Inventory for Crystalline Silicon Module Recycling

Cooperative Research and Development Final Report

CRADA Number: CRD-11-00430

NREL Technical Contact: Garvin Heath

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-6A20-87317
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NOTICE

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Cooperative Research and Development Final Report

Report Date: 2/20/2020

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the final CRADA report, including a list of subject inventions, to be forwarded to the DOE Office of Science and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Electric Power Research Institute (EPRI)

CRADA Number: CRD-11-00430 Project G (Mods 8,11)

CRADA Title: Inventory for Crystalline Silicon Module Recycling

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Sponsoring DOE Program Office(s):

Office of Energy Efficiency and Renewable Energy (EERE), Solar Technologies Office

Joint Work Statement Funding Table showing DOE commitment:

No NREL Shared Resources.

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1	$0.00
TOTALS	$0.00

Executive Summary of CRADA Work:

A critical challenge for the continued expansion of photovoltaics (PV) is to develop technically feasible, inexpensive and environmentally friendly practices for handling and recycling modules at the end of their usable life. The National Renewable Energy Laboratory (NREL) is requested by the Electric Power Research Institute (EPRI) to collect primary data regarding the environmental performance of currently operational PV module recycling facilities in Europe. Very little has been published regarding crystalline silicon (C-Si) module recycling. Thus, much effort will be needed in direct industry outreach, collection of information and other business intelligence strategies similar to NREL's approaches for developing cost models for PV manufacturing. The goal of this work effort is to produce a detailed inventory that accounts for physical (e.g., energy, water, materials) flows through each step of a C-Si recycling process. The inventory (a life cycle inventory, or LCI) shall be designed so that it can be extended to include an accounting of costs for each process step, inputs, etc. This work effort shall leverage prior LCI data collection NREL performed for the United States Department of Energy, Solar Energy Technologies Office, under the auspices of the U.S. contribution to International Energy Agency's Photovoltaics Power Systems (PVPS) Task 12 (Environmental Health and Safety), which SETO nominated NREL to chair. The primary purpose of this work effort is to augment the prior data collection to increase the sample size of manufacturers' primary data in the LCI.

Summary of Research Results:

Task 1: Data Collection from Prior-Contacted Recyclers

7 contacted, 2 respondents; goal 2-3 more respondents

Task 2: Data Collection from PV Module Recyclers Not Previously Contacted

16 contacted, 5 respondents

Task 3: Report – see url link below and related Report - Slides of data linked within that webpage and copied below.

A summary of the findings of the CRADA, referenced in the linked publication below, are as follows:

Solar photovoltaic (PV) installations must be properly dismantled and any waste treated and disposed at the end of project life. However, because most of the world's nearly 400 GW of PV systems have been built in the past decade – each expected to operate for between 20 and 30 years – current PV module waste volumes do not yet justify widespread operation of PV recycling facilities.

The necessary policies and technologies for recycling PV systems are currently under rapid development. With modifications to the European waste electrical and electronic equipment directive (WEEE 2012/19/EU) in 2012, take back and recycling of PV modules is, in fact, already mandatory in Europe. There, take back and recycling is currently performed in small but annually increasing quantities. Even though waste treatment is considered part of a module's life cycle, only a few life cycle inventories (LCI) of energy and materials flows are available for the industrial recycling processes that are used today to recycle crystalline silicon-based (c-Si) PV modules.

LCI are the data inputs that inform lifecycle assessments which quantify the environmental impacts across the full life cycle of PV modules—from manufacturing and use to end of life. To help progress the industry forward, a survey of European recyclers was performed to characterize existing commercial recycling processes and share associated life cycle inventory data.

System Boundaries

The reference unit, or "functional unit" in the vocabulary of life cycle assessment, is defined as the processing of one metric ton of crystalline silicon PV modules in recycling lines for laminated glass, metals, and electronic wastes. Today, all modules are processed in discrete batches, yet not metered at that scale. Thus the process energy for a batch is estimated based on scaled annual production data as well as on input and output streams. All the recyclers that participated indicated that the recycled output materials were processed further downstream; these were not included in the study as they are outside of the control and knowledge of the respondents. Direct emissions (e.g., dust and water emissions) were also not accounted for in the recycling processes.

Results

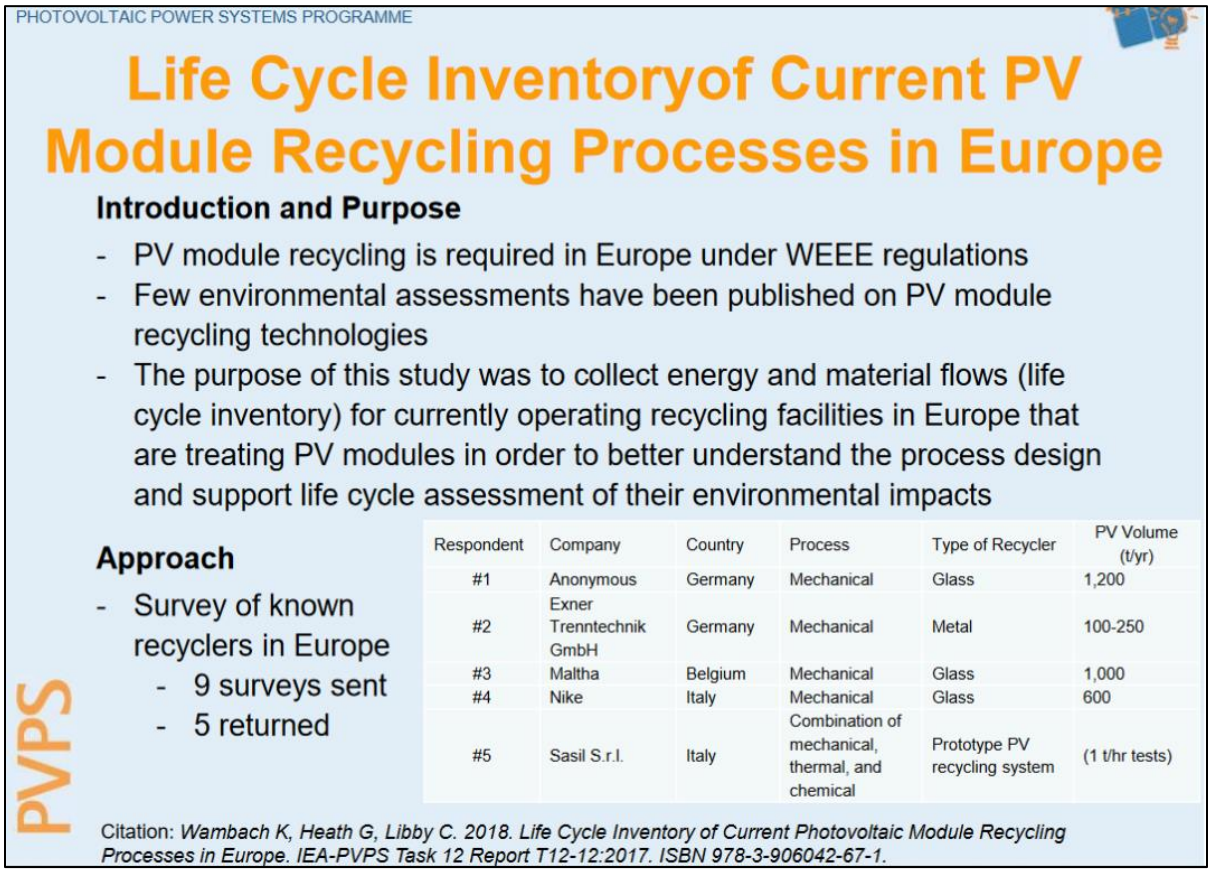
Sixteen recyclers were contacted worldwide between 2015 and 2016, of which five European companies (one in Belgium, two in Italy, and two in Germany) provided LCI data. Survey responses indicate that the participating companies are fully compliant with the WEEE directive. The companies' practices often even exceed the current demands set by the WEEE directive, though future WEEE requirements may become more stringent. In all cases, the batches of PV modules processed to date represent a small share of the total recycling capacity of the plants. Four of five recyclers incorporated the module recycling processes into their preexisting lines without any modifications except for some new parameter settings and optimizations.

Conclusions

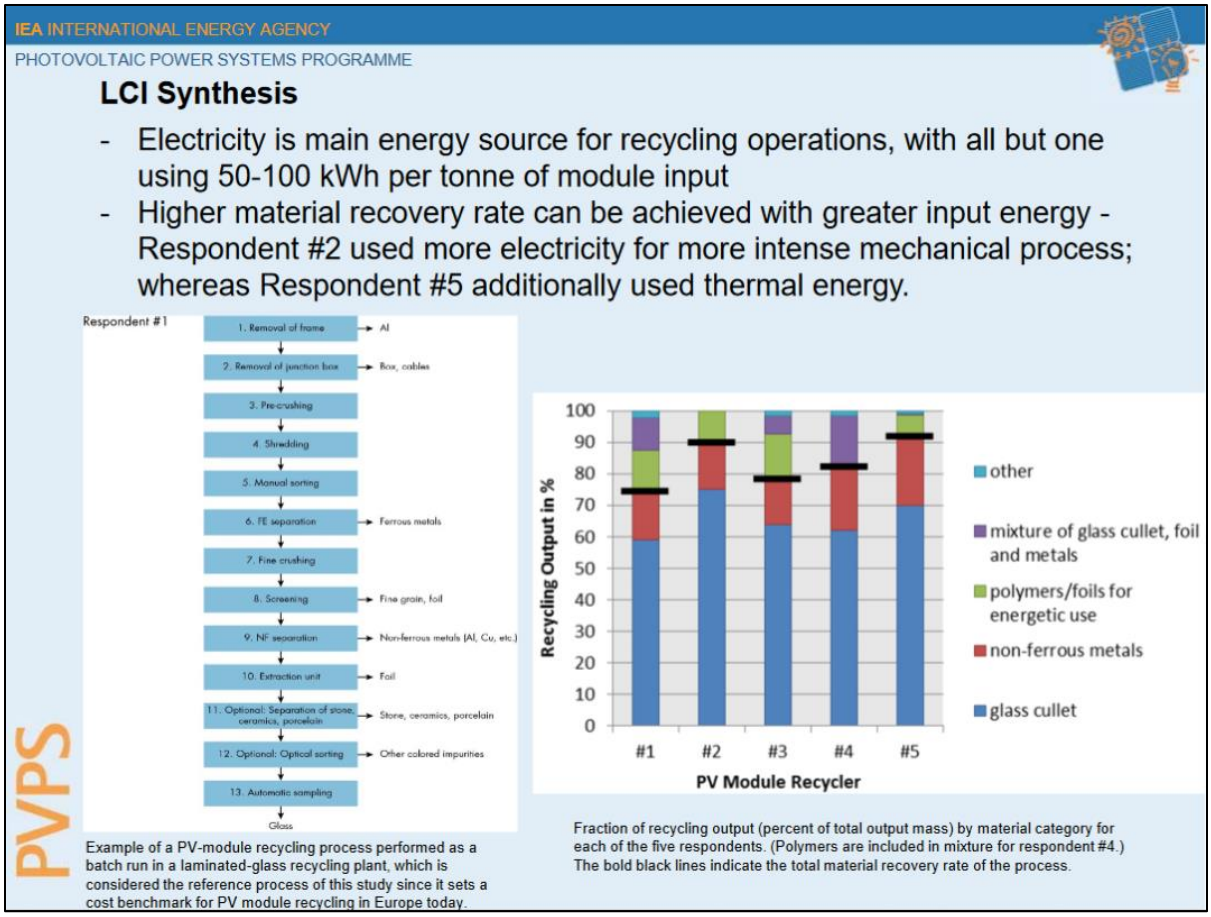
Very little public information is available regarding the environmental effects of PV module recycling processes and, more generally, options for decommissioning and disposal of PV systems. This research is valuable for understanding current recycling processes employed in Europe where PV module recycling is already mandatory according to the WEEE Directive. As such systems for the collection of modules have been implemented and commercial recyclers have started to recycle waste modules in full compliance with the laws—mostly by using excess capacity in existing recycling facilities designed to treat laminated glass, metal, or e-waste. The current WEEE mandates do not require a high enough recovery fraction of the mass of input

modules to necessitate specialized module recycling processes to recover more minor constituents. However, that seems likely to change in the near future. By contrast, there is currently no regulatory framework for PV recycling in the U.S., but state-level legislation and initiatives are under consideration.

This study also helps to inform the direction of future research. As indicated in the results reported by the five respondents of our survey, better recovery yields seem to require more process steps and greater energy consumption. To minimize the life cycle environmental impact of PV generated electricity (considering from the manufacture of the PV modules to their use and end-of-life management) and also to increase the value of module recycling, recovery of valuable but trace constituents like silver will be necessary. This will require both greater waste streams to justify dedicated recycling facilities and further research and development. Development of dedicated PV module recycling facilities that offer higher yields, recovery of valuable materials, and optimization of electricity consumption can offer environmental and economic benefits to all stakeholders involved.



Respondent	Company	Country	Process	Type of Recycler	PV Volume (t/yr)
#1	Anonymous	Germany	Mechanical	Glass	1,200
#2	Exner Trenntechnik GmbH	Germany	Mechanical	Metal	100-250
#3	Maltha	Belgium	Mechanical	Glass	1,000
#4	Nike	Italy	Mechanical	Glass	600
#5	Sasil S.r.l.	Italy	Combination of mechanical, thermal, and chemical	Prototype PV recycling system	(1 t/hr tests)



All tasks of this CRADA were completed. Further details of the CRADA work can be found in the following published report:

Wambach, Karsten, **Garvin Heath**, and Cara Libby. 2018. *Life Cycle Inventory of Current Photovoltaic Module Recycling Processes in Europe*. International Energy Agency Photovoltaic Power Systems Programme. IEA-PVPS Task 12. Report #T12-12:2017. ISBN 978-3-906042-67-

1. http://iea-pvps.org/index.php?id=460.
2. https://www.osti.gov/biblio/1561522

Subject Inventions Listing: None

ROI #: None