



ASTSWMO, Providing Pathways to Our Nation's Environmental Stewardship Since 1974

Fact Sheet: Photovoltaic Modules

The Compliance Monitoring and Enforcement (CME) Task Force within the ASTSWMO Hazardous Waste Subcommittee and the Sustainable Materials Management (SMM) Task Force within the ASTSWMO Materials Management Subcommittee collaborated to produce a series of three fact sheets on emerging wastes from renewable energy sources: lithium-ion batteries with a focus on electric vehicle batteries; photovoltaic modules; and wind turbine blades. The fact sheets are intended to be living documents to be periodically updated with new information.

ASTSWMO does not endorse trade names or recommend the use of commercial products mentioned in this document. The views expressed in this document are those of the ASTSWMO CME and SMM Task Forces and its members and have not been formally endorsed by the ASTSWMO Board of Directors.

=====

Photovoltaic Modules

Photovoltaic (PV) modules, commonly referred to as solar panels, represent one of the fastest growing energy sources in the United States and abroad. This expansion is attributable to a combination of factors, including State and national policies encouraging clean energy capacity growth and decreased panel costs. While growth in this sector is a positive development, it is not without additional environmental concerns. Indeed, PV module construction is material intensive. In addition, handling out-of-service PV modules can be problematic, as some panels have hazardous constituents, like heavy metals including lead and copper. Given these concerns, there has been an increased call for viable recycling and reuse opportunities for out-of-service PV modules. To date, five States have acted specifically to address concerns related to handling out-of-service PV modules. This fact sheet is intended to provide an overview of the potential environmental concerns presented by PV module disposal, a summary of federal regulations and recycling opportunities currently available, and an overview of unique approaches some jurisdictions have taken to attempt to address concerns presented by out-of-service PV modules.

PV Module Construction

Like other products, PV modules are constructed in numerous manners and using various materials. The exact materials and methods used in construction vary by manufacturer, type of cell, and other factors. However, there is some commonality between the various types. Most PV modules include a solar cell, panel, and a frame. In most PV modules, the solar cell is comprised of silicon wafers to hold semi-conducting materials and conductors that extract direct electrical current. Solar cells are normally connected with copper wire and contained in a protective laminate shield. This laminate is the module, which is typically constructed of glass

and polymer encapsulant. These modules also contain an outer polymer layer intended to protect the cell from the elements. PV modules are housed in aluminum frames that are also designed to protect from the elements. Most cells are designed to have a life expectancy of at least thirty years.

End-of-Life Handling

Despite the differences in material and construction, there appears to be some homogeneity between the PV module types when it comes to the weight of materials at the end of the panel's natural life. These materials include:

- Glass - 69% of the waste stream;
- Aluminum - 12% of the waste stream;
- Combination of polymer, copper, lead, tin, polyvinyl fluoride, silicon, and silver - 19% of the waste stream.

According to United States Environmental Protection Agency (USEPA), by 2030, the United States is expected to see as much as [one million total tons of PV module waste](#) annually. For comparison, the total generation of U.S. municipal solid waste in 2018 was 292.4 million tons. By 2050, the United States is expected to have the second largest number of out-of-service PV modules in the world, with as many as an estimated 10 million total tons of waste PV modules.

PV Module Recycling

PV modules can be recycled, but the existing recycling capacity in the United States is limited. To be recycled, the individual PV module components must be separated. This may occur at a specialized recycling center or at a series of locations. The recycling process typically involves three significant steps. First, the aluminum framing is separated from the PV module. In most cases, the frames can be recycled as scrap metal. Once the frame is removed, the glass and silicon wafer are separated through one of many treatment processes. The treatment process facilitates the recovery of metal components, such as copper, lead, silver, and tin. Silicon wafer treatment technology is not yet widely available in the United States and is internationally limited as well.

Federal Regulation

PV modules are not uniquely regulated by USEPA. Rather, they are handled like any other waste stream. Consequently, when a PV module becomes a solid waste, it is subject to the same hazardous waste determination standards as any other material. Some of the constituents in PV modules are potentially hazardous. These constituents include, but are not limited to, lead, cadmium, arsenic, hexavalent chromium, copper, and selenium. If these constituents are present in high enough quantities in the solar panels, PV module waste could be a hazardous waste under the Resource Conservation and Recovery Act. According to USEPA, some PV modules are considered hazardous waste, and some are not, even within the same model and manufacturer.

State Approaches

To date, five States have taken Statewide action to address concerns related to PV module waste and recycling. These approaches fall into three categories: creation of a Statewide task force, regulation as universal waste, and statutorily mandated extended producer responsibility.

New Jersey and [North Carolina](#) each constructed task forces responsible for evaluating concerns posed by PV modules at the end of their useful lives. In each State, the task force is responsible for evaluating issues posed by PV modules at disposal, examining the infrastructure available to

recover PV module components, and offering recommendations to address long-term environmental concerns PV module waste presents.

California and [Hawaii](#) issued a regulatory response to risks posed by PV module waste. Each jurisdiction amended its universal waste regulations to include PV modules among the suite of waste streams subject to heightened, State-specific, oversight. These additional regulatory requirements include labeling, accumulation time limits, employee training, and manifesting obligations applicable to entities that generate, transport, treat, or dispose of waste PV modules.

In 2021, the California Department of Toxic Substances Control [regulations](#) went into effect allowing PV modules that have been determined by the generator to be hazardous due to the characteristic of toxicity to be managed under the more relaxed universal waste regulations. The treatment allowed under universal waste rules includes removal of discrete assemblies, dismantling of PV modules, and mechanical treatments such as shredding or breaking the glass. Universal waste handlers must manage the treatment residuals based on the waste classification of the residuals. Use of chemicals including water, or heat to treat hazardous waste PV modules are not authorized under universal waste regulations.

[Washington](#) is currently the only State that has adopted a statutorily required extended producer responsibility program for PV modules. Beginning on July 1, 2025, PV module manufacturers that have not received approval of their stewardship plan are prohibited from selling PV modules in the State. The stewardship plan must include, at a minimum:

- a description of how manufacturers will finance the recycling program;
- accept all PV modules sold in Washington after July 1, 2017;
- describe how the program will minimize the release of hazardous substances into the environment and maximize the recovery of other components from PV modules;
- provide for takeback of PV modules at locations that are as convenient as reasonably practicable;
- identify how relevant stakeholders will receive information required for them to participate in the program; and
- establish performance goals for the program.

The stewardship program is intended to recycle at least 85% of the volume of PV module waste generated in Washington.

Additional Resources

U.S. Environmental Protection Agency:

End-of-Life Solar Panels: Regulations and Management:

<https://www.epa.gov/hw/end-life-solar-panels-regulations-and-management>

Solar Panel Recycling:

<https://www.epa.gov/hw/solar-panel-recycling>

Solar Panel Frequent Questions:

<https://www.epa.gov/hw/solar-panel-frequent-questions>

U.S. Department of Energy National Renewable Energy Laboratory (NREL) homepage:

<https://www.nrel.gov/>

NREL news item on renewable energy waste streams:

<https://www.nrel.gov/news/features/2019/your-renewable-energy-technology-is-growing-old-whats-next.html>