



Solar Photovoltaics and Battery Storage: Best Practices for End-of-Life Management

Overview

Solar photovoltaics and battery storage are cornerstone technologies in the transition to a clean energy economy. As the deployment of these technologies increases, so will the volume of modules and batteries that reach the end of their useful life span. Renewable Energy Vermont members and the Vermont Agency of Natural Resources are committed to proactively exploring best practices for end-of-life management for photovoltaics and batteries, including the reuse and recycling of decommissioned equipment.

All solar and battery equipment must be managed in compliance with Vermont's relevant hazardous waste and solid waste regulations. To minimize the environmental impact of solar and battery equipment reuse and recycling shall be considered when equipment is decommissioned.

Batteries may be managed under Vermont [Universal Waste Management Standards](#) and sent for recycling.

Solar modules, depending on their heavy metal components, may be considered hazardous waste when going for recycling rather than reuse. Some hazards of concern are heavy metals such as lead, cadmium, arsenic, and silver and there are different regulatory levels for each metal. A hazardous waste determination must be made either through generator knowledge or through analytical testing of the panel.

If determined to be hazardous, Vermont [Hazardous Waste Management Regulations](#) (VHWMR) apply to storing, shipping, and disposal. The VHWMR only apply to end-of-life solar panels generated by businesses. Residents with solar panels are encouraged to contact their local [Solid Waste Mgmt. Entity](#) regarding reuse or recycling options.

Currently, the solar recycling market is still developing and the volume of solar modules that are being decommissioned each year is not yet sufficient to support widespread recycling facilities. Consequently, both the cost of recycling and the cost of transporting solar equipment represent barriers to recycling efforts, especially for lower recycling volumes. Additional technological advances that reduce the cost of recycling and/or Federal and state policies will likely be required to accelerate the process of bringing solar recycling to scale.

Planning Ahead for Decommissioning

One of the key determinations about how a solar module or battery can be stored, shipped, and disposed of is whether or not it should be categorized as hazardous waste. Equipment that will be reused is not considered waste.

For equipment that is targeted for disposal, a hazardous waste determination can be made through testing such as the Toxicity Characteristic Leaching Procedure or through "acceptable knowledge" about the module manufacturing process. In solar modules, the volume of hazardous material varies significantly with newer modules generally containing lower amounts of hazardous material. Consequently, considering the composition of a particular module and acquiring Material Safety Data Sheets or other material information specifications at the time that modules are purchased is advisable.

REUSE VERSUS RECYCLING

While solar panel efficiency declines over time, in many instances, panels can continue to produce electricity long after they are decommissioned. This creates the opportunity to reuse older panels in markets where new panels would not be economically feasible. Reuse is generally considered to be the best option for decommissioned solar modules when it is available.

One challenge with the reuse of solar hardware is that older equipment may not meet newer codes and standards and may be ineligible for new, grid-tied systems. Off-grid applications provide a limited market for module reuse. The Vermont-based company Good Point Recycling is focused on developing international markets to expand global access to solar power.

Removal, storage, and handling of solar and battery storage equipment should be managed to minimize damage to equipment to maximize opportunities for reuse and minimize recycling costs. The Solar Energy Industry Association (SEIA) has published a [PV Recycling Checklist](#) providing recommendations on preparing and shipping modules for recycling. This document includes recommendations for how to pack modules to reduce the risk of damage and minimize shipping costs.

Finding a Recycler

Solar module recycling capacity is still relatively limited in the United States which can make finding a recycling partner challenging. The U.S. Department of Energy's Solar Energy Technology Office (SETO) and SEIA both maintain listings of solar recyclers. The most rigorous recycling processes include the removal of the frame and junction box, the separation of the glass and the silicon wafer, and the separation and the silicon cells and relevant metals (e.g., silver, tin, lead, copper) but some recyclers capture only the bulk materials.

SETO maintains [The U.S. Solar Photovoltaic Manufacturing Map](#), which lists solar recycling facilities. As of spring 2023, the solar recycling company that is closest to Vermont is Zeep Technologies based in western Massachusetts. The Solar Energy Industry Association (SEIA) also partners with recycling companies as part of their [National PV Recycling Program](#). In addition, the Solid [Waste Program](#) has a list of electronics recyclers who are beginning to accept solar panels for both recycling and reuse from VT. As of June 2023, REV and ANR are aware of four vendors providing solar panel recycling reuse and recycling services in Vermont. Inclusion in this list does not constitute an endorsement by REV or ANR.

- [Universal Recycling Technologies \(URT\)](#): Ray Zielke - rzielke@urtsolutions.com
- [Complete Recycling Solutions \(CRT\)](#): -Keith Boyea- kboyea@csrecycle.com
- [Veolia](#): Jason Regan - jason.regan@veolia.com
- [Goodpoint Recycling](#): Robin Ingenthron- robin@goodpointrecycling.net

Cost Management

Currently, the cost of recycling solar modules is high due to the lower volumes of modules in Vermont and the transportation costs required to get modules to a recycler. Several steps can be taken to help reduce end-of-life costs.

- **Document module composition at the time of purchase:** Documenting whether a module's composition would trigger a hazardous waste designation using manufacturer specifications at the time of purchase avoids testing costs and facilitates planning for disposal options.
- **Explore opportunities for reuse:** Solar modules that can be reused are likely to have a higher value than the value of the materials recovered in the recycling process.
- **Look for opportunities to coordinate:** Coordinating module recycling across sites/companies may offer opportunities to reduce per-module shipping costs by ensuring that all loads are full. In addition, it may provide opportunities to negotiate lower recycling rates at high volumes. SEIA's [National PV Recycling Program](#) offers pre-negotiated rates for members.

Additional Resources

Vermont Department of Environmental Conservation: [Hazardous Waste Management Program](#) and [Solid Waste Program](#)

- [Universal Waste Management Standards for Batteries](#)
- [Determining Generator Status](#)
- [Vermont Hazardous Waste Management Regulation](#)
- [Accumulation and Storage of Hazardous Waste Factsheet](#)
- [Recycling Exemptions Factsheet](#)
- [Lithium Ion Battery Management](#)

North Carolina Department of Environmental Quality, [Solar Panel Recycling and Disposal Guidance](#)

National Renewable Energy Laboratory, [Best Practices at the End of the Photovoltaic System Performance Period](#).