

DECOMMISSIONING SOLAR ENERGY SYSTEMS RESOURCE GUIDE



A RESOURCE GUIDE BY HEIDI KOLBECK-URLACHER,
CENTER FOR RURAL AFFAIRS



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DECOMMISSIONING SOLAR ENERGY SYSTEMS RESOURCE GUIDE

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Decommissioning Solar Energy Systems
Resource Guide

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When solar projects reach the end of their expected performance period, there are several management options. They include extending the performance period through reuse, refurbishment, or repowering of the facility or fully discontinuing operations and decommissioning the project. | Photo by Rhea Landholm

I. INTRODUCTION

Falling equipment costs coupled with increased demand for clean energy have led to a rapid rise in solar development over the past decade, a trend expected to continue. Although solar accounted for 3% of U.S. electricity in 2020, the U.S. Energy Information Administration projects that number will reach 20% by 2050.¹ In 2022 alone, solar will account for nearly half of all new electric generating capacity.²

Solar projects are often located in rural areas and can provide numerous benefits to nearby communities, including lease payments to landowners, tax revenue to fund infrastructure and services, and the creation of both permanent and temporary jobs.

County officials are typically responsible for enacting siting or zoning standards to help ensure solar

development is supported by local residents. This can include planning for the eventual decommissioning of energy projects that have reached the end of their life cycles.

II. UNDERSTANDING SOLAR PROJECT END-OF-LIFE OPTIONS

Solar panel lifespan is 25 to 35 years.³ Since approximately 75% of all U.S. solar capacity has been installed in the past five years, most panels are still operational and have not been decommissioned yet.⁴

When solar projects reach the end of their expected performance period, there are several management options. They include extending the performance period through reuse, refurbishment, or repowering of the facility or fully discontinuing operations and decommissioning the project.

1 Francis, Mickey, and Manussawee Sukunta. "Solar generation was 3% of U.S. electricity in 2020, but we project it will be 20% by 2050." U.S. Energy Information Administration, Nov. 16, 2021, eia.gov/todayinenergy/detail.php?id=50357. Accessed April 2022.

2 Fasching, Elesia, and Suparna Ray. "Solar power will account for nearly half of new U.S. electric generating capacity in 2022." U.S. Energy Information Administration, Jan. 10, 2022, eia.gov/todayinenergy/detail.php?id=50818. Accessed April 2022.

3 Huang, Susan, et al. "Solar Energy Technologies Office Photovoltaics End-of-Life Action Plan." U.S. Department of Energy, Office of Energy Efficiency & Renewable Technology, March 2022, energy.gov/sites/default/files/2022-03/Solar-Energy-Technologies-Office-PV-End-of-Life-Action-Plan_0.pdf. Accessed April 2022.

4 Ibid.

A. EXTENDING THE PERFORMANCE PERIOD: REUSE, REFURBISHMENT, AND REPOWERING

In some cases, photovoltaic modules can be reused or refurbished to extend the system's performance period.⁵ If equipment is still in working order, one possibility is to extend leases, permits, and interconnection agreements to continue operation. This requires no capital investment, but there are costs associated with maintaining aged equipment.⁶

- **Reuse** of the system's photovoltaic modules is the most economically and environmentally beneficial option and can provide opportunities for revenue or tax savings.⁷ Research has shown that solar panels degrade at a rate of 0.5% per year, which means that by year 20 a panel can be expected to produce 90% of the electricity it did in year 1.⁸
- **Refurbishment** involves making necessary repairs to extend the lifespan of the system's older equipment. Refurbishing older equipment can be challenging due to the difficulty of finding parts and lack of expertise in working with older technologies.⁹

5 "End-of-Life Management for Solar Photovoltaics: Recycling." Solar Energy Industries Association, January 2020, seia.org/sites/default/files/2020-11/SEIA-Recycling-Program-Factsheet-January%202020%20final.pdf. Accessed April 2022.

6 "What it Takes to Realize a Circular Economy for Solar Photovoltaic System Materials." National Renewable Energy Laboratory, April 2, 2021, nrel.gov/news/program/2021/what-it-takes-to-realize-a-circular-economy-for-solar-photovoltaic-system-materials.html. Accessed April 2022.

7 "Solar Photovoltaics: End-of-Life Management Infographic." Electric Power Research Institute, March 18, 2021, epri.com/research/products/000000003002021132. Accessed May 2022.

8 Mow, Benjamin. "STAT FAQs Part 2: Lifetime of PV Panels." National Renewable Energy Laboratory, April 23, 2018, nrel.gov/state-local-tribal/blog/posts/stat-faqs-part2-lifetime-of-pv-panels.html. Accessed April 2022.

9 "What it Takes to Realize a Circular Economy for Solar Photovoltaic System Materials." National Renewable Energy Laboratory, April 2, 2021, nrel.gov/news/program/2021/what-it-takes-to-realize-a-circular-economy-for-solar-photovoltaic-system-materials.html. Accessed April 2022.

- **Repowering** involves redesigning the system and installing new arrays and inverters to rebuild or replace the power source, and can cost about 80% of the total plant value. A repowered solar system is new in most respects but can leverage existing land-use, permitting, and utility interconnections.¹⁰

B. FULL DECOMMISSIONING: RECYCLING AND DISPOSAL OF SOLAR PANELS

Full decommissioning indicates the solar facility will be closed, all photovoltaic equipment will be removed, and land will be restored to its original condition.¹¹ Disassembly of the solar system mirrors assembly, only in reverse. It will include removing modules and sorting components by material type. Major pieces of equipment might be sourced for spare parts or sent for recycling. Labor cost of decommissioning can be half that of installation.¹²

- **Recycling** solar panels decreases waste and allows for the recovery of high-value and energy-intensive materials. Solar panels typically consist of glass, aluminum, copper, silver, and semiconductor materials that can be successfully recovered. By weight, more than 80% of a typical solar panel is glass and aluminum, both of which are common and easily recycled materials.¹³

Solar recycling technology is still a developing field. At present most recycling happens at existing glass recycling facilities, which can recover about 78% of materials.¹⁴ It is anticipated that

10 Ibid.

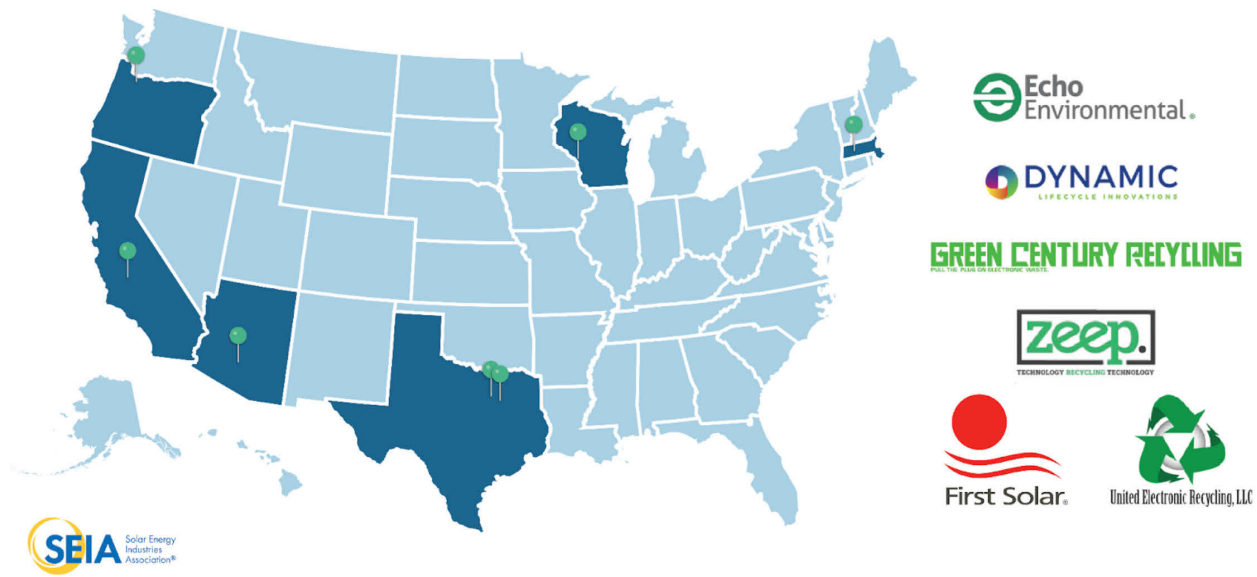
11 Ibid.

12 Curtis, Taylor, et al. "Best Practices at the End of the Photovoltaic System Performance Period." National Renewable Energy Laboratory, February 2021, nrel.gov/docs/fy21osti/78678.pdf. Accessed April 2022.

13 "End-of-Life Management for Solar Photovoltaics: Recycling." Solar Energy Industries Association, January 2020, seia.org/sites/default/files/2020-11/SEIA-Recycling-Program-Factsheet-January%202020%20final.pdf. Accessed April 2022.

14 "Solar Photovoltaics: End-of-Life Management Infographic." Electric Power Research Institute, March 18, 2021, epri.com/research/products/000000003002021132. Accessed December 2021.

FIGURE 1: SOLAR ENERGY INDUSTRIES ASSOCIATION PV RECYCLING PARTNER NETWORK



Source: Solar Energy Industries Association

with emerging technologies the amount recovered will increase. Currently, recycling may be more costly than other options.¹⁵

The Solar Energy Industries Association’s (SEIA) PV Recycling Working Group has been preparing for solar recycling needed in coming years by developing the SEIA PV Recycling Partner Network. See Figure 1 for a map of current locations.

- **Disposal** of solar system equipment by landfill is the least expensive and most accessible option, although it presents obvious environmental drawbacks.¹⁶ Disposal of solar panels should be done with careful consideration of federal, state, and local solid waste requirements.¹⁷ Some states, such as North Carolina, Washington,

and California, have enacted specific policies around the management of solar panel waste.¹⁸

Testing on solar panels indicates different varieties of panels contain different metals in the semiconductor and solder. Some of these metals, such as lead and cadmium, may be considered hazardous waste if present in high enough quantities.¹⁹ If a solar panel contains hazardous materials, those components are subject to hazardous waste regulation under the Resource Conservation and Recovery Act of 1976 (RCRA). Because recycling is encouraged over disposal, the RCRA does provide certain conditional exclusions for the recycling of solar panels containing hazardous waste.²⁰

15 Ibid.

16 Ibid.

17 Curtis, Taylor, et al. “Best Practices at the End of the Photovoltaic System Performance Period.” National Renewable Energy Laboratory, February 2021, [nrel.gov/docs/fy21osti/78678.pdf](https://www.nrel.gov/docs/fy21osti/78678.pdf). Accessed April 2022.

18 “End of Life Solar Panels: Regulations and Management.” U.S. Environmental Protection Agency, Sept. 16, 2021, [epa.gov/hw/end-life-solar-panels-regulations-and-management](https://www.epa.gov/hw/end-life-solar-panels-regulations-and-management). Accessed April 2022.

19 Ibid.

20 Ibid.

III. PLANNING FOR DECOMMISSIONING

Decommissioning requirements can be set by states and counties. Landowners and developer agreements may set additional requirements. It is prudent for local governments to plan ahead for solar decommissioning and create ordinances that spell out expectations and obligations. This ensures that financial responsibility for decommissioning falls to the project owner and not the county and landowners.

Because the majority of solar installations are decades away from being retired, project decommissioning plans may need to be revised over time. Periodic plan reviews allow local governments to accommodate necessary changes in decommissioning cost estimates, technology changes, and the availability of recycling services.

A. COMPONENTS OF A DECOMMISSIONING PLAN

Decommissioning plans often include:^{21, 22, 23, 24}

- Estimated lifespan of the project.
- Defined conditions upon which decommissioning will be initiated, such as the end of lease, inoperation of the facility for a certain period of time, or a pre-identified end date.

21 “Decommissioning Solar Panel Systems: Information for local governments and landowners on the decommissioning of large-scale solar panel systems.” New York State Energy Research and Development Authority, nysrerda.ny.gov/-/media/Migrated/NYSun/files/Decommissioning-Solar-Systems.ashx. Accessed April 2022.

22 “EERA Recommendations on Review of Solar and Wind Decommissioning Plans (Commission Docket Number E999/M-17-123).” Minnesota Department of Commerce, March 16, 2020, efiling.web.commerce.state.mn.us/edockets/searchDocuments.do?method=showPoup&documentId=%7b1024E570-0000-CD11-98E8-4EC4D05E58E7%7d&documentTitle=20203-161292-01. Accessed May 2022.

23 Curtis, Taylor, et al. “A Survey of Federal and State-Level Solar System Decommissioning Policies in the United States.” National Renewable Energy Laboratory, December 2021, nrel.gov/docs/fy22osti/79650.pdf. Accessed April 2022.

24 Curtis, Taylor, et al. “Best Practices at the End of the Photovoltaic System Performance Period.” National Renewable Energy Laboratory, February 2021. nrel.gov/docs/fy21osti/78678.pdf. Accessed April 2022.

- Identification of the party responsible for decommissioning.
- Statement defining how notification will be made of intent to start the decommissioning process.
- Description of any agreement made with the landowner regarding decommissioning.
- Plans and schedule for updating the decommissioning plan over time.
- Decommissioning tasks and timing, including:
 - Removal of all equipment, structures, fencing, roads, and foundations.
 - Restoration of property to condition prior to solar development.
 - The timeframe for completion of decommissioning activities.
- Detailed decommissioning cost estimates prepared by a knowledgeable independent party. This may or may not include the salvage value of solar equipment and infrastructure.
- A description of expected impacts on natural resources.
- Financial surety, which may be established through different financial instruments, such as trusts or escrow accounts, bonds, letters of credit, or other types of agreements.

Nebraska is one of the few states with a state-level decommissioning requirement. Nebraska Revised Statute 70-1014.02 requires that private electric suppliers comply with any decommissioning requirements adopted by local governmental entities, submit a decommissioning plan, bear all costs of decommissioning, and post a security bond or other instrument within 10 years of commercial operation securing the costs of decommissioning the facility.²⁵

B. ESTIMATING DECOMMISSIONING COSTS

Because few solar projects have yet to be decommissioned, cost estimates vary widely. Differences depend on numerous factors specific to the project,

25 “Nebraska Revised Statute 70-1014.02.” Nebraska Legislature, nebraskalegislature.gov/laws/statutes.php?statute=70-1014.02. Accessed May 2022.

site, calculation methods, local government requirements, and whether salvage value is included as part of the total. Using local, independent professionals, such as third-party engineers, to develop a project-specific decommissioning cost estimate is recommended.

1. DECOMMISSIONING COST EXAMPLES

- The New York State Energy Research and Development Authority (NYSERDA) estimates \$30,000 per megawatt in present day costs.²⁶ See Table 1 for NYSEDA’s sample list of decommissioning costs for a 2 MW solar installation.²⁷
- A 2018 Minnesota Department of Commerce solar and wind decommissioning working group estimated the net costs (total less salvage value) of solar facilities at \$21,700 to \$56,300 per megawatt.²⁸
- Decommissioning costs for South Dakota’s first two proposed utility-scale solar projects are estimated between \$9,090 and \$18,148 per megawatt.^{29, 30}

TABLE 1: SAMPLE LIST OF DECOMMISSIONING TASKS AND ESTIMATED COSTS FOR A 2 MW SOLAR INSTALLATION

Tasks	Estimated cost
Remove rack wiring	\$2,459
Remove panels	\$2,450
Dismantle racks	\$12,350
Remove electrical equipment	\$1,850
Breakup and remove concrete pads or ballasts	\$1,500
Remove racks	\$7,800
Remove cable	\$6,500
Remove ground screws and power poles	\$13,850
Remove fence	\$4,950
Grading	\$4,000
Seed disturbed areas	\$250
Truck to recycling center	\$2,250
Current total	\$60,200
Total after 20 years (2.5% inflation rate)	\$98,900

Source: New York State Energy Research and Development Authority

26 “Decommissioning Solar Panel Systems: Information for local governments and landowners on the decommissioning of large-scale solar panel systems.” New York State Energy Research and Development Authority, nyseda.ny.gov/-/media/Migrated/NYSun/files/Decommissioning-Solar-Systems.ashx. Accessed April 2022.

27 Ibid.

28 “Solar and Wind Decommissioning Working Group, Report and Recommendations.” Minnesota Department of Commerce, August 2018, efiling.web.commerce.state.mn.us/edockets/searchDocuments.do?method=showPoup&documentId=%7BF0DC9065-0000-C734-8DCC-76C867A06CD8%7D&documentTitle=20188-146145-02. Accessed May 2022.

29 “Lookout Solar Project: Application to the South Dakota Public Utilities Commission for an Energy Facility Permit.” South Dakota Public Utilities Commission, December 2018, puc.sd.gov/commission/dockets/electric/2018/e118-059/application.pdf. Accessed May 2022.

30 “Appendix D: Decommissioning Plan. Wild Springs Solar LLC.” South Dakota Public Utilities Commission, May 15, 2020, puc.sd.gov/commission/dockets/electric/2020/e120-018/AppendixD.pdf. Accessed May 2022.

B. FINANCIAL ASSURANCE MECHANISMS

Some local governments may decide to require financial mechanisms, such as trusts, escrow accounts, bonds, or letters of credit, to ensure appropriate decommissioning and reclamation. Requiring financial assurance is a tradeoff, as it provides additional protection for local governments, but may increase overall project costs, which could deter development.³¹ If requiring financial assurance, a more favorable approach for developers is if assurances can be paid over time rather than prior to project operation, as the assurance may be

31 “Decommissioning Solar Panel Systems: Information for local governments and landowners on the decommissioning of large-scale solar panel systems.” New York State Energy Research and Development Authority, nyseda.ny.gov/-/media/Migrated/NYSun/files/Decommissioning-Solar-Systems.ashx. Accessed April 2022.

absorbed as operating costs rather than upfront capital cost.³²

For example, Nebraska statute requires suppliers to post a security bond or other instrument within 10 years of a commercial operation securing the costs of decommissioning the facility.³³ Guidance from the Minnesota Department of Commerce Energy Environmental Review and Analysis (EERA) unit recommends that financial assurances be implemented in a stepwise manner with initial payments by year 10 and increased over time to ensure full funding no later than the end of the power purchase agreement.³⁴

IV. RECOMMENDATIONS

We recommend that counties:

- Require project developers to submit a decommissioning plan that defines the obligations of the project developer to remove the solar array and restore the land when the project is retired.
- Require the project developer to notify the county of its intent to stop using the facility once it has been determined the system will be fully retired. This notification should serve as the trigger for decommissioning to begin. Both the manner of notification and the deadline for decommissioning to occur once notification is given should be defined within the original decommissioning plan.
- Ensure that decommissioning plans include expected timelines for completion of tasks.

32 Curtis, Taylor, et al. “A Survey of Federal and State-Level Solar System Decommissioning Policies in the United States.” National Renewable Energy Laboratory, December 2021, [nrel.gov/docs/fy22osti/79650.pdf](https://www.nrel.gov/docs/fy22osti/79650.pdf). Accessed April 2022.

33 “Nebraska Revised Statute 70-1014.02.” Nebraska Legislature, nebraskalegislature.gov/laws/statutes.php?statute=70-1014.02. Accessed May 2022.

34 “EERA Recommendations on Review of Solar and Wind Decommissioning Plans (Commission Docket Number E999/M-17-123).” Minnesota Department of Commerce, March 16, 2020, efiling.web.commerce.state.mn.us/edockets/searchDocuments.do?method=showPoup&documentId=%7b1024E570-0000-CD11-98E8-4EC4D05E58E7%7d&documentTitle=20203-161292-01. Accessed May 2022.

For example, specifying deadlines for removal of equipment and completion of site reclamation.

- Include a provision that the project owner is responsible for the costs of decommissioning, ensuring the county and landowners do not bear these costs.
- Work with developers to ensure decommissioning cost estimates are made by a third-party professional who can provide a location and project-specific cost estimate, and plan for these cost estimates to be reviewed every 5 to 10 years to accommodate changes.
- Encourage recycling or repurposing of solar components rather than disposal in landfills.

About the Center for Rural Affairs

Established in 1973, the Center for Rural Affairs is a private, nonprofit organization with a mission to establish strong rural communities, social and economic justice, environmental stewardship, and genuine opportunity for all while engaging people in decisions that affect the quality of their lives and the future of their communities.