Solar PV Recycling Best Practices

Karen Drozdiak

First Solar

LEADING THE WORLD'S
SUSTAINABLE ENERGY FUTURE

First Solar Overview

25 years
Founded in 1999

25GW+
manufacturing capacity
expected in 2026

CadTel
semiconductor

45+
countries with
First Solar modules

~4x
lower carbon
footprint than c-Si PV

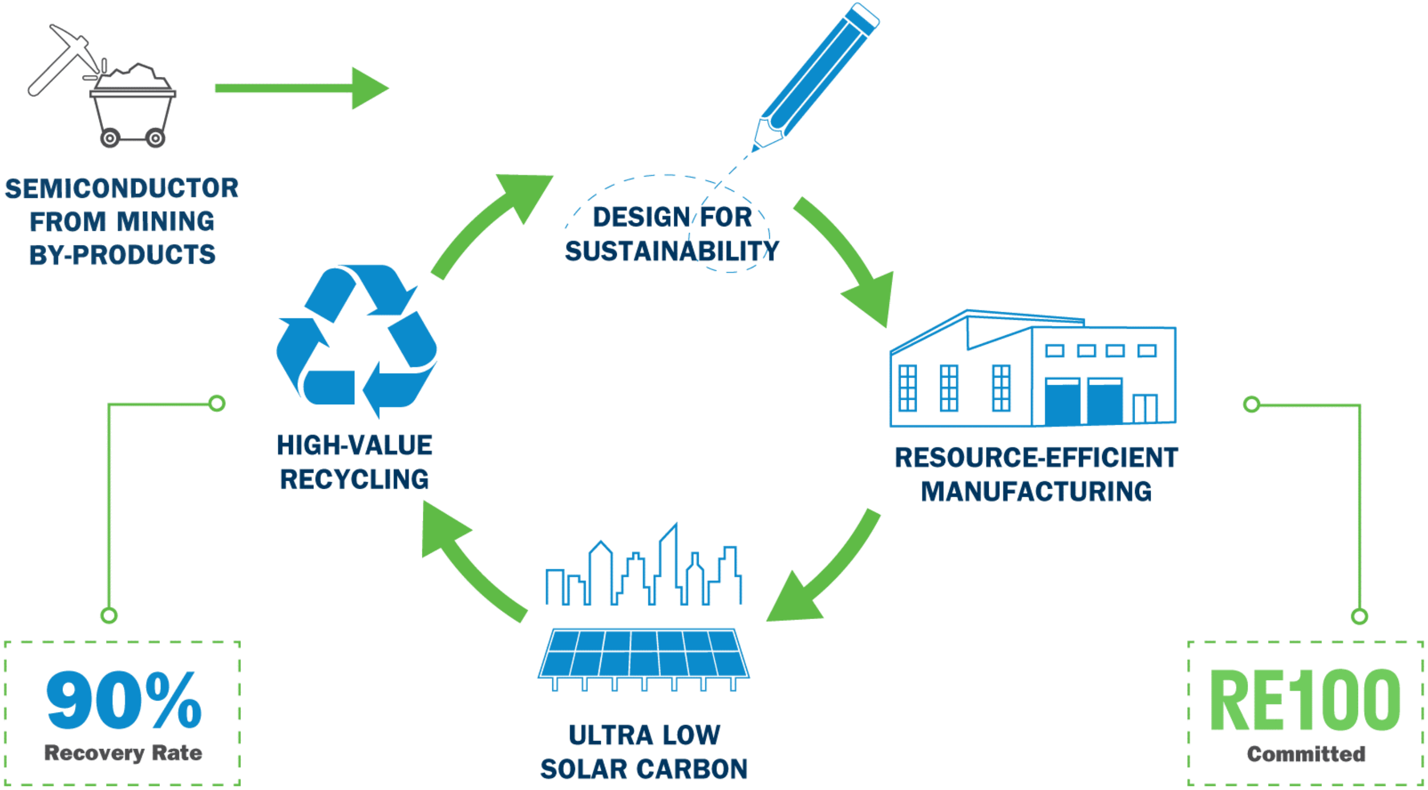
CO_2

90%+
material recovery
through recycling

$19B USD
First Solar Facilitated
project financing

$3.3B USD
2023 net sales

Embedding Circularity Across the Life Cycle



Industry-Leading PV Recycling Services

- Established 1st global PV module recycling program in the industry
- 15y+ experience operating high-value PV recycling facilities with ~400,000MT recycled
- Recycling facilities located in Germany, Malaysia, Vietnam, the U.S. and India
- Proven and scalable technology to accommodate future high volumes (global designed capacity of ~3 million modules)
- Provides closed-loop semiconductor recovery for reuse in new solar modules
- Continuously improving processes and technology and reducing operational costs

https://www.firstsolar.com/en/Solutions/Recycling

First Solar Recycling Services

Cost-effective: 2-year termed renewable pricing allows prices to decrease as recycling costs are reduced over time

No up-front fees: “pay as you go” model priced on a per-module basis using later year project cash flows

Globally available: Recycling services offered in various regions of the world

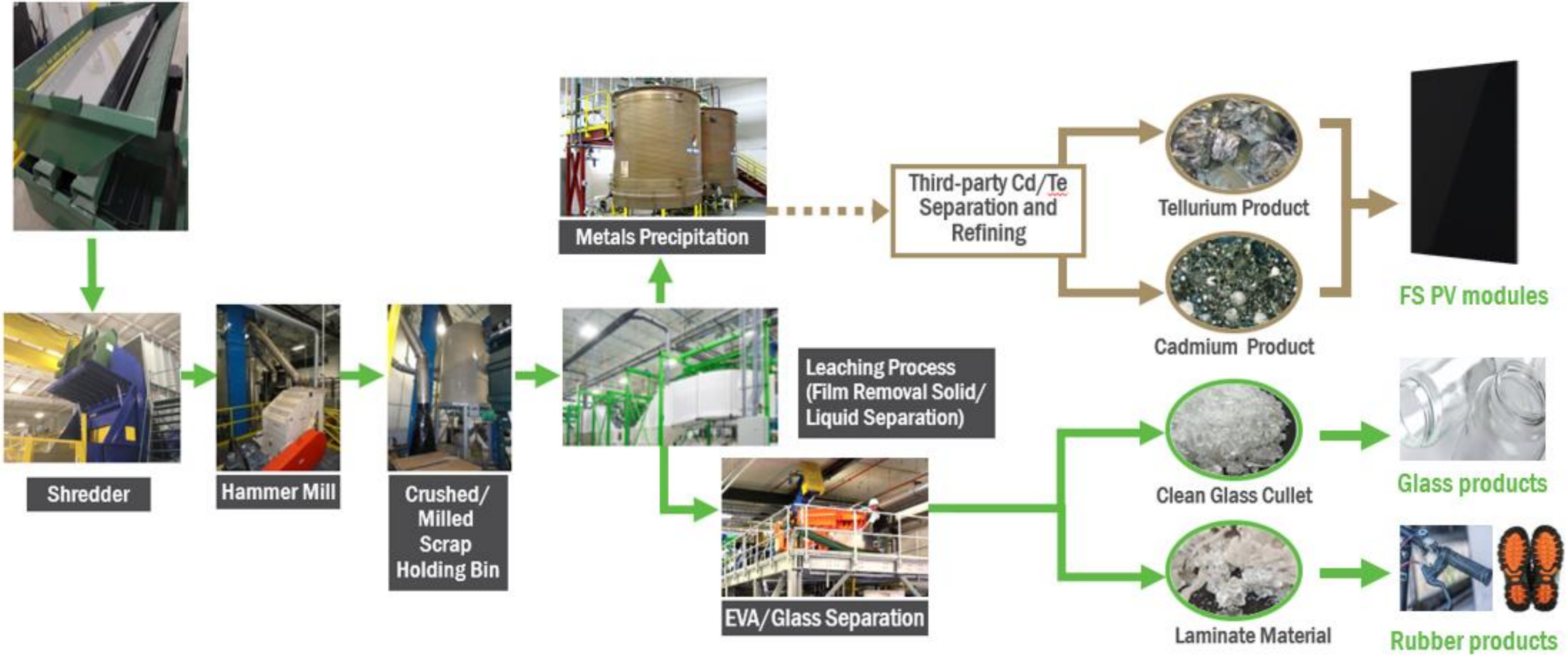
Scalable: Designed for high-volume recycling and decommissioning

Flexible: Start date at module sale, throughout plant life, and/or decommissioning

Responsible: Maximizing material recovery while operating to sound and responsible global standards

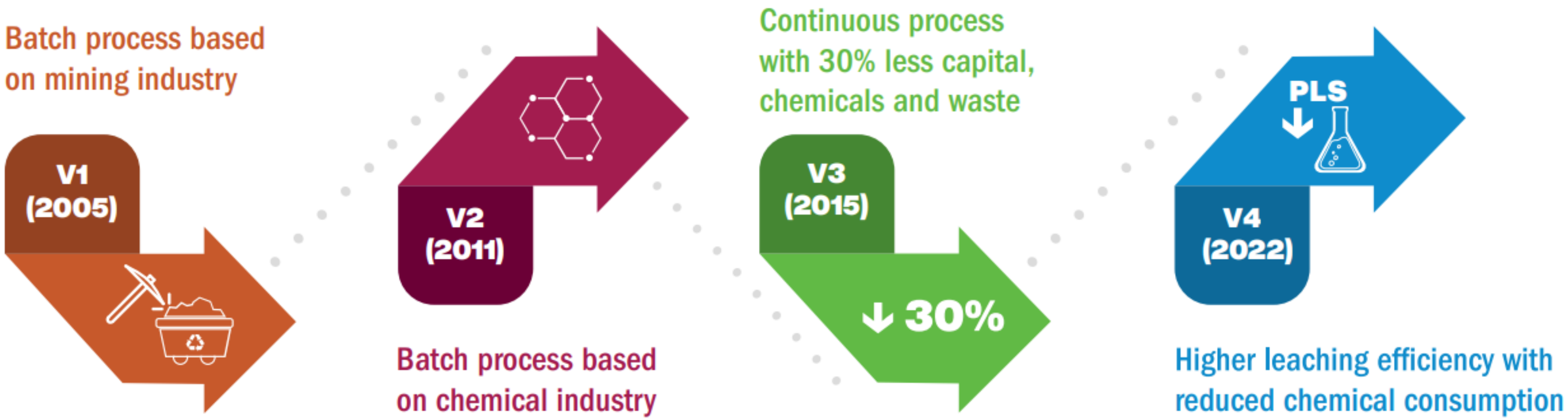
https://www.firstsolar.com/en/Solutions/Recycling

First Solar Module Recycling Process Overview



\+ 90% Recycling of Semiconductor Material and ~ 90% Recycling of Glass

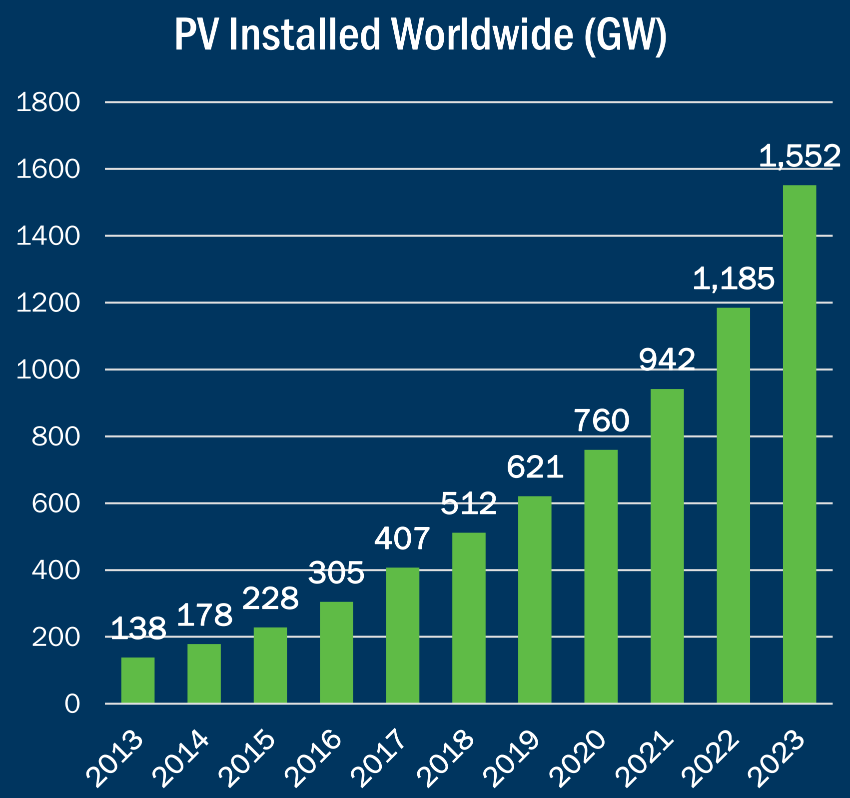
Continuously Improving Recycling Process Design



http://go.firstsolar.com/l/474372/2018-05-22/45c6f

Partnering on High-Value Recycling R&D

- Piloting high-value recycling technologies for silicon solar modules with Arizona State University and TG Companies
- Designing for recycling or reuse (closing loop on glass and aluminum) with University of Pittsburgh, University of California-Irvine, NREL
- Refining the delamination process to maximize the quantity and quality of the recyclable materials



REN21, Renewables Global Status Report, 2024.

Why Does High-Value PV Recycling Matter?

Crucial to managing large future PV waste volumes

- Over 1 Terawatt of PV installed worldwide

Recycling is important for all PV technologies

- Environmentally sensitive materials are common in the industry (Pb, Cd, Se, Ag...)

Provides socio-economic and environmental benefits

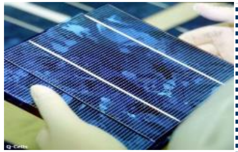
- Minimizes life cycle impacts
- Reclaims valuable and energy intensive materials
- Creates jobs and economic benefits
- Recoverable value could exceed $15bn by 2050[1]

Recycling maximizes resource recovery and increases the sustainability of PV

[1] IRENA and IEA-PVPS (2016), "End-of-Life Management: Solar Photovoltaic Panels," International Renewable Energy Agency and International Energy Agency Photovoltaic Power Systems.

A Short History of PV Recycling

1st global PV recycling program in the industry



Ökopol Study

PV Cycle Industry Initiative

EU WEEE Directive

U.S. Industry Program

PV Recycling Treatment Standard (EN 50625)

Sustainability Leadership & Recycling Standards

2005 | 2007 | 2012 | 2016 | 2017 | 2020/2021

First Solar


First Solar provides free of charge collection and environmentally responsible recycling of this solar module. Please do not dispose of this product in any manner before contacting First Solar via:

- the Web: **www.firstsolar.com/recycling**
- telephone:
  1.866.456.8938 (North American Toll free)
  +800.433.32.333*(International Freephone)
  *For more details on dialing codes please visit First Solar's website.
- email: **recycling@firstsolar.com**

First Solar bietet für dieses Solarmodul die Möglichkeit zur kostenlosen Rücknahme und umweltgerechten Wiederverwertung. Bitte kontaktieren Sie First Solar, bevor Sie das Produkt entsorgen.

First Solar ofrece gratuitamente la recogida y el reciclaje responsable con el medio ambiente de este producto de módulo solar. Por favor, no elimine de cualquier modo los residuos de este producto antes de ponerse en contacto con First Solar.

La First Solar raccoglie gratuitamente questo modulo solare e lo ricicla nel rispetto dell'ambiente. Non getti via questo prodotto prima di aver contattato la First Solar.

First Solar assure gratuitement la collecte et le recyclage de ce module solaire de manière écologique et responsable. Merci de ne pas vous débarrasser de ce produit de quelque façon que ce soit avant d'avoir contacté First Solar.

First Solar παρέχει δωρεάν συλλογή και περιβαλλοντολογικά υπεύθυνη ανακύκλωση της παρούσας ηλιακής μονάδας. Αποφύγετε την απόρριψη του προϊόντος με οποιονδήποτε τρόπο προτού επικοινωνήσετε με τη First Solar.

First Solar www.firstsolar.com


STUDY ON
THE DEVELOPMENT OF
A TAKE BACK AND
RECOVERY SYSTEM FOR
PHOTOVOLTAIC PRODUCTS

FUNDED BY BMU

CO-FINANCED BY EPIA / BSW-SOLAR

November 2007

PV CYCLE

SEIA PV RECYCLING PROGRAM

CENELEC


EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

FINAL DRAFT
FprEN 50625-2-4

May 2017

English Version

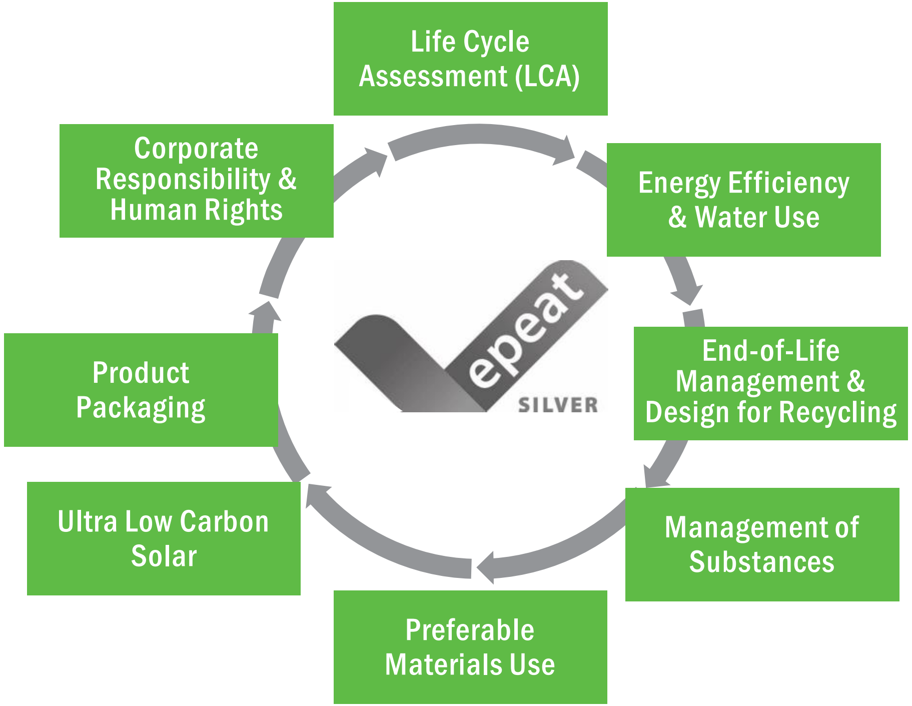
Collection, logistics & treatment requirements for WEEE - Part 2-4: Treatment requirements for photovoltaic panels

NSF

epeat

R2

EPEAT Ecolabel for Solar

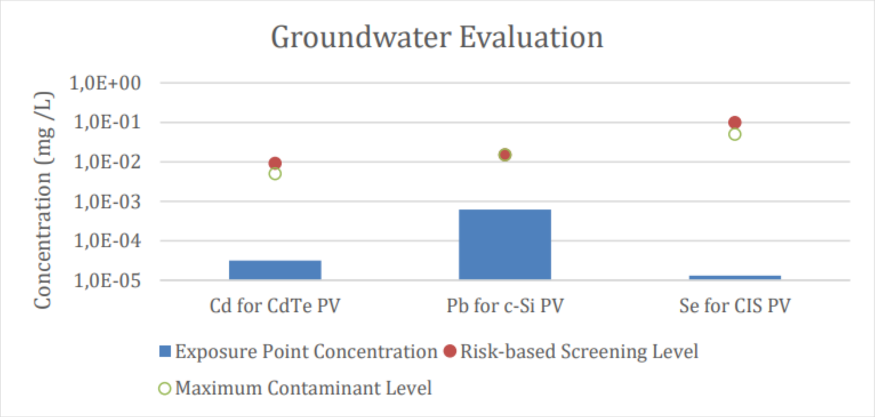


- Establishes corporate and product sustainability performance criteria that exemplify sustainability leadership in the market
- Globally recognized and independently verified Type 1 Ecolabel (designated under ISO 14024)
- Gives customers confidence that they are purchasing an environmentally-leading product from a socially-responsible company
- Includes criteria on recycled content, end-of-life management, and design for recycling

First Solar is the solar industry's first EPEAT Climate+ Champion.

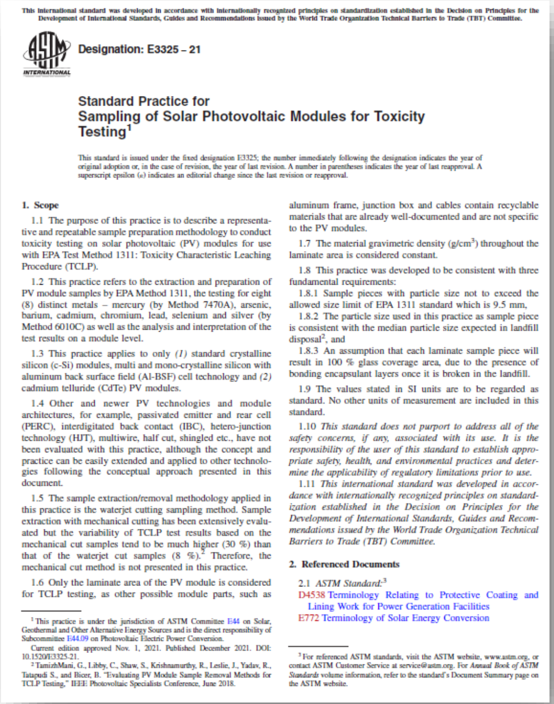
Assessing Worst-Case Risks from Improper Disposal

- CdTe PV does not have unique end-of-life management requirements
- A 2020 IEA PVPS study found that landfill disposal of c-Si, CdTe or CIGS modules is unlikely to have an adverse impact on human health even in worst case conditions[1]
  - End-of-life disposal impacts of crystalline silicon PV modules are comparable to or greater than that of CdTe PV
  - Real-life disposal options are likely to be safer than those modeled in the study since all modern landfills have a lining



[1] P. Sinha, G. Heath, A. Wade, K. Komoto, 2020, Human health risk assessment methods for PV, Part 3: Module Disposal risks, International Energy Agency (IEA) PVPS Task 12, Report T12-16:2020.

PV Waste Misconceptions and Challenges with TCLP



This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: E3325 – 21

Standard Practice for Sampling of Solar Photovoltaic Modules for Toxicity Testing[1]

This standard is issued under the fixed designation E3325; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 The purpose of this practice is to describe a representative and repeatable sample preparation methodology to conduct toxicity testing on solar photovoltaic (PV) modules for use with EPA Test Method 1311: Toxicity Characteristic Leaching Procedure (TCLP).

1.2 This practice refers to the extraction and preparation of PV module samples by EPA Method 1311, the testing for eight (8) distinct metals – mercury (by Method 7470A), arsenic, barium, cadmium, chromium, lead, selenium and silver (by Method 6010C) as well as the analysis and interpretation of the test results on a module level.

1.3 This practice applies to only *(1)* standard crystalline silicon (c-Si) modules, multi and mono-crystalline silicon with aluminum back surface field (Al-BSF) cell technology and *(2)* cadmium telluride (CdTe) PV modules.

1.4 Other and newer PV technologies and module architectures, for example, passivated emitter and rear cell (PERC), interdigitated back contact (IBC), hetero-junction technology (HJT), multiwire, half cut, shingled etc., have not been evaluated with this practice, although the concept and practice can be easily extended and applied to other technologies following the conceptual approach presented in this document.

1.5 The sample extraction/removal methodology applied in this practice is the waterjet cutting sampling method. Sample extraction with mechanical cutting has been extensively evaluated but the variability of TCLP test results based on the mechanical cut samples tend to be much higher (30 %) than that of the waterjet cut samples (8 %).[2] Therefore, the mechanical cut method is not presented in this practice.

1.6 Only the laminate area of the PV module is considered for TCLP testing, as other possible module parts, such as aluminum frame, junction box and cables contain recyclable materials that are already well-documented and are not specific to the PV modules.

1.7 The material gravimetric density (g/cm^3) throughout the laminate area is considered constant.

1.8 This practice was developed to be consistent with three fundamental requirements:

1.8.1 Sample pieces with particle size not to exceed the allowed size limit of EPA 1311 standard which is 9.5 mm,

1.8.2 The particle size used in this practice as sample piece is consistent with the median particle size expected in landfill disposal[2], and

1.8.3 An assumption that each laminate sample piece will result in 100 % glass coverage area, due to the presence of bonding encapsulant layers once it is broken in the landfill.

1.9 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.10 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.11 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standard:*[3]

D4538 Terminology Relating to Protective Coating and Lining Work for Power Generation Facilities

E772 Terminology of Solar Energy Conversion

[1] This practice is under the jurisdiction of ASTM Committee E44 on Solar, Geothermal and Other Alternative Energy Sources and is the direct responsibility of Subcommittee E44.09 on Photovoltaic Electric Power Conversion.

Current edition approved Nov. 1, 2021. Published December 2021. DOI: 10.1520/E3325-21.

[2] TamizhMani, G., Libby, C., Shaw, S., Krishnamurthy, R., Leslie, J., Yadav, R., Tatapudi S., and Bicer, B. "Evaluating PV Module Sample Removal Methods for TCLP Testing," IEEE Photovoltaic Specialists Conference, June 2018.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

https://www.astm.org/e3325-21.html

- Hazardous or non-hazardous waste characterization cannot be determined based on PV technology
- ASTM standard establishes representative and repeatable sample preparation methodology for PV TCLP testing
  - Applies waterjet cutting sampling method to avoid TCLP results variability resulting from mechanical cutting
  - Sample size (9.5 mm) is consistent with median particle size expected in landfill
  - Sample piece should have 100% glass coverage area since modules are bonded by laminate material

Lessons Learned

- High-value recycling is important for all PV technologies
- Waste characterization cannot be determined by technology, manufacturing date, or age of panels
- Pay-as-you-go-approach is more cost-effective and viable than pre-funding
- Facilitating transportation of PV modules destined for recycling is needed
- Ecolabels and material recovery targets encourage high-value PV recycling

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