may promote the battery recycling market and drive efficiency which could provide additional management opportunities for EOL lithium-ion batteries from other sources, such as energy storage systems. China also released a policy in support of energy storage industry in 2017. The Guiding Opinions on Promoting Energy Storage Technology and Industry Development promotes research and development in several key areas, including recycling.

Wind Energy Facilities

North Carolina

Article 21C of N.C.G.S. Chapter 143 directs the Department to permit the construction and operation of Wind Energy Facilities (WEF), provided those facilities meet all of the requirements set out in statute. G.S. 143-215.121 directs applicants for WEF permits to establish financial assurance that will ensure sufficient funds are available for decommissioning the facility and reclamation of the property to its condition prior to commencement of activities on the site. In addition, G.S. 143-215.119(a)(13) requires an applicant to file a decommissioning plan for the removal of the proposed WEF in order for the permit application to be deemed complete. The decommissioning plan must include an estimate of the cost for decommissioning, the anticipated life of the project, description of the manner in which decommissioning will take place, and description of the expected condition of the site following decommissioning and removal of the WEF.

Other States

Although there are no federal laws or regulations for the management of EOL onshore wind energy facilities, the 23 states listed in Table 6-3 have adopted wind energy facility decommissioning regulations in addition to North Carolina. For some states, decommissioning a wind energy facility includes removal of equipment, restoration of disturbed earth, and estimated cost of decommissioning. Several states, like North Carolina, require decommissioning plans as a component of the certification or permitting process. The majority of the states with decommissioning regulations also require a form of financial assurance except for Louisiana, Minnesota, New Hampshire, New York, Rhode Island, Vermont, and Virginia. In addition, California, Kansas, and Pennsylvania do not have statewide decommissioning requirements, but provide voluntary guidelines for decommissioning of wind energy systems.

Connecticut	Louisiana	Maine**	Maryland*	Minnesota	Montana
New Hampshire	New Jersey*	New York	North Carolina	North Dakota	Ohio
Oklahoma	Oregon	Rhode Island	South Dakota	Tennessee	Texas
Vermont	Virginia	Washington	Wisconsin	Wyoming	

* denotes states with regulations pertaining to offshore facilities only

** regulation not applicable to grid-scale facilities

Table 6.3 – States with Wind Energy Facility End-of-Life Regulations

While no national laws apply to onshore wind energy facility decommissioning, the federal Outer Continental Shelf Lands Act and implementing regulations at 30 CFR 585 set out requirements for timing of the development and implementation of decommissioning plans and for offshore wind energy facilities sited in federal waters. The regulations also provide for financial assurance in the way of a bond or other financial security for each stage of commercial development.¹⁴²

International

Many countries have established wind energy facility decommissioning regulations, including those with a large amount of wind generating capacity currently installed. For example, in Germany, an operator must dismantle wind turbines and restore the site at the end of the operating period. The facilities are subject to financial assurance in the event the operator is unable to decommission due to bankruptcy or other reasons. The financial assurance is made in different forms, such as a bond or deposit account, and the amount of financial assurance varies depending on the state in which the facility is located. France implemented similar decommissioning regulations, but adopted more stringent standards for the decommissioning process than Germany. France requires the dismantling of the entire facility, restoration of land, and that demolition waste is recovered or disposed of by authorized entities. In addition, France sets financial assurance at €50,000 per wind turbine (approximately \$59,000 in U.S. dollars). As an additional example, the Ministry of New and Renewable Energy Government of India published guidelines for the development of onshore wind projects. The guidelines require that any proposal to develop a wind energy project include a decommissioning plan.

¹⁴² 30 CFR § 585.516

VII. HB329 Section 2.(a)(7)

Whether or not adequate financial assurance requirements are necessary to ensure proper decommissioning of utility-scale solar projects upon cessation of operations.

As discussed in Section 2(a)(6), more than half of North Carolina's counties have adopted solar facility decommissioning requirements into county ordinances, nearly a quarter of which include requirements for financial assurance. Figure 7-1 depicts a map created by the Department of the locations of utility-scale solar facilities overlaid in the counties with decommissioning requirements. Table 7-1 lists solar facility information by county including the number of facilities, the sum of the facilities nameplate generating capacity, the sum of the PV modules, the sum metric tonnage of the PV modules and whether the county has adopted requirements for decommissioning and or financial assurance (it is important to note that the county data provided in this section is based on information available at the time this report was submitted).

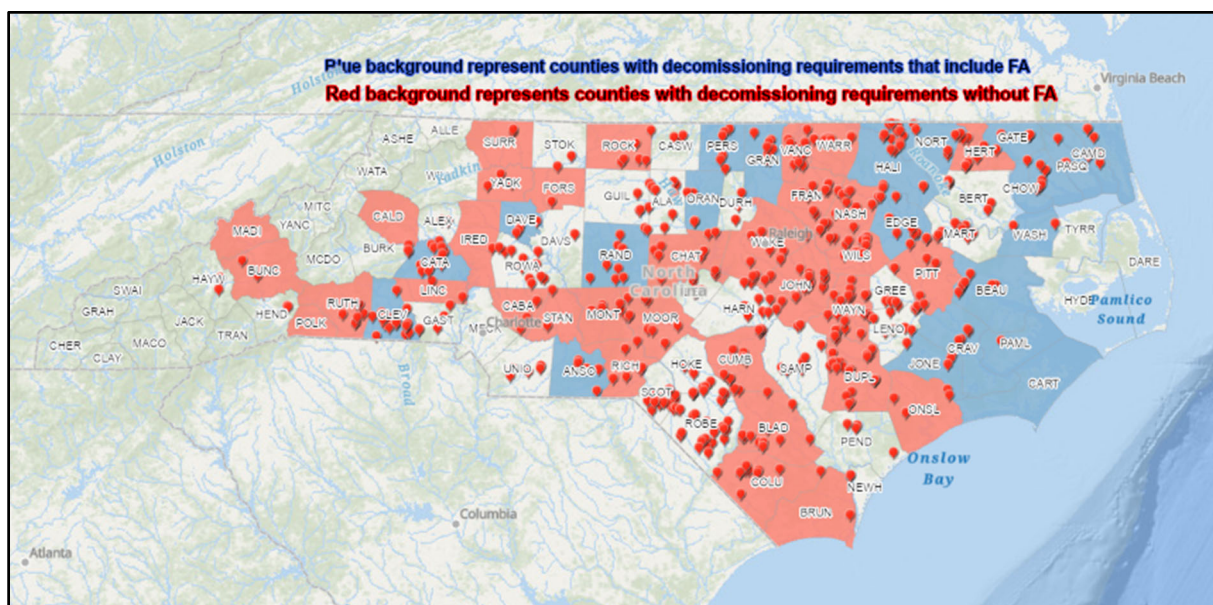


Figure 7-1. Solar Facilities and Counties with Decommissioning Requirements

Financial assurance to ensure proper decommissioning of utility-scale solar projects was the subject of many lengthy discussions and iterative communications among the Department staff and the participating stakeholders. During these discussions, the Department understood better that the contracts executed between private parties – solar developers, landowners, and operators – include financial instruments that ensure proper decommissioning to the extent acceptable to and required by the landowner. The Department was also made aware that like any other infrastructure asset, grid-connected utility-scale solar facilities represent millions of dollars of investments, never mind the value of the interconnection to the transmission grid, that owners, utilities, or third-parties have a financial incentive to maintain the project in good repair and salvage as much value from the equipment at EOL as possible to offset decommissioning costs.

Counties	# of Facilities	Sum of Calc MW	Sum of Number of PV Modules	Sum of Metric Tons Per Facility	Solar Decommissioning Regulation	Financial Assurance
Alamance	8	33	144,969	3,372	No	No
Alexander	2	6	74,224	956	No	No
Anson	7	108	566,574	11,818	Yes	Yes
Beaufort	10	142	616,102	13,794	Yes	Yes
Bertie	5	41	182,727	4,266	No	No
Bladen	13	187	820,511	19,149	Yes	No
Bladen/ Cumberland	1	70	271,510	6,453	-	-
Brunswick	3	11	44,654	1,061	Yes	No
Buncombe	2	5	21,294	492	Yes	No
Burke	3	12	59,380	1,343	No	No
Cabarrus	3	85	423,069	10,056	Yes	No
Camden	3	15	68,619	1,631	Yes	Yes
Caswell	3	15	78,000	1,757	No	No
Catawba	13	105	391,460	9,960	Yes	Yes
Chatham	8	37	251,766	4,484	Yes	No
Chowan	2	10	48,674	1,157	Yes	Yes
Cleveland	21	82	366,646	8,690	Yes	Yes
Columbus	12	54	251,595	5,749	Yes	No
Craven	6	29	208,884	3,608	Yes	Yes
Cumberland	12	116	488,460	11,610	Yes	No
Currituck	3	140	631,752	15,016	Yes	Yes
Davie	4	30	149,921	3,563	Yes	Yes
Duplin	25	150	741,471	17,507	Yes	No
Durham	4	16	80,476	1,864	No	No
Edgecombe	7	105	481,038	11,369	Yes	Yes
Forsyth	2	7	30,329	721	Yes	No
Franklin	10	87	367,697	8,720	Yes	No
Gaston	3	14	67,920	1,566	No	No
Gates	3	15	65,952	1,568	Yes	Yes
Granville	7	33	185,702	3,614	Yes	Yes
Greene	4	14	61,058	1,417	No	No

Guilford	4	18	78,050	1,814	No	No
Halifax	11	136	572,771	13,590	Yes	Yes
Harnett	10	46	236,209	4,931	No	No
Haywood	1	2	6,525	155	No	No
Henderson	2	4	16,676	396	No	No
Hertford	12	150	670,650	15,940	Yes	No
Hoke	3	15	66,806	1,588	No	No
Iredell	1	5	23,000	547	Yes	No
Johnston	23	85	427,786	9,252	Yes	No
Jones	5	25	196,278	3,174	Yes	Yes
Lee	8	39	194,572	3,983	No	No
Lenoir	11	94	430,402	10,162	No	No
Lenoir and Wayne	1	5	23,000	547	-	-
Lincoln	2	10	45,722	1,038	Yes	No
Martin	13	91	480,336	9,338	No	No
Montgomery	7	47	293,101	5,438	Yes	No
Moore	9	39	180,943	4,205	Yes	No
Nash	23	168	998,220	17,974	Yes	No
New Hanover	2	3	13,102	301	No	No
Northampton	15	223	1,531,013	25,769	Yes	Yes
Onslow	5	27	164,500	3,190	Yes	No
Orange	6	18	88,602	2,038	Yes	Yes
Pamlico	1	5	21,257	505	Yes	Yes
Pasquotank	3	43	186,761	4,439	Yes	Yes
Pender	6	125	1,207,848	17,117	No	No
Perquimans	8	51	228,710	5,436	Yes	Yes
Person	6	17	87,608	2,001	Yes	Yes
Pitt	8	84	428,996	9,359	Yes	No
Randolph	12	47	300,788	5,342	Yes	Yes
Richmond	6	70	301,004	7,154	Yes	No
Robeson	38	196	999,410	21,742	No	No
Rockingham	6	30	141,932	3,228	Yes	No

Rowan	11	46	205,386	4,814	No	No
Rutherford	8	97	387,071	9,159	Yes	No
Sampson	10	37	236,744	4,443	No	No
Scotland	14	135	773,796	15,339	No	No
Stanly	2	10	49,000	1,116	Yes	Yes
Stokes	1	4	21,780	477	No	No
Surry	2	5	23,828	566	Yes	No
Union	5	80	397,678	9,404	No	No
Vance	13	108	587,332	12,297	Yes	No
Wake	9	27	125,582	2,840	Yes	No
Warren	7	31	146,804	3,416	Yes	No
Washington	2	19	92,660	2,154	Yes	Yes
Wayne	23	97	501,770	11,082	Yes	No
Wilson	13	128	866,490	20,595	Yes	No
Yadkin	4	14	91,804	1,677	Yes	No

*The existence of 9 facilities were unable to be confirmed by NC DEQ at this time. These facilities were conservatively included in the data.

**Additional facilities may be provided by the NC Department of Agriculture and Consumer Services and added to the data in the future.

Table 7-1. Detailed Solar Facility Information by County

Taking the aforementioned points together with the projected minimum 10-year time horizon for when the first significant tranche of PV modules may reach EOL, repowering efforts notwithstanding (See Sections 2(a)(2) and (4)), and existing local government regulatory structures already in place, the Department finds:

- That mandated financial assurance requirements are not necessary to ensure proper decommissioning of utility-scale projects at this time and recommends further study on the feasibility and advisability of establishing a statewide standard for financial assurance in five years.
 - This focused review should involve stakeholders and participation by the NCUC to evaluate the feasibility of tying such financial instruments to applications to it receives.
- That local government ordinances that require financial assurance for decommissioning are already in effect in the majority of the counties where utility-scale solar projects are installed.
- That further study is needed about the salvage value of EOL PV modules, incentives to reuse, repower, or recycle EOL PV modules, and the market forces necessary to drive the Department's preferred EOL management options (See Section 2(a)(2)).

VIII. HB329 Section 2.(a)(8)

Infrastructure that may be needed to develop a practical, effective, and cost-efficient means to collect and transport end-of-life photovoltaic modules, energy storage system batteries, and other equipment used in utility-scale solar projects and wind energy facilities, for reuse, refurbishment, recycling, or disposal.

As utility-scale renewable energy facilities plan for decommissioning activities, the cost of collection and transportation of EOL equipment should be anticipated and thoroughly planned out. The distance that the EOL equipment will need to be transported can vary greatly depending on the destination for EOL management

Photovoltaic Modules

Utility-scale solar facilities will most often be removing large volumes of PV modules for decommissioning or repowering activities. With multiple truckloads of modules, the most efficient option is to coordinate direct transport to the EOL management destination, whether being sent for reuse, recycling, or disposal. Therefore, there is not a strong need for the development of collection and transport infrastructure to support utility-scale solar project decommissioning activities.

In 2018, EPRI conducted a conceptual cost estimate and determined a transportation cost of \$13 per cubic yard to transport EOL PV modules destined for recycling to a facility 65 miles away using cost data from December 2017.¹⁴³ The cost for each individual project will depend upon the volume of modules and the distance traveled, but a rough estimate of trucks needed for equipment collection and transportation can be reasonably determined. For example, a 2MW solar facility would require approximately 19 trucks to haul EOL PV modules off-site, using the following three assumptions:

1. *Modules with approximate dimensions of 65" x 39" x 1.4" (0.076 CY) are loaded into an open-top container;*
2. *Each module has a 285W capacity; and*
3. *Accounting for a 30% container void due to packing of irregular shaped objects.*

Therefore, a 40-CY container would fit 364 modules or 104 kW.¹⁴⁴

Additional efficiencies with packing and transportation can be realized if initial processing to remove junction boxes and frames is performed at the site before loading modules for transit.¹⁴⁵ This will allow for more efficient packing with less air space. EOL PV modules could then be stacked and palletized to be loaded on semi-trucks or rail for transport.¹⁴⁶ An additional benefit of removing aluminum frames and junction boxes is that these materials have widely available recycling markets through existing scrap metal and electronics recyclers (See Section 2(a)(2) for more information). These components can be recycled locally to maximize

¹⁴³ "PV Plant Decommissioning Salvage Value Conceptual Cost Estimate." EPRI, 2018.

¹⁴⁴ Ibid.

¹⁴⁵ Heath, Garvin A., et al. "Research and Development Priorities for Silicon Photovoltaic Module Recycling to Support a Circular Economy." *Nature Energy*, vol. 5, no. 7, 2020, pp. 502–510.

¹⁴⁶ Butler, Evelyn. Personal communication, Oct. 2020.

scrap value as opposed to transported longer distances at an additional cost with the EOL PV modules.

Preferred management strategies for EOL PV modules, including reuse, refurbishment, and recycling, may require PV modules to be transported for long distances, in some cases out of state. Studies have indicated that the most cost-effective recycling can be achieved by facilities that specialize in managing EOL PV modules.¹⁴⁷ These facilities require large volumes and a relatively steady stream of material to optimize operational costs. One study examined scenarios to maximize profitability and minimize cost for a theoretical recycling facility with an annual capacity of 60,000 tons of PV modules per year.¹⁴⁸ Therefore, even as recycling facilities become more prevalent, they will likely be located at distances apart and still require long trips from geographically dispersed utility-scale solar facilities.

EOL PV modules destined for landfill disposal will likely have shorter distances to travel due to the prevalence of landfills or waste transfer facilities throughout the state. However, landfill operators are authorized to adjust disposal fees or reject specific waste streams so advanced planning should be conducted to determine the ability and willingness of landfills to accept large volumes of EOL PV modules.

EOL PV modules characterized as hazardous waste that are not being recycled would need to be taken to a permitted treatment or disposal facility. North Carolina has nine permitted hazardous waste facilities, but none are obligated to take specific waste streams. Advanced planning should be conducted to identify a facility willing and able to accept hazardous EOL PV modules. Transportation costs are generally more expensive and sometimes as much as twice the cost compared to non-hazardous waste so these expenses should also be factored in. Given the specific requirements for storage, handling, and transportation, this EOL management option would also likely be coordinated as direct transport to the receiving facility and would not use intermediate collection or transportation infrastructure.

Energy Storage System Batteries

The collection and transportation of energy storage system batteries is not expected to present a logistical challenge that would necessitate the development of unique, specific infrastructure for storage batteries. An expansion of the existing battery recycling infrastructure could address this need.

Wind Energy Facilities

Decommissioning utility-scale wind energy facilities will be a logistics-intensive process, similar to installation. Due to the large size of wind energy components, transportation logistics are likely to be coordinated directly from the wind energy site to the EOL management destination. DEQ does not anticipate a need for the development of specific collection and transportation infrastructure. However, monitoring of advancement in the area of EOL wind turbine blade recycling should be addressed in time.

¹⁴⁷ EPRI 2018, Solar PV Module End of Life: Options and Knowledge Gaps for Utility-Scale Plants.

¹⁴⁸ Fthenakis, V. et al. Cost Optimization of Decommissioning and Recycling CdTe PV Power Plants. 2017.

IX. HB329 Section 2.(a)(9)

Whether or not manufacturer stewardship programs for the recycling of end-of-life photovoltaic modules and energy storage system batteries should be established for applications other than utility-scale solar project installations, and if so, fees that should be established for manufacturers that sell such photovoltaic modules, or energy storage system batteries, in or into the State, in an amount adequate to support the implementation of such requirements.

Photovoltaic Modules

DEQ does not recommend a manufacturer stewardship program for the recycling of EOL PV modules for solar project installations at this time due to a variety of considerations discussed in this section. Existing rules for the management of solid and hazardous waste provide an adequate framework for proper recycling and disposal of PV modules. As discussed in previous sections, recycling opportunities are currently limited and come at a cost which would place an additional financial burden on PV module manufacturers and consumers. This could result in the unintended consequence of disincentivizing future development of solar in the state.

As PV module recycling technology and infrastructure continues to develop, a manufacturer-based or other type of stewardship program could be reconsidered in the future. If through a similar stakeholder-engaged research effort, the state determines that a manufacturer-based or other type of stewardship program for non-utility-scale solar is appropriate, DEQ recommends that utility-scale solar is also addressed during that future effort. Effective collection strategies and funding mechanisms may differ for utility-scale versus non-utility-scale solar installations so additional industry stakeholder input would be needed to understand the differences and plan for a successful model.

While no stewardship program is recommended at this time, future manufacturer stewardship programs can be structured and financed in a variety of ways. DEQ asked stakeholders for input on manufacturer stewardship programs and other strategies to incentivize the recycling of PV modules. Responses are provided in Appendix D. The language in Section 2(a)(9) of the Session Law implies that a fee be established by the state and charged to manufacturers that sell PV modules in or into the state. A series of questions would need to be considered and answered to work out program details, including but not limited to the following:

- *How is a manufacturer defined?* It is common for PV modules to be sold or brought into the state by entities other than manufacturers, such as distributors, installers, or retail establishments. Consideration would need to be given as to whether these entities would be responsible for paying a fee, or if the manufacturer is solely responsible. If the manufacturer is responsible, the state would need to consider how to track the sale of modules in or into the state by brand and how to effectively collect fees from international manufacturers. The state of Washington includes the following under the definition of a manufacturer: any person or business that “imports or has imported a photovoltaic module into the United States [from a manufacturer that does not have a presence in the United States] that is used or sold in or into this state.” [RCW 70A.510.010(2)(e)]
- *Who would administer the collection of fees?* Fees could be collected by DEQ, similar to computer equipment and television manufacturer fees; the Department of Revenue,

similar to disposal taxes on white goods and scrap tires; or a third-party product stewardship organization.

- *Who would implement the recycling program?* An effective and convenient recycling program for non-utility-scale PV modules would need to include a collection network, transportation, and recycling. Some product stewardship models require that the manufacturer implement the program or partner with a product stewardship organization to implement the program on the manufacturer's behalf. Alternatively, manufacturer fees could be set to fully cover the costs of the program and reimburse entities operating the collection points, transportation, and recycling. If third-party entities are responsible for collection and transportation, oversight and guidance would be beneficial to help plan for effective infrastructure and to help ensure that funding adequately covers the costs. It is likely that PV module installers, distributors, and maintenance companies would play a role in the collection network. Local governments may also play a role as convenient collection points for homeowners and small businesses.
- *Would reuse and refurbishment be encouraged and included in the manufacturer stewardship program?* The language in Section 2(a)(9) of the Session Law specifies only recycling of EOL PV modules but reuse and refurbishment are preferred management strategies for panels that are still in good condition and have useful electrical output (See Section 2(a)(2) for detailed discussion).
- *Would fees paid by manufacturers in a given year be used to manage those same modules once they reach EOL in 20 to 30 years or would the fees paid in a given year cover the management of modules coming out of service in that same year?* Either scenario presents challenges and potential concerns from manufacturers.
 - If fees serve as an advanced payment to cover the cost of the modules when they reach EOL in 20 to 30 years, it will be very difficult to predict a fee for a service that will be provided in decades to come. This model would not provide funding for the recycling of PV modules that are already in service.
 - If fees are used to cover the cost of recycling modules coming out of service in that same year, manufacturers may argue that they are being assessed fees to manage "orphaned" modules, or those produced by manufacturers that have gone out of business. Additionally, it may hinder incentives for manufacturers to design for recyclability since fees are based on the recycling costs of existing modules in service, rather than new modules being produced. This model could also face challenges if a severe weather event damages a large quantity of panels that would need to be removed from service and recycled but were not anticipated in the annual fee-setting calculations.
- *How would the program be enforced, and what penalties would apply for manufacturers that do not meet the product stewardship requirements?* As one example, the State of Washington is authorized to assess a penalty of up to \$10,000 per violation for manufacturers that do not comply with the product stewardship requirements after

sending a written warning. Manufacturers that do not comply are not authorized to sell or offer for sale a PV module in the state.¹⁴⁹

The model proposed in the language Section 2(a)(9) of the Session Law has similarities to the North Carolina Discarded Computer Equipment and Television Management Program, as set forth in G.S. 130A.309.130-142. Under this Program, manufacturers of computer equipment and televisions must register annually with the state and pay a fee. Computer equipment manufacturers pay \$15,000 annually, but have the option to register at alternative levels and pay lower initial and renewal registration fees depending on the scope of recycling opportunities provided across the state. Television manufacturers pay an annual fee of \$2,500. A portion of these fees are used by the Department to administer the Program and remaining fees are distributed annually to eligible local governments on a pro rata basis. In February 2020, a total of \$500,000 was distributed to 64 local governments providing recycling opportunities to a population of 8,629,470 North Carolinians. This equates to a distribution of \$0.06 per person. The actual cost for local governments to operate electronics recycling programs is \$0.75 per person on average.¹⁵⁰ The Electronics Management Fund distributions are intended to help cover a portion of the cost of managing discarded computer equipment and televisions with supplemental support from the television manufacturer requirements discussed below.

In addition to an annual registration fee, each television manufacturer must annually recycle or arrange for the recycling of its market share of televisions. However, the financial contribution from manufacturers arranging for the recycling of their market share does not adequately cover the full cost of television recycling. In a 2016 DEQ report, the Department found that electronics recyclers reported receiving manufacturer payment for processing cathode ray tube (CRT) televisions in the range of \$0.12 to \$0.18 per pound. Market rates to receive, prepare, and deliver CRTs for recycling were approximately \$0.30 per pound in 2016. Additionally, local governments with established contracts from recyclers who receive manufacturer funds were still being charged, often more than \$0.10 per pound for CRTs, providing further evidence that manufacturer payments fail to cover the full costs of managing the materials.¹⁵¹

Conversations with electronics recyclers and local governments since 2016 indicate that television manufacturer payments are declining and now represent an even smaller portion of the full recycling costs. A presentation to the Environmental Review Commission in 2018 reported one electronics recycler receiving just \$0.04 per pound for manufacturer television quota, even though costs to recycle have remained relatively steady at \$0.25 to \$0.30 per pound.¹⁵² This places more financial burden on local governments that collect the majority of televisions across the state. In FY2018-19, local government programs collected 19,825,200 pounds of televisions while manufacturers collected 3,014,040 pounds. This equates to 87% managed by local governments and 13% managed by manufacturers.¹⁵³

With costs left to local governments to pay, the burden ultimately falls on North Carolinians who pay the price through local tax payments, recycling fees, or a combination of the two. If a

¹⁴⁹ Revised Code of Washington. 70A.510.010(8)

¹⁵⁰ "Electronics Management Program presentation to the Environmental Review Committee." DEQ, Feb. 2018.

¹⁵¹ "Study of Electronics Recycling in North Carolina." DEQ, 2016.

¹⁵² "Electronics Management Program presentation to the Environmental Review Committee." DEQ, Feb. 2018.

¹⁵³ "Consolidated Waste Management Report FY2018-19." DEQ, 2020.

product stewardship program is considered for the management of EOL PV modules, DEQ recommends evaluating language to explicitly state that the full cost of collection and recycling be covered by the program to avoid financial challenges similar to those experienced with the electronics legislation. One example to consider is the State of Washington's PV module recycling legislation, stating in RCW 70A.510.010(5)(a)(i) that a manufacturer must "finance the costs of collection, management, and recycling of photovoltaic modules and residuals sold in or into the state by the manufacturer with a mechanism that ensures that photovoltaic modules can be delivered to takeback locations without cost to the last owner or holder."

As an emerging waste issue, policies around the management of EOL PV modules have been or are actively considered in a number of states including New York, New Jersey, Arizona, Illinois, Minnesota, and Hawaii. As mentioned in Section 2(a)(6), Washington is the only state that has enacted legislation to establish a manufacturer-based stewardship program. Notably, the implementation of the program was delayed from January 1, 2021, to July 1, 2023 in House Bill 2465, signed in June 2020. In a conversation with the staff from the Washington Department of Ecology, DEQ staff learned that industry stakeholders asked Washington state legislators for more time and consideration to be put forth before the legislative requirements went into effect.¹⁵⁴ House Bill 2645 directed Washington State University to convene a stakeholder group to study EOL PV module issues and submit a report to the legislature by December 1, 2021. However, the stakeholder process has been delayed by a partial veto from the Governor due to funding uncertainty during the COVID-19 pandemic.

North Carolina can benefit from continued conversations with other states studying the issue and by following the implementation of the Washington manufacturer stewardship program to understand its successes and shortcomings. DEQ expects that the industry would appreciate a carefully considered approach, and to the extent practicable, consistency across state legislative efforts, or even a national approach to PV module recycling.

There are alternative strategies beyond manufacturer stewardship programs that could be implemented to incentivize the reuse, refurbishment, and recycling of PV modules. One stakeholder suggested that "a multifaceted regulatory approach could provide benefits and spread the burden across multiple actors to not overburden one." Options could include advanced recycling fees charged to the consumer, monthly recycling fees charged to the utility rate payer, increased landfill tipping fees, financial incentives to recycle, market development of more recycling infrastructure, tax credits for recyclers, and reduction in regulatory burden for recycling as opposed to landfilling. All options for product stewardship should be equally weighed and evaluated in future discussions.

Energy Storage System Batteries

DEQ does not recommend a manufacturer stewardship program for the recycling of EOL energy storage system batteries at this time. As discussed in Section 2(a)(2), recycling for lithium-ion, the most common type of energy storage system batteries, is limited and still in the

¹⁵⁴ Washington Department of Ecology. Personal communication, Oct. 2020.

early stages of development. DEQ recommends revisiting strategies to recycle EOL energy storage system batteries in the future.

Manufacturers and industry stakeholders have expressed support for national standards around the management of energy storage system batteries, particularly lithium-ion. They would prefer to see a national program established rather than a patchwork of varying state-by-state requirements. The U.S. Department of Energy is working to accelerate research and development for effective recycling of energy storage system batteries through a *Lithium-Ion Battery Recycling Prize* contest offering \$5.5 million through a series of phases. The funding will be awarded to improve collection, sorting, safe storage, and transportation for eventual recycling. The goal of the contest is to develop processes that can be scaled to capture 90% of all discarded lithium-ion batteries in the United States to recover materials and reintroduce them into the domestic supply chain.¹⁵⁵ The Department supports these national efforts and expects to continue collaborating with other states and federal partners to evaluate management options and policies for the recycling of energy storage system batteries.

¹⁵⁵ "Energy Department Announces Battery Recycling Prize and Battery Recycling R&D Center." *Department of Energy*, 2019.

APPENDIX A
LIST OF PARTICIPATING H329 STAKEHOLDERS

Duke Energy	Dynamic Lifecycle Innovations
Dominion Energy	TT&E Iron and Metal Foils Inc.
NC Electric Membership Cooperatives	Regional Materials Recovery, Inc.
NC Sustainable Energy Association	NC Utilities Commission-Public Staff
First Solar	Advanced Energy
Cypress Creek Renewables	EQ Research
NC Clean Energy Business Alliance	Umicore
NC Farm Bureau	Carolina Recycling Association
Energy & Environment Innovation Foundation	ecycleSecure
Ecoplexus	NC Department of Public Safety
National Renewable Energy Laboratory	Alamance County Government
Smith Gardner Inc.	Caldwell County Government
Sierra Club	Cabarrus County Government
NC Conservation Network	Chatham County Government
Southern Environmental Law Center	Cherokee County Government
Recycling Association of NC	Columbus County Government
NC State University Extension	Cumberland County Government
Solar Energy Industries Association	Currituck County Government
Electronics Recyclers International	Davidson County Government
Law Office of Robert W. Kaylor	Davie County Government
Smith Anderson	Gaston County Government
Capitol Advantage Associates	Granville County Government
Brooks Pierce & Recycling	Hoke County Government
NC Association of County Commissioners	Iredell County Government
Solterra Partners Invenergy	Jones County Government
Minnesota Pollution Control Agency	Northampton County Government
Stevens Lobby and Consulting	Onslow County Government
Southern Power Companies	Orange County Government
SunnKing	Perquimans County Government
Energy Intelligence Partners	Randolph County Government
Synergy Recycling	Rowan County Government
Metech Recycling	Transylvania County Government
Powerhouse Recycling Inc.	Wilson County Government
Institute of Scrap Recycling Industries, Inc	Stanly County Government
NC Clean Energy Technology Center	Warren County Government
GEEP Global (Global Electric Electronic Processing)	Yadkin County Government
PV Cycle	Illinois Sustainable Technology Center
Strata Solar	



**NORTH CAROLINA DEPARTMENT OF ENVIRONMENTAL QUALITY
DIVISION OF WASTE MANAGEMENT
HAZARDOUS WASTE SECTION**

**Summary of Management Requirements
When Determined to be Non-Hazardous, Hazardous or Universal Waste**

This table provides a side by side comparison of general requirements for the management of wastes determined to be non-hazardous, hazardous, or universal waste (a subset of hazardous waste). This table is not all inclusive of all hazardous waste or universal waste requirements. This table was created to highlight the overall management differences between these different waste categories (non-hazardous, hazardous, and universal waste) as they would relate to the management of photovoltaic modules (PV modules).

PV modules are not currently a universal waste in North Carolina so rulemaking needs to occur before they could be managed as a universal waste.

	Non-Hazardous Waste	Hazardous Waste (HW)	
		Full HW Regulation	Universal Waste (UW) (Less Stringent HW Regulation)
Brief Explanation of Management Option	- Wastes that are non-hazardous/solid waste are ones that do not meet the definition of a hazardous waste or are excluded from regulation as a hazardous waste. - Regulated under RCRA Subtitle D and any applicable state laws and rules.	- Hazardous wastes are wastes (described in 40 CFR 261.2), that are not excluded from regulation (under 40 CFR 261.4), that exhibit one or more hazardous waste characteristics (described at 40 CFR 261 subpart C) and/or that meet a listing description (described at 40 CFR 261 subpart D). - A waste determination in accordance with 40 CFR 262.11 must be performed on waste generated at a site that is not considered a household. - It is the generator's responsibility to determine whether a waste is a hazardous waste. However, a generator is allowed to manage a waste more conservatively as a	- Certain hazardous waste streams, can be managed under a less stringent set of hazardous waste requirements if they have been categorized as a "universal waste" and the state has adopted the federal provisions or created their own state requirements applicable to that category. - Universal waste requirements are a less stringent set of hazardous waste rules that apply to specific categories of waste (that would be a hazardous waste when disposed) to encourage the recycling and/or proper management. - Currently only the following categories of waste that would otherwise be a hazardous

		hazardous waste if it is possible the waste could meet the definition of a hazardous waste when disposed. - Regulated under RCRA Subtitle C and any applicable state laws and rules.	waste when disposed may be managed as a universal waste: lamps, batteries, mercury containing equipment, pesticides and aerosol cans may be managed as a universal waste in NC. - PV modules are not currently classified as a universal waste in NC. Rulemaking must be done to add PV modules as a universal waste.
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	Non-Hazardous Waste	Hazardous Waste (HW)	
		Full HW Regulation	Universal Waste (UW) (Less Stringent HW Regulation)
How is this management option determined?	- Waste determination required: generator TCLP (or generator use of manufacturer TCLP for the specific PV module) to show PV module is non-hazardous or - PV module is specifically excluded from hazardous waste rules (e.g., PV module is from a household so not subject to HW rules)	- Waste determination based on generator TCLP (or generator use of manufacturer TCLP for the specific PV module) to show PV module is hazardous or - Generator may be conservative and declare the PV module to be a HW without testing/generator knowledge or further waste determination	- The universal waste rules are a subset of the hazardous waste rules so in order to be a universal waste, a waste must be a hazardous waste first. - Waste determination based on generator TCLP (or generator use of manufacturer TCLP for the specific PV module) to show PV module is hazardous or - Generator may be conservative and declare the PV module to be a HW without testing/generator knowledge or further waste determination and - Must be a waste category that is considered a universal waste and adopted by the state.
Is this management option currently available in North Carolina?	Yes, but to be managed as non-hazardous, see Waste Determination, above	Yes, but to be managed as hazardous, see Waste Determination, above	No, PV modules are not currently a universal waste in North Carolina. Rulemaking must be done to add PV modules as a universal waste.
Are there different requirements that apply depending on the amount of waste?		- Yes, there are different management requirements based on the amount of waste PV modules generated in a calendar month and the total amount of waste PV modules accumulated at any one time. - The requirements are more complex/complicated as the volume of hazardous waste generated per month increases (based on specific thresholds) and/or with the amount accumulated at any time. - The threshold for applicability of the large quantity generator requirements is when 2,200 lbs. of more hazardous waste is generated in a calendar month. There is no threshold maximum limit of hazardous waste a large quantity generator may have	- Yes, there are different management requirements based on the total amount of universal waste on-site at any time. - The threshold of applicability for the large quantity handler requirements for a universal waste to apply is 5,000 kg of total universal waste on-site at any time. - There is no maximum threshold limit of universal waste a large quantity handler of universal waste may accumulate on-site as long as the site complies with the large quantity handler universal waste requirements.

		on-site at any time as long as site complies with large quantity hazardous generator requirements.	
	Non-Hazardous Waste	Hazardous Waste (HW)	
		Full HW Regulation	Universal Waste (UW) (Less Stringent HW Regulation)
Maximum Volume Threshold		There are volume thresholds applicable to the two lowest categories of hazardous waste generator (very small and small quantity generators), but a large quantity generator of hazardous waste has no maximum volume threshold for the amount of hazardous waste allowed on-site as long as all the other large quantity generator requirements are met.	There is a volume threshold (5,000 kg) that dictates which requirements apply to the universal waste accumulated at a site, but a large quantity handler of universal waste does not have a maximum volume threshold for amount of universal waste allowed to be accumulated on-site at any time as long as all of the large quantity handler of universal waste requirements are met.
Accumulation Time Limits		- There are specific limitations on the amount of time a hazardous waste may remain on-site at the site where it is generated, depending on the amount of hazardous waste generated in a calendar month and/or amount accumulated at any time. - A large quantity generator of hazardous waste may accumulate hazardous waste on-site for no more than 90 days.	Universal waste may not remain on-site at the site where it is generated/handled for more than one year, regardless of the amount accumulated on-site at any time.
What other on-site requirements apply?	Storage must comply with 15A NCAC 13B .0104 A recovered material as defined in N.C.G.S. 130A-290(a)(24) means a material that has known recycling potential, can be feasibly recycled, and has been diverted or removed from the solid waste stream for sale, use, or reuse. In order to qualify as a recovered material, a material must meet the requirements of N.S.G.S. 130A-309.05(c).	Specific requirements apply to (very briefly summarized/noncomprehensive): - Emergency preparedness, prevention, and response - Container management - Employee training - Inspections - Land Disposal Restrictions - Documentation - Notification of Hazardous Waste Activity	Specific requirements apply to (very briefly summarized/noncomprehensive): - Spill response - Container management - Employee training - Notification of Hazardous Waste Activity when threshold amount is triggered

	Non-Hazardous Waste	Hazardous Waste (HW)	
		Full HW Regulation	Universal Waste (UW) (Less Stringent HW Regulation)
Transportation Requirements	Transportation must comply with 15A NCAC 13B .0105	- A hazardous waste generator shall not transport, offer its hazardous waste for transport or otherwise cause its hazardous waste to be sent to a facility that is not a designated facility (as defined in 40 CFR 260.10) or not otherwise authorized to receive the generator's hazardous waste. - Containers must be labeled with specific hazardous waste language and in compliance with DOT hazardous materials requirements - Hazardous waste may only be transported by a registered hazardous waste transporter - In most cases, a hazardous waste manifest must be used when hazardous waste is transported. - The generator must placard the transportation vehicle with the appropriate DOT placard.	- Universal waste handlers are prohibited from sending or taking universal waste to a place other than another universal waste handler, a destination facility, or a foreign destination. - If a universal waste handler self-transportes universal waste off-site, the handler becomes a universal waste transporter for those self-transportation activities and must comply with the transporter requirements of 40 CFR 273 subpart D. -- If universal waste are shipped out of North Carolina, to a state (or through one), that has not yet adopted the category of universal waste, the universal waste may still be managed as a universal waste on-site in North Carolina, but would need to be transported as a hazardous waste (or by any other state requirements) until the receiving state (or any states the waste travels through) adopts the universal waste category.
Disposal Requirements	Generator may be subject to providing additional information and analysis (to include a non-hazardous determination) to the disposal facility, and the material may be rejected from disposal at their discretion, in accordance with their permit and any other governing rules or ordinances.	- A hazardous waste generator shall not transport, offer its hazardous waste for transport or otherwise cause its hazardous waste to be sent to a facility that is not a designated facility (as defined in 40 CFR 260.10) [see Recycling section of this document] or not otherwise authorized to receive the generator's hazardous waste. - When hazardous waste is disposed, it must go to a permitted or interim status hazardous waste treatment, storage, or disposal facility.	- Universal waste handlers are prohibited from sending or taking universal waste to a place other than another universal waste handler, a destination facility [see Recycling Section of this document], or a foreign destination. - In most cases, universal waste must be recycled and not disposed.
Can PV modules go to the landfill?	Generator may be subject to providing additional information and analysis to the disposal facility, and the material may be rejected from disposal at their discretion, in accordance with their permit and any other governing rules or ordinances. Even if the PV	No, hazardous waste is not allowed in NC landfills per 15A NCAC 13B .0103(c)	- No, hazardous waste is not allowed in NC landfills per 15A NCAC 13B .0103(c) - Universal waste handlers are prohibited from sending or taking universal waste to a place

	modules can be disposed of in the landfill, recycling part or all of the PV module is encouraged.		other than another universal waste handler, a destination facility, or a foreign destination.
	Non-Hazardous Waste	Hazardous Waste (HW)	
		Full HW Regulation	Universal Waste (UW) (Less Stringent HW Regulation)
Recycling Requirements	A recovered material as defined in N.C.G.S. 130A-290(a)(24) means a material that has known recycling potential, can be feasibly recycled, and has been diverted or removed from the solid waste stream for sale, use, or reuse. In order to qualify as a recovered material, a material must meet the requirements of N.C.G.S. 130A-309.05(c).	Recycling facility must be one that meets the definition of a "designated facility": - A permitted or interim status hazardous waste treatment, storage, or disposal facility - Facilities that recycle recyclable materials without storing them before they are recycled must comply with specific conditions including notifying the HWS of this activity, use a hazardous waste manifest, meet hazardous waste air emission requirements, and complete a biennial report.	Universal waste is recycled at a universal waste destination facility which is: - A permitted or interim status hazardous waste treatment, storage, or disposal facility - Facilities that recycle recyclable materials without storing them before they are recycled must comply with specific conditions including notifying the HWS of this activity, use a hazardous waste manifest, meet hazardous waste air emission requirements, and complete a biennial report.
Treatment		- Treatment of hazardous waste is not allowed without a hazardous waste permit. (There are a few exceptions where generators of hazardous waste and universal waste handlers are allowed to treat hazardous waste or universal waste without a permit, but those conditions would not typically apply if treating something like a PV module. Additionally, the ability for a universal waste handler to treat PV modules will depend on the definition of PV module). - "Treatment" means any method, technique or process, including neutralization, designed to change the physical, chemical or biological character or composition of any hazardous waste so as to neutralize such waste or so as to render such waste nonhazardous, safer for transport, amenable for recovery, amenable for storage or reduced in volume. "Treatment" includes any activity or processing designed to change the physical form or chemical composition of hazardous waste so as to render it nonhazardous.	
Dismantling		This depends on the definition of a PV module. If dismantling components (like separating the scrap metal from the glass) would meet the definition of treatment (above), then dismantling would not be allowed without a hazardous waste permit.	
Removing Components		This depends on the definition of a PV module. If the removing components (like a battery to be managed as a universal waste) would meet the definition of treatment (above), then removing components would not be allowed without a hazardous waste permit.	



NORTH CAROLINA DEPARTMENT OF ENVIRONMENTAL QUALITY
DIVISION OF WASTE MANAGEMENT
HAZARDOUS WASTE SECTION

Comparison of Hazardous Waste and the Universal Waste Requirements

This table provides a side by side comparison of the baseline hazardous waste generator requirements and the requirements for universal waste. Currently photovoltaic modules (PV modules) **are not a** universal waste in North Carolina. **North Carolina must complete rulemaking in order for PV modules to be managed as a universal waste.** Universal wastes are a subset of the hazardous waste rules. In order to be managed as a universal waste, the waste must first be a hazardous waste. Currently, in North Carolina, universal waste consists of batteries, lamps, mercury containing equipment, pesticides, and aerosol cans that would otherwise be a hazardous waste when disposed.

	Baseline Hazardous Waste Generator Requirements			Key Differences for Management as a Universal Waste	
	Very Small Quantity Generator (VSQG)	Small Quantity Generator (SQG)	Large Quantity Generator (LQG)	Small Quantity Handler of Universal Waste	Large Quantity Handler of Universal Waste
Generation Rate					
- Quantity of non-acute HW generated in a calendar month	< 220 lbs. (100 kg)	> 220 lbs. (100 kg) but < 2,200 lbs. (1000 kg)	≥ 2,200 lbs. (1000 kg)	- There is no monthly generation rate limit for universal waste. - An accumulation volume limit of less than 5,000 kg at any time determines whether a facility is a small quantity handler of universal waste. - Universal waste does not count towards hazardous waste generator category. - Currently, in NC, universal waste consists of batteries, lamps, mercury containing equipment, pesticides, and aerosol cans. - PV modules are not considered a universal waste. Rulemaking must be completed to add them as a universal waste category.	- There is no monthly generation rate limit for universal waste. - An accumulation volume limit of 5,000 kg or more at any time whether a facility is a large quantity handler of universal waste. - Universal waste does not count towards hazardous waste generator category. - Currently, in NC, universal waste consists of batteries, lamps, mercury containing equipment, pesticides, and aerosol cans. - PV modules are not considered a universal waste. Rulemaking must be completed to add them as a universal waste category.
- Quantity of acute HW generated in a calendar month	< 2.2 lbs. (1 kg)	< 2.2 lbs. (1 kg)	> 2.2 lbs. (1 kg)		
- Quantity of residues from a clean-up of acute HW generated in a calendar month	< 220 lbs. (100 kg)	< 220 lbs. (100 kg)	> 220 lbs. (100 kg)		
Accumulation Volume Limit	- 2,200 lbs. (1000 kg) non-acute HW at any time - ≤ 2.2 lbs. (1 kg) acute HW at any time	13,200 lbs. (6000 kg) non-acute HW at any time	None	A small quantity handler of universal waste accumulates less than 5,000 kg of universal waste (currently: batteries, pesticides, mercury-containing equipment,	- There is no maximum volume limit allowed to be accumulated. - A large quantity handler of universal waste accumulates 5,000 kg or more of universal waste (currently: batteries, pesticides, mercury-containing

	- ≤ 220 lbs. (100 kg) acute HW from a clean-up at any time			lamps and/or aerosol cans, calculated collectively) at any time.	equipment, lamps, or aerosol cans, calculated collectively) at any time.
	Baseline Hazardous Waste Generator Requirements			Key Differences for Management as a Universal Waste	
	VSQG	SQG	LQG	Small Quantity Handler of Universal Waste	Large Quantity Handler of Universal Waste
Accumulation Time Limit (without a permit)	None	180 days; 270 days if HW is transported 200 miles or more to an off-site TSD facility	90 days	- One Year Accumulation Time Limit - Must be able to demonstrate the length of time the universal waste has been accumulated from the date it becomes a waste or is received.	
Notification Requirements/ EPA Identification Number	None	Notify NCDEQ HWS (electronically using RCRAInfo) and obtain EPA ID Number		Not required to notify NCDEQ HWS of universal waste handling activities.	Must notify NCDEQ HWS (electronically using RCRAInfo) and obtain EPA ID Number (if site does not already have an EPA ID Number).
Hazardous Waste Determinations	Waste Determination in accordance with 40 CFR 262.11(a) through (d).	Waste Determination in accordance with 40 CFR 262.11(a) through (g).		Universal wastes are exempt from regulation under 40 CFR 262 through 270. However, a universal waste is defined as a hazardous waste that are managed under the universal waste requirements of 40 CFR 273. Facility must make waste determination and document an initial waste determination and then indicate the waste stream is managed under 40 CFR 273 and is exempt from other hazardous waste requirements.	
Labeling/Marking Requirements	None	All containers (satellite and central accumulation) must be marked/labeled with: - The words "Hazardous Waste," - An indication of the hazards of the contents of the container Central accumulation containers – must be marked with an accumulation start date.		Universal waste has specific marking/labeling requirements. Typically, each unit of universal waste or a container in which the universal wastes are contained, must be labeled, or marked clearly with any of the following phrases: - "Universal Waste - _____" (e.g., "Lamp(s)" or "Aerosol Can(s)"), - "Waste _____" (e.g., "Lamp(s)" or "Aerosol Can(s)"), or - "Used _____" (e.g., "Lamp(s)" or "Aerosol Can(s)").	
Container Management	None	- Hazardous waste must be placed in a hazardous waste management unit (container, tank, drip pad or containment building in compliance with 40 CFR 262.15 for satellite accumulation area or the applicable requirements of 40 CFR 262.16 (for SQGs) or 40 CFR 262.17 (for LQGs).		Container management requirements vary slightly depending on the waste category, however, typically the below applies: - Universal waste must be accumulated in a container that is structurally sound, compatible with the contents, lacks evidence of leakage, spillage, or damage that could cause leakage under reasonably foreseeable conditions.	

Inspection Requirements	None	- Weekly inspections required of central accumulation area(s) - Inspections must be documented and kept for three years	No inspections are required.
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	Baseline Hazardous Waste Generator Requirements			Key Differences for Management as a Universal Waste	
	VSQG	SQG	LQG	Small Quantity Handler of Universal Waste	Large Quantity Handler of Universal Waste
Employee Training	None	Generator must ensure that all employees are thoroughly familiar with proper waste handling and emergency procedures relevant to their responsibilities during normal facility operations and emergencies.	Training program required for all employees with HW management duties. Training program must be documented, and records kept for each employee. Annual refresher training is required.	Small quantity handlers of universal waste must inform all employees who handle or have responsibility for managing universal waste. The information must describe proper handling and emergency procedures appropriate to the type(s) of universal waste handled at the facility.	Large quantity handlers of universal waste must ensure that all employees are thoroughly familiar with proper waste handling and emergency procedures, relative to their responsibilities during normal facility operations and emergencies.
Transportation	None	- A hazardous waste generator shall not transport, offer its hazardous waste for transport or otherwise cause its hazardous waste to be sent to a facility that is not a designated facility (as defined in 40 CFR 260.10) or not otherwise authorized to receive the generator's hazardous waste. - Containers must be labeled with specific hazardous waste language and in compliance with DOT hazardous materials requirements - Hazardous waste may only be transported by a registered hazardous waste transporter - The generator must placard the transportation vehicle with the appropriate DOT placard.		- Universal waste handlers are prohibited from sending or taking universal waste to a place other than another universal waste handler, a destination facility, or a foreign destination. - If a universal waste handler self-transport universal waste off-site, the handler becomes a universal waste transporter for those self-transportation activities and must comply with the transporter requirements of 40 CFR 273 subpart D. - Prior to sending a shipment of universal waste to another universal waste handler, the originating handler must ensure the receiving handler agrees to receive the shipment. - If universal waste is shipped out of North Carolina, to a state (or through one), that has not yet adopted the regulations, the universal waste may still be managed as a universal waste on-site in North Carolina, but would need to be transported as a hazardous waste (or by any other state requirements) until the receiving state (or any states the waste travels through) adopts a universal waste regulation for that waste category.	
Disposal		- A hazardous waste generator shall not transport, offer its hazardous waste for transport or otherwise cause its hazardous waste to be sent to a facility that is not a designated facility (as defined in 40 CFR 260.10) or not otherwise authorized to receive the generator's hazardous waste.		- Universal waste handlers are prohibited from sending or taking universal waste to a place other than another universal waste handler, a destination facility, or a foreign destination. - In most cases, universal waste must be recycled and not disposed. - A "destination facility" is a permitted or interim status hazardous waste treatment, storage, or disposal facility or	

		- When hazardous waste is disposed, it must go to a permitted or interim status hazardous waste treatment, storage, or disposal facility	- A facility that recycles recyclable materials without storing (processes within 24 hours) them before they are recycled must comply with specific conditions including notifying the HWS of this activity, use a hazardous waste manifest, meet hazardous waste air emission requirements, and complete a biennial report.
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	Baseline Hazardous Waste Generator Requirements			Key Differences for Management as a Universal Waste	
	VSQG	SQG	LQG	Small Quantity Handler of Universal Waste	Large Quantity Handler of Universal Waste
Manifests	None	- Hazardous waste manifest must be prepared for each off-site shipment of hazardous waste. Containers and manifests must include RCRA HW waste codes. - Signed, completed manifests must be kept for three years.		- Not required to keep records of shipments of universal waste. - It is recommended to maintain bill of lading or other tracking documentation of the shipment. - See "Transportation" section of this document for information if receiving state has not yet adopted the universal waste requirements yet.	Large quantity handler of universal waste must maintain: - Records of each shipment of universal waste received at the facility - Records of each shipment of universal waste sent from the handler to other facilities. - Records must include specific information including the name and address of the originating handler, the quantity of each type of universal waste sent, and the date the shipment left the facility. - Records must be retained for three years. - See "Transportation" section of this document for information if receiving state has not yet adopted the universal waste requirements yet.
Land Disposal Restrictions	None	Must comply with the land disposal restrictions of 40 CFR 268.		Universal waste handlers are not required to meet land disposal restrictions of 40 CFR 268. However, any releases of universal waste that are not immediately cleaned up are subject to the hazardous waste requirements including land disposal restrictions of 40 CFR 268.	
Preparedness and Prevention and Emergency Response	None	- Facilities must be maintained and operated to prevent fire, explosion, or release of hazardous waste. Appropriate equipment and procedures must be in place. Arrangements must be made with local authorities. - Facility must have a designated emergency coordinator.		- A universal waste handler must manage universal waste in a way that prevents releases of any universal waste or component of a universal waste to the environment. - A universal waste handler must immediately contain all releases of universal waste and other residues from universal wastes and determine whether any material resulting from the release is a hazardous waste. If it is a hazardous waste, it must be managed in accordance with applicable requirements of 40	

		- Emergency information must be posted at the facility (SQG) or submitted to the local emergency authorities (LQG). - Facility must immediately contain all spills and manage clean-up material by applicable HW requirements.	CFR 260 through 272. The handler is considered the generator if a release is hazardous waste.
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	Baseline Hazardous Waste Generator Requirements			Key Differences for Management as a Universal Waste	
	VSQG	SQG	LQG	Small Quantity Handler of Universal Waste	Large Quantity Handler of Universal Waste
Treatment	- Treatment of hazardous waste is not allowed without a hazardous waste permit. (There are a few exceptions where generators of hazardous waste or universal waste handlers are allowed to treat hazardous waste or universal waste without a permit, but those conditions would not typically apply if treating something like a PV module. The ability to treat universal waste will depend on the definition of the PV module). - "Treatment" (defined by N.C.G.S. 130A-290(a)(42)) means any method, technique or process, including neutralization, designed to change the physical, chemical or biological character or composition of any hazardous waste so as to neutralize such waste or so as to render such waste nonhazardous, safer for transport, amenable for recovery, amenable for storage or reduced in volume. "Treatment" includes any activity or processing designed to change the physical form or chemical composition of hazardous waste so as to render it nonhazardous.				
Recycling	Recycling facility must be one that meets the definition of a "designated facility": - A permitted or interim status hazardous waste treatment, storage, or disposal facility - Facilities that recycle recyclable materials without storing them before they are recycled must comply with specific conditions including notifying the HWS of this activity, use a hazardous waste manifest, meet hazardous waste air emission requirements, and complete a biennial report.			Universal waste is recycled at a universal waste destination facility which is: - A permitted or interim status hazardous waste treatment, storage, or disposal facility - Facilities that recycle recyclable materials without storing them before they are recycled must comply with specific conditions including notifying the HWS of this activity, use a hazardous waste manifest, meet hazardous waste air emission requirements, and complete a biennial report.	
Exports	Generators who send hazardous waste to foreign destination are subject to the requirements of 40 CFR 262 subpart H.			Handlers of universal waste who send universal waste to foreign destination are subject to the requirements of 40 CFR 262 subpart H.	

Status Quo

End-of-life management decisions for utility-scale photovoltaic (PV) modules will be made and fully financed by the owners of the modules. If modules are not being reused or refurbished, owners are responsible for determining whether or not a PV module is a hazardous waste and can make end-of-life management decisions accordingly. The Department of Environmental Quality (DEQ) proposes to add PV modules as a universal waste, which would ease storage and transportation requirements and provide additional recycling opportunities. If not recycled, modules classified as hazardous waste must be taken to a hazardous waste treatment, storage and disposal facility. Modules that are non-hazardous can be recycled or taken to a Subtitle D municipal solid waste landfill for disposal. While the state recommends reuse, refurbishment and recycling as preferred waste management strategies, there are no disposal prohibitions or recycling requirements for non-hazardous PV modules.

1. Regulatory mechanisms and enforcement are already established. It is not necessary to establish a new program to manage, or create a new entity.
2. Unlike the other options enforcement of disposal regulations at the landfill gate is hard to circumvent or evade.
3. TCLP testing for hazardous/non-hazardous waste determination is not particularly burdensome and widely available
4. The proposal to categorize PV modules as universal waste does not seem to provide a benefit, as every TCLP test we have run found the modules to be non-hazardous (by a wide margin).
5. Status Quo may work itself out appropriately; however, it would be a much safer option to put requirements in place ahead of time to get the desired outcome.
6. The “status quo” option is good with responsibility on the panel owner.
7. Chances are the cheaper method, landfilling, will be chosen at EOL
8. Solar is “green energy” and adding to landfills takes away from that and will not look good in the media, similar to what we are seeing with wind blades right now
9. Missing out on the opportunity to recycle materials and avoid the issues with buying virgin materials
10. No incentive for manufacturers to design panels for easier recycling at EOL or use recycled materials in their panels
11. Going to potentially put a black eye on solar installations that could actually slow down installations, opposite of what we want
12. Status quo is base case and does not appear to address findings and regulations that H329 directs the agency to pursue.
13. ‘Utility-scale’ is not well defined in H329 and the scope of the impact of this and other alternatives for ‘utility scale’ and ‘all other’ is also not well defined.
14. State may already have certain regulations for utility installations and that is not discussed, if applicable. For example, in MN, investor-owned utilities are required to plan for, finance, and include end of life decommissioning in the rate base.
15. Scenario does not do much to alter the default EOL option of landfilling. There is a management hierarchy in H329 and this scenario doesn’t move actual management options up the hierarchy.
16. Preferred option.
 - a. However, we recommend that the Department consider changing the title of this option as status quo implies no changes, which may lead to confusion.
17. Limits the need for unnecessary fees/government spending.
18. Provides the greatest flexibility (e.g., no testing requirement for hazardous waste determination, less stringent storage and manifest requirements) and would be preferable from a project management perspective.
19. Applies the fees of recycling to the generator of the “waste.”

- b. This would also apply to PV modules currently in use (pre-HB329 solar facilities), helping to ensure that more modules are properly recycled at end of life.
20. Would encourage recycling of more PV modules. The EPA's universal waste regulation expressly promotes recycling, so less waste goes into a landfill.
21. The Universal Waste classification would create an incentive to continue to explore better recycling, reuse, and manufacturing options.
22. We support designating PV modules as a Universal Waste. This could expand opportunities for recycling while balancing the compliance obligations (training, storage, record keeping, transportation, etc.) associated with management of panels that are characteristically hazardous. These benefits would likely become even more apparent as the utilization of PV modules becomes more widespread and applications continue to expand beyond utility scale solar arrays such as rooftop solar. Similar to aerosol cans, which were recently added to the federal universal waste program, this designation for PV modules could make recycling more attainable for all owners, regardless of quantities being managed.
23. If moving forward with this designation, DEQ should also ensure that the universal waste classification applies to both intact and broken or cracked PV modules. As recognized in DEQ's status quo description, designation as a universal waste should not be implemented in such a way as to include PV modules that do not exhibit any hazardous characteristics.
24. Of the options presented, the Universal Waste designation would appear to offer the most benefits toward managing PV modules in a responsible and cost-effective manner, provided certain additional aspects are considered.
25. Preferred option in short term while developing a shared model for the future.
26. While the status quo is working, if the panels were designated as universal waste, this would be beneficial and would help with recycling. A universal waste designation would help lower waste management costs. The universal waste option would work best if more states treat panels as universal waste, but ideally, they would be designated universal waste at the federal level. Additionally, handling panels as universal waste may help incentivize the recycling market.
27. Continued pushback on solar growth if no change – though addition of universal waste category would be an additional management too. Recommendation is low due to con.

Questions/Concerns:

- If TCLP regulations are likely to be revised within the next 1-2 years to include a standard method for testing PV panels, it would be beneficial to have a caveat for revisiting the Universal Waste classification.
 - With more accurate testing procedures, it may be determined that most panels are not hazardous.
- If NC classifies PV panels as Universal Waste, will they also encourage an NC-based recycling program?
 - The closest recycling facility (of ~20 recyclers in US) is in Ohio.

Product Stewardship (modeled after Washington State)

Require a product stewardship program for all PV modules used or sold in or into the state following a certain date. Manufacturers or their stewardship organization will operate the program to fully finance the convenient takeback and recycling of all PV modules used or sold in or into the state after the implementation date. The combined reuse and recycling must equal at least eighty-five percent by weight of all PV modules collected. Each manufacturer must prepare and submit a stewardship plan to DEQ to describe the mechanism for financing a convenient takeback and recycling program that will result in no cost to the last owner or holder of the PV module. The plan must also describe how the

program will maximize recovery and minimize the release of hazardous substances into the environment. An annual administrative fee will be collected from each manufacturer to cover the costs of DEQ program management and plan review.

1. As a non-hazardous waste, what justification is there for fees and regulation beyond that required for other non-hazardous waste?
2. This option does not address the modules already installed in NC.
3. Given a product life of 25+ years it is quite likely that there will be manufacturers which will not be in business when it comes time to take back modules. I don't see a means to absolve the module owner of the responsibility for appropriate reuse/recycle/disposal of the module. Existing regulations seem appropriate to ensure that (see status quo above)
4. The costs and administrative headache of a take back program will likely cause manufacturers to exit the NC market, thereby reducing supply and driving up cost.
5. The grey market will make it difficult or impossible to enforce a take back obligation. Manufacturers may exit the NC market (see #4 above), but their product could still show up in NC if purchased in other states and then brought to NC
6. Product Stewardship is the best option. It allows the manufacturer or their stewardship organization the flexibility of financing without additional upfront cost of a recycling fee. It also allows each manufacturer to develop a takeback and recycling program specific to their panels and system components.
7. Note that we suggest it is important to include reuse in addition to recycling for compliance. It is also important that recyclers have incentives to improve recycling processes to recover high-quality multi-materials. A potential solution would be to periodically raise the required reuse and recycling rate. In addition, a multifaceted approach could provide benefits and "spread the burden" across multiple actors to not overburden one. Such an approach could incorporate other actors within the PV value/supply chain. For example, a fee/tax at the time of purchase, financial incentive to recycle, landfill ban (requirements on end users and landfill owners), or reduction in regulatory burden for those that recycle over landfill.
8. Incentivizes manufacturers to think of the design of their panels for reuse/refurb, EOL and to use recycled materials in their panels
9. Creates a consistent flow of panels to create enough weight to advance recycling of solar panels
10. Reduces the need for virgin materials
11. Include all panels
12. Need recycling in the US so the US doesn't rely on materials from other countries, such as rare earth metals
13. Helps fund orphan panels
14. Least favorite option.
15. Adds unnecessary oversight for relatively small facilities.
16. Calls for manufacturers to manage a plan, but there is concern about how many of these manufacturers will be around at end of life?
 - This is the issue that is driving the FA discussions under HB329—will the one who is responsible for end of life be around in 20 years and how do we guarantee this?
 - If the manufacturer were to go into Chapter 11 or be acquired, there is no guarantee that the product stewardship plan would be transferrable. This again leaves us without a responsible party.
17. Lacks feasibility due to the complex global manufacturing industry.
 - There are too many players; many are overseas and will not likely cooperate with a US state-based regulation.

- It will act to limit supply options and transactional costs outside of the recycling objective.
18. Would encourage the manufacturer to improve designs for environmental ease of recycling and reclamation.
 19. System Owner Responsibility (Product Stewardship model)
 - Requires a system owner to coordinate with and pay decommissioning service to remove PV modules and the accompanying system at end-of-life and properly and responsibly recycle or refurbish the PV modules. Owners could include the cost of decommissioning in their service contract with their contracted Operations & Maintenance provider (who is also properly licensed and permitted to remove solar equipment) over the lifetime of their system's service life OR owners can pay a removal fee at the time of decommissioning and donate the panels for reuse or refurbishment or pay for the recycling of panels at disposal (which would also require the use of a properly licensed and permitted disposal company based upon the waste characterization of the modules).
 20. Extended Producer Responsibility (Product Stewardship model that follows Washington State)
 - Require an extended producer responsibility (EPR) stewardship program for all PV modules used or sold in or into the state following a certain date. Manufacturers or their stewardship organization will operate the program to fully finance the convenient takeback and recycling of all PV modules used or sold in or into the state after the implementation date. The combined reuse and recycling must equal at least eighty-five percent by weight of all PV modules collected. Each manufacturer must prepare and submit a stewardship plan to DEQ to describe the mechanism for financing a convenient takeback and recycling program that will result in no cost to the last owner or holder of the PV module. The plan must also describe how the program will maximize recovery and minimize the release of hazardous substances into the environment. An annual administrative fee will be collected from each manufacturer to cover the costs of DEQ program management and plan review. Fees for support the EPR model will likely be added to the wholesale cost of the modules at point of sale and not internalized. Similarly, product equipment and performance warranties will likely change to accommodate the increased liability of manufacturers to manage takeback or recycling responsibility well into the future. Similarly, O&M service providers will likely have to increase their service contracts and costs if needed to remove modules intended for warranty claims or for recycling at end-of-life.
 21. While we generally support producer responsibility for the recycling of products (like the WA model) we would recommend a slow phase in of requirements and fees (if there is to be a recycling fee) because of the years it will take for there to be a high volume of panels ready to be recycled in NC. Recycling costs may decrease as the volume of panels increases.
 22. We believe this option may disincentivize manufacturers from selling within the state, limiting vendor options for solar panels in NC. This type of program would be best if done at the federal level (similar to the EU).
 23. Due to complexity, may slow solar growth in NC.
 24. Require the combined reuse and recycling must equal at least eighty-five percent by weight of all PV modules collected "and at least 60% of semiconductor materials"
 25. The quality and safety of PV module reuse may be achieved by requiring use of national certifications such as UL reuse standards to be developed per recommendation of NCDEQ.
 26. The plan must also describe how the program will maximize recovery and minimize the release of hazardous substances into the environment

Questions:

A product stewardship program could also offer incentive for recycling, but some outstanding questions remain:

- Would North Carolina's proposed program clearly include utility scale PV modules? Currently, Washington State guidance is unclear as to whether utility scale PV modules are included.
- Would a product stewardship program require that end users in NC manage their panels within this program only or would it be optional? Some end users may seek to manage spent panels in bulk, combine those modules across their footprint, and send to a specific recycling vendor outside of NC.
- Under this program, would end users lose the option to dispose of non-hazardous panels via landfill?
- Would there be safeguards to avoid administrative costs for managing the supplier program being passed on to the purchaser at the point of sale? This could increase the cost of solar development in NC and ultimately to customers.
- How would an annual administrative fee be assessed for out-of-state manufacturers?
- What happens if the panel manufacturer or stewardship organization operating the program dissolves and the user is left with no entity to take back the PV modules?

Advanced Recycling Fee

Establish an advanced recycling fee to be charged for PV modules used or sold in or into the state following a certain date. An advanced recycling fee could be established for (1) utility-scale PV modules only, to be collected at the point of construction or registration; or (2) all PV modules used or sold in or into the state, to be collected at the point of sale. The advanced recycling fee funds would be transmitted to an entity operating a statewide collection program to manage PV modules being removed from service. The statewide management program must reuse or recycle at least eighty-five percent by weight of all PV modules collected. Fees may change over time depending on the needs of the program.

1. Setting a fee today for a service or activity to occur 25+ years from now will not be easy. Presuming that the monies would be held in escrow, not only would it be necessary to project costs a quarter century from now, but also what rate of return the funds would achieve over that time.
2. Unless this is a pay-as-you-go approach, this option does not address the modules already being recycled or disposed of today.
3. Alternative #1 (payment at registration) only works for the first modules used at a site. Modules for repair or for wholesale repowering would not be captured by the pay-at-registration approach. Large scale repowering is quite likely to occur, as finding sites for new solar farms is increasingly difficult.
4. Alternative #2 (fee at time of sale) is subject to a grey market end run in which modules are purchased elsewhere and brought to NC.
5. While Advanced Recycling Fee may be the easiest/safest option for the regulating authority, it would be a financial burden placed on a use that I'm not aware of any other use requiring. Given this logic, an Advanced Recycling fee should be charged to any use with recyclable components (i.e. other utilities – wind/electrical substations/etc. and even some non-utility uses). The fee may prevent the start-up and expansion of clean energy facilities.
6. In the two recycling schemes, the recycling rate was set at 85%...I feel this might be a little low, especially given how much weight the frame and other non-cell components can make up. The recycling could essentially just be the "easy parts" and the more complex and impactful components of the panels could be landfilled while the program was deemed a recycling success which would have occurred anyways likely.

7. How reuse or recycling is defined seems important: I worry that panels will be resold into a secondary market for "reuse" before they are landfilled somewhere else in the near future. This seems like a work around to actually recycling since they could just be moved to other "markets".
8. In the end the "consumer" always ends up paying, so this is an acceptable choice
9. Should be for all PV modules sold in or into the state, limiting to the not well defined category of 'utility scale' means that the financial and material impacts of the scenarios are unclear
10. Tailor the fee to show is purchasing it
11. Creates a consistent flow of panels to create enough weight to advance recycling of solar panels
12. Reduces the need for virgin materials
- 13 Include all panels
14. Need recycling in the US so the US doesn't rely on materials from other countries, such as rare earth metals
15. Helps fund orphan panels
16. Consider this a viable option but would need further clarification.
17. Is this similar to a core charge when purchasing a new car battery where the fee is refunded upon return of the old battery, thus ensuring proper disposal/recycling?
 - OR-Is this similar to a landfill tipping fee, where funds are collected as a tax and used to keep the landfills in compliance with the new regulations?
18. We would need clarification on what "manage the PV modules" means.
 - a. Would the state-run entity remove and recycle the panels from the site?
19. We would suggest applying the fee to all PV modules sold. The PV module on a home or small solar array takes no fewer resources to recycle than the one in a large solar facility.
 - a. By applying the fee to all PV modules, it also helps to educate every purchaser on the necessity for recycling and how NC is being proactive about this issue.
20. This introduces a state-run entity with an ever-evolving fee structure.
 - a. As the technology evolves and installations increase, it will be difficult for the regulations/fee structures to keep up.
21. Who would collect and hold the money?
22. There would appear to be similar obstacles as described above to a proposed advanced recycling fee scenario. Like in a product stewardship program, additional fees could potentially increase solar development costs within the state and limit access to recycle options outside of NC. Additional administrative costs beyond the recycling fee (e.g., program management) may also be passed on to the end users. Also, this type of fee could potentially disincentivize manufacturers from continuing to refine their PV module manufacturing practices and reducing or eliminating the use of certain materials.
23. An advanced recycling fee would need to be reasonable and not act as a disincentive to solar development overall given that solar is a much cleaner energy option than burning fossil fuels.
24. We are neutral on this option, however, we have questions regarding this option – listed below.
 - a. Is the concept that rules would be put in place such that the state program takes the responsibility/ownership of the panels once collected?
 - b. How would the state program deal with HW panels?
 - c. Are there enough recycling facilities to meet this option?
 - d. What type of testing would be required for the panel to get into the program (characterization of panel)?
25. Adds up-front development cost to long-lifetime system and can require considerable state resources for administration and oversight. Depending on fee amount, could slow solar growth in NC. Recommendation is low due to con.

26. Require the combined reuse and recycling must equal at least eighty-five percent by weight of all PV modules collected “and at least 60% of semiconductor materials”
27. Note that we suggest it is important to include reuse in addition to recycling for compliance. It is also important that recyclers have incentives to improve recycling processes to recover high-quality multi-materials. A potential solution would be to periodically raise the required reuse and recycling rate. In addition, a multifaceted approach could provide benefits and “spread the burden” across multiple actors to not overburden one. Such an approach could incorporate other actors within the PV value/supply chain. For example, a fee/tax at the time of purchase, financial incentive to recycle, landfill ban (requirements on end users and landfill owners), or reduction in regulatory burden for those that recycle over landfill.

Other Recycling Incentives?

1. Create means for market participants to connect.
2. Publicize best practice for module end-of-life.
3. Assist recyclers in the means to process this new waste stream.
4. Develop markets and uses for the “products” stemming from recycling activity. Anecdotally I’ve heard that once the aluminum frame is removed, the remaining glass and silicon can be ground and used for the nightly cover on sanitary landfills.
5. Encourage the aggregation of modules for recycling. There may be opportunity here for DEQ & NCCEBA to partner with e-waste associations (there seem to be several, CAER, SWANA, NWRA)
6. Invite out-of-state companies which already recycle modules to set up in NC. NC has been the #2 market for solar energy for close to a decade so in the next 10-15 years there will be a significant number of modules reaching end of life. The issue of proximity is especially important. A semi truck can typically only carry 300-400 modules per load and a typical 5 MW solar farm is going to have 15,000 modules or 50 truck loads.
7. Although Washington State has not listed PV modules as a universal waste, the Washington State Department of Ecology has created an alternative “interim enforcement policy” that allows PV modules when recycled to be regulated under alternative standards that are less stringent than the state’s hazardous waste regulations (Wash. Admin. Code § 173-303-040; WSDE 2020, n.d.)
8. Universal waste regulation may ease storage and transportation requirements for certain categories of hazardous waste, but typically treats materials being recycled and disposed of in the same manner
9. Similar to universal waste regulation, the EPA has also created alternative regulatory controls for certain materials when they are recycled to encourage the collection and recycling of certain categories of hazardous waste. For example, federal EPA regulation allows lead-acid batteries to be regulated as universal waste *or* pursuant to regulatory controls that have less stringent requirements for the handling, regeneration, collection and storage of spent lead acid batteries before reclamation (40 C.F.R. § 266.80). A similar designation for PV modules could reduce liability concerns and make the economics of recycling PV modules more desirable.
10. Landfill ban to prohibit anyone from disposing in a solid waste landfill, requiring PV modules be sent to a state approved recycling facility (See Arizona Bill 2828)
11. Require any person who sells or leases PV modules in the state to pay a fee, fee is used to state recycling fund for orphaned waste caused by improper disposal of PV modules (see Arizona Bill 2828)
12. An agent-based model was developed to assess the circularity potential of the PV sector (manuscript in preparation). As a dynamic, bottom-up approach, agent-based modeling can represent the different PV stakeholders, their behaviors and their interactions. Some of our preliminary results indicate that:

- Incentives to recyclers, such as tax credit, could be a suitable solution when conditioned to continuous improvement of recycling processes. It would cause both higher recycling from PV owners due to lower recycling fees and ensure that high-quality multi-materials recycling processes are developed. The incentives could be later scaled-down once recycling becomes profitable.
 - As it potentially provides more value to PV owners (and is environmentally preferable), reuse should be the preferred pathways. It is, however, limited by technical and market factors. First, only the least damaged PV modules can be reused. Second, the secondary market needs to be developed enough to absorb the PV modules that PV owners want to sell. A recent interesting [article](#) by Energy Bin (broker of used modules) compares the secondary markets for PV and cars and explains how a secondary market for used PV as strong as the one for used car could be envisioned (Schmid, 2020). Such secondary market needs to be encouraged to provide prospects for end of life PV modules. However, our results highlight that a more mature secondary market would also mean that less PV modules are recycled hindering potential economies of scale for recyclers (and therefore lower recycling costs). This result shows that it is critical to consider all circular strategies simultaneously to manage potential trade-off (strong recycling-weak secondary market versus strong secondary market-weak recycling). As a solution (and is already the case for certain recyclers), recycling activities could be encouraged to include triage of still working PV modules and brokerage of used PV modules to diversify revenue and avoid unnecessary competition between circular pathways.
 - Higher landfill fees could encourage recycling. [Deng and colleagues](#) found that landfill costs have the most potent effect on recycling (with the recycling costs the second most potent factor) (Deng et al., 2019) while we found that recycling costs have the most potent effect followed by landfill costs. It shows that regulations aiming at increasing landfill costs for PV modules could be beneficial.
 - Another option could be to leverage peer influence. This could be achieved through nudging (e.g., with ad campaigns such as for electronic wastes) and free recycling programs for specific PV owners (e.g., commercial PV owners) that could push others to recycle as well. Free used PV modules could also be distributed to low and middle income communities which could ultimately develop the secondary market for used PV modules, a strategy called “seeding” and already proposed for new [PV modules adoption](#) (Zhang et al., 2016).
 - Finally, combination of different levers may go beyond the simple application of one of the levers or the other. Our results show that decrease recycling costs and increased landfill costs, for instance, improves the material circularity rate beyond the simple addition of each lever effect.
13. H329 directs the Environmental Management Commission to adopt rules to establish a regulatory program. H329 does not discuss incentives or charge the commission with a study of incentives for any management option for panels, batteries, inverters, and other equipment. The focus on incentives is not consistent with the legislative charge.
 14. If all panels aren’t addressed, might not have financial means or enough material to move up the hierarchy as addressed in H329
 15. Work with SEIA right away to create a national program vs. state by state
 16. Work with other states to create similar policy, which starts with reviewing WA’s PS law
 17. MN’s 4 potential models (options may include recycling requirement, landfill disposal ban, designation of material as Universal Waste):
 18. Commerce/PUC Decommissioning Plan ‘permittee responsibility’ model extended to solar facilities under 50 MW

19. Product Stewardship model [panel mfr responsibility]
20. Rate payer funded model, statewide end of life program
21. Permittee funded model, statewide end of life program
22. Utility environmental fee
 - An environmental fee would be placed on the utility bill of every customer in the state.
 - A utility fee would need to show benefits to the entire public such as with health and safety.
 - Environmental fee would be based on kWh used by utility customers on each month's bill.
 - The fees would go into the statewide management program fund (outlined above).
 - Statewide management program would have oversight of the program funds which will be used to pay the costs of establishing approved vendors for collection, transportation, reuse and recycling.
23. Prior comparisons to e-Waste methods of disposal and recycling often target PV module manufacturers as the primary responsible party for end-of-life management, but this model is not wholly applicable to the solar industry considering the vast difference in service lifetime and durability of the products (i.e., an electronics product may have a 3-7 year service lifetime before replace and disposal; however, PV module may operate for over 40-50 years). Therefore, the overall ownership benefits of employing a PV system should align with the responsibility of the disposition, disposal and / or recycling of these durable products. That is, manufacturers and the broader solar industry can support a shared model in which the manufacturers are actively participating in developing the infrastructure and network for recycling, refurbishment or reuse, and owners are responsible for the practices and related costs at actual end-of-life. In our edits to DEQ's original list of recycling incentives, we seek to provide recycling incentives that recognize the unique nature of ownership and financing models and allow for hybrid options to be considered.

In summary, we recommend a model which:

- Engages the manufacturers in the development and foundation of the recycling, refurbishment infrastructure
 - Requires the system / project owners to follow responsible practices of refurbishment, resale, recycling, or disposal
 - The relevant stakeholders engage to ensure fairness and reasonable actions are committed to and acted upon
 - Such a framework can ensure that the required waste management and recycling laws are met, deployment of solar continues at levels to meet state clean energy goals, and society in general is able to enjoy the benefits of the renewable energy generated from solar. This shared responsibility model should apply to all solar operators equally regardless of whether they are independent power producers or regulated utilities.
 - While such a shared model is being developed by DEQ and stakeholders, the associations recommend DEQ take these immediate steps:
 - Strengthen enforcement of current landfill disposal regulations.
 - Instruct the Division of Environmental Assistance and Customer Service (DEACS) to develop a network of recycling companies knowledgeable in module recycling/disposal
 - Instruct DEACS to provide outreach and education to module owners about regulatory compliance and recycling/disposal options
24. We are supportive of a fair shared model in which the manufacturers and owners are jointly responsible for recycling and the costs so that solar development is not discouraged and North Carolina can continue to move away from a very polluting fossil fuel powered energy system.

25. All states have industrial development entities within their state university systems. Give a state university funding to work on recyclability of solar panels.
26. Subsidize panels that are constructed to be modular and broken down into their recyclable pieces-parts similar to other electronics. The corollary is to assign a fee to panels that aren't modular.
27. Make recycling programs/facilities easier to implement in the state – incent companies to develop recycling facilities.
28. Make a “bottle bill” for panels. Get your nickel back when you turn in your panel for recycling. This concept would work best with a statewide collection program.
29. Require either product stewardship program or EPEAT label for all PV modules used or sold in or into the state following a certain date.
30. The environmental, health, and safety of PV module recycling may be achieved by requiring use of national certifications: i) ISO 14001 and ISO 45001 for recycling facilities or ii) R2 recycling standard to be developed per recommendation of NCDEQ.
31. Owner Stewardship model requiring decommissioning plans with reuse/recycling requirements
 - Builds on existing decommissioning plans with addition of formal reuse/recycling requirements. Sensible for utility-scale solar and long-lifetime products. Decommissioning includes balance of system which can provide scrap revenue. Avoids risk of slowing solar growth by building on existing decommissioning practices.
 - The quality and safety of PV module reuse may be achieved by requiring use of national certifications such as UL reuse standards to be developed per recommendation of NCDEQ10.
 - The environmental, health, and safety of PV module recycling may be achieved by requiring use of national certifications: i) ISO 14001 and ISO 45001 for recycling facilities or ii) R2 recycling standard to be developed per recommendation of NCDEQ.
32. EPEAT label for PV modules used or sold in or into the state following a certain date or one of the above non-status quo approaches.
 - Creates market pull for high value recycling of PV components by encouraging procurement practices which require verified PV recycling solutions to be available.
 - EPEAT requires PV manufacturers to provide nationwide recycling service certified to ISO 14001 and 45001.
33. The majority of the solar panels in North Carolina were installed in the past five years. There is no fixed end date for the productive life of a solar panel, but they typically will operate for at least 25 years. Accordingly, it will be nearly 20 years before there is a significant number of projects decommissioned and panels retired in the state. This gives us plenty of time to figure out how best to apportion responsibility for retired panels.
 - Responsibility for retired panels should be apportioned fairly across the various participants in the solar industry. A given solar panel will not be deployed unless each of those participants is involved, from the manufacturer through the system owner. In addition to being fair, the incentive system should be efficient and effective. We encourage DEQ to lean on the solar industry to propose an incentive system, in consultation with stakeholders, that the industry believes meets these criteria and then to review the proposal to verify that it does so.

This proposal is consistent with DEQ's mandate. House Bill 329 directs “the Environmental Management Commission shall adopt rules to establish a regulatory program to govern (i) the management of end-of-life photovoltaic modules” by January 1, 2022. If DEQ pursues the suggestion above, it would simply adopt a rule that convened an industry-and

TABLE 1
Summary of Written Comments Received and Responses

Comments Submitted on 12/7/20 by Jan Clyncke, Managing Director, PV Cycle		
Comment Number	Comment	Response to Comment
1	It is not recommendable to include in the definition of 'utility scale solar project' (see the bill HB 329 v5) , 'solar thermal". Photovoltaic and Thermal are 2 different worlds.	Solar thermal is included in the “utility-scale solar project” definition written in the Bill, however, solar thermal was not addressed in the final report as this technology was not identified in our compilation of utility scale solar facilities currently installed in NC.
2	Good to read that NC looks for an alternative – ASTM – for the TCLP testing.	
3	In Europe, PV Panels are classified as NON-hazardous waste. All hazardous substances in a PV Panel are below the thresholds of the ROHS-legislation (EU Directive 2011/65/EU) (if the panels would be under its scope) and PV Panels are excluded from the scope of this directive. We do not understand why California has classified PV Panels as Universal Waste; In your study, we notice that NC might also tend in the direction of Universal Waste which is not recommendable. The cost for collection, shipment and waste treatment are much higher for universal waste and hazardous waste and without any financial funding (as you also foresee), this opens the door of free-riding and non-environmentally sound management of waste PV Panels.	If a panel is deemed to be non-hazardous after a TCLP test, then the panel would not be subject to hazardous or universal waste rules. The UW classification would only apply to hazardous PV modules and modules that are assumed to be hazardous without testing. A universal waste classification for hazardous PV modules is designed to promote recycling. After a literature review and review of studies submitted by stakeholders, DEQ found that a UW classification could lower waste management costs and alleviate transportation difficulties. Many stakeholders agreed with the potential benefits of a UW classification when surveyed.
4	PV Panels are preventing waste for many years waste and thus avoid costs for the society. PV Panels are significantly supporting and contributing to the first step of the waste hierarchy “prevention of waste”.	
5	Re-use, refurbishment, repairing are interesting options. However, today there is no legislation nor standards regarding the item of re-useable, reparation for re-use and re-use of second PV Panels. Especially, as PV Panels are a product which is “generating” electricity the re-use option without proper guidance opens the door for uncontrolled management of end-of-life PV Panels. Re-use of “consuming” electricity products is a complete different environment as thus re-use of laptops , washing machines and mobile phones can never be used as benchmark for the re-use activities of PV Panels.	The Solar Energy Industries Association (SEIA) stated that re-used/re-furbished modules must continue to meet the appropriate building codes and safety standards. A recent report written in part by NREL also discussed that re-used modules must be inspected and tested or re-certified for safety and performance. In addition, modules could be returned to the manufacturer for inspection and repair. The repaired modules may be suitable for return and use by the original owner or could be sold as replacements. DEQ agrees that the re-use of PV modules is a different sector than consuming electricity products and thus cannot be used as a standard for re-use activities of PV modules. However, the North Carolina Discarded Computer Equipment and Television Management Program sets a baseline model for a future possible PV module stewardship program.
6	Regarding waste treatment: the future is not landfilling but pushing to recovering the materials as much as possible: glass, aluminum, precious metals, ferrous and non-ferrous metals. To enable recycling and treatment capacity for at least 500,000 tons of PV Panels waste, NC must impose a landfill ban on PV Panels.	Decommissioning won't be necessary for the majority of the 500,000 tons of panels currently installed in NC for over a decade. Until then, the volume of decommissioned panels would be low compared to future amounts. Due to low volumes of panels that will need decommissioning in the immediate future, DEQ believes that a landfill ban could prematurely force modules into an underdeveloped recycling marketplace.
7	Financing of the upcoming PV Panels waste: implement a mandatory recycling fee which is charged at the time of purchase of the panels and implement a Stewardship Program, even though when a vast majority of the currently installed PV Capacity is utility scaled. Stewardship Program must put the legal responsibility on the shoulder of the “company which puts for the first time a PV Panel or Battery on the territory of NC State” and the financial responsibility on the one who pollutes at the end-of-usage the planet by introducing a visible fee (displayed on the invoice) which is the same but can differ per PV Technology. This then allows the disposer of the PV Panels waste to dispose these products free of charge at the end of their lifetime.	This suggestion for financing PV module EOL management can be considered in the future.

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Comments Submitted on 12/14/20 by David Waggoner, Chief Scientist/Director of Environmental Management, Institute of Scrap Recycling Industries, Inc.		
1	Supports designating reusable used PV modules (and ancillaries) as products that are not waste and not subject to DEQ waste regulations, as indicated by the Hazardous Waste Determination for Photovoltaic Modules Flowchart (Appendix C) and the statement, "[i]f a PV module is not suitable for refurbishment or reuse, it becomes a waste and a determination must be made as to whether or not the PV module is considered hazardous" (p. 14).	
2	Agrees that existing regulations for management of batteries is adequate in the short term for energy-storage system batteries;	
3	Agrees that a PV module includes any component that cannot be readily detached;	
4	Agrees that "[c]omponents that are not integrated into the PV module such as brackets, braces, supports, wiring, inverters, and batteries should be evaluated and managed separately from the PV module" (part of proposed addition to the definition for photovoltaic module), enabling their classification as scrap metal or another category that may have an applicable recycling exclusion or exemption;	
5	Does not oppose designation of PV modules as universal waste (UW), as long as DEQ consults in advance with the recycling industry about proposed regulatory details (e.g., allowed activities by UW handlers and status of removed components such as glass, circuit boards, and scrap metal), provides a comment period, and does not automatically adopt California's UW program for PV modules; and	DEQ will carefully review California's UW program that was recently codified and monitor its implementation in 2021 to help inform our work going forward.
6	Agrees with assessments that (1) product stewardship programs can fail to cover the total of cost of recycling, which harms recyclers who may be captive to such programs by regulation, and (2) "[t]o avoid a similar scenario for the management of EOL PV modules, a product stewardship program should explicitly state that the full cost of collection and recycling be covered by the program" (p. 58).	
Comments Submitted on 12/14/20 by Nick Jimenez, Staff Attorney, Southern Environmental Law Center. Comments submitted on behalf of the Sierra Club, North Carolina Conservation Network, and the Southern Environmental Law Center		
1	The shift from fossil fuels to renewable energy is good for the environment, public health, and the economy. We should make sure not to raise unnecessary burdens on renewable energy generation on the basis of concerns that may not materialize. There remain at least ten years before the first significant tranche of solar facilities reaches end-of-life and approximately fifteen to twenty years before the majority of the existing solar facilities in North Carolina will be decommissioned or retrofitted. Furthermore, even if double the currently installed capacity were landfilled immediately it would not negatively impact North Carolina landfill capacities. Finally, module recycling is continuing to improve. We urge DEQ to keep this timeframe, perspective, and the changing landscape in mind as it develops the H329 regulatory program, and to minimize the extent to which a program developed so far in advance of its likely use establishes burdens that become superfluous. We also urge DEQ to monitor changes in these industries and to propose corresponding updates to the program.	DEQ presents the volume of estimated panel waste by year in the final report and the data agrees with the timeline mentioned in this comment. If the entirety of present-day PV modules suddenly needed landfilling, the 500,000 tons of waste would still be dwarfed by the current year's disposal of 11.7 million tons of waste (FY 2018-19). The capacity of landfills in North Carolina will be barely impacted by a 4% increase in tonnage that will most likely be spread out over years or even decades. DEQ agrees that a PV program should not be developed so far in advance, while re-visiting key areas, such as financial assurance or a landfill ban, in the future. DEQ will be monitoring developments in the renewable energy recycling industry, reuse/refurbishment markets, technological developments, and states' regulatory requirements, as resources allow.
2	Second, solar photovoltaic generation is overwhelmingly safe. It poses negligible risks in operation and even as waste it would be premature to classify the technology as hazardous by default. To further clarify the limits of the Draft Report's conclusions concerning any hazardous characteristics of solar photovoltaic waste, we recommend that DEQ explain that the Draft Report does not address the safety of solar	In section 2(a)(1), it is stated that photovoltaic modules that contain hazardous materials pose minimal risks to the environment and human health during normal operation. The report has been revised to state that in the case of module breakage, risk assessments using EPA leaching and fate methods found levels of hazardous materials to be below EPA human health thresholds. To clarify, the flow chart presented shows that if a PV module does not originate from a household, then a TCLP test must be completed in order to opt out of hazardous or universal waste rules (if adopted). If

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	photovoltaic systems that are in operation, and that DEQ has no reason to believe that these systems pose any significant risks to the public. We suggest adding a short statement explicitly addressing these clarifications as a preface to Section 2(a)(1). We request that DEQ clarify that a PV module does not present hazardous characteristics upon simply breaking but only, potentially, under the extreme conditions of the TCLP. We further request that DEQ clarify that the TCLP test will determine whether a particular model of PV module should be classified as hazardous waste once it can no longer be used. DEQ determined that TCLP testing shows most PV modules are not hazardous although some may contain small quantities of toxins. Importantly, the flow chart does not indicate that PV modules would be classified as hazardous waste or universal waste by default. To the contrary, TCLP testing would determine their status. Furthermore, if TCLP testing showed that a model of PV module demonstrated hazardous characteristics it would be managed as universal waste rather than general hazardous waste, once the appropriate rulemaking was complete. This does not appear to be sufficient information on which to determine that all waste PV modules should be classified as hazardous waste by default unless testing proves otherwise. We believe that this is more consistent with stakeholders’ consensus during the process, namely, that TCLP testing will determine a PV module model’s waste classification and if TCLP testing shows hazardous characteristics the model will be universal waste. We request DEQ revise the report accordingly.	the TCLP test concludes that the module is not hazardous, then it would not be subject to hazardous waste or universal waste rules (if adopted). If the module tests above regulated thresholds, then the module must be managed as hazardous waste or under universal waste rules (if adopted). Alternatively, the generator can also conservatively declare the PV module to be a hazardous waste without testing and manage as hazardous or universal waste. The flow chart will be moved from the Appendix into the Section 2(a)(1) for reference. Although DEQ recommends for un-tested PV modules to be managed as hazardous or universal waste, DEQ provides the option for generators to conduct TCLP testing to determine if a PV module can be managed as solid waste instead.
3	Finally, statewide standards for financial assurance may offer some regulatory efficiency and help this important North Carolina industry to grow. We support DEQ’s decision to study, in consultation with stakeholders and the North Carolina Utilities Commission, the advisability and feasibility of a statewide standard for financial assurance within the next five years. The Draft Report cites a need to “ground truth” claims by the solar industry about the salvage value of solar photovoltaic systems and related economic incentives. This is a good topic for the financial assurance study process that DEQ proposes in the Draft Report and it is certainly proper for DEQ to develop an independent estimate of salvage value. When it does so, DEQ should use the best information available to calculate the actual salvage value experienced and expected. Not only is the solar industry changing quickly, as noted above, but the recycling value of materials used on solar photovoltaic systems can change significantly over time and the values will need to be updated regularly. In any case, DEQ should not assume that the salvage value will be nothing simply because the value will change. We urged DEQ not to take that arbitrary approach during the stakeholder process and we support its decision not to do so.	DEQ agrees that a salvage value shouldn’t be assumed to be nothing and will consider salvage value estimates when re-visiting financial assurance requirements.
Comments Submitted on 12/14/20 by Daniel Brookshire, Regulatory and Policy Manager, NC Sustainable Energy Association. Comments submitted on behalf of the North Carolina Clean Energy Business Alliance, Solar Energy Industries Association, and NC Sustainable Energy Association.		
1	General comment: it is not clear why there is differentiation between technologies. Given that we have 1000s of different PV module types and models on the market encompassing different cell and module architectures, it isn’t relevant at all to cluster technologies into two different “types” – especially in view of future technologies	It is helpful to categorize PV modules given that there are many different types and models. When researching and discussing various characteristics of PV modules, some aspects may differentiate depending on the technology, such as potential hazardous characteristics. In addition, Section 2(a)(4) asks to determine the lifecycle of various different types of PV modules currently installed in NC. According to facility data that was collected, DEQ identified 3 different panel types used in utility-scale solar facilities, including c-Si, CIGS, and CdTe.
2	The ASTM method is not an alternative to TCLP – rather it specifies how to prepare a PV module sample for use in TCLP. Revise first sentence in paragraph to: “With respect to PV modules, the Department has asked the American Society for Testing and Materials (ASTM) to develop a sample preparation procedure for use in TCLP testing of PV modules for representative and accurate waste characterization.”	DEQ agrees with this comment and revised the report accordingly.

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3	The sampling test method for PV modules that undergo the TCLP test is not directly relevant to the bill study requirements and we recommend it be reported elsewhere as an additional action that is good for the DEQ to endorse/request. To be clear, the proposed test sampling method is not a current requirement of the EPA Test method for TCLP so that needs to be noted.	DEQ has already requested for ASTM to develop a standard procedure to use in TCLP testing of PV modules.
4	This is beyond the scope of the legislation. Why is the Department seeking to do so when even California has not determined that is necessary due to the fact that most PV module waste tests as nonhazardous? Can DEQ provide more justification and evidence that there is a necessity to seek a remedy at a federal level? Other states such as Washington, California, and New Jersey have also not identified the need for a federal level approach. In practice a federal level approach is contemplated IF the waste presents such ambiguity as to its handling, that a broader law on handling is required.	California has recently approved regulation to manage EOL PV modules as universal waste. Similarly, only PV modules designated as waste that exceed regulatory thresholds following a TCLP test will be considered subject to universal waste rules (if adopted) in North Carolina. The generator has the option to opt out of universal waste rules and manage as solid waste if the module is non-hazardous. In order to provide more regulatory certainty and similarities nationwide, DEQ may petition the EPA to add PV modules as universal waste. DEQ found that PV modules are appropriate universal waste candidates and fit the common characteristics typically present in this type of waste stream. Classifying hazardous PV modules as universal waste at the federal level will encourage reuse, refurbishment, and recycling as opposed to landfilling, and would alleviate management difficulties and costs typically associated with hazardous waste.
5	Revised to be consistent with the IEA risk assessment described in “Photovoltaic Modules Disposal – MSW Landfill” subsection of section III. The purpose of the referenced report (footnote 7) is to show that standard end-of-life leaching tests (e.g., TCLP) are more aggressive than actual field breakage conditions. In other words, TCLP is a conservative method for assessing leaching risks from broken modules. As previously written, the language implies that broken panels may immediately leach toxic contaminants which is not supported by the literature nor research. DEQ needs to make it abundantly clear that broken panels are not an immediate toxic waste threat.	The report has been updated to clarify that the risk assessment showed concentrations below EPA human health screening levels. However, DEQ included that if a module containing toxic materials is broken, the module <i>may</i> leach toxic contaminants into the environment as stated in several studies.
6	I'm a little confused by this statement, wouldn't any battery be subject to Title 40 CFR part 273 when it is deemed waste? The federal designation takes priority and sets the characterization clearly.	According to 40 CFR 273.2, batteries that are not a hazardous waste are not covered under the UW rules. The EPA states that it is the generator's responsibility to determine if a waste is hazardous.
7	This is not completely accurate, lithium- ion batteries that are used in consumer electronics do have an infrastructure; Li-on batteries at the size used for energy storage can be accommodated in that same infrastructure; although some scaling is needed.	Following a literature review, it is widely stated that there are many challenges for lithium-ion battery infrastructure and EOL management options. Studies did not discuss that existing lithium-ion battery recycling could be applied to larger stationary batteries. In general, it appears to be a consensus that much work is needed to prevent lithium-ion batteries from ending up in a landfill. In addition, it was found that a very small percent of lithium-ion batteries used in portable electronics are recycled, and the U.S. remains among the lowest rate of recycling for lithium-ion batteries when compared to other countries. DEQ will revise the sentence to be more clear that the country lacks <i>efficient and wide scale</i> lithium-ion battery EOL management. References that support the lack of an efficient nationwide infrastructure and recycling/re-use process can be found on page 16 and 147.
8	The same can be said for PV module waste destined for recycling, particularly in NC. So shouldn't advancements toward a mature PV module recycling industry drive clearer regulatory frameworks and best practices as well?	DEQ agrees that PV module recycling is still developing and will affect future considerations and recommendations.
9	The industry would recommend a minor tweak to the suggested hierarchy as follows: modules should be 1) reused if not in need of repair; then 2) refurbished according to industry safety and reliability standards (there is a UL program for remanufactured PV modules) or support the development of such standards if not specific; 3) recycled if 1 and 2 are not feasible and, as a last resort, 4) landfill.	DEQ agrees with this comment and revised the report accordingly.
10	A module is characterized as hazardous if it exceeds the TCLP threshold. There is no pass/fail of the TCLP test method, there is merely a value. Then the table is referenced to determine if below or above the threshold and suitably characterized.	DEQ agrees with this comment and revised the report accordingly.
11	Currently G.S. 62-110.1 (g) only requires a CPCN for non-utility facilities that are under 2 MW. This presents some inconsistency with the DEQ recommendation that these decommissioning regulations apply to facilities that are 1 MW or greater.	DEQ acknowledges that there are other entities that utilize alternative capacities to define a utility scale solar facility. However, in the report it is discussed that DEQ identified the EIA reporting format as the most comprehensive and dynamic database for extracting current and future facility level information. Also, any utility scale solar facility less than 2

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		MW is just required to submit a proposed construction report to the NCUC, which does not allow for any tracking of these projects in a formal manner. In addition, a good portion of NC solar facilities are between 1 and 2 MW and DEQ would be missing hundreds of thousands of panels and other key information from statewide data if the project notification requirement is set to 2 MW or greater. It does not increase burden to solar facilities under 2 MW to submit this information as it is also reported under EIA requirements and FERC forms. As a result, DEQ is recommending the EIA's threshold of 1 MW as the applicability threshold for developing minimum notification requirements.
12	Is this table referring to the PV system lifetime based on power purchase agreement (PPA)? If so, please clarify. Otherwise, it is not clear why these lifespans differ from the standard 25-year warranty lifetime for most modules.	No, although PPA lengths were collected, they were not used in the table for facility lifespans or to calculate the estimated decommissioning year for each facility. CPCNs or other forms collected by the NCUC included lifespan or ranges that were generally longer than the PPA term.
13	We recommend highlighting the current difficulty in tracking energy storage systems in NC right now and make recommendations for improvement. Currently NCUC rule R8-64 doesn't require energy storage systems to be filed with the NCUC. The current regulations just focus on filing information about "energy generating" equipment. Recommend amending the rule requirements so that informational filings are required for utility scale energy storage systems (like CPCN projects).	Thank you for the comment. DEQ added a sentence stating the lack of information on currently installed energy storage systems. We do recommend that the DEQ, in it's data gathering program, augment the informational filing of the NCUC and that we copy the NCUC with the additional information.
14	Flagged in a previous comment but it may be more efficient for the NCUC to make this request for additional reporting from solar operators. At minimum these reports should be cross-filed with the NCUC so we don't end up with two potentially conflicting repositories of data on solar facilities.	Thank you for the comment. DEQ is in agreement that cross-filing should be part of the tracking of energy systems. DEQ believes that additional reporting for solar facilities would be best implemented by the Department.
15	TCLP records would only be available at EOL. TCLP is not applicable to specific technologies, but rather on a case-by-case basis for each unique waste stream. (i.e., a manufacturer is not able to make broad claims that its technology is characterized as nonhazardous waste just because one sample of a waste product tested within limitations to be characterized as nonhazardous)	Details will be addressed through statutory changes or rulemaking. If "technologies" means "model of PV module constructed by a particular company than one TCLP test could be used to characterize all of the modules under that brand and model.
16	This requires defining since life-cycle is depending upon many factors, including operations, maintenance, environment and usage.	Details will be addressed through statutory changes or rulemaking.
17	Not necessarily accurate, the EU has an active requirement for recycling due to the WEEE directive but that is not considered a robust PV module EOL management approach. For instance, there is not a documented, nor regulated approach to reuse or refurbishment.	Following a literature review and conversations with stakeholders, the EU <i>appears</i> to have the most mature PV module EOL management program <i>currently in place</i>. It's possible other programs may develop and be more robust in the future. However, not only does the Directive mandate recycling but also take back by of the modules by the producers. The collection, transport, and recycling of PV modules must be regulated in the EU.
18	Again, as per First Solar's European policy expert: This is misleading – the WEEE directive (and the national transpositions) differentiate the classification of equipment when put on the market – i.e. equipment primarily used by private households (B2C), equipment used by other users than private households (B2B) and dual use equipment. This classification only triggers specific financing requirements but is not related to any waste classification – see comment above.	This was taken from the WEEE website, which specifies that PV modules are household waste. It's possible there is discrepancy between the French and the English translation. The sentence has been removed.
19	It may be more beneficial to summarize the county ordinances (ex. X number of counties) rather than provide details on a county-by-county basis (map) since several counties are currently in the process of updating their ordinances and there is a lot of nuance between counties with decommissioning requirements that isn't captured in the current summary/map.	DEQ updated the text to recognize that the county data is based on the ordinances in place at the time the report was submitted.
20	Need specificity if this is at the legislative or regulatory level.	Rulemaking is regulatory and DEQ has statutory authority to proceed.

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Comments Submitted on 12/16/20 by Amanda Cotton, Electronic Waste Program Coordinator, Minnesota Pollution Control Agency		
1	Experience has shown that while recycling and reuse may be noted as a higher priority over landfilling, the cheaper method of landfilling will be the chosen option if not restricted; material will always flow to the cheapest, least regulated option that’s available.	
2	NC notes that there isn’t strong recycling in the US and that it is expensive. In order to help that challenge, states need to mandate recycling so that there is an increase in material flow. This is a ‘regulatory driven market.’ What “market forces” other than low price of landfilling, will “...drive the Department’s preferred EOL management options?” [page ES-4] We do not see any recommendations or existing factors that will drive preferred EOL options.	DEQ believes that current and future waste volumes within the next decade will be too low to mandate alternative EOL management options. As PV module recycling technology and infrastructure continues to develop, a manufacturer stewardship program could be reconsidered in the future. In addition, DEQ recommends for PV modules classified as hazardous waste to be managed as universal waste. A universal waste classification is intended to promote recycling.
3	With a legislative directive and the second-highest number of solar installations in the country, the agency has an unparalleled opportunity to be really forward looking and be ready for the flood of panels and other equipment that will come, instead it seems to have confirmed the status quo of landfilling highly. engineered high value resource intensive green energy capital equipment. Life cycle assessment does not stop at the landfill for a product like this, energy and resource security for the US, plus overall CO2 reductions, depend on recapturing the materials in renewable energy equipment rather than relying on mining of virgin resources elsewhere in the world.	Same response as above.
4	The report has strong policy statements in favor of reuse and recycling, but proposes no mechanisms to achieve the favored outcomes and defaults to landfilling because it is the cheapest. Is today’s cost of landfilling the paramount consideration? If so, is that consistent with the Department’s waste hierarchy and the legislative direction for this study?	The main considerations were not only the cost-effectiveness of landfilling, but also the lack of a widespread PV module reuse, refurbish, and recycling industry. In addition, landfill capacity would be very minimally impacted by the worst-case scenario of landfilling all utility-scale PV modules currently installed in NC. DEQ also found that MSW landfill disposal is a safe and acceptable alternative that does not present risks to human health or the environment for non-hazardous PV modules. The PV module recycling industry is still developing and will affect future considerations and recommendations to better promote the waste hierarchy. A strong-armed policy of reuse or recycling may disincentivize future development of solar in the state given the limited efficient alternative EOL management options.
5	Industry will always state that any controls on their products or cost in increases will stifle growth, but experience has shown with other products this is not the case.	
6	What about recyclers that have stated they can handle all the PV panel material generated right now, such as Cascade Eco Minerals, not mentioned in this document and a SEIA PV Recycling Partner?	This commenters information is quite helpful. Cascade Eco Minerals has drop off locations in Kentucky and South Carolina. DEQ will be looking into additional avenues of recycling and ways to build in-state resources.
7	There is one passing mention of early decommissioning because of weather, this must be a serious consideration with hurricanes in North Carolina.	There are panels are specifically designed to outlast hurricanes. Each panel is built several meters off the ground to avoid floods and reinforced to withstand winds of category 5 hurricanes (156mph). In recent Hurricanes several of the existing fields were severely damaged but will be rebuilt in the same locations. In regards to hurricane damaged panels, if other amounts of other debris are interspersed with PV waste, it is probably not possible to recycle, reuse or refurbish damaged PV modules.
8	Stating there is enough space in the landfills is missing the point that this is “green energy” and that the industry should be recycling the materials vs. mining for virgin materials all over the world.	DEQ prefers alternative EOL management options over landfilling, as supported by the waste management hierarchy. Due to the limited current PV module recycling market, it’s important to acknowledge that landfilling of PV modules is a safe and cost-effective management option at this time. It is also a benefit for the solar industry in NC that the state can handle all current PV module waste if hypothetically sent to landfills since alternative EOL management are not well developed at this time.
9	We encourage inclusion of residential panels, or installations less than 1MW – homeowners making this significant green investment will not be keen on landfilling and potentially have difficulty getting their panels recycled because the state system hasn’t taken them into account. The number of panels installed and the removal forecasts are not included in this report, but could be significant.	Consideration of residential PV modules is beyond the scope of HB329. The volume of PV modules currently installed in non-utility scale applications has not been researched during this stakeholder process.

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10	Are there waste diversion goals for NC?	NC General Statutes do include diversion goals. GS 130A-309.04(b) “It is the goal of the State to reduce the MSW stream, primarily through source reduction, reuse, recycling, and composting, by forty percent (40%) on a per capita basis by 30 June 2001.”
11	Report states that mandating recycling could slow down installations. On the other side of the coin, landfilling of green technologies and the resulting “black eye” on the industry could slow down installations as well.	
12	Question: pg. 11 under “Recycling”: does NC require that every panel get tested if not being reused or refurbished because it could be hazardous waste? And does every panel destined for landfill need to be tested too?	Any person generating a solid waste (as defined in 40 CFR 261.2) is required to make a waste determination (in accordance with 40 CFR 262.11). When the PV modules can no longer be used for their intended purpose as-is they would be considered a solid waste and subject to a waste determination. Hazardous waste is banned from the landfill based on Solid Waste Section Rules (15A NCAC 13B .0103(c)). The landfill determines the criteria for the waste that is claimed to be non-hazardous to enter the landfill. Typically, the landfill will require a TCLP to prove non-hazardous for any particular industrial waste stream, in the case of PV modules this may be for a particular manufacturers’ model and one TCLP test is sufficient for all modules of that model unless the construction changes to include a different chemical makeup. However, any requirements imposed on the NC solid waste landfill would be due to the landfill and/or Solid Waste Section and not Hazardous Waste Section. Each panel does not need to individually tested. Once a particular model is tested it will not need to be tested again unless the chemical components are changed.
13	Question: pg. 11 under “Recycling”: What is the source of the statement that glass is commonly landfilled? This is an argument against recycling but it is not documented.	DEQ has revised the report to say that glass needs additional processing to be pure enough for recycling.
14	Pg. 14, last line: This misses components of a life cycle analysis and the human factors, environmental damage, and global conflicts involved with mining.	
15	Pg. 20 under “photovoltaic modules”: we disagree on the value of scrap metal and reliance on it. Too tough to predict in the future, and reliance on scrap value will lead to overestimates so that other financial assurance can be minimized.	
Comments 12/9/20 by Dr. A. Stanley Meiburg, Chairman, NC Environmental Management Commission		
1	I appreciate the sense of the Division in trying to not make overly burdensome regulations that would be burdensome on businesses and would be disproportionate to the risks that were involved and create inequity with other responsibilities which are borne by other sectors within the power generation energy sector businesses and that we also avoid the outcome that no one would want which is filling up limited hazardous waste landfill capacity with inert material.	
2	Pleased to see the DEQ is going to continue to review this because while there is a substantial installed base now it is likely to continue to move forward. Happily, we have a little time before EOL really becomes a major consideration. So we have some time to think of what is an appropriate structure and whether we can rely on local assurances or if there needs to be statewide consistency.	
Comments 12/6/20 by Donald van der Vaart, Commissioner, NC Environmental Management Commission		
1	The draft report contains important information. I did have a few specific questions that I wanted to send in before the meeting. My biggest concern is with the draft conclusion that no financial surety mechanism should be required at the state level. I do not understand the reason for this. The decommissioning costs are substantial and many of the plants are currently owned by undercapitalized limited liability companies. The substantial costs some 15 years from now may well rest either on the landowner or the counties as a result. I believe they should be apprised of such a burden.	Undercapitalized limited liability companies are a waste management problem for all aspects of industry in NC and the US. Continued efforts in the next 5 years are recommended to augment the local government controls and the parent company controls without stifling the clean energy market.

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2	The short answer for all three major components of these technologies, i.e., the solar panels, the batteries, and the wind turbine components, is that recycling is not yet a reality that can be relied on for the final disposition of the decommissioned parts. This leaves sending these components to the local landfill as the current method of choice.	
3	I remember years ago that landfill space was an issue although this was disputed, but happily this report does not echo that concern. Estimates were given in terms of the mass each of these components would represent to be land-filled, but it would also be helpful to understand what the volume of these components would be as a fraction of the waste stream.	DEQ estimates that approximately 500,000 tons of PV modules are currently installed in the state and installations are projected to double in the next 5 years. At a conservative 1,000,000 tons, EOL PV modules would account for less than 10% of the tonnage disposed in landfills relative to FY2018-19, if all panels are disposed of at once.
4	The costs for decommissioning solar plants appear to be low but on the same order of magnitude as another study that I did not see referenced in this report that looked at the decommissioning costs for a number of solar plants. That report was published by the independent non-partisan group Resources for the Future (RFF). In particular, the report lists estimated decommissioning costs for a number of photo-voltaic (PV) solar plants. The numbers vary based on the size of the plants but looking just at the three plants in the range of 20 – 50 MW, the average decommissioning cost was \$106,000/MW. (See Table 9 on page 36). These costs were for returning the sites to greenfield conditions and does not include a cost of recycling. Instead, a recycling value of \$0 was used. https://media.rff.org/documents/RFF20Rpt20Decommissioning20Power20Plants.pdf	Salvage values are to be researched in the next 5 years as more information becomes available.
5	As that report notes, NC is an outlier from the other states in the study in that the solar developers have represented that solar panels have a substantial salvage value.	DEQ agrees that the decommissioning estimates for NC appear to be outliers. Salvage value estimates will be re-evaluated in the next 5 years.
6	Information on recycling solar panels does not support this claim. Typical recycling costs given for the US are on the order of \$12 - \$25/panel after transportation costs. https://grist.org/energy/solar-panels-are-starting-to-die-what-will-we-do-with-the-megatons-of-toxic-trash/ Another study of both the recycling and the environmental costs of solar panels gives a recycling cost for a panel of \$15-20: https://solarmetric.com/learn/solar-panel-waste-could-leasing-be-the-answer/#:~:text=It%20currently%20costs%20%2415%2D20,latter%20option%20is%20still%20legal. If I read that report correctly, using an estimate of 5000 panels/MW and a recycling cost of \$20/panel would give a cost of \$100,000/MW. Note that this would cover only the cost of disposing of the solar panels and not the other costs of dismantling the plant and returning the land to greenfield conditions.	
7	I believe the value given in the report was \$83,000/MW. Using an estimate of \$100,000/MW the decommissioning cost for a typical 5MW plant would be \$500,000 although I am not sure that would return the land to greenfield conditions.	If the EPRI conceptual cost estimate was updated to reflect the cost of recycling at \$20/panel instead of landfill disposal, the total decommissioning cost would increase from \$83,000/MW to \$148,442/MW. This value includes the cost to restore the site to greenfield conditions.
8	In addition, there is at least one study that found the ground under a small solar plant showed elevated levels of certain heavy metals including selenium. https://www.jnrd.info/2019/05/10-5027-jnrd-v9i0-02/	The report states that Si panels are not known to contain appreciable amounts of Se and the source of Se observed in the study is unclear. This study indeed raises concerns to the leaching of metals into soils, however, the findings were below regulatory thresholds. DEQ will consider including this study in our research in the next 5 years. Please share with us if there are other studies concerning metals (or other contaminants) leachability into soil from solar plants.
9	Given the fact that many of the solar farms are owned by a diverse set of limited liability companies with varying levels of capitalization, I cannot understand why the department would argue against the requirement of a financial assurance mechanism.	The DEQ is assessing the pros and cons of converting NC energy needs from fossil fuels to the risks involved from contaminants in soil or expenses of cleaning up PV modules waste. Clearly more information is needed and the non-immediate EOL offers time to research and act carefully.
10	Indeed, many counties do so, and Stanly County recently passed a very protective ordinance requiring financial assurances which was not discussed in the report.	The report has been updated to include the recently revised FA requirements in Stanly County. Stanly County's strict solar facility requirements are not representative of the decommissioning requirements seen throughout counties in NC and thus do not need to be discussed in the section.

TABLE 1
Summary of Written Comments Received and Responses

11	The financial assurance requirement will also serve as the motivating force for the development of many of the programs the report argues for but does not provide a pathway for implementation.	
Comments 12/9/20 by Marion Deerhake, Commissioner, NC Environmental Management Commission		
1	The Department needs to plan carefully regarding the classification of the PV module waste in order to avoid sending excessive or unnecessary waste to hazardous end-of-life facilities.	
2	Asked whether EPA considered making PV modules a K-listed waste.	If EPA made the PV modules a K-listed waste, ALL PV modules would be considered hazardous waste and there would be a formal delisting process to have them not be a hazardous waste (not just a TCLP test). Each individual generator would have to go through the delisting process for their individual waste stream. Anything that comes into contact with a listed waste also becomes a listed waste (by the mixture rule). So anything that came into contact with PV modules once they were a waste, would also be a K-listed waste. To qualify as a K-listed hazardous waste, a waste must fit into one of the 13 categories on the list and the waste must match one of the detailed K list waste descriptions in 40 CFR 261.32. The 13 industries that generate K list wastes are: wood preservation, organic chemicals manufacturing, pesticides manufacturing, petroleum refining, veterinary pharmaceuticals manufacturing, inorganic pigment manufacturing, inorganic chemicals manufacturing, explosives manufacturing, iron and steel production, primary aluminum production, secondary lead processing, ink formulation, and coking (processing of coal to produce coke). Currently the PV module does not fall into one of the 13 categories. It is unlikely that the EPA would create another category for PV modules in the K-listings because of the restrictions in management and disposal it would cause for the entire waste stream when there are only a portion of the waste stream that are actually hazardous.
3	Inquired if DWM had petitioned for a different test method (either in lieu of TCLP or specific test method for PV modules) for determining the toxicity characteristic. She mentioned 40 CFR 260.21 (Petitions for equivalent testing or analytical method).	DEQ's understanding is that the federal regulation that is incorporated by reference in our state rules is meant for entities that we regulate. For instance, if an industry would like to use an equivalent test method, they would submit a petition to us to approve. When the state wants to amend state rules to include a different test method, we would submit similar information (as that described in 40 CFR 260.21) to prove equivalency and get EPA's buy in, but do not actually go through a formal petitioning process with EPA.
Comments 12/9/20 by Mitch Gillespie, Commissioner, NC Environmental Management Commission		
1	My only comments I have never heard address or ever spoke out on but something that I have thought about from day one since this discussion started. That is the huge investment some up to a million dollars to hook up to the grid and the huge cost of site prep, clearing on a lot of sites, finish grading, fencing, roads, storm water control etc. My thoughts are these sites will never be returned to a greenfield site but used over and over again and the sites will become more valuable as the industry grows and solar becomes viable with battery technology.	

Citrola, Jessica L

From: Mundt, Jennifer
Sent: Tuesday, December 15, 2020 8:24 AM
To: David Waggoner
Cc: Citrola, Jessica L
Subject: RE: [External] Re: H329 Draft Final Report for Review-Comments by COB Dec 14, 2020

Good afternoon, David,

We are in receipt of your comments and appreciate your feedback on behalf of ISRI. We will review and take them into consideration as we ready the final version of the report in the coming weeks.

Best,
Jennifer

From: David Waggoner [mailto:DWaggoner@isri.org]
Sent: Monday, December 14, 2020 4:41 PM
To: Mundt, Jennifer <Jennifer.Mundt@ncdenr.gov>
Subject: [External] Re: H329 Draft Final Report for Review-Comments by COB Dec 14, 2020
Importance: High

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Dear Ms. Mundt / Jennifer,

The Institute of Scrap Recycling Industries (ISRI) appreciates the opportunity to provide feedback on your draft "Final Report on the Consideration of Establishing a Regulatory Program for the Management and Decommissioning of Renewable Energy Equipment". ISRI would like to thank you and your colleagues for your efforts in developing the draft final report and considering stakeholders' views in its development and finalization.

As outlined in these brief comments, ISRI largely agrees with what DEQ proposes to do, especially concerning the following:

- Supports designating reusable used PV modules (and ancillaries) as products that are not waste and not subject to DEQ waste regulations, as indicated by the Hazardous Waste Determination for Photovoltaic Modules Flowchart (Appendix C) and the statement, "[i]f a PV module is not suitable for refurbishment or reuse, it becomes a waste and a determination must be made as to whether or not the PV module is considered hazardous" (p. 14).
- Agrees that existing regulations for management of batteries is adequate in the short term for energy-storage system batteries;
- Agrees that a PV module includes any component that cannot be readily detached;
- Agrees that "[c]omponents that are not integrated into the PV module such as brackets, braces, supports, wiring, inverters, and batteries should be evaluated and managed separately from the PV module" (part of proposed addition to the definition for photovoltaic module), enabling their classification as scrap metal or

another category that may have an applicable recycling exclusion or exemption;

- Does not oppose designation of PV modules as universal waste (UW), as long as DEQ consults in advance with the recycling industry about proposed regulatory details (e.g., allowed activities by UW handlers and status of removed components such as glass, circuit boards, and scrap metal), provides a comment period, and does not automatically adopt California's UW program for PV modules; and
- Agrees with assessments that (1) product stewardship programs can fail to cover the total cost of recycling, which harms recyclers who may be captive to such programs by regulation, and (2) "[t]o avoid a similar scenario for the management of EOL PV modules, a product stewardship program should explicitly state that the full cost of collection and recycling be covered by the program" (p. 58).

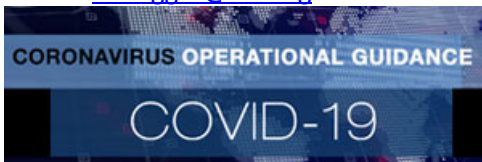
These are the main issues that ISRI identified in the draft final report.

Thank you very much for your consideration. If you or your colleagues have any questions, please feel free to contact me here.

Sincerely,

/s/

David L. Waggoner, Ph.D.
Chief Scientist/Director of Environmental Management
Institute of Scrap Recycling Industries, Inc.
1250 H Street, NW, Suite 400
Washington, DC 20005
TEL: 202-662-8533
MOB: 240-479-1911
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The Institute of Scrap Recycling Industries, Inc. (ISRI) is the "Voice of the Recycling Industry™." ISRI represents 1,300 companies in 20 chapters in the U.S. and more than 40 countries that process, broker, and consume scrap commodities, including metals, paper, plastics, glass, rubber, electronics, and textiles. With headquarters in Washington, DC, the Institute provides education, advocacy, safety and compliance training, and promotes public awareness of the vital role recycling plays in the U.S. economy, global trade, the environment and sustainable development. Generating nearly \$110 billion annually in U.S. economic activity, the scrap recycling industry provides more than 500,000 Americans with good jobs.

From: Mundt, Jennifer <Jennifer.Mundt@ncdenr.gov>

Sent: Friday, November 20, 2020 10:58 AM

To: Aaron Chalker <achalker@wilson-co.com>; ABuros (ABuros@thinkdynamic.com) <ABuros@thinkdynamic.com>; sarah.adair@duke-energy.com <sarah.adair@duke-energy.com>; alex (alex@alexmillernc.com) <alex@alexmillernc.com>; alicia.jackson (alicia.jackson@eridirect.com) <alicia.jackson@eridirect.com>; Cotton, Amanda (MPCA) <amanda.cotton@state.mn.us>; Amanda Vanega <avanega@eq-research.com>; ameadwell@daviecountync.gov <ameadwell@daviecountync.gov>; Andy Lucas <alucas@stanlycountync.gov>; Angela Plummer <angela.plummer@chathamnc.org>; asalib (asalib@geepglobal.com) <asalib@geepglobal.com>; Barnes,

Citrola, Jessica L

From: Mundt, Jennifer
Sent: Monday, December 7, 2020 4:49 PM
To: Lorscheider, Ellen; Ragan, Jamie; Masemore, Sushma; Skolochenko, Sandy; Citrola, Jessica L; Mussler, Ed; Hicks, Joy A
Cc: Scott, Michael
Subject: FW: [External] RE: H329 Draft Final Report for Review-Comments by COB Dec 14, 2020

Good afternoon, everyone,

Please see below, the first suite of substantive feedback I have received on the draft H329 report.

Jessica, may I ask you to begin compiling a list of suggestions/feedback as they pertain to the relevant sections of the report in a SharePoint document for our collaborative use?

Thanks in advance, and see y'all for our lunch chat tomorrow!
Jennifer

From: Mundt, Jennifer
Sent: Monday, December 7, 2020 4:44 PM
To: Jan Clyncke <jan.clyncke@pvcycle.org>
Cc: Bertrand Lempkowicz <bertrand.l@pvcycle.org>; sunstar13 <sunstar13@aol.com>
Subject: RE: [External] RE: H329 Draft Final Report for Review-Comments by COB Dec 14, 2020

Good afternoon, Jan,

Thank you for sharing your comments and feedback. We will review and take them into consideration as we ready the final version of the report in the coming weeks.

Best,
Jennifer

From: Jan Clyncke [<mailto:jan.clyncke@pvcycle.org>]
Sent: Monday, December 7, 2020 2:56 PM
To: Mundt, Jennifer <Jennifer.Mundt@ncdenr.gov>
Cc: Bertrand Lempkowicz <bertrand.l@pvcycle.org>; sunstar13 <sunstar13@aol.com>
Subject: [External] RE: H329 Draft Final Report for Review-Comments by COB Dec 14, 2020

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Dear Jennifer,

Thank you for sharing the draft report.
I briefly share some thoughts and feedback on the Executive summary chapter.

1. It is not recommendable to include in the definition of 'utility scale solar project' (see the bill HB 329 v5) , 'solar thermal'. Photovoltaic and Thermal are 2 different worlds.
2. Good to read that NC looks for an alternative – ASTM – for the TCLP testing.

3. In Europe, PV Panels are classified as NON-hazardous waste. All hazardous substances in a PV Panel are below the thresholds of the ROHS-legislation (EU Directive 2011/65/EU) (if the panels would be under its scope) and PV Panels are excluded from the scope of this directive.
We do not understand why California has classified PV Panels as Universal Waste;
In your study, we notice that NC might also tend in the direction of Universal Waste which is not recommendable.
The cost for collection, shipment and waste treatment are much higher for universal waste and hazardous waste and without any financial funding (as you also foresee), this opens the door of free-riding and non-environmentally sound management of waste PV Panels.
4. PV Panels are preventing waste for many years waste and thus avoid costs for the society. PV Panels are significantly supporting and contributing to the first step of the waste hierarchy “prevention of waste”.
5. Re-use, refurbishment, repairing are interesting options. However, today there is no legislation nor standards regarding the item of re-useable, preparation for re-use and re-use of second PV Panels.
Especially, as PV Panels are a product which is “generating” electricity the re-use option without proper guidance opens the door for uncontrolled management of end-of-life PV Panels.
Re-use of “consuming” electricity products is a complete different environment as thus re-use of laptops, washing machines and mobile phones can never be used as benchmark for the re-use activities of PV Panels.
6. Regarding waste treatment: the future is not landfilling but pushing to recovering the materials as much as possible: glass, aluminum, precious metals, ferrous and non-ferrous metals.
To enable recycling and treatment capacity for at least 500,000 tons of PV Panels waste, NC must impose a landfill ban on PV Panels.
7. Financing of the upcoming PV Panels waste: implement a mandatory recycling fee which is charged at the time of purchase of the panels and implement a Stewardship Program, even though when a vast majority of the currently installed PV Capacity is utility scaled.
Stewardship Program must put the legal responsibility on the shoulder of the “company which puts for the first time a PV Panel or Battery on the territory of NC State” and the financial responsibility on the one who pollutes at the end-of-usage the planet by introducing a visible fee (displayed on the invoice) which is the same but can differ per PV Technology. This then allows the disposer of the PV Panels waste to dispose these products free of charge at the end of their lifetime.

I remain available for additional questions.

Best regards, Cordialement, mit freundlichen Grüßen, met vriendelijke groeten,

Jan Clyncke
Managing Director

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MPCA staff comments: H329 draft final report

We appreciate your research, forecasts, and survey of activities around the world. Thank you for the opportunity to participate in your process and provide input. We offer the following comments based upon our previous work with similar products and our current work on PV panels.

- Experience has shown that while recycling and reuse may be noted as a higher priority over landfilling, the cheaper method of landfilling will be the chosen option if not restricted; material will always flow to the cheapest, least regulated option that's available.
- NC notes that there isn't strong recycling in the US and that it is expensive. In order to help that challenge, states need to mandate recycling so that there is an increase in material flow. This is a 'regulatory driven market.' What "market forces" other than low price of landfilling, will "...drive the Department's preferred EOL management options?" [page ES-4] We do not see any recommendations or existing factors that will drive preferred EOL options.
- With a legislative directive and the second-highest number of solar installations in the country, the agency has an unparalleled opportunity to be really forward looking and be ready for the flood of panels and other equipment that will come, instead it seems to have confirmed the status quo of landfilling highly engineered high value resource intensive green energy capital equipment. Life cycle assessment does not stop at the landfill for a product like this, energy and resource security for the US, plus overall CO2 reductions, depend on recapturing the materials in renewable energy equipment rather than relying on mining of virgin resources elsewhere in the world.
- The report has strong policy statements in favor of reuse and recycling, but proposes no mechanisms to achieve the favored outcomes and defaults to landfilling because it is the cheapest. Is today's cost of landfilling the paramount consideration? If so, is that consistent with the Department's waste hierarchy and the legislative direction for this study?
- Industry will always state that any controls on their products or cost increases will stifle growth, but experience has shown with other products this is not the case.
- What about recyclers that have stated they can handle all the PV panel material generated right now, such as Cascade Eco Minerals, not mentioned in this document and a SEIA PV Recycling Partner?
- There is one passing mention of early decommissioning because of weather, this must be a serious consideration with hurricanes in North Carolina.
- Stating there is enough space in the landfills is missing the point that this is "green energy" and that the industry should be recycling the materials vs. mining for virgin materials all over the world.
- We encourage inclusion of residential panels, or installations less than 1MW – homeowners making this significant green investment will not be keen on landfilling and potentially have difficulty getting their panels recycled because the state system hasn't taken them into account. The number of panels installed and the removal forecasts are not included in this report, but could be significant.
- Are there waste diversion goals for NC?
- Report states that mandating recycling could slow down installations. On the other side of the coin, landfilling of green technologies and the resulting "black eye" on the industry could slow down installations as well.
- Question: pg. 11 under "Recycling": does NC require that every panel get tested if not being reused or refurbished because it could be hazardous waste? And does every panel destined for landfill need to be tested too?
- Question: pg. 11 under "Recycling": What is the source of the statement that glass is commonly landfilled? This is an argument against recycling but it is not documented.
- Pg. 14, last line: This misses components of a life cycle analysis and the human factors, environmental damage, and global conflicts involved with mining.
- Pg. 20 under "photovoltaic modules": we disagree on the value of scrap metal and reliance on it. Too tough to predict in the future, and reliance on scrap value will lead to overestimates so that other financial assurance can be minimized.

SEIA, NCSEA, and NCCEBA appreciate the opportunity to review and provide comment on the staff's draft H329 Final Report. Overall, we found the report to thoroughly and thoughtfully address the questions posed in H329. The rules recommended in the draft report appear to strike a good balance between the various stakeholders that provided feedback throughout the working group process. However, there are several areas where we believe there is room for improvement in the report. Key feedback is summarized below, and we have also prepared a redline version of the report for staff's consideration (attached).

- The recognition that reuse and refurbishment is a future viable channel for decommissioned PV modules in addition to recycling which would decrease the volume of PV modules treated as waste.
- Taken out of context, the summary of Section 2. (a)(1)'s PV waste characterization recommendations could lead readers to believe that *all* PV module waste is hazardous. The language should be revised clarified to align with the staff recommendations more consistently in the detailed discussion in this section. Our redline proposes revised language.
- In the overview of "Photovoltaic Modules" on the third page of section I, the statement on potential leaching risks from broken modules has been revised to be consistent with the IEA risk assessment described in "Photovoltaic Modules Disposal – MSW Landfill" subsection of section III.
- It is important to clarify between operational, fully intact PV modules and PV module waste. We adjusted language throughout to make this distinction.
 - Primarily, at decommissioning, if reuse or refurbishment of the PV equipment is not pursued, then the equipment would be deemed waste and the necessary steps should be taken, according to RCRA and NC laws and regulations. Products that are reused or refurbished are not considered waste and therefore, should be clearly exempted from any future regulations or requirements.
 - Similarly, a TCLP test is necessary for proper categorization of PV waste and is not necessary to determine if a PV module can be reused or refurbished. The report seems to imply that the TCLP test is applicable for other paths besides recycling or disposal. Relative to TCLP, we would also ask staff to clarify that there is not pass/fail outcome of the TCLP test method. There is a value that is used to compare to the threshold of what is then categorized as nonhazardous or hazardous.
- It also appears that the DEQ intends to petition the regional EPA authority to include PV modules as universal waste. It is unclear why DEQ would potentially petition EPA to add PV waste to its universal waste regulations, particularly when most technologies have demonstrated an ability to classify as nonhazardous waste through TCLP testing.
 - We ask for clarity on 1) whether DEQ will request that at the federal level; or 2) whether at the state level, if additional legislation is necessary to pursue the petitioning process or if NC can proceed with regulations directly.
- In terms of the definition of "utility-scale solar", the suggested 1 MW threshold varies from the current G.S. 62-110.1 (g), which only requires a CPCN for non-utility facilities that are under 2 MW. This presents some inconsistency with the DEQ recommendation that these decommissioning regulations apply to facilities that are 1 MW or greater.

- The description of the EU WEEE programs included some misstatements that have been clarified by First Solar's European sustainability experts.
- In the section about county ordinances, it may be better to summarize the ordinances (ex. X number of counties) rather than provide details on a county-by-county basis (map) since several counties are actively updating their ordinances. There is also a lot of nuance between counties with decommissioning requirements that isn't captured in the current summary/map.
- In the section that considers stewardship programs, it is not clear what DEQ's recommendations are in relation to utility-scale solar. While we understand that H329 specifically asks that the Department consider non-utility-scale solar, we strongly recommend that DEQ offer a clear recommendation as it applies to utility-scale solar.
 - It could be interpreted that the DEQ is recommending both a decommissioning plan and a stewardship program for utility-scale solar, holding manufacturers responsible for take-back and recycling. We do not recall discussing this option in the stakeholder meetings and request more information about this approach and recommendation.

Batteries:

- Overall, we request that DEQ recognize and affirm that the Federal Universal Waste requirements for batteries applies to energy storage batteries.

Wind Turbines:

- We understand that DEQ would like to monitor the progress of wind turbine blade recycling development. We would like additional clarity on how DEQ is treating those components of a wind turbine such as motors, cabling, inverters, generators, gears, conduit, flooring, concrete, metals rails and stairs and if there is direction regarding reuse, recycling or disposal of those products.

SOUTHERN ENVIRONMENTAL LAW CENTER

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December 14, 2020

Via Email

Jennifer R.F. Mundt
Senior Policy Advisor
North Carolina Department of Environmental Quality
1601 Mail Service Center
Raleigh, North Carolina 27699-1601
jennifer.mundt@ncdenr.gov

Re: Comments on draft H329 renewable energy equipment end-of-life and decommissioning report

Dear Ms. Mundt,

On behalf of the Sierra Club, North Carolina Conservation Network, and the Southern Environmental Law Center (“SELC”), we submit these comments on the draft House Bill 329 (“H329”) renewable energy equipment end-of-life and decommissioning report (the “Draft Report”) prepared by the Department of Environmental Quality (“DEQ”). Thank you for your work over the past year convening the stakeholder group that helped to inform the Draft Report, for the work you and your staff have put into drafting it, and for considering our comments. We look forward to working with DEQ and the Environmental Management Commission during 2021 to help to prepare the rules establishing the regulatory program outlined in the Report.

These comments raise three main concerns relating to the Draft Report. The first is that the regulatory program required by H329 be kept in perspective. The shift from fossil fuels to renewable energy is good for the environment, public health, and the economy. We should make sure not to raise unnecessary burdens on renewable energy generation on the basis of concerns that may not materialize. Second, solar photovoltaic generation is overwhelmingly safe. It poses negligible risks in operation and even as waste it would be premature to classify the technology as hazardous by default. Finally, statewide standards for financial assurance may offer some regulatory efficiency and help this important North Carolina industry to grow.

1. Renewable energy provides clean electricity generation, strengthens our economy, and should not be unduly burdened.

To begin, we must put the proposed regulatory program in context and two facts must inform DEQ’s development of our state’s end-of-life and decommissioning regulatory program for renewable energy facilities. First, the renewable energy technologies addressed by the program are vital sources of clean electricity generation, especially when compared to alternative

sources of electricity.¹ In the Southeast, our electricity has traditionally come from fossil fuel sources, like coal-fired power plants, which produce negative environmental impacts, from dirty air to coal ash waste to overburdened water resources and carbon emissions. Fossil-fuel fired generating units are the second-leading contributor of climate-altering pollution in the United States, just behind transportation, and the leading contributor in North Carolina.²

By contrast, clean and renewable sources of power generation are largely carbon- and pollution-free. Even when considering lifecycle greenhouse gas emissions—those that occur from manufacturing, operation and maintenance, and decommissioning solar facilities—solar generation produces less than one twentieth of the emissions of coal generation.³ Wind generation produces even less.⁴ Storage is capable of providing a wide array of crucial grid-related services,⁵ making it easier to integrate more renewable energy into the grid. Storage on its own is growing cost-competitive with conventional peaking capacity,⁶ and solar-plus-storage facilities have begun to out-compete new fossil gas facilities—not just peaking units—across the country.⁷

The benefits of renewables extend beyond purely environmental concerns. By avoiding the conventional pollution caused by fossil generation sources, renewable generation improves air quality and consequently improves public health. This is extremely important in its own right regardless of any economic valuation, but attempts at valuation have estimated savings of many billions of dollars.⁸ The value of solar photovoltaic (“PV”) generation in the Southeast in terms

¹ See generally, SOUTHERN ENVIRONMENTAL LAW CENTER’S SOLAR INITIATIVE, THE ENVIRONMENTAL REVIEW OF SOLAR FARMS IN THE SOUTHEAST U.S. (2017),

https://www.southernenvironment.org/uploads/words_docs/Solar_EnvReviewProcess_SitingSolar_Final.pdf.

² DEQ, N.C. GREENHOUSE GAS INVENTORY (1990-2030) at 5 (2019), <https://files.nc.gov/ncdeq/climate-change/ghg-inventory/GHG-Inventory-Report-FINAL.pdf>.

³ NAT’L RENEWABLE ENERGY LABS., LIFE CYCLE GREENHOUSE GAS EMISSIONS FROM SOLAR PHOTOVOLTAICS 2 (2012), <https://www.nrel.gov/docs/fy13osti/56487.pdf>; NAT’L RENEWABLE ENERGY LABS., THE ENVIRONMENTAL AND PUBLIC HEALTH BENEFITS OF ACHIEVING HIGH PENETRATIONS OF SOLAR ENERGY IN THE UNITED STATES 11 (2016), <https://www.nrel.gov/docs/fy16osti/65628.pdf>.

⁴ *Id.*

⁵ See NC STATE ENERGY STORAGE TEAM, ENERGY STORAGE OPTIONS FOR NORTH CAROLINA at ii (2019), <https://energy.ncsu.edu/storage/wp-content/uploads/sites/2/2019/02/NC-Storage-Study-FINAL.pdf>; THE CADMUS GROUP, SOLAR + STORAGE: A GUIDE FOR LOCAL GOVERNMENTS 3-4 (2019), https://solsmart.org/wp-content/uploads/SolSmart_SolarPlusStorage_Guide_06-25-2019.pdf.

⁶ See, e.g., NAT’L RENEWABLE ENERGY LABS., AN OVERVIEW OF BEHIND-THE-METER SOLAR-PLUS-STORAGE REGULATORY DESIGN 6 (2020), <https://www.nrel.gov/docs/fy20osti/75283.pdf>.

⁷ See William Driscoll, *Solar+storage can outcompete “mid-merit” gas units, not just peakers*, PV MAG. (Apr. 22, 2019), <https://pv-magazine-usa.com/2019/04/22/solarstorage-can-outcompete-mid-merit-gas-units-not-just-peakers/>.

⁸ See, e.g., NAT’L RENEWABLE ENERGY LABS., THE ENVIRONMENTAL AND PUBLIC HEALTH BENEFITS OF ACHIEVING HIGH PENETRATIONS OF SOLAR ENERGY IN THE UNITED STATES 34 (2016), <https://www.nrel.gov/docs/fy16osti/65628.pdf> (estimating value of avoided air pollution emissions that would be caused by realizing Department of Energy of Sunshot goal \$167 billion, along with 46 trillion gallons of avoided water use, and \$259 billion in avoided greenhouse gas emissions); ABT ASSOCIATES, ANALYSIS OF THE PUBLIC HEALTH IMPACTS OF THE REGIONAL GREENHOUSE GAS INITIATIVE, 2009–2014 at 2 (2017), <https://static1.squarespace.com/static/5ab0544a9d5abb6d42468691/t/5b2842f56d2a73363e8961da/1529365238457/RGGI+Health+Study+Executive+Summary+%28Jan+2017%29.pdf> (estimating value of avoided health effects as a result of Regional Greenhouse Gas Initiative at \$3 billion to \$8.3 billion).

of health-related air-quality benefits is on the order of eight cents per kilowatt hour.⁹ In addition, renewable energy development grows and strengthens our economy. Between 2007 and 2018, the total economic impact of the renewable energy industry in North Carolina was over \$28 billion.¹⁰ Renewables provide good jobs¹¹ and substantial county tax revenue.¹²

Second, as the Draft Report makes clear, the regulatory program that H329 requires will be one of the most comprehensive in the nation.¹³ Only Washington and California have more comprehensive programs. Because North Carolina wisely has invested developing its solar industry we are fortunate to have the second-most installed solar capacity in the nation, following only much larger California. As a solar leader, it can be prudent to plan for eventual decommissioning and we have participated in DEQ's efforts to do so pursuant to H329. Our organizations have long track records of working to ensure that North Carolina keeps its residents safe from the risks and burdens of waste and related pollution, and we believe that the waste generated by renewable energy facilities at the end of their lives must be managed responsibly. We strongly support reducing waste at the source through improved design, and reusing, refurbishing, or recycling modules rather than disposing of them as waste.¹⁴

However, there remain at least ten years before the first significant tranche of solar facilities reaches end-of-life and approximately fifteen to twenty years before the majority of the existing solar facilities in North Carolina will be decommissioned or retrofitted.¹⁵ Furthermore, even if double the currently installed capacity were landfilled immediately it would not negatively impact North Carolina landfill capacities.¹⁶ Finally, module recycling is continuing to improve.¹⁷ We urge DEQ to keep this timeframe, perspective, and the changing landscape in mind as it develops the H329 regulatory program, and to minimize the extent to which a program developed so far in advance of its likely use establishes burdens that become superfluous. We also urge DEQ to monitor changes in these industries and to propose corresponding updates to the program.

⁹ N.C. CLEAN ENERGY TECH. CTR., HEALTH AND SAFETY IMPACTS OF SOLAR PHOTOVOLTAICS 1 (2017), https://nccleantech.ncsu.edu/wp-content/uploads/2018/05/Health-and-Safety-Impacts-of-Solar-Photovoltaics-2017_white-paper.pdf.

¹⁰ JEFFREY PETRUSA, ET AL., RTI INTERNATIONAL, ECONOMIC IMPACT ANALYSIS OF CLEAN ENERGY DEVELOPMENT IN NORTH CAROLINA—2019 UPDATE at 2-15, Table 2-8, https://energync.org/wp-content/uploads/2019/05/v3NCSEA_Economic_Impact_Analysis_of_Clean_Energy_Development_in_North_Carolina_2019.pdf.

¹¹ See *Solar Energy Industry Jobs*, N.C. CLEAN ENERGY TECH. CTR. (July 29, 2019), <https://nccleantech.ncsu.edu/2019/07/29/solar-energy-industry-jobs/>.

¹² See CLAIRE CARSON, ET AL., N.C. SUSTAINABLE ENERGY ASSOC., INCREASED NORTH CAROLINA COUNTY TAX REVENUE FROM SOLAR DEVELOPMENT (2019), https://energync.org/wp-content/uploads/2019/07/Small_Increased-NC-County-Tax-Revenue-from-Solar-Developmentv3.pdf.

¹³ See Draft Report 42-49.

¹⁴ See Draft Report 9.

¹⁵ See Draft Report 36, Fig. 5-2.

¹⁶ Draft Report 33.

¹⁷ Draft Report 11-14.

2. Solar photovoltaic health and safety risks are minimal.

The North Carolina Clean Energy Technology Center has determined that health and safety risks associated with solar photovoltaic technology are “extremely small, far less than those associated with common activities such as driving a car, and vastly outweighed by health benefits of the generation of clean electricity.”¹⁸ According to the Center’s analysis, some solar photovoltaic systems may implement small amounts of toxic materials but do not endanger public health.¹⁹ The solar cells in photovoltaic panels are typically encapsulated in two layers of plastic, along with a layer of tempered glass in front and a polymer sheet behind.²⁰ With this design, even when damaged, a module largely remains together as one piece.²¹ The Center concluded that solar photovoltaic systems pose “negligible” risks related to toxicity, electromagnetic fields, electric shock and arc flash, and fire.²²

The Draft Report properly states that “only end-of-life (EOL) PV modules – those modules that no longer serve the purpose for which they are intended – are evaluated in this report.”²³ It further states that “[a]ny module, panel, or associated equipment that is in operation and continues to serve the purpose for which it is intended is not considered a waste for purposes of this report.”²⁴ Finally, it properly states that “[p]hotovoltaic modules that contain hazardous materials pose minimal risks to the environment and human health during normal operation.”²⁵ However, a reader might potentially lose track of these points in the discussion of testing and leaching procedures.

To further clarify the limits of the Draft Report’s conclusions concerning any hazardous characteristics of solar photovoltaic waste, we recommend that DEQ explain that the Draft Report does not address the safety of solar photovoltaic systems that are in operation, and that DEQ has no reason to believe that these systems pose any significant risks to the public. We suggest adding a short statement explicitly addressing these clarifications as a preface to Section 2(a)(1).

We also request that DEQ clarify the basis for its finding that PV modules at end-of-life should be deemed hazardous until proven otherwise through testing. The Draft Report states that if a module containing toxic materials is broken then it may leach toxic contaminants into the environment.²⁶ It also explains that modules “may test above the regulatory limits presented in Table 1, in 40 CFR 261.24, following the TCLP,”²⁷ which is used to determine whether waste is

¹⁸ N.C. CLEAN ENERGY TECH. CTR., HEALTH AND SAFETY IMPACTS OF SOLAR PHOTOVOLTAICS 1 (2017), <https://nccleantech.ncsu.edu/wp-content/uploads/2018/05/Health-and-Safety-Impacts-of-Solar-Photovoltaics-2017-white-paper.pdf>.

¹⁹ *Id.* at 2.

²⁰ *Id.* at 3.

²¹ *Id.* at 3-4.

²² *Id.* at 15.

²³ Draft Report 1.

²⁴ *Id.*

²⁵ *Id.* at 3.

²⁶ *Id.*

²⁷ *Id.* at 2.

hazardous or non-hazardous.²⁸ The Toxicity Characteristic Leaching Procedure or “TCLP” requires crushing, cutting, or grinding a panel into pieces of a maximum size of 9.5mm, with no minimum size.²⁹ The pieces are then submerged in an acid bath to promote leaching.³⁰ This is meant to simulate the conditions that could be found in a landfill and it does not accurately represent the conditions that would be found at a solar facility in the field.³¹ Accordingly, we request that DEQ clarify that a PV module does not present hazardous characteristics upon simply breaking but only, potentially, under the extreme conditions of the TCLP.

We further request that DEQ clarify that the TCLP test will determine whether a particular model of PV module should be classified as hazardous waste once it can no longer be used. As we understand the Draft Report, DEQ proposes to assume as a rule that non-homeowner PV modules are hazardous waste unless the results of the TCLP indicate otherwise, and once a model of PV module has been tested DEQ will follow the results of the testing.³² DEQ further proposes to initiate rulemaking to classify PV modules as “universal waste” as the default or if a model tests as hazardous under the TCLP.³³ H329 directed DEQ to determine whether any PV modules (or energy storage system batteries) exhibit any of the characteristics of hazardous waste or whether any such waste is properly characterized as solid waste.³⁴ DEQ determined that TCLP testing shows most PV modules are not hazardous although some may contain small quantities of toxins.³⁵ This does not appear to be sufficient information on which to determine that all waste PV modules should be classified as hazardous waste by default unless testing proves otherwise.

DEQ and stakeholders generally agreed that TCLP testing should determine whether a model of PV module should be classified as hazardous waste once it can no longer be used. The Draft Report states that at the June meeting stakeholders generally agreed with the guidance document in Appendix C for making hazardous waste determinations for PV modules.³⁶ Stakeholder generally agreed that the flow chart was consistent with State and federal rules for making hazardous waste determinations. Importantly, the flow chart does not indicate that PV modules would be classified as hazardous waste or universal waste by default. To the contrary, TCLP testing would determine their status.³⁷ Furthermore, if TCLP testing showed that a model of PV module demonstrated hazardous characteristics it would be managed as universal waste rather than general hazardous waste, once the appropriate rulemaking was complete.³⁸ We believe that this is more consistent with stakeholders’ consensus during the process, namely, that

²⁸ *Id.* at 4.

²⁹ *Id.*

³⁰ N.C. CLEAN ENERGY TECH. CTR., HEALTH AND SAFETY IMPACTS OF SOLAR PHOTOVOLTAICS 9 (2017), <https://nccleantech.ncsu.edu/wp-content/uploads/2018/05/Health-and-Safety-Impacts-of-Solar-Photovoltaics-2017-white-paper.pdf>.

³¹ *See id.*

³² Draft Report 1.

³³ Draft Report 1, Appx’ C.

³⁴ H329, Section 2(a)(1), <https://www.ncleg.gov/Sessions/2019/Bills/House/PDF/H329v5.pdf>.

³⁵ Draft Report 2-3.

³⁶ Draft Report 3.

³⁷ Draft Report, App’x C.

³⁸ *Id.*

TCLP testing will determine a PV module model's waste classification and if TCLP testing shows hazardous characteristics the model will be universal waste. We request DEQ revise the report accordingly.³⁹

3. Establishing statewide standards may reduce burdens on clean-energy development and help North Carolina's economy grow.

We support DEQ's decision to study, in consultation with stakeholders and the North Carolina Utilities Commission, the advisability and feasibility of a statewide standard for financial assurance within the next five years.⁴⁰ As DEQ has documented in the Draft Report, there is currently a patchwork of different financial assurance requirements in North Carolina varying by county.⁴¹ Establishing a statewide standard would streamline the regulatory process for solar developers, facilitating more solar development that would bring the public health, economic, and environmental benefits discussed above. Representatives from the Utilities Commission could help to investigate whether it could oversee any necessary financial assurance mechanism.

The Draft Report cites a need to "ground truth" claims by the solar industry about the salvage value of solar photovoltaic systems and related economic incentives. This is a good topic for the financial assurance study process that DEQ proposes in the Draft Report and it is certainly proper for DEQ to develop an independent estimate of salvage value. When it does so, DEQ should use the best information available to calculate the actual salvage value experienced and expected. Not only is the solar industry changing quickly, as noted above, but the recycling value of materials used on solar photovoltaic systems can change significantly over time and the values will need to be updated regularly. In any case, DEQ should not assume that the salvage value will be nothing simply because the value will change. We urged DEQ not to take that arbitrary approach during the stakeholder process and we support its decision not to do so.

Conclusion

Solar and wind energy generation, supported by energy storage, will play deciding roles in expanding North Carolina's clean-energy economy in the coming years. These technologies represent enormous opportunities to reduce emissions, improve public health, and strengthen the state's economy. We support responsibly managing renewable energy equipment when it reaches end-of-life and at decommissioning. At the same time, the state should remain flexible as this new and evolving industry develops, let the regulatory program governing end-of-life and decommissioning follow the best available information, and avoid establishing any unnecessary burdens on clean energy and a healthy future.

³⁹ For example, on the first page the Draft Report states that DEQ finds that "EOL PV modules are deemed hazardous, unless testing indicates otherwise." This should instead say that whether end-of-life PV modules are deemed hazardous will be determined by testing.

⁴⁰ See Draft Report 53.

⁴¹ *Id.* at 50-53.

Sincerely,

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SEIA, NCSEA, and NCCEBA appreciate the opportunity to review and provide comment on the staff's draft H329 Final Report. Overall, we found the report to thoroughly and thoughtfully address the questions posed in H329. The rules recommended in the draft report appear to strike a good balance between the various stakeholders that provided feedback throughout the working group process. However, there are several areas where we believe there is room for improvement in the report. Key feedback is summarized below, and we have also prepared a redline version of the report for staff's consideration (attached).

- The recognition that reuse and refurbishment is a future viable channel for decommissioned PV modules in addition to recycling which would decrease the volume of PV modules treated as waste.
- Taken out of context, the summary of Section 2. (a)(1)'s PV waste characterization recommendations could lead readers to believe that *all* PV module waste is hazardous. The language should be revised clarified to align with the staff recommendations more consistently in the detailed discussion in this section. Our redline proposes revised language.
- In the overview of "Photovoltaic Modules" on the third page of section I, the statement on potential leaching risks from broken modules has been revised to be consistent with the IEA risk assessment described in "Photovoltaic Modules Disposal – MSW Landfill" subsection of section III.
- It is important to clarify between operational, fully intact PV modules and PV module waste. We adjusted language throughout to make this distinction.
 - Primarily, at decommissioning, if reuse or refurbishment of the PV equipment is not pursued, then the equipment would be deemed waste and the necessary steps should be taken, according to RCRA and NC laws and regulations. Products that are reused or refurbished are not considered waste and therefore, should be clearly exempted from any future regulations or requirements.
 - Similarly, a TCLP test is necessary for proper categorization of PV waste and is not necessary to determine if a PV module can be reused or refurbished. The report seems to imply that the TCLP test is applicable for other paths besides recycling or disposal. Relative to TCLP, we would also ask staff to clarify that there is not pass/fail outcome of the TCLP test method. There is a value that is used to compare to the threshold of what is then categorized as nonhazardous or hazardous.
- It also appears that the DEQ intends to petition the regional EPA authority to include PV modules as universal waste. It is unclear why DEQ would potentially petition EPA to add PV waste to its universal waste regulations, particularly when most technologies have demonstrated an ability to classify as nonhazardous waste through TCLP testing.
 - We ask for clarity on 1) whether DEQ will request that at the federal level; or 2) whether at the state level, if additional legislation is necessary to pursue the petitioning process or if NC can proceed with regulations directly.
- In terms of the definition of "utility-scale solar", the suggested 1 MW threshold varies from the current G.S. 62-110.1 (g), which only requires a CPCN for non-utility facilities that are under 2 MW. This presents some inconsistency with the DEQ recommendation that these decommissioning regulations apply to facilities that are 1 MW or greater.

- The description of the EU WEEE programs included some misstatements that have been clarified by First Solar's European sustainability experts.
- In the section about county ordinances, it may be better to summarize the ordinances (ex. X number of counties) rather than provide details on a county-by-county basis (map) since several counties are actively updating their ordinances. There is also a lot of nuance between counties with decommissioning requirements that isn't captured in the current summary/map.
- In the section that considers stewardship programs, it is not clear what DEQ's recommendations are in relation to utility-scale solar. While we understand that H329 specifically asks that the Department consider non-utility-scale solar, we strongly recommend that DEQ offer a clear recommendation as it applies to utility-scale solar.
 - It could be interpreted that the DEQ is recommending both a decommissioning plan and a stewardship program for utility-scale solar, holding manufacturers responsible for take-back and recycling. We do not recall discussing this option in the stakeholder meetings and request more information about this approach and recommendation.

Batteries:

- Overall, we request that DEQ recognize and affirm that the Federal Universal Waste requirements for batteries applies to energy storage batteries.

Wind Turbines:

- We understand that DEQ would like to monitor the progress of wind turbine blade recycling development. We would like additional clarity on how DEQ is treating those components of a wind turbine such as motors, cabling, inverters, generators, gears, conduit, flooring, concrete, metals rails and stairs and if there is direction regarding reuse, recycling or disposal of those products.

Citrola, Jessica L

From: Lorscheider, Ellen
Sent: Monday, December 21, 2020 2:13 PM
To: Citrola, Jessica L
Subject: FW: [External] Re: FW: H329 draft legislative report

Ellen Lorscheider, Deputy Director
Division of Waste Management
Department of Environmental Quality
Phone 919.707.8245 (Office) Cell 919.621.3695
Ellen.Lorscheider@ncdenr.gov

From: Donald van der Vaart <dvatemc@gmail.com>
Sent: Friday, December 4, 2020 4:33 PM
To: Lorscheider, Ellen <ellen.lorscheider@ncdenr.gov>
Cc: dandersonemc@gmail.com; ArataEMC@gmail.com; baileyemc@gmail.com; carterdenr@gmail.com; ddavis.ncemc@gmail.com; m.e.deerhake@gmail.com; Barbaranell1@charter.net; pkharrisemc@gmail.com; stevepkeenemc@gmail.com; McAdams.EMC@mcadamsco.com; suzannelazorick@gmail.com; maggiemonast@gmail.com; pamlicojd@gmail.com; jd.solomon@jdsolomoninc.com; Scott, Michael <michael.scott@ncdenr.gov>; Thomas, Lois <lois.thomas@ncdenr.gov>; meiburgemc@gmail.com
Subject: [External] Re: FW: H329 draft legislative report

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Comments on Draft Decommissioning Report

The draft report contains important information. I did have a few specific questions that I wanted to send in before the meeting. My biggest concern is with the draft conclusion that no financial surety mechanism should be required at the state level. I do not understand the reason for this. The decommissioning costs are substantial and many of the plants are currently owned by undercapitalized limited liability companies. The substantial costs some 15 years from now may well rest either on the landowner or the counties as a result. I believe they should be apprised of such a burden.

The short answer for all three major components of these technologies, *i.e.*, the solar panels, the batteries, and the wind turbine components, is that recycling is not yet a reality that can be relied on for the final disposition of the decommissioned parts. This leaves sending these components to the local landfill as the current method of choice.

I remember years ago that landfill space was an issue although this was disputed, but happily this report does not echo that concern. Estimates were given in terms of the mass each of these components would represent to be land-filled, but it would also be helpful to understand what the volume of these components would be as a fraction of the waste stream.

The costs for decommissioning solar plants appear to be low but on the same order of magnitude as another study that I did not see referenced in this report that looked at the decommissioning costs for a number of solar

plants. That report was published by the independent non-partisan group Resources for the Future (RFF). In particular the report lists estimated decommissioning costs for a number of photo-voltaic (PV) solar plants. The numbers vary based on the size of the plants but looking just at the three plants in the range of 20 – 50 MW, the average decommissioning cost was \$106,000/MW. (See Table 9 on page 36). These costs were for returning the sites to greenfield conditions and does not include a cost of recycling. Instead, a recycling value of \$0 was used. <https://media.rff.org/documents/RFF20Rpt20Decommissioning20Power20Plants.pdf>

As that report notes, NC is an outlier from the other states in the study in that the solar developers have represented that solar panels have a substantial salvage value.

Information on recycling solar panels does not support this claim. Typical recycling *costs* given for the US are on the order of \$12 - \$25/panel after transportation costs. <https://grist.org/energy/solar-panels-are-starting-to-die-what-will-we-do-with-the-megatons-of-toxic-trash/>

Another study of both the recycling and the environmental costs of solar panels gives a recycling cost for a panel of \$15-20:

<https://solarmetric.com/learn/solar-panel-waste-could-leasing-be-the-answer/#:~:text=It%20currently%20costs%20%2415%2D20,latter%20option%20is%20still%20legal.>

If I read that report correctly, using an estimate of 5000 panels/MW and a recycling cost of \$20/panel would give a cost of \$100,000/MW. Note that this would cover only the cost of disposing of the solar panels and not the other costs of dismantling the plant and returning the land to greenfield conditions.

I believe the value given in the report was \$83,000/MW. Using an estimate of \$100,000/MW the decommissioning cost for a typical 5MW plant would be \$500,000 although I am not sure that would return the land to greenfield conditions.

In addition, there is at least one study that found the ground under a small solar plant showed elevated levels of certain heavy metals including selenium. <https://www.jnrd.info/2019/05/10-5027-jnrd-v9i0-02/>

Given the fact that many of the solar farms are owned by a diverse set of limited liability companies with varying levels of capitalization, I cannot understand why the department would argue against the requirement of a financial assurance mechanism.

Indeed, many counties do so, and Stanly County recently passed a very protective ordinance requiring financial assurances which was not discussed in the report.

The financial assurance requirement will also serve as the motivating force for the development of many of the programs the report argues for but does not provide a pathway for implementation.

I look forward to the discussion on the 9th.

On Mon, Nov 23, 2020 at 12:00 PM Lorscheider, Ellen <ellen.lorscheider@ncdenr.gov> wrote:

From: Lorscheider, Ellen

Sent: Thursday, November 19, 2020 5:35 PM

To: meiburgemc@gmail.com; Thomas, Lois <lois.thomas@ncdenr.gov>

Cc: Holman, Sheila <sheila.holman@ncdenr.gov>; Mundt, Jennifer <Jennifer.Mundt@ncdenr.gov>; Scott, Michael <michael.scott@ncdenr.gov>

Subject: FW: H329 Weekly Staff meeting

Citrola, Jessica L

From: Lorscheider, Ellen
Sent: Monday, December 21, 2020 2:12 PM
To: Citrola, Jessica L
Subject: FW: [External] Re: FW: H329 draft legislative report

Ellen Lorscheider, Deputy Director
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Phone 919.707.8245 (Office) Cell 919.621.3695
Ellen.Lorscheider@ncdenr.gov

From: Albert Stanley Meiburg <meiburgemc@gmail.com>
Sent: Monday, December 7, 2020 11:51 AM
To: Donald van der Vaart <dvatemc@gmail.com>; Lorscheider, Ellen <ellen.lorscheider@ncdenr.gov>; Scott, Michael <michael.scott@ncdenr.gov>
Subject: [External] Re: FW: H329 draft legislative report

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Don, thanks for your thoughtful comments; they really got me to thinking, and I too look forward to the discussion. I agree that financial assurance mechanisms are very important tools for protecting the environment. But we should be consistent. I assume you would agree that financial assurance requirements should not be greater for this line of business than they are for businesses whose relative risks appear to have the potential to be greater, such as municipal solid waste disposal, hardrock mining, chemical production, oil and gas exploration, production, refining and transportation, and fossil fuel electric power generation.

I was curious to know what you thought about the various financial assurance mechanisms. There are quite a range, from corporate guarantees to such things as insurance mechanisms, surety bonds, and letters of credit. Are there particular mechanisms that you think appropriate for this sector?

Any analysis need not lock in today's costs for recycling these renewable components. Given an appropriate regulatory framework, the unit costs of today that you cite are likely to decrease thanks to both innovation and economies of scale which we don't now have (e.g., for separating out the more valuable metals in solar panels from the large volume of ground glass). At a minimum, there should be a range of costs in any analysis that reflects this.

I agree that RFF is a very reputable organization and appreciate your reference to their review. I haven't had time to read it all the way through, but I did note the table on page 3 used ranges of estimated costs, with a minimum, mean and maximum. The report, of course, is about decommissioning all forms of electric power, not just solar facilities. Of note is that the highest decommissioning costs are associated with coal plants. The estimates for solar PV facilities range from a net benefit of \$87 (e.g., you make money from decommissioning them, based on materials reuse and recovery) to a maximum cost of \$179/MW, as compared to a maximum cost at a coal fired power plant of \$466/MW.

Other sectors that face similar challenges are looking to technological innovation for solutions (e.g., the recycling of spent automobile catalysts). And as the Grist article you cited notes, the volume of waste generated by renewable energy is dwarfed at present by the volume of electronic waste from other sources (TV's, computers, stereo equipment,

and the like), which are now being landfilled. This issue is upon us today and deserves at least as much if not more attention as the renewable energy sector, as it is far more ubiquitous and decentralized. The Grist article makes another point that I found compelling: "For the solar recycling industry to grow sustainably, it will ultimately need supportive policies and regulations."

Again, I am looking forward to this discussion.

Best wishes,

Stan

On Fri, Dec 4, 2020 at 4:33 PM Donald van der Vaart <dvatemc@gmail.com> wrote:

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Sent: Thursday, November 19, 2020 5:35 PM
To: meiburgemc@gmail.com; Thomas, Lois <lois.thomas@ncdenr.gov>
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Subject: FW: H329 Weekly Staff meeting

Good Afternoon Commissioners,

As you are aware, Thursday's meeting was adjourned before I could present an info item on DEQ's findings and recommendations pursuant to Section 2 of H329 – our consideration of matters and whether to adopt rules for the management of end-of-life (EOL) renewable energy equipment. H329 directs DEQ and the EMC to jointly submit a report of our findings. Attached are two documents: (1) DEQ's draft final report for your review and comment and (2) the authorizing Session Law, for your information.

To ensure we comply with the January 1, 2021, submission deadline, we request the Commission's feedback and comment by close of business on Monday December 14. As was mentioned in the Commission meeting today, this info item will be rescheduled for the Dec 9 or 10 Commission meeting, providing an opportunity for questions or comment on the draft as written. Please let me know if you would like us to distribute the documents to the other Commission members or if you will forward them.