Comminution and Electrodynamic Eddy Current Separation Studies of End-of-Life Photovoltaic Materials

York R. Smith*, Pamela Bogust, and Raj K. Rajamani
Department of Metallurgical Engineering, University of Utah
*e-mail: york.smith@utah.edu

IEEE Photovoltaic Specialist Conference 2017, Washington, D.C.

BACKGROUND

- Photovoltaic materials have been the focus of recent work on resource scarcity and material criticality [1-3].
- Overburden of end-of-life (EOL) solar panel materials is currently not an issue, as many panels have yet to reach their maturity (15-20 years).
- The annual waste from the photovoltaic industry from EOL panels is expected to be 250,000 tons (2016 estimate), and according to early-loss scenarios, this value could reach up to 78 Mt by 2050 [4] (Fig. 1). Currently, most EOL PV materials are disposed in landfills as an economically viable recycling process has yet to be realized.
- Rotary drum eddy current separators (Fig. 2(a)) have demonstrated industrial recovery of non-ferrous metals (e.g., Al, Cu, Pb, brass)
- Excitation frequency (~1 kHz) limited by rotary speed of magnets and struggle to economically recover particles >5 mm
- New design (Fig. 2(b)) has minimal mechanical parts and higher excitation frequencies are achievable (~50 kHz)
- Previously has demonstrated successful sorting of Al/Cu, Cu/Brass, Al/Brass, and Alxxxx series alloys (i.e., Al-110/Al-2024, Al-110/Al-6061, and Al-6061/Al-2024 mixtures) [5]

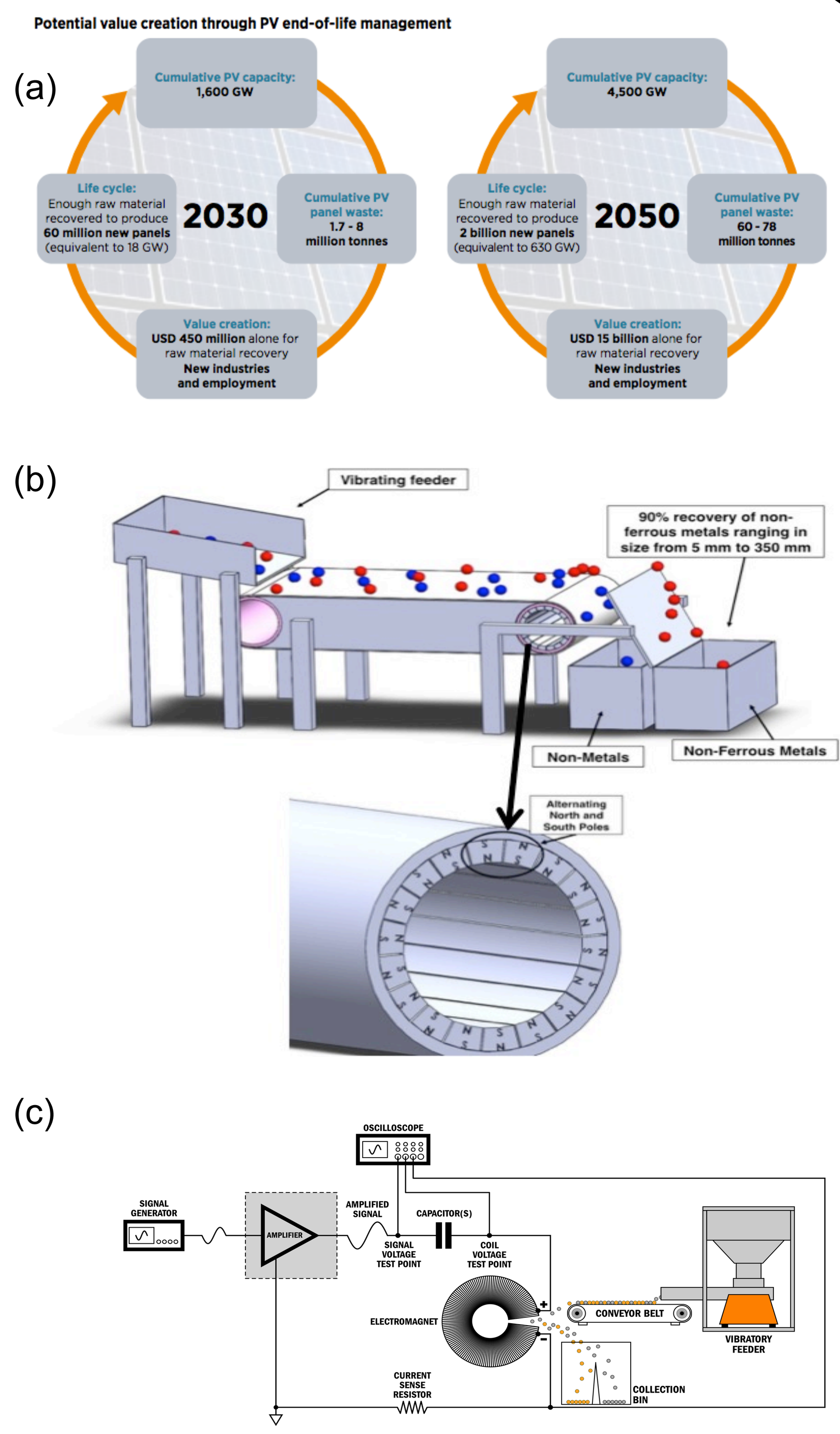

Figure 1: (a) Potential value opportunity projections for PV waste in 2030 and 2050 (figure adapted from [4]). (b) Typical design for rotary drum eddy current separators. (c) Schematic for new design of eddy current separator with variable frequency.

OBJECTIVES

- Examine the efficacy of EECS to recover valuable materials from EOL PV modules
- Comminution studies of PV materials
- Examine methods of benefication and overall energy requirements for PV recycling

EXPERIMENTAL METHODS

- Experimental setup shown in Fig 2. For a more detailed description is see reference [5].
- Particles (granular chunks) 1-3 mm in diameter (Si, Al, CdTe, American Elements, 99.9%)
- Ferrite core (CMD5005 NiZn ferrite), OD of 160 mm and ID of 120 mm, with a custom 1.1 cm gap. The core was wound with two windings in parallel on either side of the gap
- 400 W power supply, operating at 52.8 V and 6.6 A with resonance frequency of 21.4 kHz, B ~ 60-80 mT
- 200 g of each material used for a total of 400 g per sorting experiment

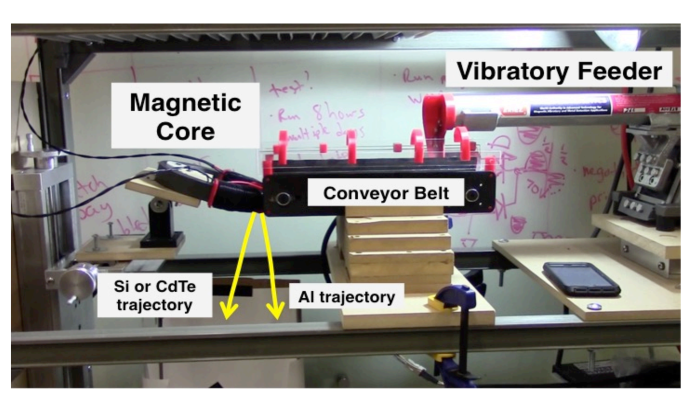

Figure 2: Picture of experimental setup used for electrodynamic eddy current separation.

RESULTS & DISCUSSION

- The results of the experimental campaign [6] demonstrate the capability of this technology to separate Si/Al and CdTe/Al particles mixtures of 1-3 mm with recoveries and grades >85% under the given conditions
- Deviation from a perfect sort due to non-spherical particles (especially thin sheet-like particles which do not kick as strong) and how the particles are fed to the core gap.
- Although energy consumption is low, the throughput needs to increase by an order of magnitude while maintain high recovery and grade (>95%) if commercial application is to be realized.
- Milled PV panels will have much smaller particles, requiring greater excitation frequencies.

Table 1: Summary of experimental results for sorting 1-3 mm particles of Si/Al and CdTe/Al.

	Si	Al	CdTe	Al
Recovery, %	97.5	98.2	95.1	98.8
Grade, %	99.5	98.3	85.7	99.5
	Si/Al		*CdTe/Al*	
Feed Rate, kg/h	5.6		12.4	
Energy Consumption, kWh/short ton	68.0		68.0	

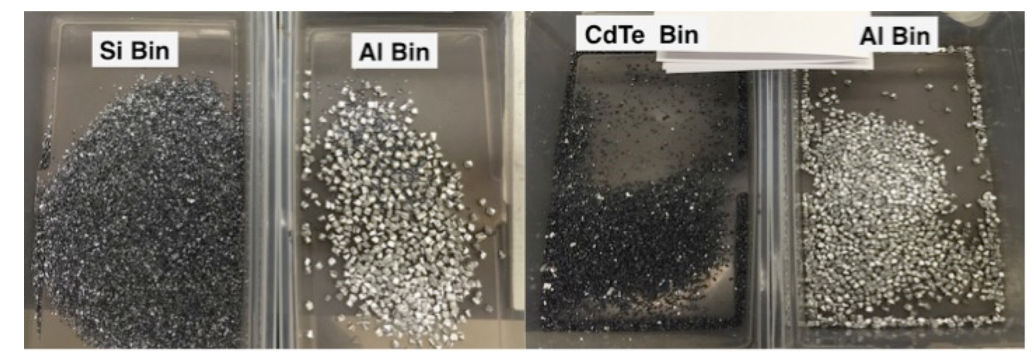

Figure 3: A photograph of an example of a typical sorting experiment for Si/Al and CdTe/Al 1-3 mm particle mixtures.

CONCLUSION & FUTURE WORK

- EECS of Si/Al and CdTe/Al 1-3 mm particles mixtures is successfully demonstrated; however, separation of smaller particles approaches the physical limitations of the system. The technology may be better utilized as a pre-concentration step.
- Future work includes detailed studies on the comminution of PV materials to understand the breakage kinetics, particle size distribution and composition, and energy demand.
- Removal of ethylene-vinyl acetate (EVA) has initially been investigated by various means such as thermally or chemically (Figure 3)
- Cryogenic milling experiments.

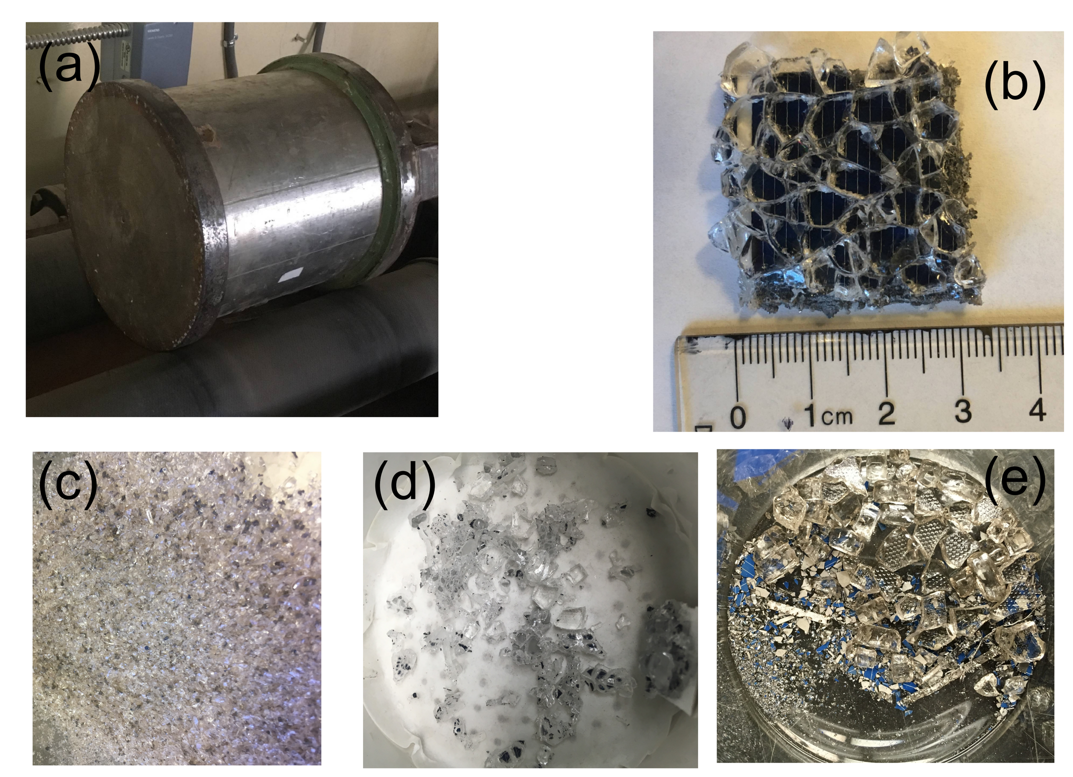

Figure 3: (a) A 0.2 [m] ball mill which will be utilized for grinding studies. (b) A photograph of a chopped polycrystalline solar panel. (c) The fine material, mostly glass, resulting form the polycrystalline panel being ground in the ball mill. (d) The polycrystalline panel with bloated EVA after being chemically treated with toluene. (e) The polycrystalline panel after cryogenic treatment to remove backing and then thermal treatment removing the top layer of EVA.

ACKNOWLEDGMENT

YRS and PB would like to acknowledge support provided by the U.S. Department of Energy, Office of Science, Energy Efficiency & Renewable Energy, Sunshot Initiative. This publication was developed under an appointment to the Energy Efficiency and Renewable Energy (EERE) Research Participation Program, administered for the U.S. Department of Energy (DOE) by the Oak Ridge Institute for Science and Education (ORISE). ORISE is managed by ORAU under DOE contract number DE-SC0014664. This document has not been formally reviewed by DOE. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of DOE, or ORAU/ORISE. DOE and ORAU/ORISE do not endorse any products or commercial services mentioned in this publication.

REFERENCES

[1] M. Goe and G. Gaustad, Estimating direct climate impacts of end-of-life solar photovoltaic recovery, *Solar Energy Materials and Solar Cells*, 156 (2016) 27-36.
[2] M. Goe and G. Gaustad, "Identifying critical materials for photovoltaics in the US: A multi-metric approach," *Applied Energy*, 123 (2014) 387-396.
[3] N.T. Nassar et al. "Criticality of the geological copper family," *Environmental Science & Technology* 46 (2012) 1071-1078.
[4] Weckend, Stephanie, Andreas Wade, and Garvin Heath. End-of-Life Management: Solar Photovoltaic Panels. No. NREL/BK-6A20-66178. NREL (National Renewable Energy Laboratory (NREL), Golden, CO (United States)), 2016.
[5] N. Dholu et al. "Eddy Current Separation of Nonferrous Metals Using a Variable-Frequency Electromagnet," *KONA Powder and Particle Journal* http://doi.org/10.14356/kona.2017012 (2016) 1-7.
[6] Smith, York R., James R. Nagel, and Raj K. Rajamani. "Electrodynamic Eddy Current Separation of End-of-Life PV Materials." *Energy Technology 2017*. Springer International Publishing, 2017. 379-386.