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PPRP

TECHNICAL MEMORANDUM

Review of Decommissioning Considerations for Solar Energy Projects in Maryland

MARYLAND POWER PLANT
RESEARCH PROGRAM

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1.0 Introduction

Decommissioning refers to the process of permanently removing a facility from operation. In the power industry, plant decommissioning can include removing some or all of the physical components; however, some power plant structures may remain in place, especially if they may have value for future reuse or redevelopment. Decommissioning aims to restore the site to its original condition to enable a range of potential uses for the land.

As the number of renewable energy projects proposed in Maryland has grown, there has been an increased focus on plans for decommissioning these facilities. Since 2001, the Public Service Commission (PSC) has established through case law that solar and wind energy projects in Maryland are required to plan for equipment removal in the event these facilities are non-operational for at least one year because of equipment failure or damage; because the plant has reached the end of its operating lifetime; or because the plant is no longer economically viable.[1]

The Maryland Department of Natural Resources (DNR) Power Plant Research Program (PPRP) is responsible for assessing the potential impacts from new and modified power plants within the state. PPRP evaluates how the design, construction, and operation of power plants and transmission lines impact Maryland's environmental, socioeconomic, and cultural resources, coordinating the review of multiple State agencies.[2] As the result of this consolidated evaluation, PPRP develops recommended license conditions to the PSC that may be included if a Certificate of Public Convenience and Necessity (CPCN) is granted for a project. The PSC is the regulating entity whose jurisdiction includes licensing power generating facilities and overhead transmission lines greater than 69 kilovolts (kV) within the state.

To date, PPRP has reviewed and recommended approval or suggested modifications to decommissioning plans for solar and wind projects on a case-by-case basis. The purpose of this report is to review issues associated with decommissioning renewable power plant facilities and to provide a framework to help ensure that the State uses best practices in the review and approval of decommissioning plans associated with solar energy facilities. Appendix A presents a draft checklist that a solar facility should consider in the development of its decommissioning plan.

The discussion of these topics is intended to assist in any future policy discussions, legislative action or regulatory rulemaking.

[1] This report focuses on solar photovoltaic development since that is the dominant form of new capacity proposed in Maryland over the past 10 years. Wind energy is discussed where relevant; however, the potential for new wind energy projects in the state is limited. Decommissioning of other types of generating facilities is outside the scope of this report. Although traditional fossil fuel facilities do not have formal decommissioning plans, utilities must adhere to environmental regulations. Nuclear facilities, such as Calvert Cliffs, have extensive decommissioning regulations that are administered by the U.S. Nuclear Regulatory Commission.

[2] Departments of Agriculture, Commerce, Environment, Natural Resources, Planning, Transportation, and Maryland Energy Administration.

2.0 Technical Issues Associated with Utility-Scale Solar Decommissioning

New generation projects are subject to increasing scrutiny regarding end-of-plant-life concerns, including decommissioning and subsequent land availability. The increased attention can be attributed, in part, to development pressure and sensitivity to land use issues in general across the state. Moreover, utility-scale renewable energy in the form of wind and solar requires significantly larger amounts of land to generate the same amount of power as a traditional fossil fuel or nuclear power plant. Recent closures of coal-fired power plants that are no longer economically viable have also raised awareness of the end-of-life issues associated with power plants.

Solar energy generation capacity operating in Maryland has increased from 0.1 megawatt (MW) in 2007 to 1,636 MW as of December 2022. More than half of this capacity is distributed solar on commercial, industrial and residential sites (either rooftop or ground-mounted), which does not require a CPCN from the Maryland PSC. As of December 2022, the PSC had issued CPCNs to 45 solar projects,[3] representing a combined capacity of 1,396 MW, and 296 MW of that capacity had been placed in commercial operation.

Maryland needs to add approximately 3,000 MW of solar generating capacity (utility-scale plus distributed) to achieve renewable energy targets – an additional 15 million panels over the next three decades.[4]

2.1 Equipment Recycling

Currently in the United States, approximately 10% of solar modules taken out of service are recycled. Comparatively, as much as 90% of solar panel material is recycled in the European Union.[5] One significant difference between the two systems is regulation. In the European Union, recycling of decommissioned solar panels is required under the Waste from Electrical and Electronic Equipment (WEEE) Directive.[6] In the United States, decommissioning of solar projects and solar panel disposal is handled by individual states and localities, which have varying requirements. For instance, Washington State requires the producers of solar panels used within the state to operate a takeback program for panel recycling.[7]

Additional factors affecting solar panel recycling in the United States are waste classification and testing procedures. Whether solar modules are classified as hazardous or non-hazardous waste can influence the ease of their handling after decommissioning. The Toxicity Characteristic Leaching Procedure (TCLP) test is used in the United States to determine whether materials must be handled as hazardous wastes. However, TCLP results for solar panels are highly variable depending upon panel type, manufacturer and sample collection method. One state, California, has dealt with this uncertainty by allowing solar modules to be classified as "universal waste," a regulatory designation that entails handling and disposal

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[3] Excluding those projects that have abandoned their CPCNs.
[4] These are rough estimates based on a current panel capacity equivalent to 200 kilowatts of alternating current output (kW AC); the number of panels requiring disposal in the future may be somewhat smaller as a result of improved technology.
[5] https://www.nrel.gov/docs/fy21osti/74550.pdf
[6] https://hbr.org/2021/06/the-dark-side-of-solar-power
[7] https://www.nrel.gov/docs/fy21osti/74550.pdf

restrictions more stringent than those for non-hazardous waste, but less stringent than those for hazardous waste.[8]

Solar panels have traditionally been recycled at general-purpose glass recycling facilities, where the metal frames and glass parts are salvaged but the remaining parts are disposed of or burned. Recycling options include one of two methods: Private company or organization recyclers or manufacture recyclers.

- Private Company/Organization recyclers include organizations such as Veolia in the European Union, and Recycle PV in the United States , and the Solar Energy Industries Association (SEIA), an international trade association. As noted above, regulations in the European Union require recycling of solar panels, resulting in a more developed solar recycling market in Europe. Under the WEEE, European solar panel owners must recycle their panels once they are done using them. Veolia collaborates with the non-profit PV Cycle in Europe to collect and recycle solar panels. Veolia opened its first recycling plant in 2018, where robots separate glass, silicon, plastics and metals from solar panels. SEIA works with existing industry/commercial recyclers to familiarize them with solar technology and helps them adjust their processes and equipment to recycle PV products. SEIA also works with new PV recycling companies to maximize the recovery of materials from PV modules.

- Solar panel manufacturers are also pursuing solar recycling efforts. Companies like SunPower and First Solar run global recycling programs for their customers, allowing them to return old solar panels to the manufacturer to be recycled or repurposed. Several of SEIA's solar manufacturers and developers – including Canadian Solar, First Solar, Flex, JinkoSolar, SunPower, Panasonic and Trina Solar – are working together to create a network of recyclers that can properly handle PV waste and ensure solar components are not sent to landfills.

There are a number of methodologies and technologies available now for recycling or disposing of solar panels, including:

- <u>Module discharge to landfills after decommissioning</u>: End-of-life disposal of solar products in the US is governed by the Federal Resource Conservation and Recovery Act (RCRA) and individual state policies that govern waste disposal or other disposition.

- <u>Module reuse</u>: Repowering a solar system with newer technology that is more efficient or has a higher nameplate capacity can provide more electricity from the same amount of space. The replaced PV modules can be reused in other projects as they may still have plenty of useful life left. These modules can find new opportunities in charitable, off-grid or even grid-connected projects, provided they continue to meet the appropriate building codes and safety standards.

- <u>Module repair</u>: PV modules can be damaged during transit, installation or moving. Some of these modules can be repaired for minor issues and there are several new organizations pursuing this option. If the product is still under warranty, the installer or manufacturer can be contacted to

[8] https://www.nrel.gov/docs/fy21osti/74550.pdf

determine if repair is an option. Many modules that are repaired today are often reused in off-grid or non-grid connected applications.[9]

- Module component & material extraction: PV panels typically consist of glass, aluminum, copper, silver and semiconductor materials that can be successfully recovered and reused. By weight, more than 80 percent of a typical PV panel is glass and aluminum – both common and easy-to-recycle materials.[10]

Lower cost and higher efficiency solar modules, as well as federal tax incentives, are prompting some organizations to predict a sharp increase in repowering of solar PV facilities, even if the plants have not been in operation for the expected 25- to 35-year lifetime.[11] Although the net impact may be more efficient solar generating facilities that can generate more power over the same amount of surface area, one potential negative side effect is an increase in the quantity of solar module waste to be either recycled or disposed of.

2.2 Potential Soil Contamination

Solar panels and their structural support systems (e.g., cement) may contain potentially toxic/hazardous elements,[12] including zinc, copper, nickel, gallium, lead, indium, cadmium, and chromium.[13] The testing of solar panels using the TCLP method yields variable results. The TCLP test requires that materials be crushed prior to leaching, and leaching is performed at a solid-liquid ratio of 1:20 for 18 hours. The leaching reagent is designed to mimic the weak acid content of a municipal landfill. In some cases, TCLP tests for solar modules return hazardous results. EPA's website on solar panel decommissioning notes that some solar panels are classified as hazardous waste, while others are not.[14]

According to the U.S. Department of Energy, research has found that "leaching of trace metals from the PV panels is unlikely to present a significant risk due to the sealed nature of the installed cells."[15] This is buttressed by a 2017 study which indicated that soils located proximal to a PV system determined that soil enrichment of lead and cadmium did not occur closer to the PV systems and, on average, no elements were above screening thresholds established by the EPA's Eco-SSL.[16] However, if the panels become damaged or are improperly disposed of during decommissioning, there is the potential for environmental contamination.

2.3 Biological Impacts and Land Restoration

Typical solar projects in Maryland include a condition for decommissioning, which involves dismantling, and disposal of all components, including cables, wires, and foundations above and below

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[9] https://www.seia.org/sites/default/files/2020-01/SEIA-EOL-Considerations-PV-Factsheet-May2019.pdf
[10] Ibid.
[11] https://www.nrel.gov/docs/fy21osti/74550.pdf, , accessed September 2, 2022.
[12] https://docs.google.com/viewerng/viewer?url=https://www.jnrd.info/wp-content/uploads/2019/05/1831.pdf&hl=en_US
[13] https://www.sciencedirect.com/science/article/abs/pii/S0883292719301738
[14] https://www.epa.gov/hw/end-life-solar-panels-regulations-and-management
[15] https://www.energy.gov/eere/solar/farmers-guide-going-solar
[16] Robinson, Seth A. and Meindl, George A. (2017). Journal of Natural Resources and Development: *Potential for leaching of heavy metals and metalloids from crystalline silicon photovoltaic systems.* Vol. 9, 19-24, https://doi.org/10.5027/jnrd.v9i0.02

the ground. The decommissioning plan also addresses the site conditions after decommissioning, which includes stabilization, grading and seeding all disturbed areas, and evenly distributing topsoil if stockpiled onsite. Typical decommissioning recommendations in Eastern states include stabilization and re-vegetation of the site.[17] Some counties, such as Charlotte County, Virginia, have enacted ordinances for stabilization and revegetation. The Charlotte County ordinance provides that :

> Decommissioning shall include removal of all solar electric systems, buildings, cabling, electrical components, security barriers, roads, foundations, pilings, and any other associated facilities, so that any agricultural ground upon which the facility and/or system was located is again tillable and suitable for agricultural uses. Disturbed earth shall be graded and re-seeded unless the landowner requests in writing that the access roads or other land surface areas not be restored. Hazardous material from the property shall be disposed of in accordance with federal and state law.[18]

Solar energy plants have an anticipated operational lifespan of 25 to 35 years, although the technology is evolving, and operational experience is still relatively limited. In 2020, researchers at the University of Alberta noted that at the end of the lifespan, plant components are expected to be decommissioned or the facility could be replaced or repowered, depending on locations and objectives of the facility.[19] The reclamation phase includes removing the power generating equipment and all infrastructure, recontouring the site and access roads, replacing or supplementing soil, and revegetation to suit the original land use. The goal of reclamation is to develop a fully functioning ecosystem after disturbance (e.g., native grasslands reclaimed to native grasslands, or forest sites reclaimed to forest or pasture) depending on the reclamation target.[20] The researchers also recommended that the area initially should be revegetated between and under rows of solar panels once installed and monitoring should continue as the vegetation develops. Control of undesirable plant species such as weeds may be necessary throughout the operational phase which will allow for a better restoration process following decommissioning.

Project activities during the decommissioning/reclamation phase may impact soil resources, as it could involve ground disturbances that increase the potential for soil compaction, soil horizon mixing, soil erosion and deposition by wind, soil erosion by water and surface runoff, and sedimentation of nearby surface water bodies.[21] Ground-disturbing activities during decommissioning typically include removal of most, if not all, equipment, and removal of permanent structures and improvements (including on-site and access roads). Direct adverse impacts may be smaller than during construction, because the objective of this project phase is to return the site to its native condition (e.g., by re-establishing native vegetative communities) and the use of existing access roads would reduce impacts such as compaction

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[17] NYSERDA, 2020. Solar Guidebook for Local Governments. Section page 159-Decommissioning Solar Panel Systems: Information for local governments and landowners on the decommissioning of large-scale solar panel systems. https://www.nyserda.ny.gov/All-Programs/Programs/NY-Sun/Communities-and-Local-Governments/Solar-Guidebook-for-Local-Governments

[18] SolUnesco, 2018. Review of Counties Solar Decommissioning Requirements in Virginia. http://www.solunesco.com/wp-content/uploads/2018/09/VA-County-Decommissioning-Requirements-3.0-20180831.pdf

[19] Dhar, A., M. A. Naeth, P. D. Jennings, and M. Gamal El-Din. 2020. Perspectives on environmental impacts and a land reclamation strategy for solar and wind energy systems. Science of the Total Environment. 718:1-17. https://doi.org/10.1016/j.scitotenv.2019.134602

[20] Dhar, A., *et al*. 2020.

[21] Patton, L., L. Almer, H. Hartmann, and K.P. Smith (eds). 2013. An overview of potential environmental, cultural, and socioeconomic impacts and mitigation measures for utility-scale solar energy development. Argonne National Laboratory, ANL/EVS/R-13/5. http://www.evs.anl.gov/downloads/Solar_Environmental_Impact_Summary.pdf

and erosion.[22] Soil contamination could result from fuel and oil releases related to the use of trucks and mechanical equipment and toxic metal releases if solar cells are broken during facility dismantling.[23] Mitigation practices and principles that could apply to the decommissioning/reclamation phase of a solar energy project include the following:

- Develop and implement a site-specific Project Decommissioning and Site Reclamation Plan.
- Apply mitigation measures developed for the construction phase to similar activities during the decommissioning and reclamation phase.
- Maximize the area reclaimed to minimize habitat loss and fragmentation.
- Expedite the re-establishment of vegetation for site stabilization.
- Leave facility fencing in place for several years to preclude large mammals and vehicles from disturbing revegetation efforts.
- Remove all aboveground structures from the site and avoid leaving debris on the ground where wildlife regularly moves.
- Backfill any foundations, pits, and trenches, preferably with excess excavation material generated during prior ground-disturbing activities.
- Reclaim access roads when they are no longer needed.
- Use topsoil removed during the installation of the project or during decommissioning activities to reclaim disturbed areas.
- Reestablish the original grade and drainage pattern to the extent practicable.
- Implement a site reclamation plan.
    - Reclaim all areas of disturbed soil using weed-free native shrubs, grasses, and forbs.
    - Restore the vegetation cover, composition, and diversity to values commensurate with the ecological setting.
    - Review reclamation efforts and weed control periodically until the site is determined to have been successfully reclaimed.

The following mitigation practices and principles can be used to protect water resources during decommissioning:

- Develop and implement a decommissioning plan that includes the removal of all aboveground facilities and full reclamation of the site.

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[22] Patton, L., *et al*. 2013.
[23] Patton, L., *et al*. 2013.

- Reestablish the original grade and drainage pattern to the extent practicable.
- Restore the banks of waterbodies to their natural condition.
- Backfill any foundations and trenches, preferably with excess excavation material generated during construction.
- Adhere to groundwater and/or surface water monitoring activities as outlined in an established Water Resources Monitoring and Mitigation Plan for the site.
- Contour soil borrow areas, cut-and-fill slopes, berms, water bars, and other disturbed areas to approximate naturally occurring slopes.
- Feather edges of vegetation to reduce form and line contrasts with the existing landscapes.
- Salvage and reapply topsoil from all decommissioning activities during final reclamation.

2.5 Land Use and Community Considerations

Anticipated socioeconomic impacts from decommissioning renewable energy facilities in Maryland are dependent upon several factors relating to past and future use of underlying lands, their location, and the extent to which the surrounding economic landscape changes over their operational life. Few utility-scale solar and wind projects have reached the end of their lifespan in the U.S., and presently none have reached that point in Maryland. The projects that have come to their end-of-life horizons, particularly wind facilities, have more often been repowered rather than decommissioned.[24] Repowering utility-scale PV facilities is expected to become an attractive option for the solar industry.[25]

Restoration of a site to “pre-existing condition” is typically the goal of a decommissioning plan for a solar project. Restoration includes the physical removal of all ground-mounted structures, equipment, security barriers, below-ground supports, cabling, conduits and transmission lines from the site; disposal of all solid and hazardous waste in accordance with local, state, and federal waste disposal regulations; and stabilization or re-vegetation of the site.

However, restoration requirements may be dependent on the post-decommissioned use of the site. For projects sited on agricultural land, restoration for agricultural use may not be the best option if farming the property is no longer financially or otherwise feasible. For example, Morgnec Solar is proposed to be sited on two agricultural parcels within Chestertown’s designated growth area, and while development of the parcels for residential use is not imminent, the land would essentially be preserved for future development if the project is permitted.[26] Two other proposed utility-scale solar PV projects in Maryland are located on brownfield (Jade Meadow) or abandoned, partially developed (Spectrum)

[24] Wyatt, Jessi. 2020. Great Plains Institute: *Repowering and Decommissioning: What Happens in Communities When Solar and Wind Projects End?* Retrieved from: https://www.betterenergy.org/blog/repowering-and-decommissioning-what-happens-in-communities-when-solar-and-wind-projects-end/

[25] Parnell, James. 2020. GTM: Solar Repowering Could be Coming Sooner Than You Think. Retrieved from: https://www.greentechmedia.com/articles/read/solar-repowering-could-be-coming-sooner-than-you-think

[26] PPRP’s recommended license conditions for this case would require the project to be decommissioned after 25 years if the PSC determines it is in the public convenience and necessity to allow for Chestertown’s residential growth.

parcels. In such cases, the landowner or operator may choose to leave designated below-grade foundations in order to minimize erosion and disruption to vegetation. This suggests some flexibility needs to be built into decommissioning plans since future uses of land are uncertain after solar projects are decommissioned.

For a site previously used for agriculture, restoration of a site to its condition prior to development typically means being returned to an agriculturally productive state that allows for safe agricultural practices. This requires complete removal of below ground structures and cabling. Decommissioning the site for the resumption of agricultural production may also have to address soil compaction caused by equipment used to construct the facility. Deep tilling, where soils are ripped to at least one foot below the surface, is the primary method for relieving compaction.

Most utility-scale solar PV projects in Maryland are required by County land use regulations and to mitigate visual impacts. Landscaping consists typically of a combination of shrubs and trees within a linear, unraised buffer up to 50 feet wide, planted outside perimeter security fencing. Depending on existing vegetation outside its limit of disturbance, and whether there is a need to shield the solar panels from all surrounding viewpoints, landscape buffers may partially or completely enclose an array. Proposed buffer landscape plans for current and active solar PV projects in Maryland usually include a variety of evergreen and deciduous shrubs plus evergreen trees, with shrubs approximately 18 inches and trees 6-foot height at planting. Depending on the species, shrubs can grow to 6-15 feet at maturity, with trees maturing to 50-80 feet. Since shading of solar panels needs to be avoided, tree heights may vary within a buffer depending on their location.

Landscape buffers are a form of afforestation within project parcels. The 50-foot landscape buffer that completely encloses the proposed Perennial Solar project, for example, occupies approximately 6 acres within a limit of disturbance of 58 acres. A decommissioning plan's goal of restoring a site to its condition prior to development suggests landscape buffers will be removed with other project components, although buffer removal is not specified in decommissioning plans reviewed to date by PPRP. Permitting for decommissioning activities could also trigger Maryland's Forest Conservation Act (FCA) requirements if the landscape buffer is removed.

However, decommissioning plans generally defer to the landowner regarding the removal of project components, of which a landscape buffer is one. If the project site is returned to agricultural use, particularly crop production, the benefit of a landscape buffer as a windbreak would have to be weighed against the loss of cropland, shading and other considerations. Residential and commercial land developers might consider landscape buffer removal to reduce view impedance of their projects. Because landscape buffers present a visual contrast to viewers due to their linearity and uniformity of design, they are not universally appreciated. Proposed landscaping has been described as "a wall of unnatural proportions" in one case before the PSC, while in other cases, members of the public have expressed their concern over loss of view because of landscape buffers. In the absence of a visual disamenity, such as a solar project, it is unclear whether landscaping serves any purpose after decommissioning is completed. Depending on site-specific conditions, PSC review of decommissioning plans may need to address whether landscape buffer removal should be included as a requirement.

2.6 Traffic and Transportation

Transportation impacts from renewable energy decommissioning are expected to be similar to construction-related impacts. Passenger vehicle traffic will be generated by a "de-construction" labor force, while trucks will be used to transport excavation equipment and cranes for dismantling project components and site restoration. Combination vehicles will transport project components to landfills and recycling centers. Vehicle scheduling and traffic management will be the responsibility of the project owner. Transport logistics associated with the removal of decommissioned wind turbine blades can be simplified (although not eliminated) if they are cut into sections and loaded onto standard trailers hauled away by tractor trailers.

The destination where decommissioned project components will be transported is less clear. Many common components of renewable energy systems, such as copper and aluminum in cables, steel in array supports or turbine towers can be recycled and/or disposed locally. However, components of both solar and wind energy systems present a disposal challenge.

For solar PV, the majority of solar panels in utility-scale solar PV installations are silicon-based, of which more than 90% is glass, polymer and aluminum, classified as non-hazardous waste. However, panels also contain trace amounts of potentially hazardous waste.[27] And while some solar panels in the United States are refurbished or repurposed, currently most end up in a landfill. There is no solar PV-specific waste law in the United States nor are there national regulations requiring the recycling of end-of-life panels.[28] Some states, such as Washington and California, have enacted policies requiring manufacturers to collect panels for recycling (see additional discussion in Section 2.1).[29] Waste volume is not significant at present, but millions of solar panels are expected to reach their end-of-life in the coming decades. With few qualified recycling locations within the U.S. at present, transport of retired solar PV components needs to be a cost and logistical consideration in solar decommissioning plans.

2.7 Financial Surety Mechanism

The costs and risks related to the proper decommissioning of a solar facility in Maryland are subject to tremendous uncertainty, due in part because of the early stage of utility-scale solar development and the small number of solar plants that are near retirement. (The typical operating life of a utility-scale solar power plant is assumed to be 25 to 35+ years.)[30,31] Decommissioning costs can vary over time due to a number of factors including the costs of disposal, land restoration, labor, and the scrap value of

[27] Stephanie Weckend, Andreas Wade, and Garvin Heath, End-of-Life Management: Solar Photovoltaic Panels, IRENA and International Energy Agency Photovoltaic Power Systems Programme, June 2016.

[28] According to the Solar Energy Industries Association (SEIA), end-of-life disposal of solar products in the U.S. is governed by the federal Resource Conservation and Recovery Act (RCRA).

[29] https://earth911.com/eco-tech/the-state-of-solar-panel-recycling-in-the-u-s/

[30] Existing solar plants may also be repowered over time, with newer and more advanced solar panels replacing existing panels, delaying plant retirement beyond the 25- to 35-year lifetime discussed above. Because the site is permitted and interconnection agreements are in place, repowering existing sites will be easier than developing new greenfield sites. Some older wind projects are being repowered with newer turbines, for example, in states such as California, Illinois, Iowa, and Texas.

[31] Ryan H. Wiser, Mark Bolinger, and Joachim Seel, "Benchmarking Utility-Scale PV Operational Expenses and Project Lifetimes: Results from a Survey of U.S. Solar Industry Professionals," National Renewable Energy Laboratory, June 2020, https://emp.lbl.gov/publications/benchmarking-utility-scale-pv.

constituent materials. The risks depend on the likelihood of site abandonment, which in turn stems from a variety of environmental and economic factors.

Because of these uncertainties, landowners, regulatory commissions, municipalities, and state governments are employing a variety of approaches to utility-scale solar plant decommissioning during the agreement, certification, and/or licensing stages of project development. This section will describe some of the most common financial and regulatory mechanisms intended to ensure that a responsible party has appropriate financial resources in place to undertake and administer decommissioning of the renewable facility.

Imposing specific requirements for decommissioning solar projects involves tradeoffs. For example, requiring upfront financial assurance for decommissioning costs guarantees compliance, but increases development costs and may act as a disincentive for solar construction. As a result, public and private entities have developed a range of strategies that accommodate different financial preferences and levels of risk tolerance. Table 2-1 summarizes these approaches.

Table 2-1. Financial and Regulatory Approaches to Solar Decommissioning	
Financial Mechanisms	
CORPORATE GUARANTEE	A company agrees to be held liable and/or responsible for completing the duties and obligations of a project developer, usually a parent or affiliated entity.
SURETY BOND	A project owner submits a bond that is equal to the full decommissioning costs of a project and payable to the landowner or government. Under this arrangement, a third party agrees to pay the landowner or government if the developer fails to complete its duties and obligations. The project owner pays an annual premium to the bond company.
INSURANCE	An insurance provider guarantees compensation equal to a project's full decommissioning costs as applicable under specific conditions following a developer failing to meet its obligations.
LETTER OF CREDIT	A bank assures a landowner payment equal to full decommissioning costs of a project as applicable under specific conditions whereby a developer fails to meet its obligations. Typically, a letter of credit is renewed annually for a fee.
TRUST FUNDS	Escrow accounts, sinking funds, or cash accounts dedicated to accumulating sufficient funds to afford eventual decommissioning efforts. The developer makes payments during the facility lifecycle until the full decommissioning costs are reached.
LAND-LEASE AGREEMENT PROVISIONS	Contractual provisions included in a land-lease agreement that require a developer to remove equipment and restore leased land. These agreements reflect participant preferences for how to assign responsibility, allocate costs, and distribute risk.
Regulatory Mechanisms	
SPECIAL APPROVAL PERMITTING	A mandate that the developer submit a decommissioning plan as part of siting and approval processes. In the case of noncompliance, this plan can serve as justification for a lien on the facility property.
TEMPORARY VARIANCE PERMITTING	A re-licensing system that allows regular reassessment of land use and decommissioning costs. If the permit is not reissued, the developer is subject to zoning enforcement and related civil penalties and fines.
ZONING	Abandonment and removal clauses in the zoning code that make decommissioning a zoning enforcement matter. Project owners can be mandated to fulfill their decommissioning duties and obligations at the risk of civil penalties, fines, and/or a lien on the facility property.

Adapted from: New York State Energy Research and Development Authority, *Decommissioning Solar Panel Systems*, September 2016, https://www.nyserda.ny.gov/-/media/NYSun/files/Decommissioning-Solar-Systems.pdf.

Corporate guarantees help overcome risk by assigning liability to larger and more stable commercial entities. For example, instead of relying on the long-term financial security of a project-specific, special purpose entity, a government may require a corporate guarantee from a diversified holding company.

However, the beneficiary must be sure to independently verify the financial wherewithal of the parent company.[32]

Insurance, bonds (sureties), and letters of credit mitigate risk by assigning the liability for improper disposal and/or restoration to third-party financial institutions with expertise in risk management. Both bonds and letters of credit are common options for ensuring the proper decommissioning of solar projects because they transfer the financial risk to a third party to ensure taxpayers and customers are not forced to pay the liability thereby allowing project developers to concentrate their focus on project management and operation.

Trust accounts allow for the gradual accumulation of the funds necessary for decommissioning. The amount and frequency of payments can be specified in a land-lease contract. However, there is a high opportunity-cost associated with this approach, since it ties up a significant portion of decommissioning funds years before they are needed. Thus, trust accounts have rarely been used for financial assurance in Maryland.[33] In a sinking fund approach, the owner allocates increasing amounts of cash to a third party based on the total estimated costs necessary to decommission a facility. The trust should be developed in a manner such that funds allocated for the provision of decommissioning remain solely applicable for that express purpose. In the case of Costen Solar (PSC Case No. 9662), the PSC approved a financial surety based on a sinking fund approach combined with property and casualty insurance. The PSC further required Costen Solar to annually report on the status of its external trust and provide evidence that it has secured appropriate insurance coverage to compensate for the balance of its unfunded liabilities. The decommissioning cost estimate must be updated every five years.

Adding conditions to a land-lease agreement is a flexible means to contractually provide mechanisms for eventual decommissioning of the solar project. For example, an agreement could include buyout provisions, whereby the landowner can take control of the facility and use project revenues to pay for eventual decommissioning, or pass-through provisions, whereby the landowner pays the decommissioning costs and passes them through to the solar developer.

Governmental entities can also exercise control over solar decommissioning by requiring solar decommissioning plans, schedules, and financial measures as a condition of receiving a siting permit or zoning approval. These regulatory interventions motivate decommissioning efforts through the threat of siting invalidation or the loss of needed permits. Although not financial in nature, these mechanisms allow for collection of the full decommission costs through the assessment of civil penalties, fines, and liens on facility property.[34]

For financial and regulatory mechanisms to remain effective over a 25-to-35-year period, it is essential that the estimated financial liability be regularly updated over the course of the service life of the

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[32] In Maryland, the PSC has no precedent of accepting a corporate guarantee as financial surety to cover solar facility decommissioning costs. The applicants for solar CPCNs are typically limited liability entities and are subject to multiple transfers of ownership during facility development, construction and operation, which makes it overly burdensome to perform due diligence and reliably assess the financial health of the guaranteeing entity.

[33] A variation on this approach involves the use of a pooled fund, which aggregates contributions of facility owners by type (e.g., nuclear plants). Contributors may use the fund to pay for decommissioning of their facility. Not surprisingly, this approach is considered risky by those who would be harmed if a fund were depleted before a given project could be decommissioned.

[34] A lien on developed property, however, is less effective when a facility is already near the end of its expected useful life.

renewable facility. Decommissioning plans typically include provisions for cost and salvage value estimates to be updated on a regular basis, such as every two, five (as is currently the case in Maryland), or 10 years. Additionally, the decommissioning process must be unambiguous and include specific time frames and restoration conditions. The process for updates ensures that whatever financial assurance was used for the facility can be properly updated to reflect market conditions with the ultimate goal of ensuring that taxpayers and utility customers are not left exposed to costs. No Maryland facility has yet reached a point in its service life that would require the project owner to update the estimated decommissioning costs. The earliest CPCNs granted for solar facilities in Maryland have varying requirements for updating their decommissioning cost estimates:

- Case 9272, MCI Solar – Although it was not in the CPCN condition language, the Applicant (Maryland Solar) agreed to provide 10-year updates to decommissioning costs as part of the process of obtaining PSC approval for its decommissioning plan and financial assurance. Maryland Solar, LLC, provided updated documentation in 2017 and 2018 to reflect ownership changes with respect to the surety bond. The surety bond was further revised in 2022 and approved by the PSC via letter order dated 21 December 2022.
- Case 9314, Church Hill Solar Farm – The Queen Anne's County ordinance applicable at the time this project was reviewed required a decommissioning bond; however, the County Board of Appeals determined that salvage value exceeded decommissioning costs and therefore, no bond was required. Church Hill Solar submitted its decommissioning plan to the PSC in September 2015; no condition was imposed by the PSC or Queen Anne's County to provide periodic updates to the decommissioning cost estimate.
- Case 9351, Rockfish Solar, was the first solar project in Maryland that submitted a decommissioning plan in accordance with a CPCN condition that also requires 10-year updates. The plan, cost estimate and financial mechanism for Rockfish Solar were submitted in December 2014 and are due to be updated by December 2024.
- Case 9348, Cambridge Solar, represents the first CPCN that was granted with a condition requiring 10-year updates to the decommissioning plan, cost estimate and financial mechanism. The applicant did not submit its plan to the PSC until September 2016; an update is due in September 2026.
- Two solar projects submitted decommissioning plans in 2015, with 10-year updates required in 2025 – LS Egret and Wye Mills.
- In Case 9380, Great Bay, the Applicant requested a modification from the PSC to address changes made during Phase II of construction. As part of the Phase II CPCN modification review process, PPRP recommended and the PSC imposed a five-year update period for the decommissioning plan and cost estimate, for the first time. PSC approval of the decommissioning plan prior to the start of construction was also required. The decommissioning plan, cost estimate and financial assurance for the entire Great Bay solar facility (Phases I and II) was approved by the PSC in August 2020; the five-year update is due in August 2025.

2.8 Cost Estimates and Decommissioning Plans

Because most utility-scale solar projects came online in the past few years, and solar PV projects can be in operation for 25 to 35 years, few utility-scale solar projects have been decommissioned to date. With little real-world data to rely upon, it is perhaps to be expected that estimates of the decommissioning costs of solar projects vary widely. For example, in 2018, a Solar and Wind Decommissioning Working Group in Minnesota noted that decommissioning plans for permitted solar facilities in the state contained net cost estimates (i.e., costs less salvage value) ranging between $22,000/MW and $56,000/MW.[35,36] The lack of standardization of costs and benefits across solar decommissioning plans is a known issue in the solar industry; decommissioning costs will have to be reviewed on a case-by-case basis for the foreseeable future, until more data and analysis are available.

An illustrative sampling of solar decommissioning cost estimates from multiple states is provided below in Table 2-2. The net cost estimates range from a high of $95,000/MW to a net benefit of $84,000/MW. Three solar PV decommissioning plans filed in 2019-2020 with the Maryland PSC include net decommissioning cost estimates under $10,000/MW. These plans assume that the salvage value will nearly offset decommissioning costs that range from $112,000-$147,000/MW.

Table 2-2. Illustrative Cost and Benefit Estimates from Recent Decommissioning Plans

				Total Costs/Benefits ($M)			**Average Costs/Benefits ($/MW)**		
Project	**State**	**Size (MWac)**	**Filing Date**	**Costs**	**Recycling/ Salvage**	**Net Cost**	**Costs**	**Recycling/ Salvage**	**Net Cost**
Hebron Solar	MD	15.0	May-15	$2.9	($1.5)	$1.4[2]	$195,000	($98,800)	$95,000
RE Poplar	VA	100.0	Jan-20	11.2	(5.0)	6.2	111,832	(50,154)	61,678
East Point Energy Center	NY	50.0[1]	Sep-19	3.0	0	3.0	60,161	0	60,161
Community Solar Facilities	NY	2.0	Jul-17	0.1	0	0.1	30,100	0	30,100
Spotsylvania Solar Energy Center	VA	500.0	Dec-18	36.7	(25.7)	11.0[2]	73,411	(51,466)	21,945
Beacon Solar	MA	4.0	May-19	0.3	(0.2)	0.1[2]	76,531	(55,665)	20,866

[35] Minnesota Commerce Department, Solar and Wind Decommissioning Working Group Report and Recommendations, August 2018, Minnesota Public Utilities Commission, Docket No. E-999/M-17-123.

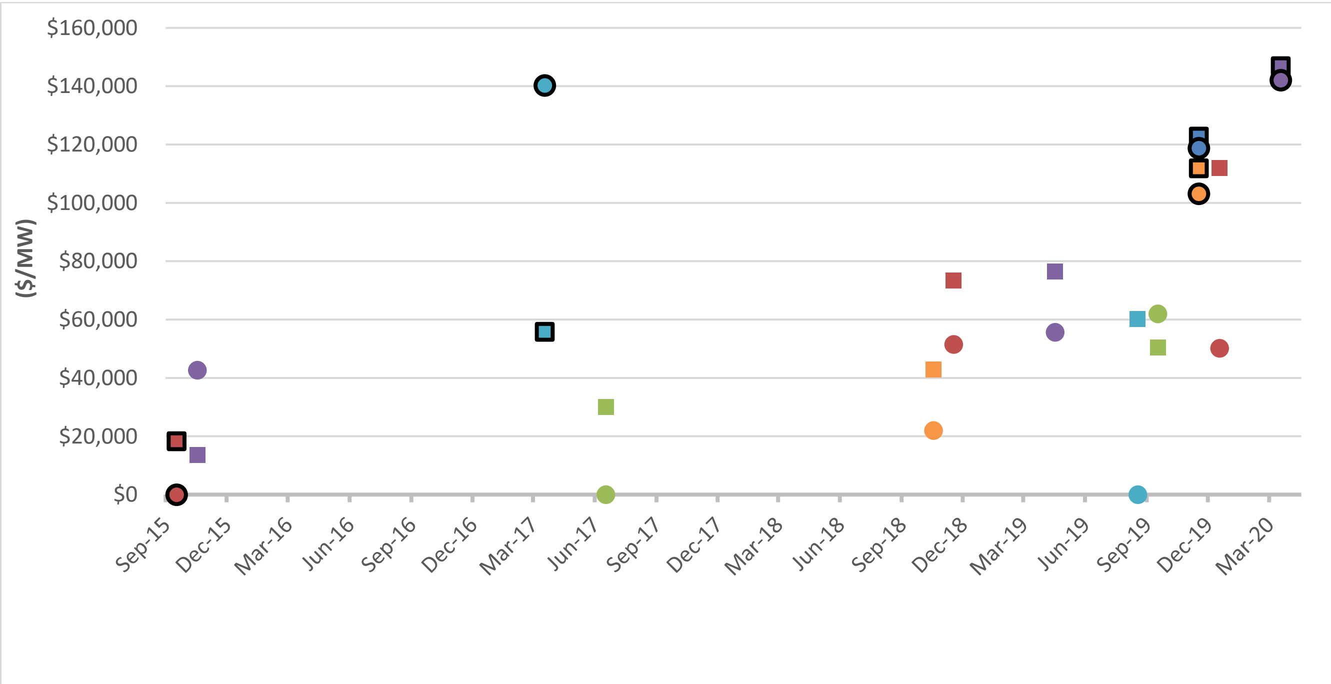
[36] The report also states that recent decommissioning cost estimates for wind (less salvage value) ranged from $26,000-$145,000/MW.

Boutilier Road Solar Project	MA	5.0	Nov-18	0.2	(0.1)	0.1	42,916	(21,964)	18,744
OneEnergy Wye Mills Solar	MD	10.0	Oct-15	0.2	0	0.2	18,315	0	18,315
Rockfish Solar Project	MD	10.0	Dec-14	0.5	(0.3)	0.2	48,300	(31,500)	16,800
Bluegrass Solar	MD	80.0	Dec-19	8.9	(8.3)	0.7	111,874	(103,161)	8,713
Great Bay Solar I & II	MD	118.0	Apr-20	17.3	(16.8)	0.6	146,864	(142,059)	4,805
Union Bridge Solar	MD	8.2	Dec-19	1.0	(1.0)	0.0	122,704	(118,785)	3,919
Reams Solar I	VA	5.0	Oct-19	0.3	(0.3)	(0.1)[2]	50,413	(61,949)	(11,636)
Abby Solar	MA	16.9[3]	Nov-15	0.2	(0.7)	(0.5)	13,625	(42,626)	(29,001)
OneEnergy Baker Point Solar	MD	8.2[3]	Apr-17	0.5	(1.1)	(0.7)	55,795	(140,270)	(84,475)

[1] Value not specified as AC or DC; assumed to be AC.
[2] Net cost calculations in the decommissioning plan appear to have minor mathematical inconsistencies. That is to say, Cost – Benefits ≠ Net Cost. Only in one case is the discrepancy between the printed value for Net Cost and a calculated value for this term above 1.5% of Net Cost. This is the Boutilier Road cost estimate, which does not include an $11,041 value labeled "Contractor Mark-up – 10%" in the final Net Cost.
[3] Values converted from DC to AC using a ratio of 1.3(DC):1.0(AC).

Figure 2-1 shows selected decommissioning cost and benefit forecasts from 2015-2020. Four of the benefit estimates from Maryland-based projects are among the highest in the decommissioning plans that were reviewed. The most recent projects also have the highest estimates for decommissioning costs.

Figure 2-1. Selected Cost and Benefit Forecasts (Sept 2015-April 2020)



Note: Decommissioning plans with benefit shown as $0/MW did not forecast project benefits at all.

A high-level review of individual line items from 14 solar decommissioning plans,[37] all submitted within the past five years, was conducted to identify significant drivers of decommissioning costs and benefits.

To make comparisons across these (non-standardized) decommissioning studies, closely related line items were grouped into broader "umbrella" cost and benefit categories. For example, the costs or benefits of both DC line removal and AC line removal were grouped under the category "Wiring/Metal." Likewise, the costs of a number of discrete activities, such as seeding, grading, and erosion control, were grouped under the cost category "Site Restoration."

2.8.1 Top Drivers of Decommissioning Costs

When grouped as described above and then ranked by total cost, the cost categories that most commonly appear in one of the top five slots are listed, and briefly described,[38] below:

[37] The plans are a subset of those listed in Table 2. Illustrative Cost and Benefit Estimates from Recent Decommissioning Plans: RE Poplar, Bluegrass, Baker's Point, Boutilier Road, Citizens UB, Abby, Beacon Solar, Great Bay I, Great Bay II, Hebron, Reams, Spotsylvania, East Point, Community Solar, Wye Mills.

[38] In many cases, decommissioning plan line items are listed without further description. Those plans that do provide prose descriptions naturally differ with respect to the specific tasks listed and/or the scope of work included. The descriptions in this section are meant to be illustrative, not definitive. They are drawn primarily from the decommissioning plan for the Bluegrass Solar project in Queen Anne's County, MD.

1. Modules – the inspection of modules for physical damage, testing for functionality, disconnection from racks, packing and shipping for reuse, resale, recycling or disposal.
2. Posts – the removal of structural foundation posts, processing of posts to an appropriate size for recycling, and shipping to a recycling facility.
3. Site Restoration – the treatment of soil to re-establish pre-construction drainage patterns and fertility, seeding intended to restore natural hydrology and plant communities.
4. Tables/Racking – the disassembly of racking, processing of racks to an appropriate size for recycling, and shipping to a recycling facility.
5. Wiring/Metal – the removal of overhead and underground cables and conduits, backfill and compaction of excavated areas, topsoil redistribution.

Among the plans reviewed, these five cost categories collectively represented, on average, 70% of a PV project's total projected decommissioning expenses.[39]

As shown in Table 2-3 below, each of these "Top 5" cost categories exhibits dramatic cost variation when viewed on a simple cost per MW basis. The variation below is likely due to both (a) differences in the amount of decommissioning work to be done and (b) methodological differences in cost estimation. As an example of the former, the decommissioning plans for Great Bay I and Great Bay II each contain a line item for the removal of a buried AC line to a substation. In each plan, this represented the single most expensive component of the decommissioning plan. Other projects may simply interconnect to an overhead tap, and therefore have no analogous removal expense. Because individual line items were grouped for purposes of this high-level review, specific individual line items were not closely reviewed, but differences in cost estimates among individual line items were noticeable even at high level. One example is the costs per unit of equipment (e.g., $/linear foot (LF) for wiring removal). The removal of underground AC wiring for Great Bay I and II was estimated to cost $122/LF, while removal of other forms of wiring was estimated to cost $0.07/LF-$0.78/LF.

Table 2-3. The Most Common Major Cost Drivers in Decommissioning Plans ($/MW)

Cost Category	**Cost Range Across Plans ($/MW)**	**Average Cost ($/MW)**
Modules	1,225-40,027	16,752
Posts[1]	250-34,237	16,145
Wiring/Metal[2]	1,630-56,881	12,607
Table/Racking[1]	806-27,561	10,999
Site Restoration	888-18,127	9,081

[1]Does not include RE Poplar, which has a line item that combines table/racking and posts at a cost of $3,131/MW
[2]Does not include Baker's Point line item for removal of fiber optic lines at a cost of $2,933/MW

There are several other elements that are included less frequently in decommissioning plans –meaning the item does not have a separate line item. However, when these elements do appear in a plan, they may

[39] For the analyses in this section, Total Costs have been represented without markups, e.g., for contingency costs or inflation.

well rank among the top five plan elements by cost. For the plans reviewed, the following cost categories fit this description:

- Battery – the removal of a battery system co-located with a PV facility.
- Equipment – the use of heavy equipment such as bulldozers, backhoes, and dumpsters.
- Fencing – the removal of project fence parts and foundations.
- Foundations – the excavation and removal of concrete equipment pads, and subsequent refilling of excavated areas.
- Labor – the use of manpower to inspect, disassemble, remove, etc. facility elements.
- Transformers/Electrical – the disconnection, disassembly, and removal of all electrical equipment.
- Shipping – the transport of heavy materials, such as PV modules, for resale, recycling, or disposal.
- Wiring/Other – the removal of fiber optic wiring (as opposed to standard DC/AC wiring).

2.8.2 Top Drivers of Salvage/Recycling Values

Of the fourteen plans reviewed, three did not assume any salvage or recycling value, likely at the instruction of the jurisdictional county or a state regulatory agency such as a public utility commission. For the other 11 plans, decommissioning components projected to have salvage and/or recycling value were also grouped by type and then ranked. Four of the "Top 5" drivers of salvage and/or recycling value—modules, tables/racking, wiring/metal, and posts—are also "Top 5" drivers of decommissioning costs. The sole difference here is that Transformers/Electrical rounds out the list instead of Site Restoration. There is less diversity among value drivers; these "Top 5" categories represent an average of 96% of projected value, across the projects reviewed.

Table 2-4 shows the PV facility components that most commonly appear as a "Top 5" driver of salvage and/or recycling value (and their corresponding cost from Table 2-2, if applicable). Many of the observations made earlier with respect to cost projections apply here as well: (1) the value categories exhibit dramatic variation when viewed on a simple cost per MW basis; (2) this variation may be due to a combination of (a) real-world differences between the projects, e.g., differences in the amounts of a given material to be salvaged and (b) differences in valuation assumptions and methodologies; and (3) further analysis of projected benefits on a $/unit basis and/or by line item could help to clarify what factors are in play. In the case of Modules, Tables/Racking, and Posts, the anticipated salvage/recycling value is significantly greater than the cost of disassembly and or removal. Modules are projected to yield almost four times their cost, when decommissioned. However, Modules are the facility component with the lowest amount of real-world historical data upon which to base salvage/recycling value projections.

Table 2-4. The Most Common Top Salvage/Recycling Value Drivers in Decommissioning Plans ($/MW)

Cost Category	Benefit Range Across Plans ($/MW)	Average Benefit ($/MW)	Average Cost (from Table 3) ($/MW)	Ratio of Projected Value: Cost
Modules	$13,020-$115,676	$64,073	$16,752	3.8

Tables/Racking	$8,772-25,000	$18,827	$10,999	1.7
Wiring/Metal	$886-$45,000	$12,608	$12,607	1.0
Posts	$1,341-24,936	$9,641	$16,145	0.6
Transformers/electrical	($31)-$5,733	$3,338	NA	NA

2.8.3 Sources of Cost and Benefit Estimates

In most, if not all cases, an engineering firm is charged with developing a solar PV project's decommissioning plans, including the embedded cost and benefit estimates. Often a blanket statement is made indicating that all cost estimates are based on the engineering firm's in-house resources and experience as well as industry benchmark resources for cost estimation. Two examples of such statements are provided below:

- This Opinion of Probable Cost is based on professional experience and interpretation of project documents, and is based on Swinerton[40] resource data, current in-house information and estimators' judgment regarding this type of product. (Spotsylvania)
- Hatch-developed values for [projects of] similar scope, industry benchmarks, and built-up labor estimates. (Great Bay Solar)

The level of cost detail provided beyond this varies. At one extreme, some plans include absolutely no documentation of the underlying assumptions and methodology used to develop line item cost estimates. These tend to be older plans. The trend is towards documentation, unless a project is quite small, e.g., 2 MW. At the other extreme, some plans provide a paragraph-long description of each line item, spelling out the product and/or personnel assumptions used (e.g., product dimensions, metal composition, weights and/or placement depth; types of personnel expertise required, full- or part-time status; etc.) and data sources relied upon (e.g., regional labor costs from the U.S. Bureau of Labor Statistics).

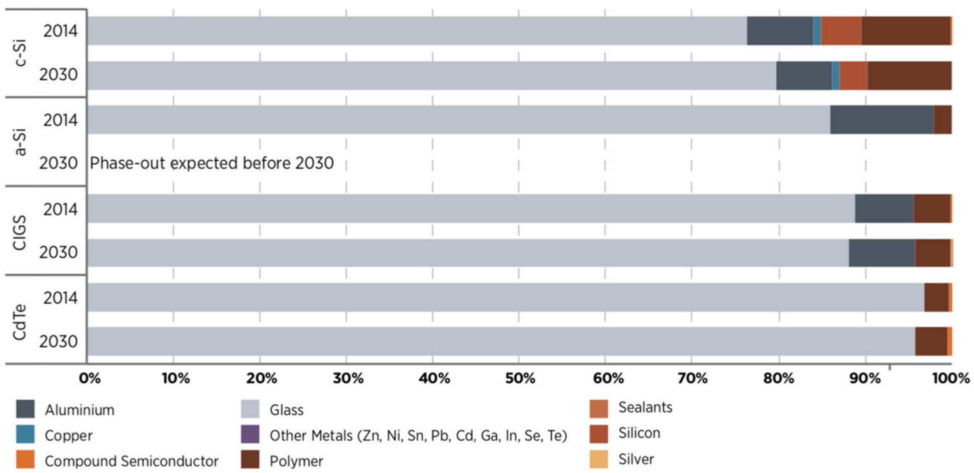
Benefit estimates display more standardization. For major items with easily quantifiable scrap values, such as bulk cables, racking and pile steel/aluminum, and certain power electronics, scrap value is usually assigned based on currently available scrap prices, frequently sourced from Scrapmonster.com or a similar website. When the basis for PV module value projections is specified (five cases), it is either Department of Energy (DOE) price projections or a statement provided by We Recycle Solar, a firm that specializes in solar plant recycling. We Recycle Solar will provide price quotes that are specific to the type of PV module proposed for a project and estimated salvage value for the PV modules 20+ years in the future. This latter value may be discounted by 15%, to be conservative. If DOE projections are used, it is assumed that modules' power output degrades 0.4%/yr for 25 years and 5% of modules are broken during disassembly. The agency's projected price ($/W) for new PV modules in Year 25 is discounted by 50% and then applied to the facility's projected capacity.

[40] Swinerton is a global construction company.

2.8.4 Salvage Value for Panels and Other Components

As the preceding discussion suggests, assumptions regarding salvage value play a large role in the estimation of decommissioning costs. Solar PV panels and associated equipment do have significant reclamation value in many cases. Based on mass, more than 85% of crystalline-silicon (c-Si) PV panels, the world's most popular form of PV panel,[41] consist of materials such as glass, aluminum, and copper that can be recovered (see Figure 2-2).[42] In addition, steel and wood supports retain value as commodities.

Figure 2-2. Materials Used for Different PV Panel Technologies as a Percentage of Total Panel Mass (2014 and 2030)



Note: a-Si = amorphous silicon; c-Si = crystalline silicon; CIGS = copper indium gallium (di) selenide; CdTe = cadmium telluride. *Source:* IRENA and IEA, *End-of-Life Management: Solar Photovoltaic Panels*.

Table 2-5 provides an example of the salvage value estimates that are taken from the data in Figure 2-2. The three primary sources of salvage value, in this case, are the racking system, the copper wiring, and the crystalline solar modules. Because most salvage value estimates are keyed to current commodity prices, the future salvage value of PV facility elements is inevitably uncertain.

[41] As of 2015, two-thirds of PV panels installed worldwide were c-Si. Mainstream PV products, particularly c-Si panels, are expected to continue dominating the PV market through 2030.
[42] Stephanie Weckend, Andreas Wade, and Garvin Heath, *End-of-Life Management: Solar Photovoltaic Panels*, IRENA and International Energy Agency Photovoltaic Power Systems Programme, June 2016.

Table 2-5. Sample Itemized PV Facility Salvage Values

ITEM	COST TO REMOVE/ RESTORE	TOTAL SALVAGE VALUE	NET GAIN/ LOSS
Wire {Copper)	$7,933.65	$102,993.32	$95,059.66
Wire {Aluminum}	$217.59	$913.87	$ 643.54
Racking System	$65,168.00	$107,154.07	$ 41,986.07
Solar Modules {Crystalline)	$33,384.00	$65,098.80	$31,714.80
Inverters	$4,500.00	$3,663.28	$ (836.72)
Transformers	$10,000.00	$25,000.00	$15,000.00
Concrete Pad	$6,000.00	$0.00	$(6,000.00)
6' Chain Link Fencing	$19,862.50	$976.10	$(18,886.40)
Battery Storage System	$30,000.00	$4,000.00	$(26,000.00)
Land Restoration	$15,000.00	$0.00	$(15,000.00)

Source: "Holocene Clean Energy, Building the Foundation for the Future," Presentation to Dinwiddie County, Virginia Planning Commission, September 2019, http://www.dinwiddieva.us/AgendaCenter/ViewFile/Item/3072?fileID=3454.

To eliminate the risk associated with salvage value uncertainty, some jurisdictions have reportedly disallowed the use of salvage value in calculating decommissioning costs. In lieu of this sweeping approach, which could severely impede solar project development, states or counties can take other measures to mitigate the risk from the volatility of salvage prices. For instance, decommissioning regulations may require plans to reduce the expected salvage value of a facility by a fixed percentage or require that a decommissioning plan include a reserve amount to hedge against future fluctuations in salvage value.[43] Various counties in Virginia offer examples of the diversity of possible approaches to salvage value in decommissioning cost estimates:

- Halifax County has prohibited the use of salvage value through conditions placed on several projects;[44]
- Southampton County requires that decommissioning cost estimates give 50% credit for the salvage value of any elements of a project;[45] and
- Accomack County requires that decommissioning cost estimates reduce salvage value by 20% while increasing the gross cost estimate by 20%.[46]

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[43] Lea Maamari, "Decommissioning of Solar Sites: A Key Consideration of the Project," SolUnesco.com, September 10, 2018, https://www.solunesco.com/2018/09/10/decommissioning-of-solar-sites-a-key-consideration-of-the-project/.
[44] SolUnesco, *Review of Counties Solar Decommissioning Requirements in Virginia, Updated August 20, 2018, Version 3,* https://www.solunesco.com/wp-content/uploads/2018/09/VA-County-Decommissioning-Requirements-3.0-20180831.pdf.
[45] Southampton County, VA Code, Chapter 18, Article XXII, Section 18-637, https://library.municode.com/va/southampton_county/codes/code_of_ordinances?nodeId=CO_CH18ZO_ARTXXIIUTSCSOENPRSOCO_S18-637DE.
[46] SolUnesco, *Review of Counties Solar Decommissioning Requirements in Virginia*.

3.0 Decommissioning Outside of Maryland

Since utility-scale solar facilities in Maryland are not expected to be decommissioned until about 2035 (based on a projected lifetime of at least 25 years), we do not yet have empirical data to indicate what solar facility decommissioning looks like in practice. This section focuses on the efforts taken in other jurisdictions to regulate solar decommissioning and address PV panel waste, in advance of the future surge in panel removal that is likely to accompany solar decommissioning or repowering.

According to a 2021 National Renewable Energy Laboratory (NREL) report,[47] 15 states as well as the U.S. Bureau of Land Management (BLM) have established solar decommissioning policies in some form. Among these 15 states, six have state level policies that require solar project owners to submit decommissioning plans and proof of financial assurance. Another eight states have hybrid state and local decommissioning policies that include some state-wide requirements but allow localities to impose additional ones. (Although not included in NREL's report, Maryland fits into this category.) One state, Washington, allows solar project owners the option of pursuing a state certification process instead of obtaining local city and government approvals. In the remaining states plus the District of Columbia, the NREL report indicates local governments have jurisdiction over solar panel decommissioning policies.[48]

Private landowners may also impose additional solar decommissioning requirements, such as site restoration and reclamation. Other factors that vary among states with state-wide decommissioning requirements include whether or not financial assurances for decommissioning are required, how these are calculated and whether the value of recycled panels may be counted toward the financial assurance.

3.1 State Initiatives to Address Solar Panel Waste Management

As of April 2021, only Washington State had enacted a law that requires recycling of solar panels. In 2017, Washington passed Senate Bill 5939 which, in addition to promoting a sustainable local renewable energy industry, requires manufacturers selling photovoltaic modules in Washington after July 1, 2017, to provide recycling of solar panels. No other documented instances of state or local statutes that require recycling of decommissioning waste have been identified. Legislation has been put forth in the following states that address decommissioning waste; legislative activity is underway in additional states regarding decommissioning policy generally without focusing on waste management issues.

California

Prior to January 2021, retired or discarded PV solar panels were classified as hazardous waste in California because they may contain high levels of heavy metals including cadmium, lead and arsenic. The classification as hazardous waste put the burden of testing on the solar plant owner which increases

[47] Curtis, Taylor L., Ligia E.P. Smith, Heather Buchanan and Garvin Heath. 2021. *Survey of Federal and State-Level Solar System Decommissioning Policies in the United States*. NREL/TP-6A20-79650. https://www.nrel.gov/docs/fy22osti/79650.pdf.

[48] Ongoing legislative activity in several U.S. states makes this a dynamic topic; see further recommendations in the Summary and Discussion section of this report.

disposal costs and could discourage recycling of PV solar waste.[49] Recent legislation in California now classifies photovoltaic modules as universal wastes, [50] a less toxic subset of hazardous waste, eliminating the need for solar panel testing and allowing waste to be collected and stored on-site at scrap consolidation facilities for transportation in bulk to recycling facilities.

New York

New York State Assembly Bill A8430,[51] considered by the New York Senate Environmental Conservation Committee in 2022, would require solar panel manufacturers to establish a program to track, collect, transport and recycle solar panels and to develop free educational programs to encourage collection and recycling of decommissioned solar panels. This bill did not advance before the 2022 legislative session ended.

North Carolina

In July 2019, North Carolina passed a law directing the state's Environmental Management Commission to develop regulations for decommissioning utility-scale solar and wind energy projects and management of end-of-life PV panels.[52] As of December 2022, the state has published the following technical reports; however, regulations have not yet been promulgated:

- Final Report on the Activities Conducted to Establish a Regulatory Program for the Management and Decommissioning of Renewable Energy Equipment, January 1, 2021[53]
- Plan and Recommendations for Financial Resources for Decommissioning of Utility-Scale Solar Panel Projects, March 1, 2022[54]

Hawaii

House Bill 2413[55] requires the Hawaii Natural Energy Institute (HNEI), in consultation with the state's Department of Health, to conduct a comprehensive study of best practices for disposal and recycling of solar panels, solar water heaters and other appliances that operate using solar energy. HNEI published an interim report in December 2021; a final report is scheduled for submission to the Hawaii legislature in January 2023.

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[49] Bandyk, Matthew. 2020. WasteDive: *New California regulation could jump-start solar panel recycling sector*. Retrieved from: https://www.wastedive.com/news/california-solar-panel-recycling-landfill/581330/#:~:text=For%20example%2C%20under%20the%20current,to%20recycling%20facilities%20in%20bulk.

[50] https://www.nrel.gov/docs/fy21osti/74124.pdf

[51] The New York State Senate: *Assembly Bill A8430: Enacts the "solar panel collection act.*" Retrieved from: https://www.nysenate.gov/legislation/bills/2021/A8430

[52] https://www/bdlaw.com/publications/nc-to-regulate-the-decommissioning-of-renewable-prjects-and-managing-end-of-life-equipment

[53] https://deq.nc.gov/media/17785/open

[54] https://deq.nc.gov/media/28068/open

[55] House of Representatives, 13th Legislature, 2020. State of Hawaii. H.B. 2413. https://www.capitol.hawaii.gov/session2020/bills/HB2413_.HTM

3.2 Decommissioning Outside the U.S.

While some countries have more experience with renewable energy development than the U.S., decommissioning of utility-scale solar decommissioning is still very limited. In Europe, solar PV waste is classified as electronic waste and subject to the EU Waste Electrical and Electronic Equipment (WEEE) Directive adopted in 2012. WEEE requires all producers supplying PV panels to the EU market (wherever they may be based) to finance the costs of collecting and recycling end-of-life PV panels sold in Europe.[56]

Available information on recycling solar project components in selected countries is summarized below.

Australia

In the southern state of Victoria, Australia, the government recently implemented a ban on all electronic waste entering a landfill that aligns its policy on PV solar waste with the WEEE directive in Europe.[57] Australia does face unique and difficult challenges in its recycling efforts. Long transportation distances to recyclers, low landfill fees and the current low volume of retired PV solar facilities make recycling PV panels in Australia unprofitable.

France

Recognizing that solar waste could be worth up to 15 billion dollars by 2050, France has built Europe's first solar recycling center.[58] With a capacity to recycle 1,400 tons of solar debris in 2018, the French water and waste company Veolia hopes to ramp up to 4,400 tons of recycling capacity by 2022.

Korea

Anticipating the increase in solar PV waste, Korea is building another dedicated solar recycling plant to complement the nation's only other solar recycling facility. Currently capable of recycling 4,000 tons of solar waste, the second government-built public recycling plant will add an additional 4,000 tons of recycling capacity augmented by another privately built facility with 2,700 tons of recycling capacity slated to be operational in 2022.[59] Retired panels that are in operating condition are typically sold to developing countries, while damaged panels are often stripped of their aluminum only and then incinerated. The high cost of recovering trace metals such as silver and copper makes full recycling economically unattractive.

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

[57] Milbank, Dr. Juliette. 2019. Renew Magazine. Retrieved from: https://renew.org.au/renew-magazine/sustainable-tech/recycling-solar/

[58] Clercq, Geert De. 2018. European's first solar panel recycling plant opens in France. Reuters: Environment. Retrieved from: https://www.reuters.com/article/us-solar-recycling/europes-first-solar-panel-recycling-plant-opens-in-france-idUSKBN1JL28Z

[59] Byung-wook, Kim. 2020. The Korean Herald. *Green Paradox What will Korea do with dead solar panels?* Retrieved from: http://www.koreaherald.com/view.php?ud=20201018000088

4.0 Summary and Discussion

4.1 Key Technical Findings

Since the development of utility-scale solar energy projects is still a relatively recent phenomenon, there are few projects that have reached the end of their lifetime. Therefore, there is limited published information available discussing the success (or failure) of properly decommissioning such facilities.

Key findings from this report include the following:

- Few states or counties in the U.S. have specific decommissioning policies in place for solar and wind projects, relying instead on siting and permitting authority to condition approval on the preparation of an acceptable decommissioning plan.
- Much of the material in a solar PV module can be recycled or salvaged, although the salvage values (and costs of removal and transport) can vary widely.
- Recycling and disposal of solar PV modules in the U.S. are at an early stage, and available data suggest that most solar panels that are decommissioned are disposed in landfills. Solar industry recycling initiatives and potential state recycling requirements that may emerge over time could result in more recycling of solar panels as solar decommissioning occurs more frequently.
- There are many financial arrangements for covering future decommissioning costs; most popular mechanisms that we found in our research were surety bonds and letters of credit.
- It is not feasible for Maryland to ensure that decommissioning plans filed today or in the near future include accurate cost and benefit forecasts for the duration of a solar facility's operating life. Therefore, as part of the licensing review process, PPRP has adopted the practice of recommending that solar developers be required to file periodic updates of decommissioning and salvage costs. As long as a project's approval is conditioned upon these forecasts (and any associated financial assurances) being updated regularly, the likelihood is that today's decommissioning plans can be updated over time with better data, well before decommissioning of the renewable facility actually occurs.

4.2 Considerations for Solar Decommissioning Policy in Maryland

Maryland has taken a case-by-case approach towards solar decommissioning which has evolved over time in response to CPCN case experience and new information. Maryland's approach has been to provide guidance and allow CPCN applicants to propose their desired approach for meeting solar decommissioning requirements. Applicants must submit decommissioning plans, including financial surety mechanisms, and receive PSC approval prior to construction. Some Applicants have provided decommissioning plans as part of their CPCN applications; however, most solar developers wait until after the PSC grants approval of a CPCN and then submit a decommissioning plan once the detailed design is complete. The CPCN condition text has evolved over time to include specific items that must be addressed in a decommissioning plan; the checklist in Appendix A to this report presents the requirements that have been incorporated into the most recent CPCNs.

The details of decommissioning plans to be implemented more than 25 years into the future are subject to change for a variety of reasons. Therefore, PPRP has recommended, and the PSC has incorporated into CPCN conditions, a five-year review interval to ensure that plans, cost estimates and financial surety mechanisms are updated to reflect market conditions and industry best practices.

The PSC has oversight responsibility for solar generating facilities 2 MW or greater. Developing standard requirements for solar decommissioning plans and procedures can be accomplished through a PSC rulemaking process, allowing for input from State agencies, counties, legislators, solar industry representatives, interested citizens and other stakeholders.

The recommendations below are offered for consideration, either as part of a rulemaking process or by incorporation into appropriate State policies and procedures.

1. The decommissioning plan checklist in Appendix A should be updated as appropriate to ensure it continues to reflect the requirements for solar decommissioning plans in Maryland. PPRP can provide it to applicants as a guidance document.
2. CPCNs should continue to require applicants to submit updated decommissioning plans, cost estimates and financial assurance documentation every five years to reflect updated market conditions and industry best practice. At a minimum, these updates should include the following:
    a. Plan revisions that may be needed to reflect the as-built specifications of the solar facility, changes in the physical setting or surrounding land use, or potential future use of the solar site after decommissioning;
    b. Updates to the line-by-line cost estimates for decommissioning activities, including references and documentation as appropriate to provide a basis for the cost calculations;
    c. Updates to the line-by-line salvage value estimates, including references and documentation;
    d. Evidence of the financial surety mechanism updated to reflect the current decommissioning cost estimate.
3. Decommissioning plans should provide the anticipated year of decommissioning, and if that changes during the five-year interval between updates, applicants should explain why it has changed.
4. Applicants should be required to submit a preliminary decommissioning plan as part of the initial CPCN application. The preliminary plan should include cost estimates and estimates of salvage value, as well as a proposed financial surety mechanism, which allows for PSC and PPRP staff to evaluate the proposed decommissioning measures and costs as part of the full CPCN review. If a CPCN is granted, the applicant can make adjustments to the decommissioning plan and cost estimates if needed during the detailed engineering design and construction phase. This will be more administratively efficient than the current process in which the applicant files a full decommissioning plan only after a CPCN is granted.
5. The PSC should also consider developing a list of acceptable financial assurance mechanisms rather than giving applicants freedom to propose their own. To date, the PSC has approved Surety Bonds, Insurance, Letters of Credit, Trust Funds, and Sinking Funds. Based on input from PSC Staff, PPRP's recommended conditions should specify that any of these mechanisms, as

well as Land-Lease Agreements,[60] are acceptable means of minimizing the financial risks of decommissioning.

6. If applicants seek to incorporate salvage value into their cost estimates, they should be limited to a credit of no more than 85% of the expected salvage value to account for the expected swings in salvage value over time in respond to market conditions and demand. Recent solar project decommissioning plans and cost estimates submitted to the Maryland PSC have applied this factor in their salvage value estimates; it represents a prudent and conservative approach for taking salvage value into account. Given that applicants are already applying this factor in several CPCN cases, it appears to be emerging as a best industry practice, at least in Maryland. Over time, as more experience is gained with decommissioning not only in Maryland but in other states, the Maryland PSC and the solar industry can consider revisiting this discount in expected salvage values. Going forward, additional guidance may be helpful for applicants to standardize the format of decommissioning cost estimates and present a pre-determined set of line items.
7. The early solar CPCNs issued in Maryland included decommissioning plan requirements but did not explicitly require periodic updates to cost estimates and financial assurances (see examples in Section 2.7 of this report). PPRP and PSC Staff should collaborate to develop a process for tracking the status of updates that will be required starting in December 2023:
8. PPRP should engage with relevant counties to ensure that State decommissioning policies do not pose conflicts with local ordinances. Several counties have imposed specific requirements and these ordinances continue to evolve. In the case of Church Hill Solar, because no periodic update to the decommissioning plan is required, a discussion with Queen Anne's County could determine whether they have any helpful information regarding operating experience and decommissioning or repowering plans. PPRP should consider convening a work group with representatives of County government planning or zoning boards, PSC Staff, and other interested parties to review whether solar decommissioning policies at the State level conflict with county or municipal ordinances, and to make any recommendations as necessary.

Additional research would provide valuable updates on some of the topics mentioned in this report. If a rulemaking on decommissioning is established, the most current and relevant data on the following topics should be assessed:

- Reliability of decommissioning cost estimates, variability between projects, key drivers of cost estimates and the accuracy of forecasted data used in decommissioning plans;
- Status of the market for used solar panels – resale value for used panels, potential for salvaging component materials, waste management considerations;
- Regulatory and policy actions in other states that could identify best practices or lessons learned; and
- Reasonableness of various financial assurance mechanisms and evaluation of potential risks.

[60] To PPRP's knowledge, land-lease agreements have not yet been proposed as a financial surety mechanism in any Maryland solar licensing case before the PSC.

Even if a rulemaking on decommissioning is not instituted, the experience with solar and wind decommissioning should be periodically revisited. As noted earlier, many wind and solar projects are relatively new and decommissioning is rare, but that will change with the passage of time. PPRP should also coordinate with Maryland Department of the Environment (and the U.S. Department of Energy and the U.S. Environmental Protection Agency, as appropriate) to understand and keep current with the available research and best practices for solar panel waste management and recycling and apply that understanding to the licensing of renewable energy facilities.

APPENDIX A
Draft Checklist for Solar Decommissioning Plan Review

[Note: This is proposed introductory language and checklist contents; it has been used for internal purposes by PPRP contractors when reviewing decommissioning plans, but has not been provided to CPCN applicants.]

CPCNs for solar project development in Maryland include a requirement to submit a decommissioning plan, and to obtain PSC approval of the plan prior to construction. The following checklist describes the elements that should be addressed. The checklist is intended for guidance only and does not constitute regulatory requirements. It is provided to a CPCN applicant for informational purposes and is subject to periodic review and update by the State of Maryland.

Recommended Plan Elements	**Reviewer Notes**
Party(ies) responsible for decommissioning activities	
Time required to accomplish decommissioning	
Anticipated schedule	
Criteria that would trigger decommissioning	
Activities associated with dismantling and removing/disposing of all components, including cables, wiring, and foundations below and above ground	
Maximizing the extent of component recycling and reuse, where practicable	
Materials handling in accordance with applicable federal, State, county and local requirements	
Post-Decommissioning Site Conditions	
Stabilization, grading and seeding all disturbed areas	
Distribution of topsoil stockpiled on site	

Decommissioning Cost Estimate	
Prepared by third party consultant	
Costs broken down by task or activity	
Tasks/activities are consistent with narrative description of planned decommissioning activities	
Transportation costs included for disposal/recycling	
Safe removal and proper disposal of components containing hazardous materials	
Unit costs identified	
Detailed costing assumptions clearly identified	
Documentation of salvage value (if included in the cost estimate)	
Requirement for periodic update of cost and benefit calculations	
Financial instrument specified	