

End-of-Life Management of PV Modules: Challenges and Opportunities

Garvin Heath, NREL ([Garvin.heath@nrel.gov](mailto:Garvin.heath@nrel.gov))

Mike Woodhouse, NREL

Teresa Barnes, NREL

Jill Engel-Cox, NREL

Rachelle Ihly, NREL

An important but heretofore largely overlooked consideration in the development of new PV module designs is their fate at the end of their useful life. Increasing PV deployment eventually leads to increasing end-of-life module waste, analogous to other consumer electronic waste (e-waste). **The best available projections suggest that waste PV modules could constitute more than 10% of e-waste globally by 2030** (Figure). Given the historical and anticipated growth in PV module deployment, US regulators will likely soon require and consumers may soon demand affordable, sustainable end-of-life management solutions for waste modules.



Currently, there are few recycling solutions offered in the US, partly because there are no market drivers or mandates. A 2012 European Union Directive added PV modules to the list of electronic products requiring the collection and recycling of discarded end-of-life products by the manufacturer selling into the EU market.

End of life management entails costs that will be added to those already borne by the manufacturer, thus are important to anticipate and manage, and yet are not currently included in TEA analyses of PV LCOE. The US will need technology and policy solutions soon to address what could become a serious environmental weakness for PV if waste modules start filling landfills or are shipped to developing countries as e-waste.

We propose to develop a nationally-unique research and analysis capability in PV recycling and materials recovery for purposes of addressing this growing need. This capability will integrate strategic technoeconomic and sustainability analysis, particularly life-cycle and cost modeling, with materials science and PV device fabrication and manufacturing supply chain expertise. It will incorporate principles of design for recyclability for module and systems. Module and component manufacturers, federal agencies (DOE's SunShot program and Advanced Manufacturing Office; NIST) and regulators (EPA, California Department of Toxic Substances) are all potential clients and collaborators.

**Define from an industry perspective what near term 1 year and long term 5 year successful use of the capability would be**

In year 1 we would convene a consortium of PV manufacturers, recyclers and other stakeholders to anonymously pool data regarding recycling process costs and sustainability. Benefits of a consortium approach are that firms could learn from peers and benchmark their systems against others in the field. Analysis of the pooled data would provide insight into cost drivers and identify environmental hot spots, and can inform development of technology R&D roadmaps. Roadmaps should lead to funding opportunities that accelerate and advance innovation. Such roadmaps should be established and initially executed within 5 years. Alongside, considerations of module design for recyclability can be developed, e.g., establishing benchmarks based on specific technical criteria.