SOLAR PHOTOVOLTAICS END-OF-LIFE MANAGEMENT



Decommissioning solar photovoltaic (PV) plants at end of life (EoL) requires removal and management of a variety of materials. Based on an EPRI study for a conceptual 11 MW_{AC} plant, PV modules represent ~22% of total material by weight. Balance of plant materials include concrete foundations, crushed stone surfacing, fencing, building debris, racking, transformer, inverters, and wiring.



The scale of module EoL management challenges is projected to grow rapidly in the years ahead, mirroring deployment trends around the world but with a time lag consistent with module lifetime of about 20 to 25 years. By 2030, global cumulative EoL PV modules may rise to 8 million metric tons (equivalent to 1.2 million dumpsters). By 2050, those numbers are expected to grow to 78 million metric tons (12 million dumpsters). U.S. EoL module volumes are about 1/8th of the global totals.



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Crystalline silicon (c-Si) modules currently hold ~95% market share, while the remaining market is mostly served by thin-film cadmium telluride (CdTe) modules. Glass-glass c-Si modules are emerging quickly, with bifacial glass-glass modules expected to hold ~70% market share by 2030. The upper end of the c-Si glass fraction range (83%) reflects glass-glass modules, whereas the lower end (76%) represents conventional c-Si modules with front glass and polymer backsheets. Public data are limited on trace hazardous metals, and module toxicity testing is often required to determine EoL management options.







Data Sources: Nature Energy, 2020; EPRI, Alliance for Sustainable Energy, and Wambach-Consulting, 2017; First Solar, 2021

Today, EoL module volumes are low, and most recycling of c-Si modules happens at existing glass recycling facilities on a batch basis. Since the processes aren't customized for PV, only about 78% of materials are recovered by weight. Bulk materials like glass, aluminum frames, and copper wires are recovered for reuse, while high-value materials like silver and silicon are lost. A pilot-scale system, Full Recovery End of Life Photovoltaic (FRELP), that uses a combination of thermal, mechanical, and chemical processes, has achieved 92% recovery. Recycling of CdTe modules is primarily performed by manufacturer First Solar as part of its take-back program. About 90% of glass and up to 95% of Cd and Te is recovered for reuse in new modules.



Solar decommissioning cost estimates reported in decommissioning plans vary widely, from -\$70.5/kW_{pc} to \$142/kW_{pc}, depending on salvage value assumptions, module management options (reuse, recycling, landfilling, or hazardous waste), and site restoration requirements. Module reuse is by far the most attractive option in the US—economically and environmentally—and may provide the time needed for recycling technology and infrastructure development.

- Reuse provides opportunities for revenue or tax savings
- Recycling for crystalline silicon modules is currently ~\$10-\$30 per module (anecdotal)
 - Landfilling modules is cheapest option at \$0.50-\$1.80/module
 - Hazardous waste disposal starts at \$3.60/module, and depends on volume and treatment method

MARKETS FOR MATERIALS



R&D NEEDS

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- Revise estimates of EoL volumes at country, state, or finer level, including early loss scenarios
- Expand knowledge of EoL management options and costs through documentation of EOL experiences and development of standardized tools for estimating EoL net costs
- Demonstrate high-value recycling technologies customized for PV modules and conduct techno-economic and life-cycle assessments
- Develop processes, such as silicon purification and new glass chemistries, to increase value of recovered materials
- Improve sampling methods for module leach testing to reduce variability in toxicity test results
- Develop PV module collection systems and recycling infrastructure
- · Assess second-life opportunities and challenges for PV modules
- · Explore opportunities to design PV modules for recycling

ADDITIONAL EPRI RESEARCH

This fact sheet summarizes current and prior EPRI research deliverables on EoL management PDF topics for renewable energy and battery energy storage technologies: EPRI Research Activities on Renewable and Battery End-of-Life Management. EPRI, Palo Alto, CA: 2020. 3002019572.

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