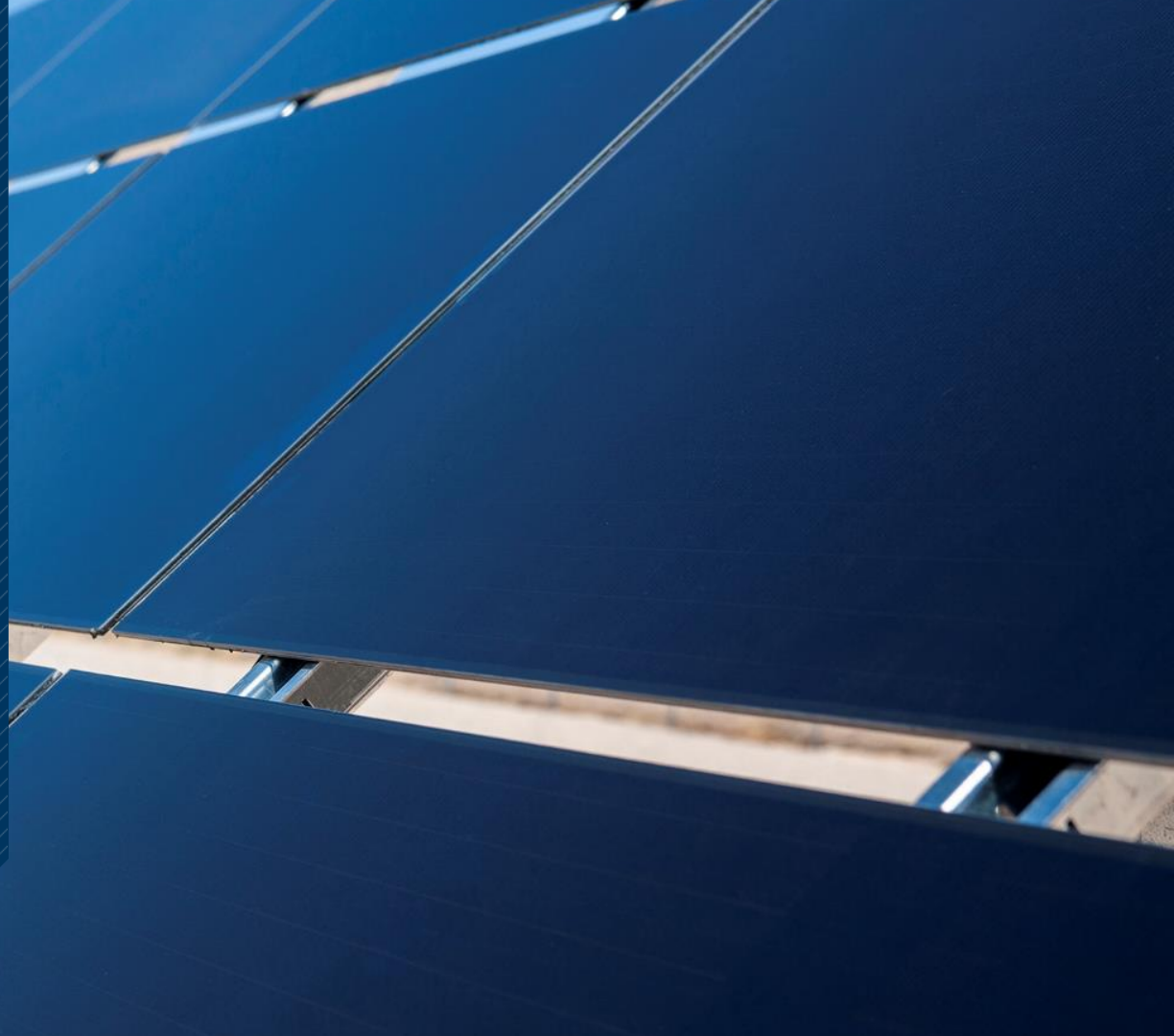
ENABLING A VIRTUOUS CYCLE

LIFE CYCLE MANAGEMENT IN PHOTOVOLTAICS

Andreas Wade
Global Sustainability Director

First Solar®



OUTLINE

1. Introduction to First Solar
2. Life Cycle Management in Photovoltaics – IEA & IRENA
3. A Short History of PV Recycling at First Solar
4. Life Cycle Benefits of High Value Recycling

INTRODUCTION TO FIRST SOLAR

FIRST SOLAR AT A GLANCE

Over 17GW sold worldwide and over $14.5B in project financing facilitated

Partner of choice for leading utilities and global power buyers since 1999

Solar energy that is economically competitive with fossil fuel

Strongest financial stability & bankability in the industry

FIRST SOLAR AT A GLANCE

History of solar innovation with **world record efficiency**

High-efficiency technology with a **proven energy advantage**

Lowest environmental impacts
generating clean electricity with
NO carbon emissions or air pollutants

GLOBAL OFFICES & MANUFACTURING

~4,100
Associates

~26,760
2017 Global Supply Chain Jobs

TRUSTED AND BANKABLE PARTNER

CORPORATE RENEWABLES

UTILITY-SCALE

DEVELOPERS & EPC

O&M

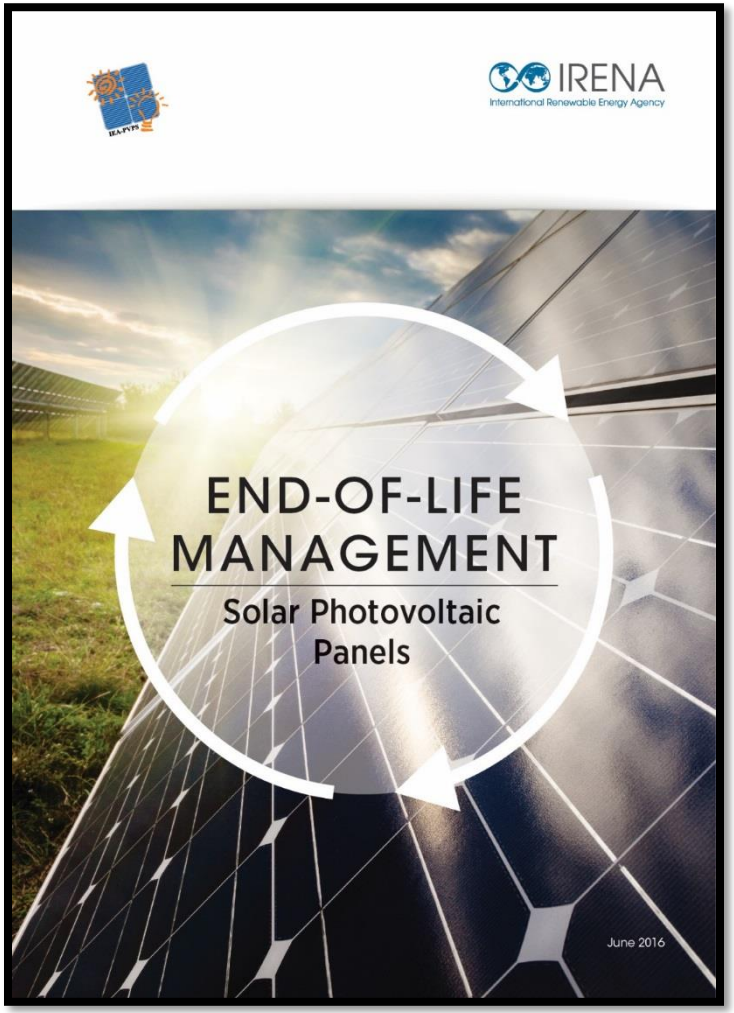
"We create **enduring value for our customers** through innovation, customer engagement, industry leadership and operational excellence."

— Mark Widmar
First Solar CEO

17GW+ SOLD WORLDWIDE

First Solar®

LIFE CYCLE MANAGEMENT IN PHOTOVOLTAICS – IEA & IRENA



CHALLENGES AND OPPORTUNITIES

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Contributors
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KEY FINDINGS

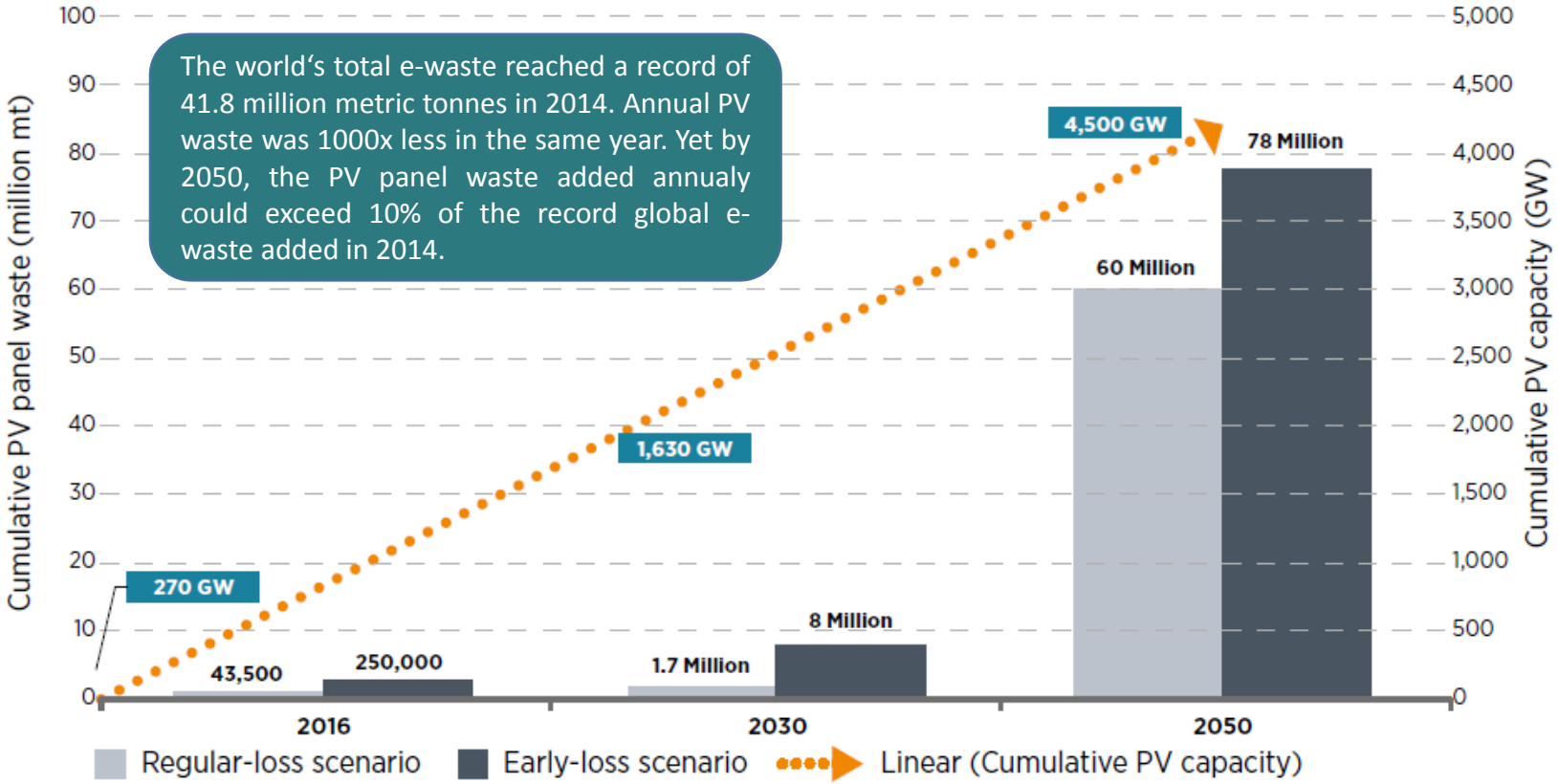
- Growing PV panel waste represents a new environmental challenge, but also unprecedented opportunities to create and pursue new economic avenues.
- This report presents global projections for future PV panel waste volumes to 2050 in two scenarios.
- Policy action, R&D and supporting analyses are needed to address the challenges ahead; enabling frameworks can be adapted to the needs and circumstances of each region or country.
- End-of-life management could become a significant component of the PV value chain and can spawn new industries, supporting considerable economic value creation.

KEY FINDINGS

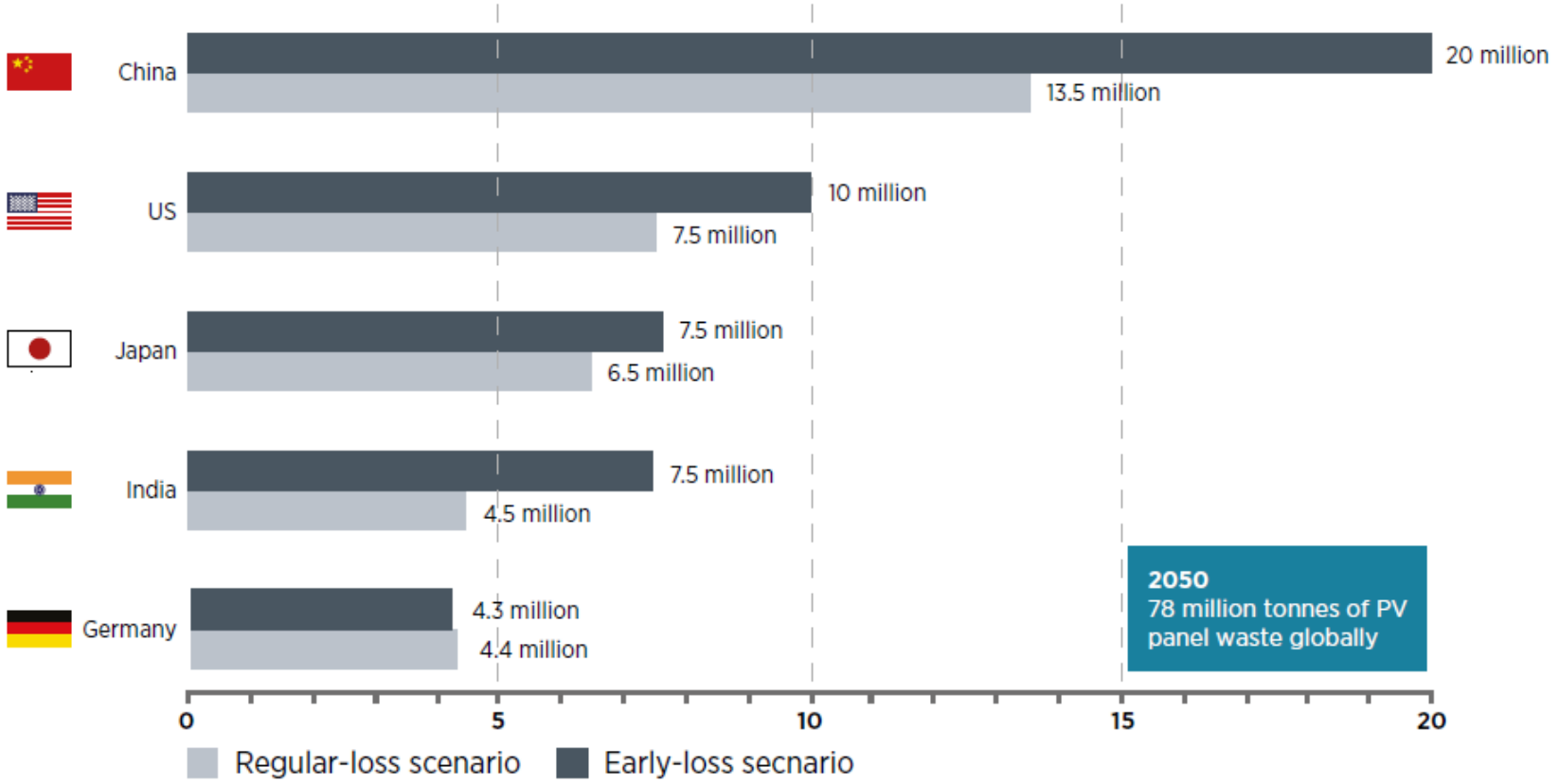
- Lessons can be learned from the experience of the European Union in developing its regulatory framework to help other countries move up the learning curve faster and adapt locally-appropriate approaches.
- Considerable technological and operational knowledge about PV panel end-of-life management already exists in many countries. This can guide the development of effective waste management solutions, helping to address the projected large increase in PV panel waste.

GLOBAL PV PANEL WASTE PROJECTION 2016-2050

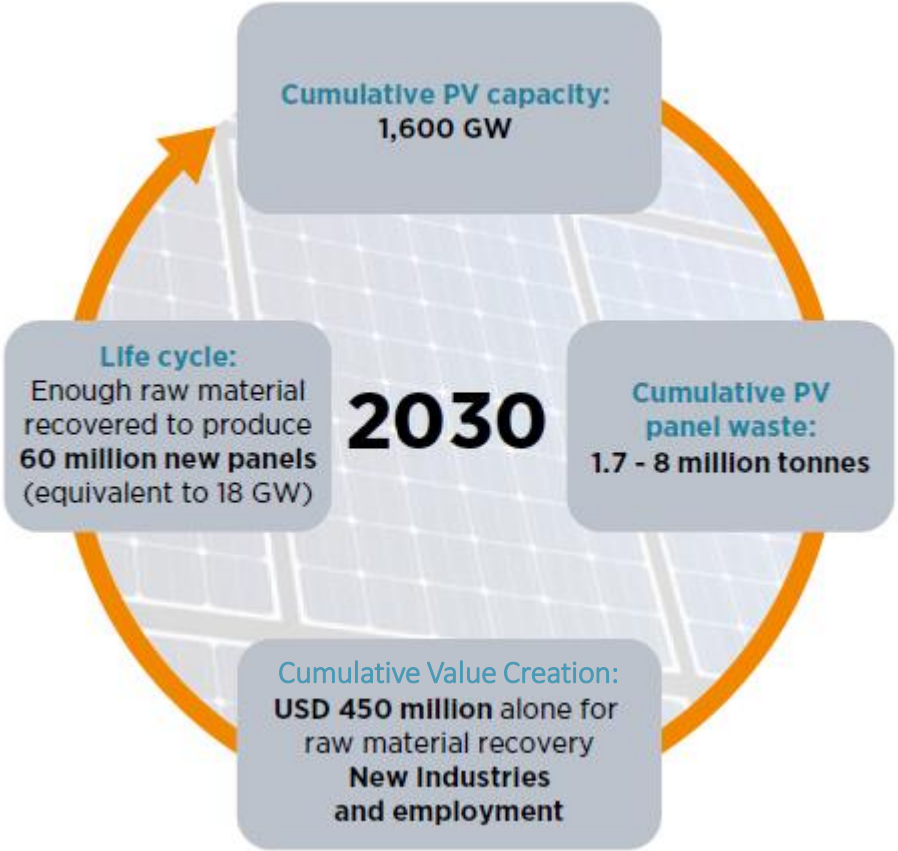
The world's total e-waste reached a record of 41.8 million metric tonnes in 2014. Annual PV waste was 1000x less in the same year. Yet by 2050, the PV panel waste added annualy could exceed 10% of the record global e-waste added in 2014.

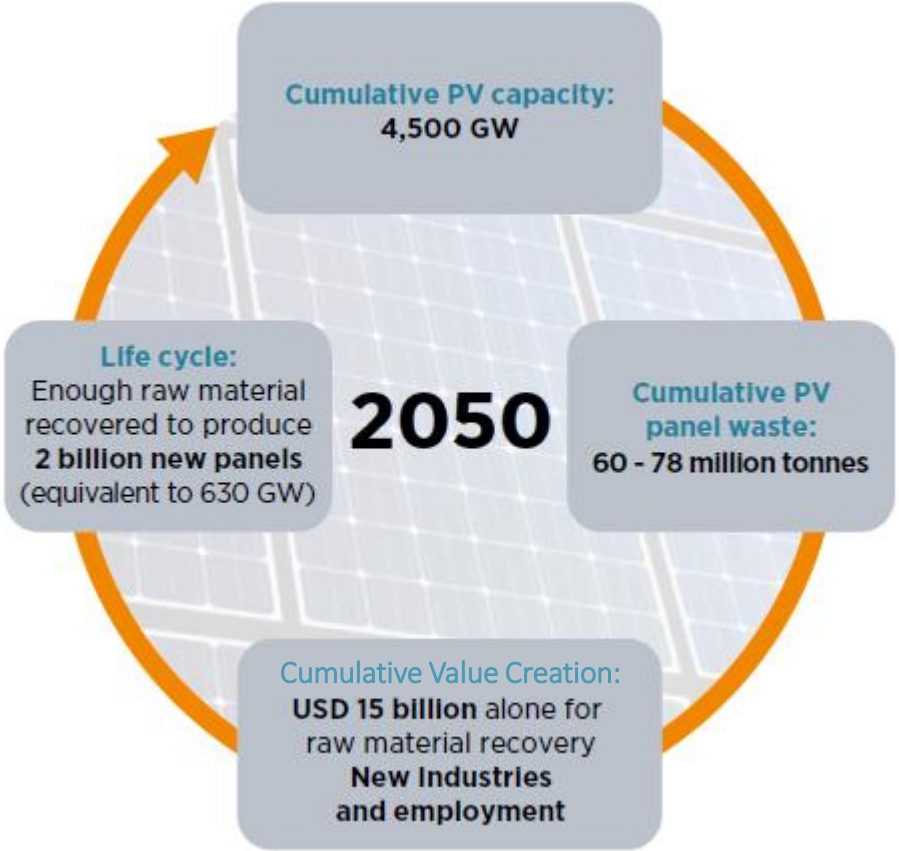


CUMULATIVE PV WASTE: TOP 5 REGIONS 2050

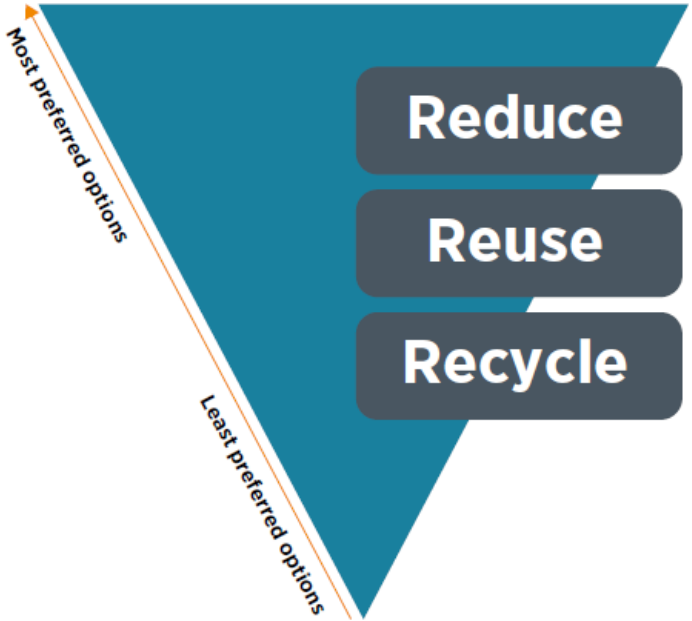


POTENTIAL VALUE CREATION





INNOVATION OPPORTUNITIES



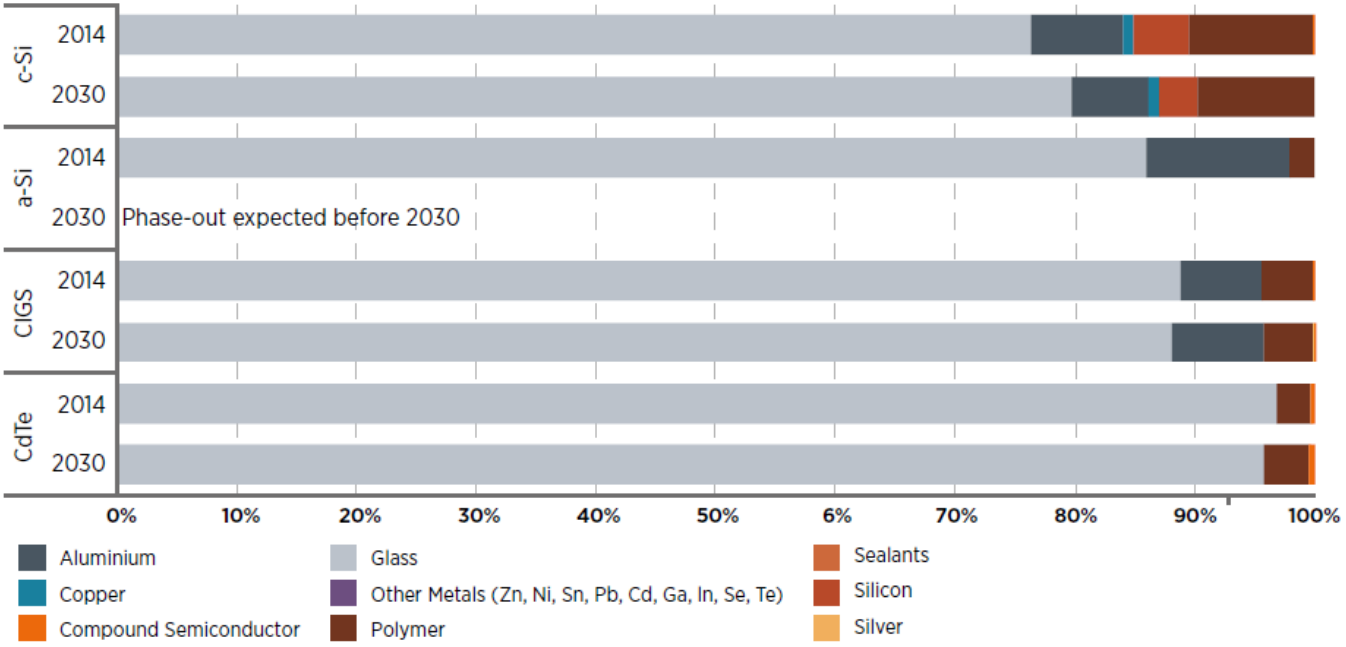
As R&D and technological advances continue with a maturing industry, the composition of PV panels is expected to require less raw materials.

Rapid global PV growth is expected to generate a robust secondary market for panel components and materials.

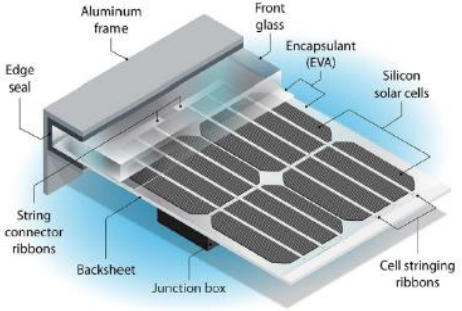
As current PV installations reach the final decommissioning stage, recycling and material recovery will be preferable to panel disposal.

PV PANEL COMPOSITION AND WASTE CLASSIFICATION

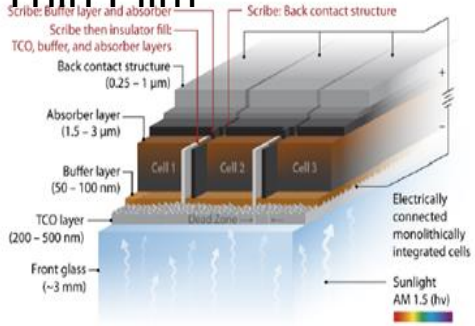
PANEL COMPOSITION & TECHNOLOGY TRENDS



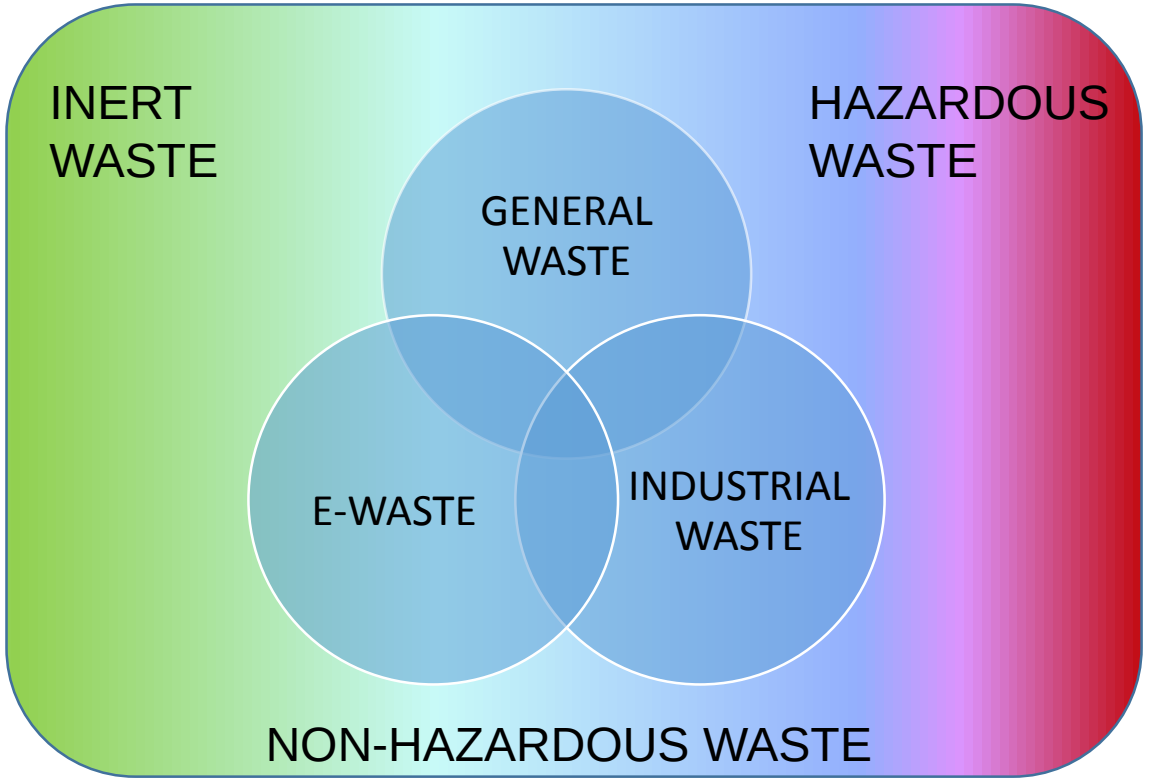
C-Si



Thin Film



WASTE CLASSIFICATION



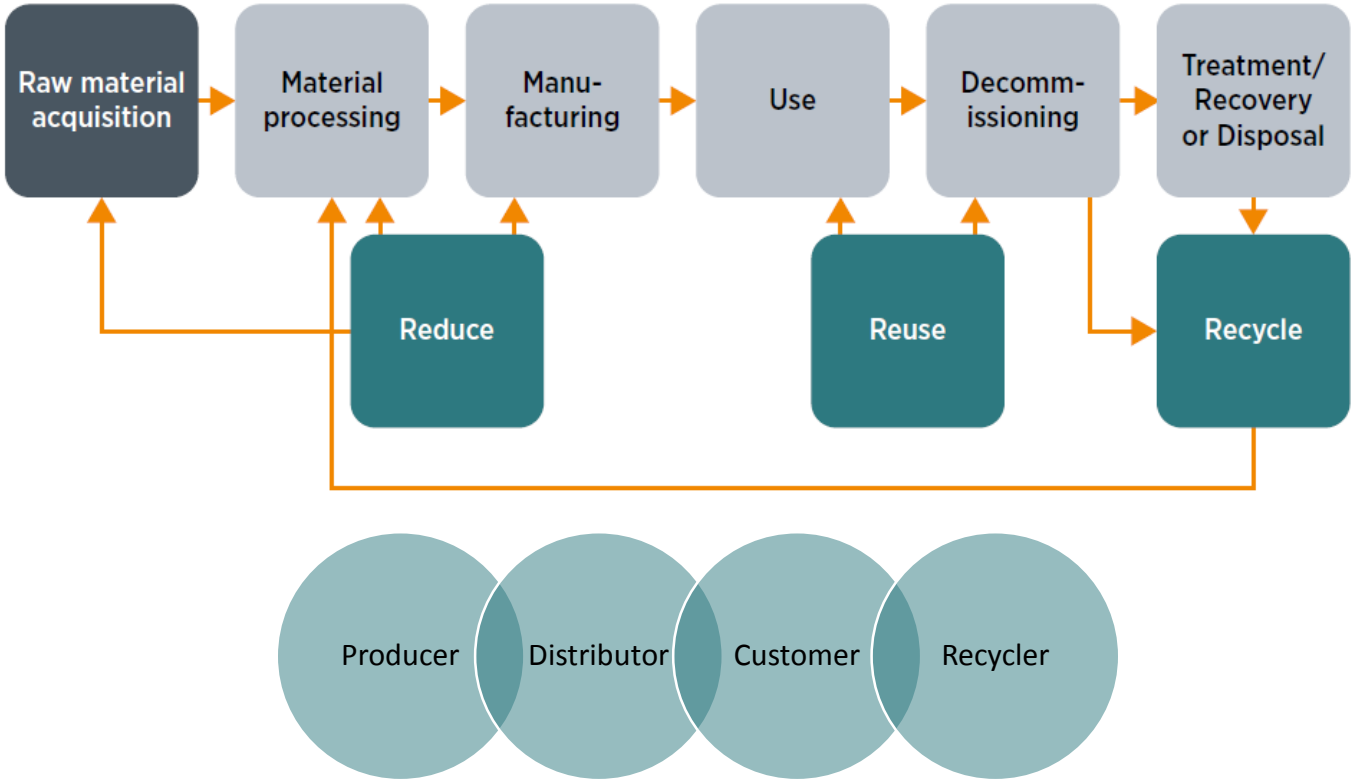
All PV Panel technologies contain trace amounts of hazardous materials such as lead, tin, zinc, cadmium, selenium, indium, gallium and others.

Depending on the jurisdiction, different waste characterization tests and methods can lead to different classifications of PV panel waste.

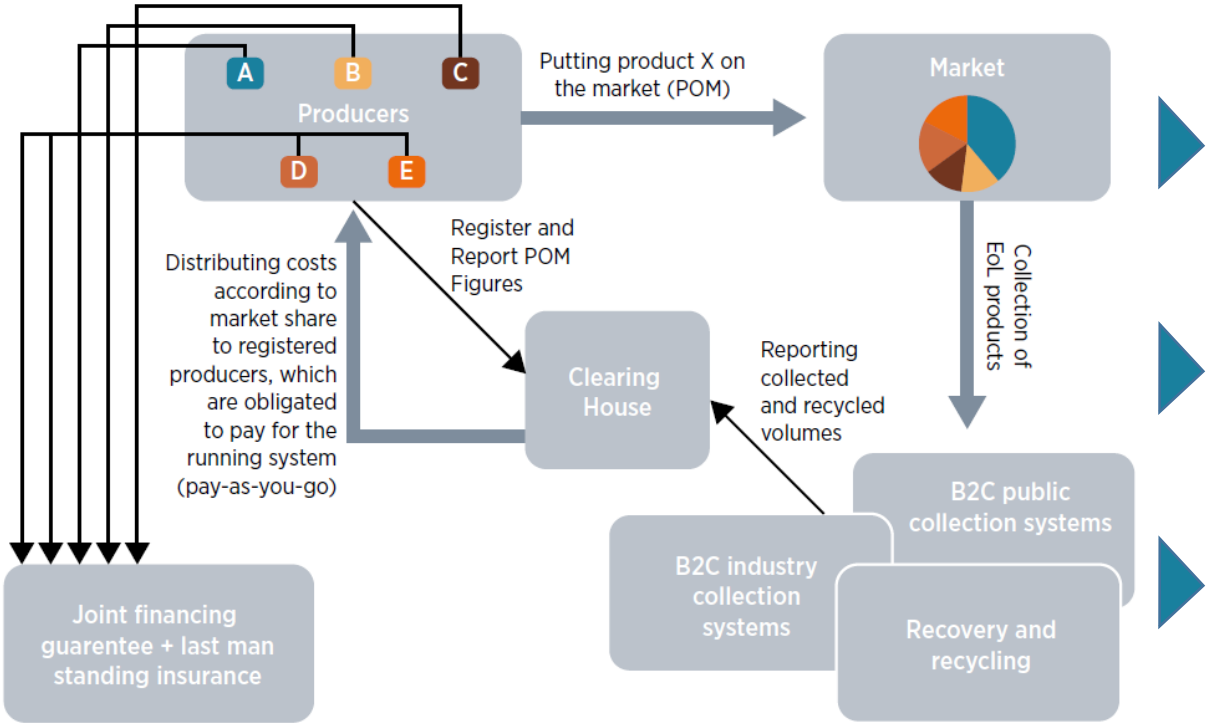
Typically, standardized leaching tests and material concentration limits determine the classification and minimum requirements for treatment and disposal.

PV PANEL WASTE MANAGEMENT OPTIONS

LIFE CYCLE & STAKEHOLDERS



MANAGEMENT SYSTEMS



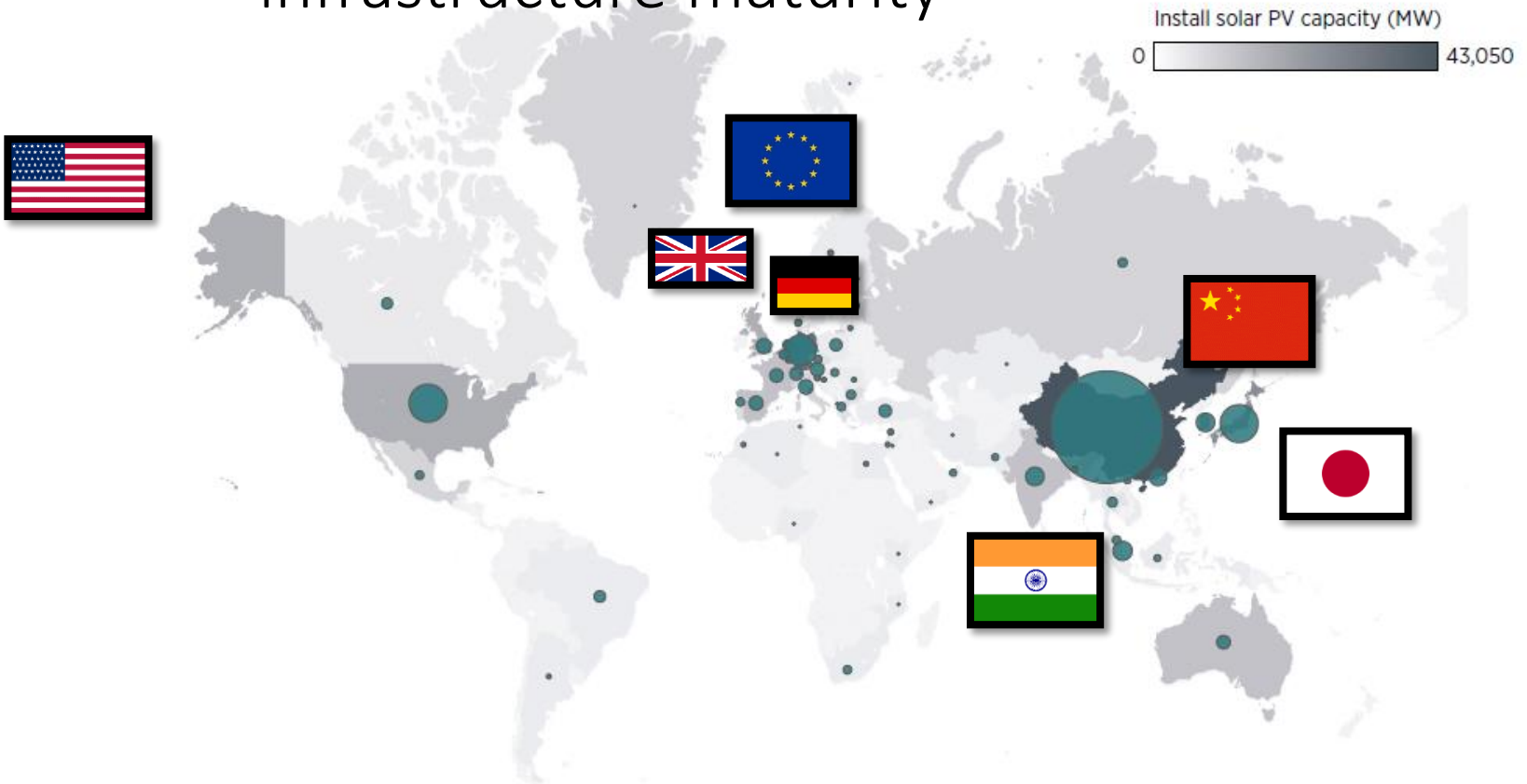
There are a variety of options for end-of-life management structures and financial responsibility: Extended Producer Responsibility, Polluter-Pays-Principle, Public-Private-Partnerships, B2B & B2C solutions.

Physical and financial management systems

Minimum Requirements & High Value Recycling

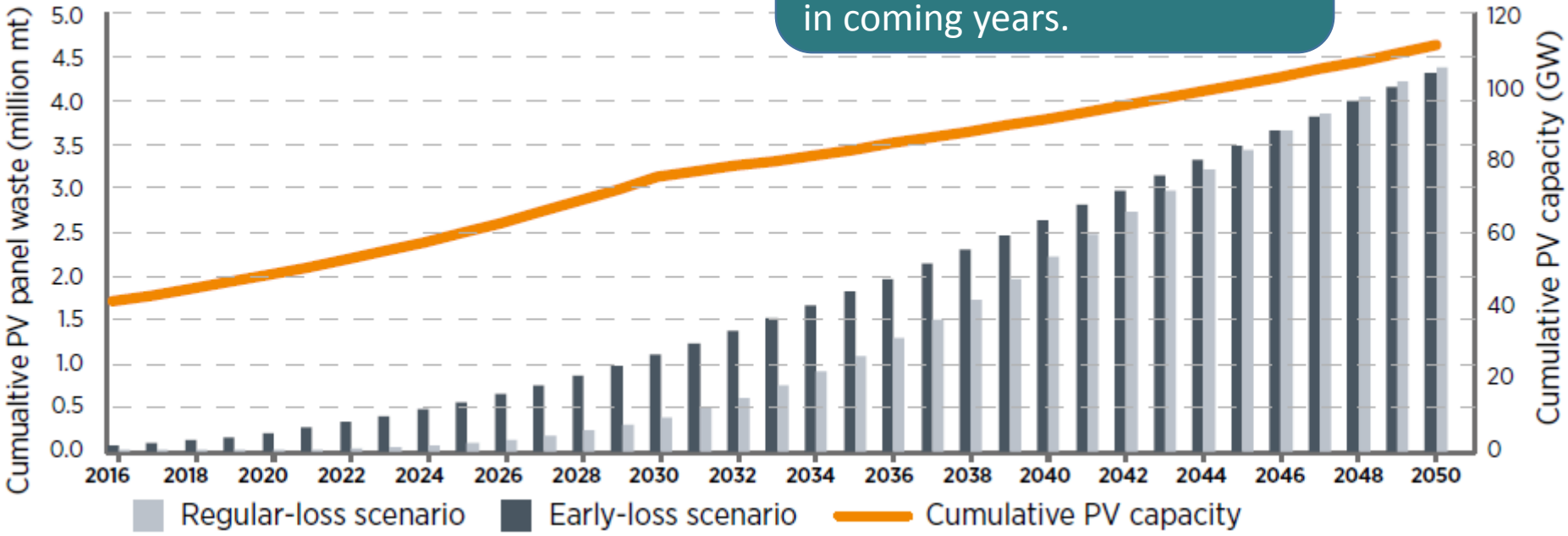
CASE STUDIES

CASE STUDIES span range of market and recycling infrastructure maturity

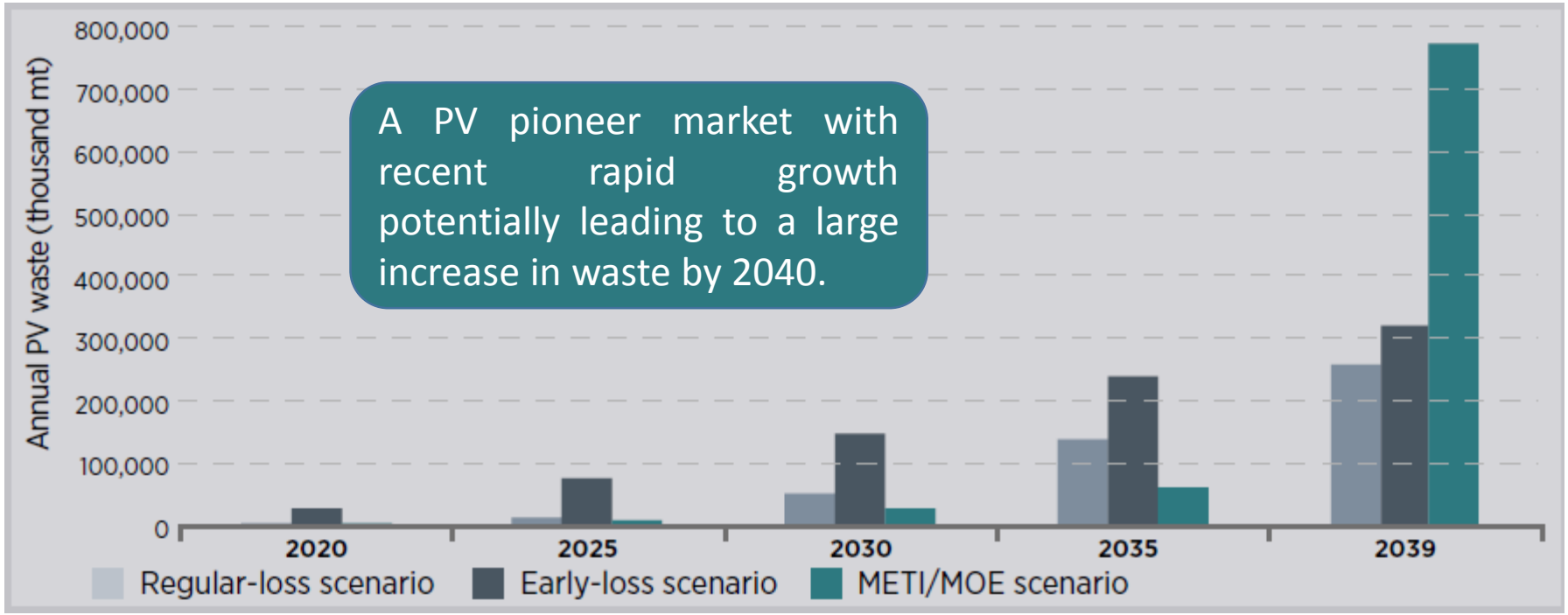


GERMANY – a mature market

Germany will clearly be one of the first and largest markets for PV recycling technologies in coming years.

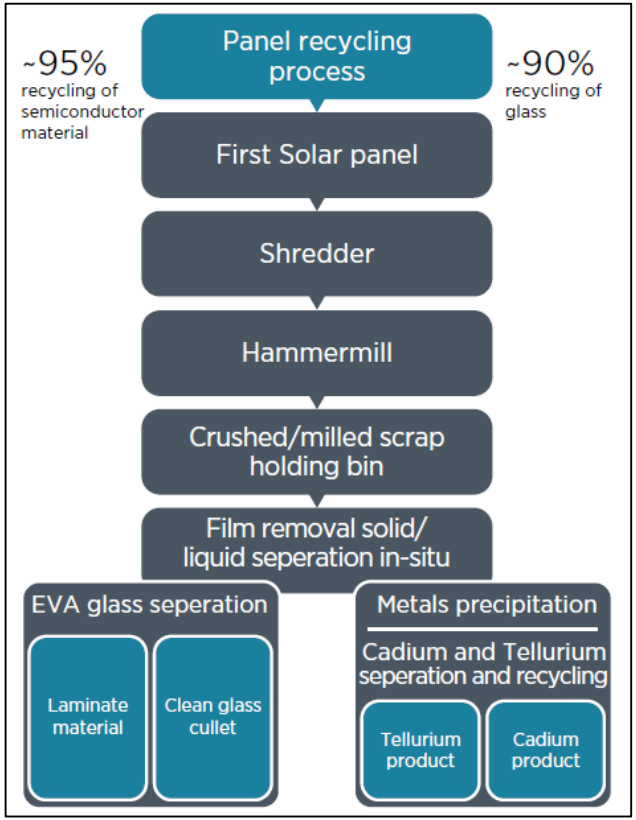


JAPAN – advanced market without PV specific waste regulations

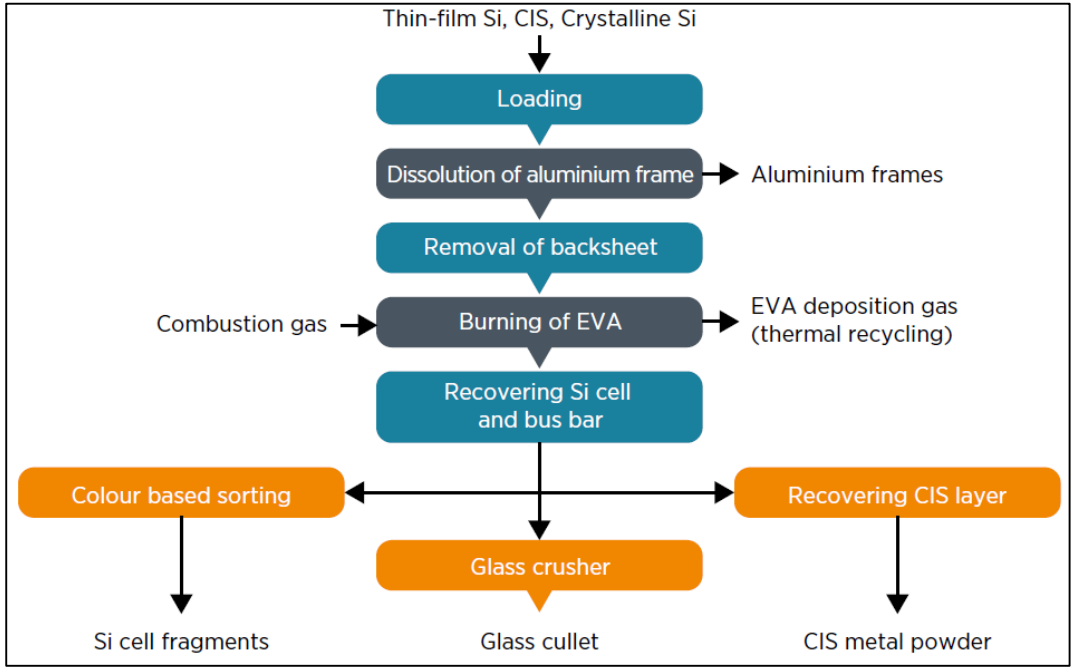


VALUE CREATION FROM END-OF-LIFE PV PANELS

RECYCLE – example processes for CdTe and C-Si



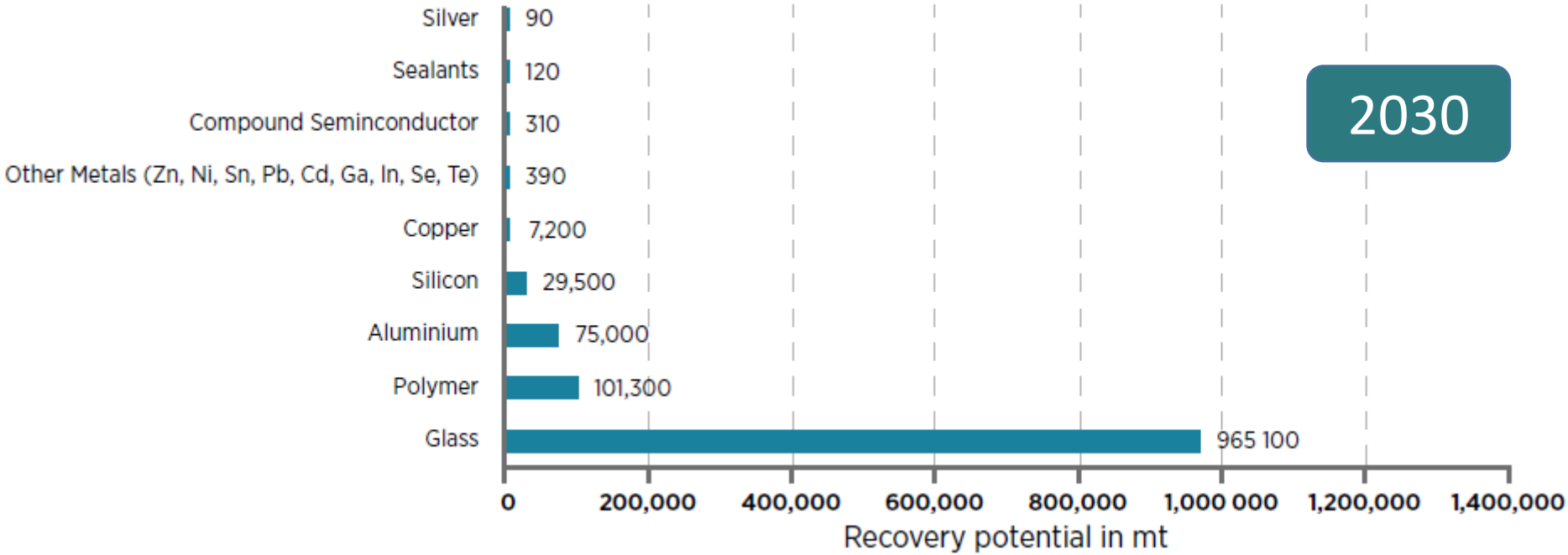
First Solar Recycling Process



Recycling Scheme proposed by NEDO/FAIS in Japan

MATERIALS RECOVERY

Cumulative technical potential for end-of-life material recovery under regular-loss scenario.



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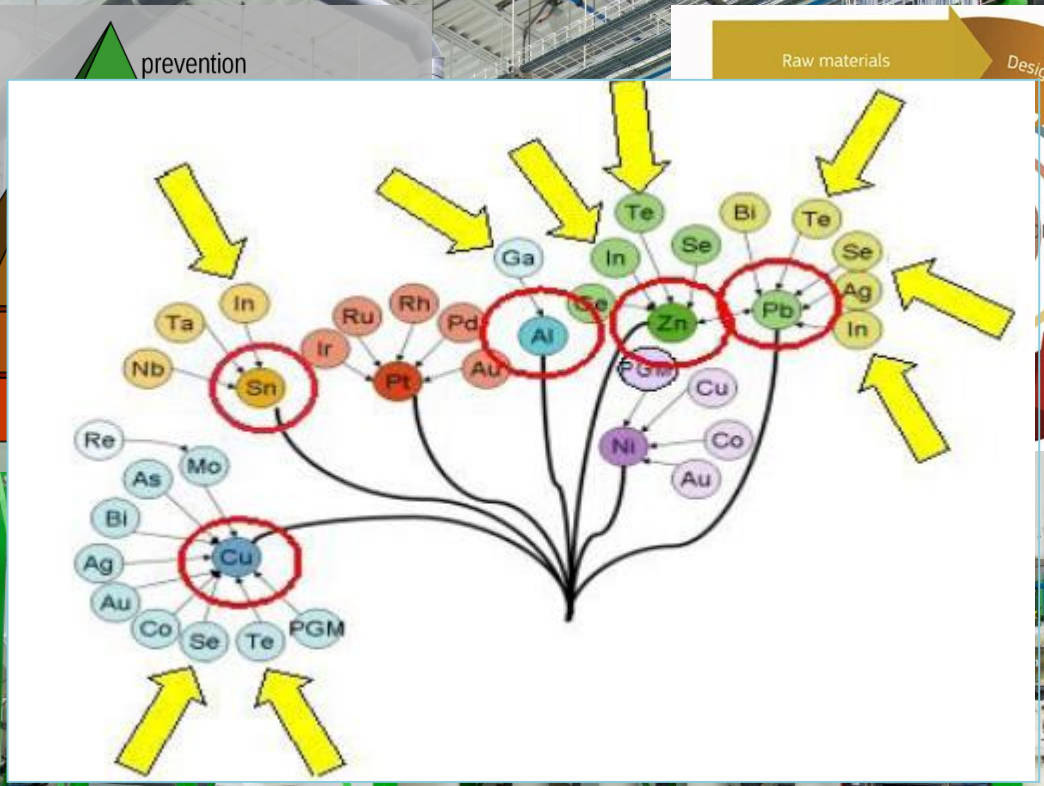
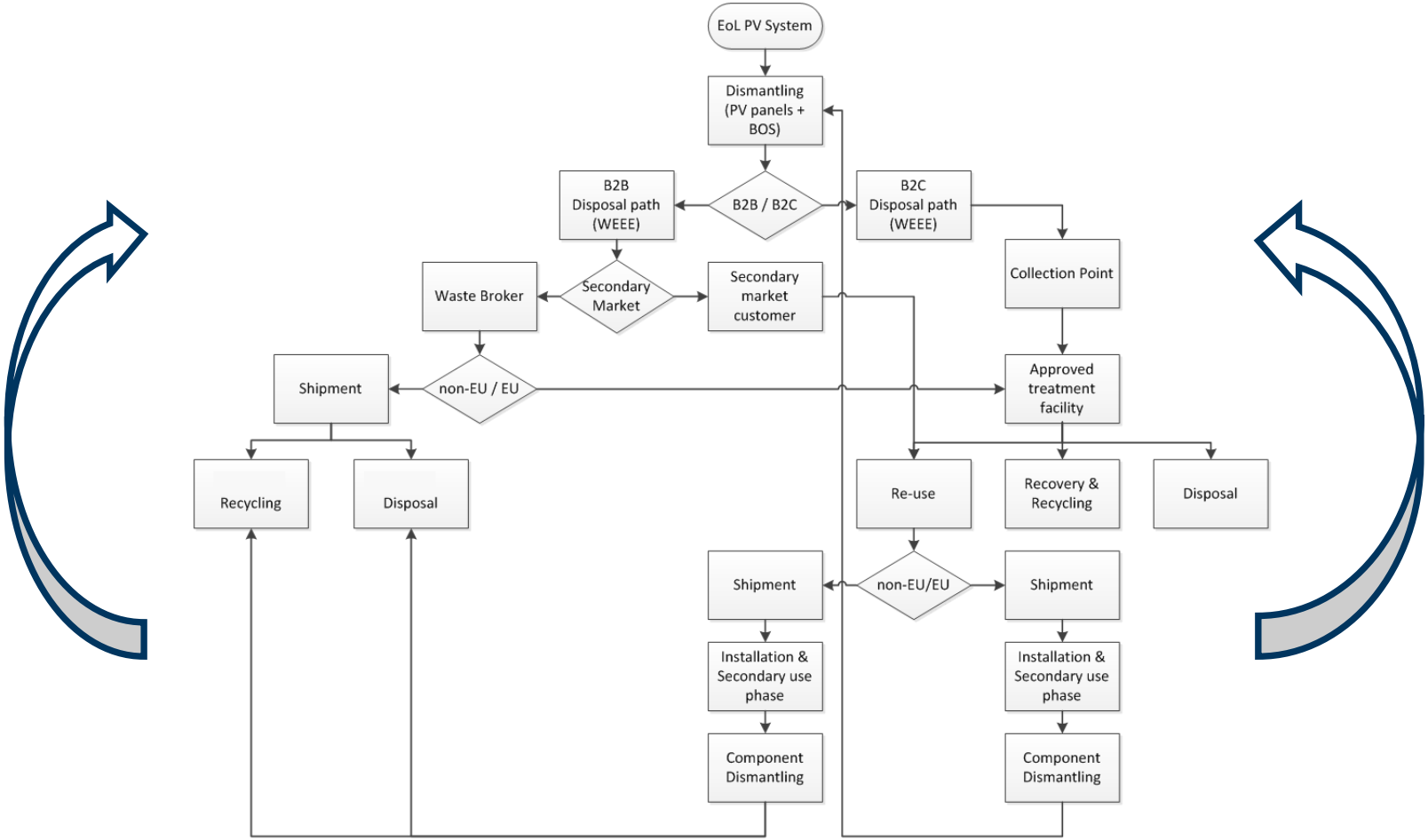
SHORT HISTORY OF PV RECYCLING

THE ENERGY TRANSITION – CIRCULAR ECONOMY NEXUS



Graphs taken from European Commission, EASME, https://ec.europa.eu/easme/en/news/r2-supporting-transition-circular-economy ; Wecend, Wade, Heath, et.al. End of Life Management: Photovoltaic Panels, IRENA, IEA PVPS Task 12, 2016

PATHWAYS TO A CIRCULAR ECONOMY FOR PV SYSTEMS MATERIALS



A SHORT HISTORY OF PV RECYCLING

First Global Collection and Recycling Program (2005)

Ökopol Study (2007)

PV CYCLE (2007)

WEEE Directive (2012)

EN50625: PV Recycling Standard (2017)

Binding Treatment Ordinance in Germany (2019)


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 gettli 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. Απορρίψτε την απόρριψη του προϊόντος με οποιονδήποτε τρόπο πριτού 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

GRANT NUMBER 03MAP092

CO-FINANCED BY EPIA / BSW-SOLAR

November 2007

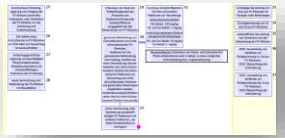

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

FINAL DRAFT
FprEN 50625-2-4

May 2017

English Version

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




DIRECTIVE 2012/19/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 4 July 2012

on waste electrical and electronic equipment (WEEE)

(recast)

(Text with EEA relevance)

Enabling a level playing field for the collection, treatment and recycling of photovoltaic panels in the EU has accelerated the learning curve for the industry. To ensure further progress and enable a sustainable recycling and recovery value chain, a viable secondary resource market outlet is of paramount importance.

FULLY INTEGRATED RESPONSIBLE PRODUCT LIFE CYCLE APPROACH

Material Sourcing

Converting mining byproducts into a stable semiconductor

Product Design

Designed for high-value recycling

Manufacturing

Manufacturing with less energy, water, and GHG emissions

Product Use

Faster CO_2 reductions and greater return on energy invested

Collection & Recycling

Recovering over 90% of materials at end-of-life for new PV modules

WHY DOES HIGH-VALUE PV RECYCLING MATTER?

Crucial to managing large future PV waste volumes

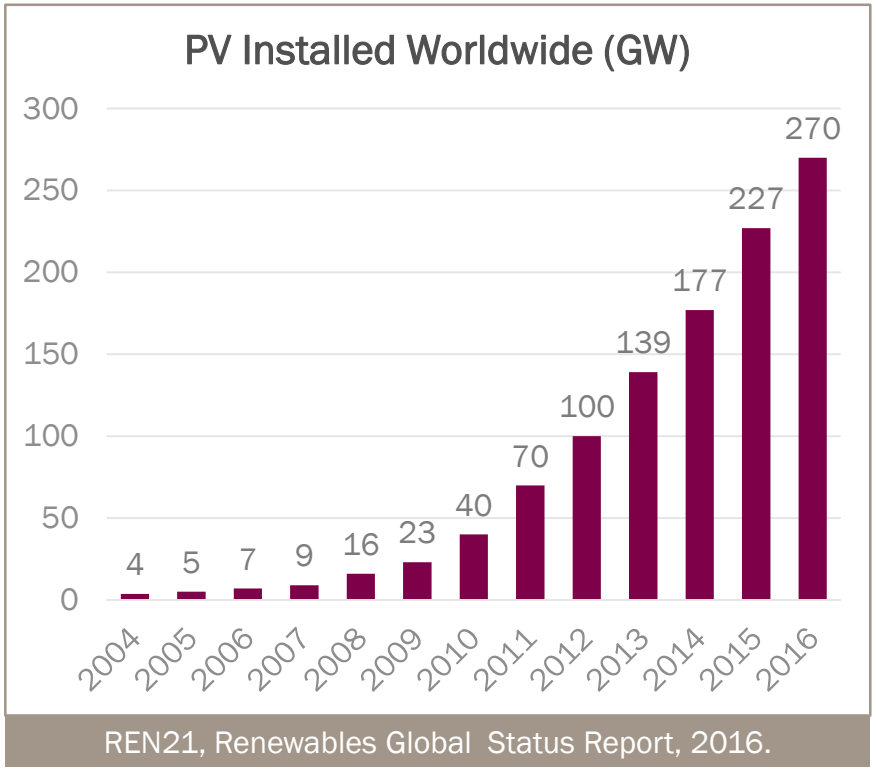
- Over 300 GW PV installed worldwide

Recycling is important for all PV technologies

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

Provides socio-economic and environmental benefits

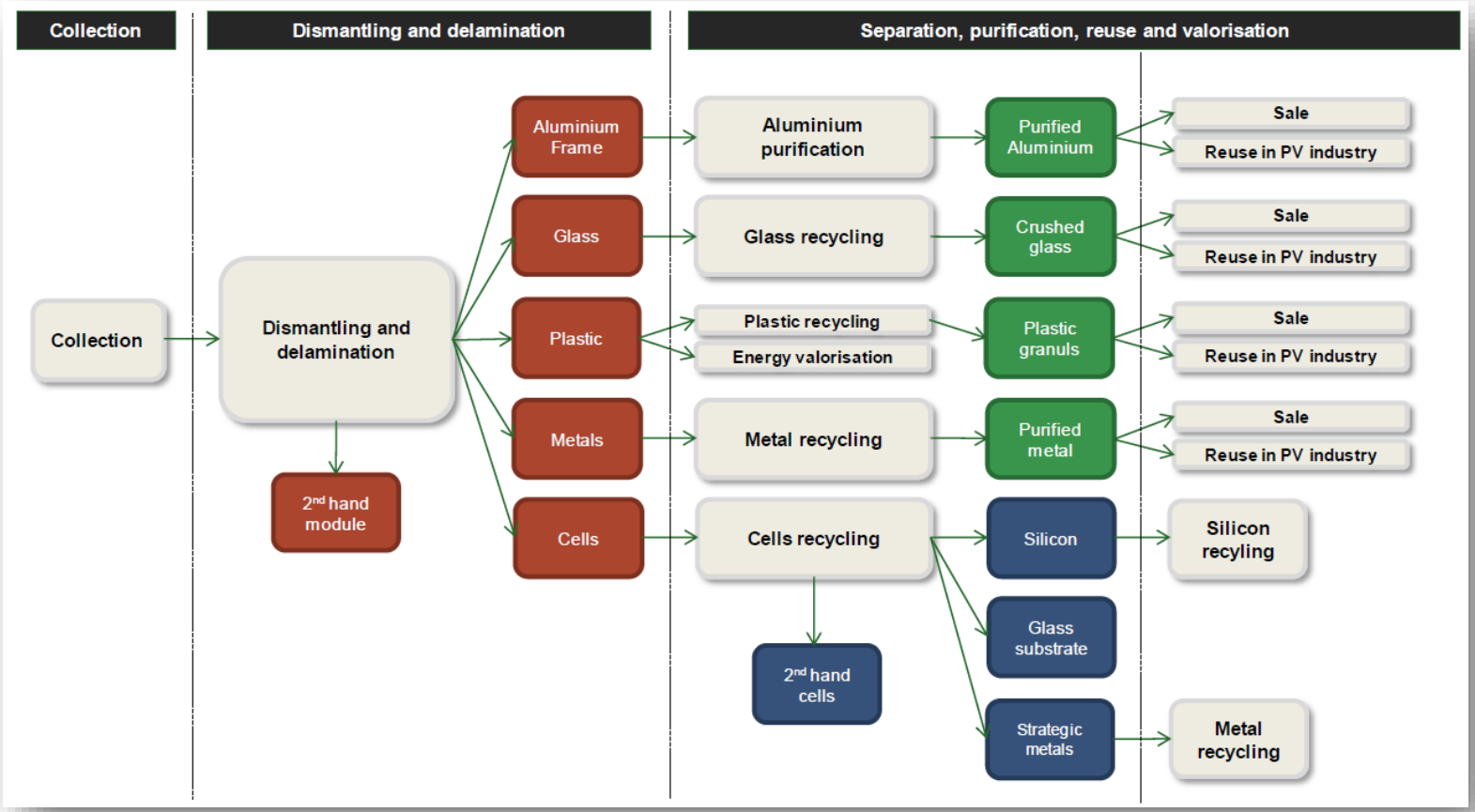
- Minimizes life cycle impacts
- Reclaims valuable and energy intensive materials
- Creates jobs and economic benefits
- Recoverable value could exceed $15bn by 2050



REN21, Renewables Global Status Report, 2016.

Recycling maximizes resource recovery and increases the sustainability of PV.

PV RECYCLING VALUE CHAIN



Source: RECORD/ ENEA Consulting, 2012

CIRCULAR ECONOMY: BEYOND WASTE

TYPICAL RECYCLING RATES

AUTOMOTIVE
~75%

INFORMATION TECHNOLOGY
~45%

FIRST SOLAR MODULES
~90%

THE VALUE LOOP

SEMICONDUCTOR FROM MINING BY-PRODUCTS

THIN FILM PV MANUFACTURING

Resource-Efficient Manufacturing

DISPLACE GRID EMISSIONS

25+
Years of Deployment

FIRST SOLAR RECYCLING SERVICES

90% RECOVERY RATE

GLASS: Used to make glass products

ENCAPSULANT: Used to make rubber products

SEMICONDUCTOR: Reused to produce First Solar modules

1Kg	40x	1,230 years
Of CdTe Semiconductor	Times it can be recycled	Years it can generate electricity

First Solar.

FIRSTSOLAR.COM/SUSTAINABILITY

FIRST SOLAR'S RECYCLING PROCESS DESIGN PROGRESSION

V1 Recycling (2006)

- Based on the mining industry
- Batch process
- Moving glass and liquid from process to process
- Volume output – 10 tons/day
- Capital investment - $5M

V2 Recycling (2011)

- Based on the chemical industry
- Batch process
- Based on keeping the glass fixed and moving the liquids thru the material
- Volume output – 30 tons/day
- Capital investment - $7M

THIRD GENERATION CONTINUOUS PROCESS RECYCLING (2015)

- More efficient 7/24 operations
- Compact plant with smaller footprint
- Increased daily recycling capacity from 30 tons to 150 tons/day capacity
- Requires 30% less capital, chemicals, waste and labor
- Achieves superior glass and semiconductor purity

FIRST SOLAR MODULE RECYCLING PROCESS

Shredder

Hammermill

Crushed/ Milled Scrap Holding Bin

Metals Precipitation

Film Removal Solid/ Liquid Separation

EVA/Glass Separation

Third-party Cd/Te Separation & Refining

Te Product

CdTe

Cd Product

FS PV Modules

Clean Glass Cullet

Glass Products

Laminate Material

Rubber Products

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

GLOBAL AND PROVEN INDUSTRY-LEADING RECYCLING EXPERTISE

- 1st global PV module recycling program in the industry
- Recycling facilities are operational in the USA, Germany and Malaysia
- Scalable to accommodate future high volumes: ~165,000MT recycled (end of ‘16)
- Recovering over 90% of semiconductor materials and approximately 90% of glass
- Continuously improving processes and technology and reducing operational costs

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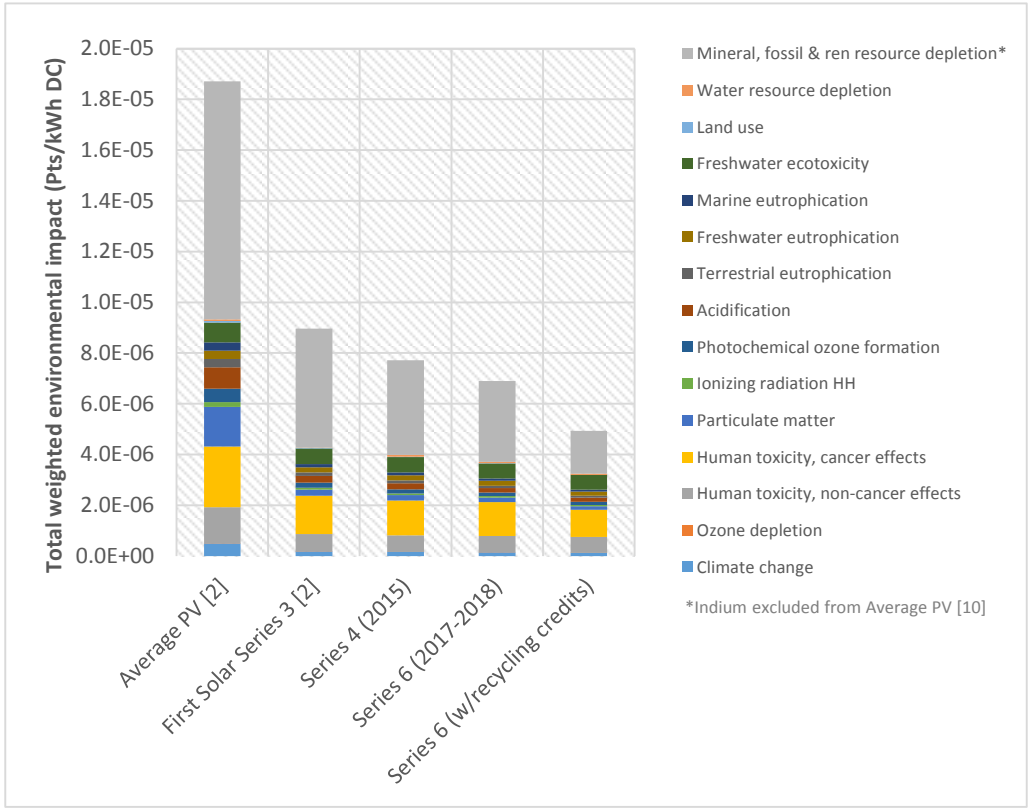
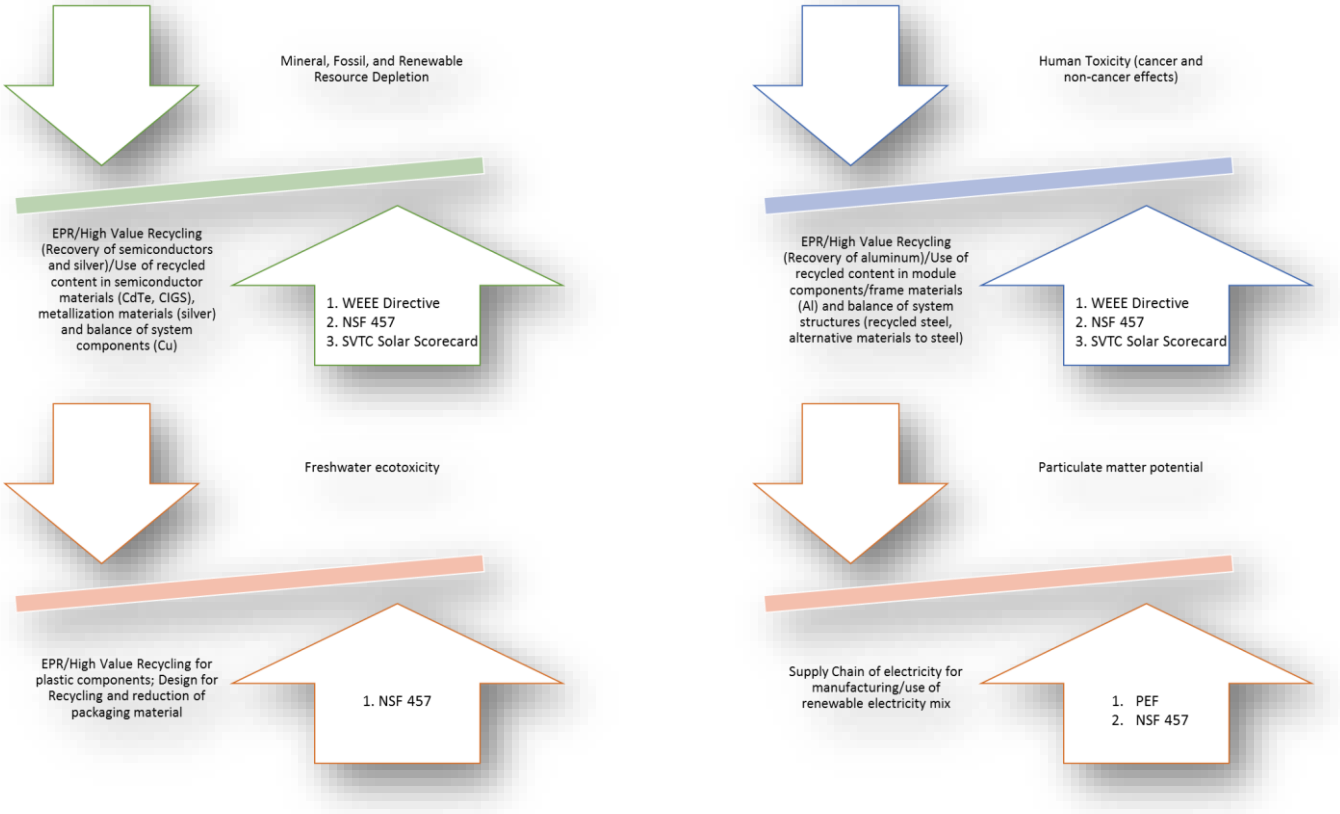
LIFE CYCLE BENEFITS OF HIGH VALUE RECYCLING

BENEFITS OF HIGH VALUE RECYCLING

Measures that enable and encourage circular economy and the decarbonization of the supply chain of electricity would help to effectively relieve some of the major hotspots by addressing resource depletion (through recycled content) and reducing emissions from fossil-fuel based electricity generation.



ENABLING MORE SUSTAINABLE PHOTOVOLTAICS

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