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Managing India's PV Module Waste

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a) Recycling companies – PV CYCLE and Recycle PV;

b) E-waste recyclers and Producer Responsibility Organisations – Saahas and Karo Sambhav;

c) Module and equipment manufacturers – REC, First Solar, Vikram Solar and DSM;

d) Consultancy firm - Wambach-Consulting;

We are especially grateful to Wambach-Consulting and First Solar for reviewing the final report and providing their valuable feedback.

Foreword

The Governmet of India has made earnest efforts in line with its global commitments to promote installation of solar energy over the last decade. This combined with high investor interest, healthy market competition and favourable equipment prices has resulted in the phenomenal growth of solar energy in India. The ultimate aim behind the government's push to solar energy is to ensure a greener and a more sustainable energy mix.

It is a well-known fact that there are no harmful emissions at the point of generation in case of solar energy. However, there is a need to increase general market awareness about the fact that a large quantum of solar equipment waste is likely to be generated not only at the end of the useful life of solar power plants but also from to early-retirement of solar equipment due to various reasons. We completely understand, as is also highlighted by this report, the importance of acting now to avoid the potentially harmful environmental impact from an anappropriate treatment of this waste.

The National Institute of Solar Energy, which is the apex national research and development institution in the field of solar energy, has been encouraging discovery as well as adoption of advanced technologies in the sector, be it for manufacturing, performance monitoring or for operation and maintenance. With an aim to leave no stone unturned, we are also actively considering carrying out a pilot project to assess best technological options available to recycle solar PV waste.

I believe that an effective mechanism for solar waste disposal can be put in place if the entire industry collectively works towards it and cooperates with each other. While the government works out a policy, we are happy to provide our inputs on appropriate recycling technologies. We also encourage other stakeholders to come together to contribute towards ensuring that solar remains to be a completely clean source of energy.

Being one of the apex institution in the field of solar energy, I believe that it is alsoour moral responsibility to set the right example in solar waste recycling and its safe disposal. I appreciate the efforts of BRIDGE TO INDIA to increase awareness about solar PV recycling and safe disposal through this report and hope that we as a nation take timely action on the matter rather than wait for the problem to become too big to handle.

DR. ARUN K. TRIPATHI

Director General,
National Institute of Solar Energy

Foreword

Solar power capacity has grown from a mere 2,300 MW in 2013 to over 27,000 MW in 2008 at a CAGR of 64%, making India one of the top three solar countries in the world. The Government of India is committed towards utilisation of our solar energy potential to make our economy green and reduce carbon emissions.

While growth in solar capacity addition is commendable, it also brings along a set of responsibilities with regards to operating this capacity and handling PV waste at the end of its useful life. These aspects need to be proactively considered and planned for to create a sustainable vision for the sector and to ensure that there is no environmental downside to solar power output.

The Ministry of New and Renewable Energy endeavours to make solar a truly green source of energy by not only ensuring zero emission at the point of generation but also ensuring that end-of-the-life treatment is sustainable. We believe that the large potential quantities of solar waste may also present a new economic opportunity to recover, recycle and build a more circular energy system.

In the absence of adequate standards, market protocols and operational infrastructure, the PV waste may be inappropriately landfilled or incinerated to the detriment of human health and environment. The use of potentially hazardous materials, as pointed out by this report, necessitates putting in place an appropriate mechanism to ensure safe disposal of solar modules. Fortunately, we can draw on lessons from our own e-waste experience as well as global examples in formulating a clear policy framework for PV recycling.

I am really pleased that this timely report on PV module recycling is now available for all industry stakeholders. I hope that this will provide a good starting point for all stakeholders including Ministry of Environment, Forests and Climate Change, Ministry of New and Renewable Energy, government agencies including National Institute of Solar Energy, SECI and NTPC as well as solar power developers and equipment manufacturers to come together and develop a framework for recycling of PV waste in India.

RUCHIN GUPTA

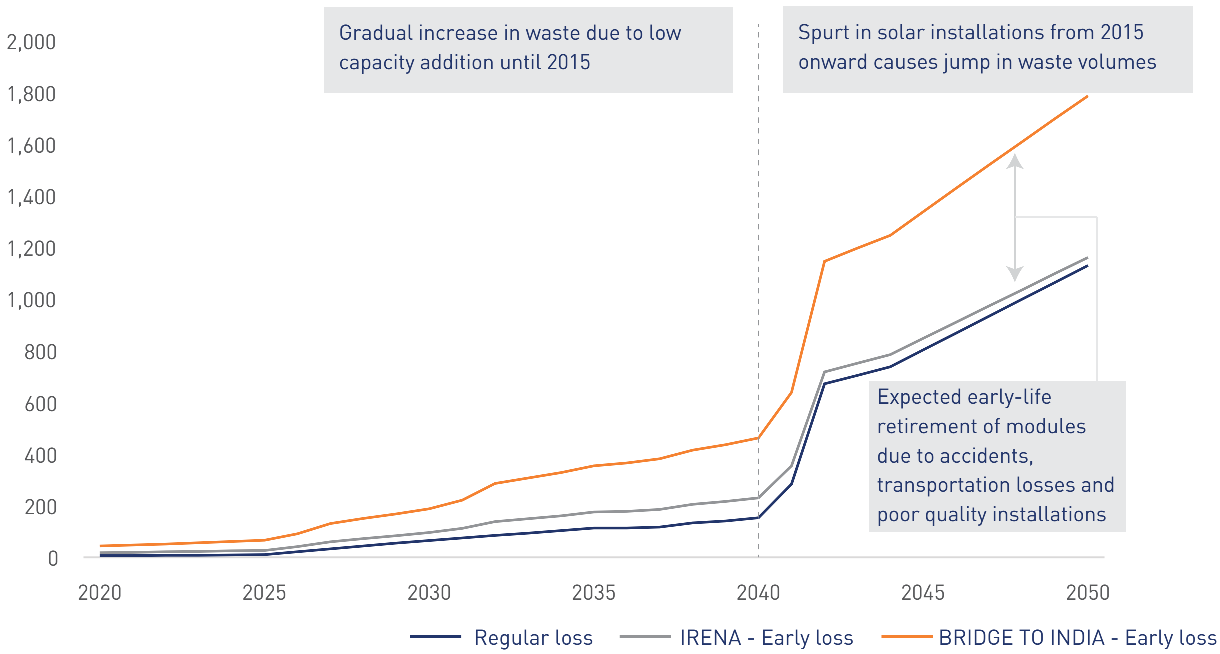
Director,
Ministry of New and Renewable Energy, Government of India

Contents

Executive summary

Solar energy is seen as a key component in the fight against climate change. Backed by political commitment and falling costs, the sector is growing rapidly in India and across the world. While policy makers lay emphasis on more capacity addition, critical aspects related to module manufacturing and disposal at the end of their useful life are being ignored.

Figure 1: Estimated annual PV module waste generation in India, thousand tonnes



Source: IRENA and IEA-PVPS; BRIDGE TO INDIA research

Notes:

1. We have conservatively assumed average annual solar capacity addition of 13 GW until 2025 to estimate waste volume. This is much lower than the Government of India's targets for the sector.
2. 'Regular loss' scenario assumes that all modules are retired 25 years after being commissioned.
3. 'BRIDGE TO INDIA – Early loss' scenario assumes higher than average global early life losses (as assumed by IRENA and IEA-PVPS)[1] based on higher incidence of poor quality and site accidents in India.

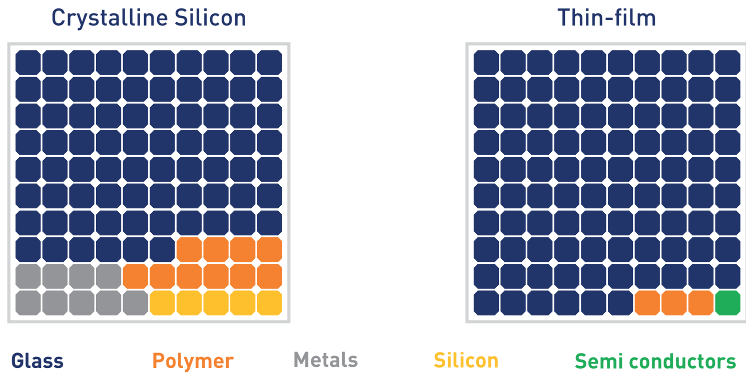
PV waste volume in India is estimated to grow to 1.8 million tonnes by 2050

PV waste volume in India is estimated to grow to 200,000 tonnes by 2030 and around 1.8 million tonnes by 2050. A PV module is essentially made up of glass, metal, silicon and polymer fractions. Glass and aluminium, together constituting around 80% of total weight, are non-hazardous. But a few other materials used including polymers, metals, metallic compounds and alloys are classified as potentially hazardous.[2]

[1] End-of-life management, solar photovoltaic panels, (2016) http://iea-pvps.org/fileadmin/dam/public/report/technical/IRENA_IEAPVPS_End-of-Life_Solar_PV_Panels_2016.pdf

[2] Use of lead, cadmium telluride as well as halogens in polymers are environmentally hazardous, if not appropriately treated and disposed at the end of useful life.

Figure 2: Material composition of solar modules by weight

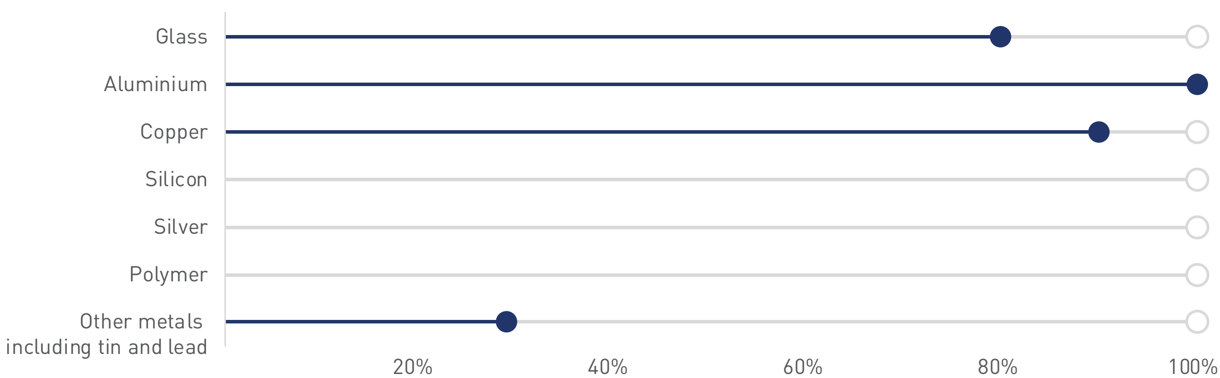


Source: IRENA and IEA-PVPS; BRIDGE TO INDIA research

PV waste recycling is still at a nascent stage globally, both in terms of technical standards and physical infrastructure

PV waste recycling is still at a nascent stage globally, both in terms of technical standards and physical infrastructure. The waste is usually sent to laminated glass and metal recyclers that recover 70-80% of the material by weight.[3] Advanced recycling technologies can potentially push this up to 92%. Most materials other than glass, aluminium and copper are usually not recovered and must be incinerated or landfilled. Unfortunately, PV module recycling is still not commercially viable. Total estimated cost including transportation can vary between USD 400-600/ tonne, far exceeding value of the recovered material.

Figure 3: Raw materials recovered by conventional recycling



Source: BRIDGE TO INDIA research

[3] Unless otherwise stated, the report refers to c-Si PV panels, which are predominantly used in Indian solar market.

Use of potentially hazardous material in manufacturing and lack of commercially viable module recycling technologies warrant a strong regulatory approach

Use of potentially hazardous material in manufacturing and lack of commercially viable module recycling technologies warrant a strong regulatory approach to this problem. The European Union (EU) has taken the lead with a comprehensive plan for allocating liability, setting recovery and recycling targets, treatment requirements, and consumer awareness.

India is poorly positioned to handle PV waste as it doesn't yet have a policy guideline on the same. Most of the central bidding documents rest the responsibility of handling and disposing PV waste on the developers as per E-waste (Management and Handling) Rules, 2011. However, the E-waste rules make no mention of solar PV waste. A lack of a policy framework is coupled with the fact that even basic recycling facilities for laminated glass and e-waste are unavailable. Despite the e-waste regulation being in place for over seven years, only less than 4% of estimated e-waste is recycled in the organised sector as per the latest CPCB estimates.

Formulating appropriate quality standards for use of environmentally sustainable materials in manufacturing of modules will also go a long way

It is imperative that policy makers and private stakeholders act proactively and in concert for long-term growth of the sector. Immediate efforts are required to formulate a robust regulatory framework for allocating responsibility and specifying standards for PV waste management. Formulating appropriate quality standards for use of environmentally sustainable materials in manufacturing of modules will also go a long way in minimising potentially hazardous end-of-life module waste in India.

Our suggestions for way forward for India to tackle the imminent PV waste problem are as follows:

Regulatory framework

- Mandate module manufacturers to use environmentally sustainable design and materials with end-of-life in mind (similar to eco-design initiatives of the EU);
- Specify liability and responsibility of each stakeholder for waste management and treatment;
- Lay down standards for PV waste collection, treatment and disposal;
- Strengthen Producers Responsibility Organisations (PRO) to handle PV waste;
- Promote use of sustainable materials and module design in bidding specifications;

Financing

- Lay down a collective compliance scheme based on a combination of PAYG and, joint and several liability principles;
- Encourage mutual recycling responsibility agreements between module suppliers, project developers and power purchasers;

Operational infrastructure

- Undertake regular surveys of recycling facilities to understand technology and capacity levels;
- Identify investment and technical requirements for dedicated PV recycling facilities focusing on high-value recovery;

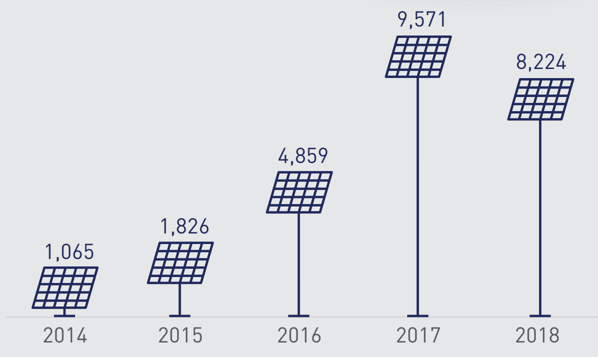
MANUFACTURING

Need to mandate use of sustainable raw materials and design

OPERATION

- Increasing instances of poor quality installations
- Higher likelihood of early life losses

INSTALLATION



Annual solar installation, MW

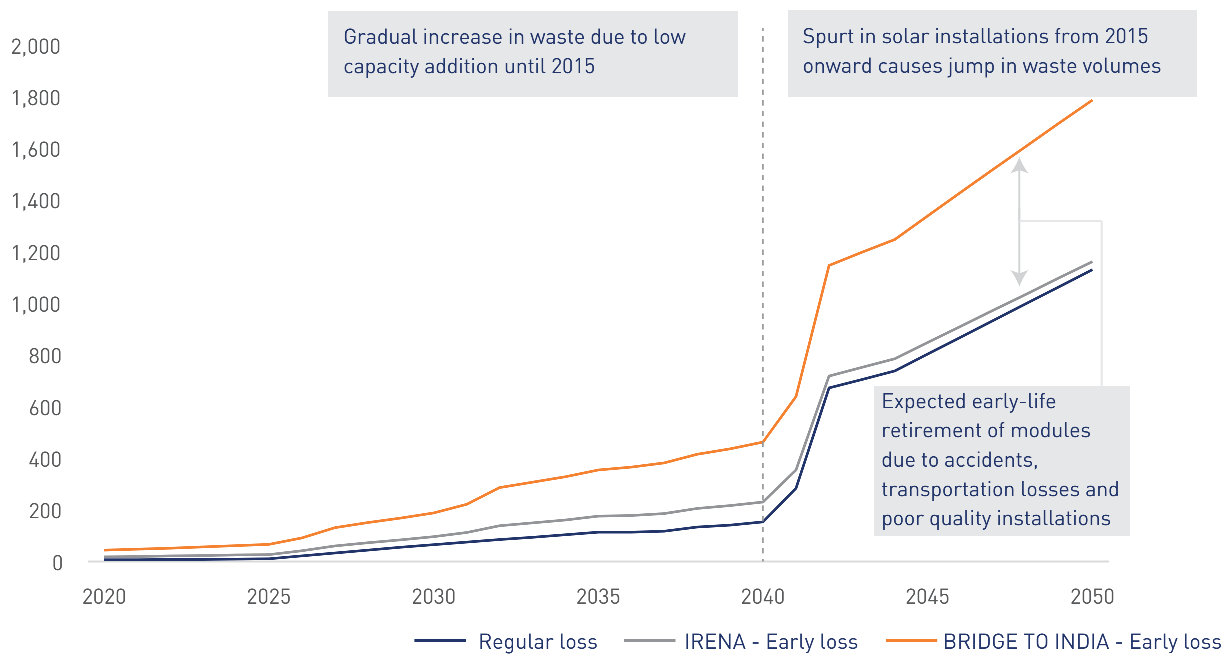
Estimated PV module waste volume, thousand tonnes

1. Introduction

Solar is a very compelling energy source for India. Driven by strong political commitment, falling cost, operational simplicity, and high irradiation across the country, solar capacity in India has grown rapidly from just 1 GW in 2012 to 28 GW. The Indian government has set an ambitious target of achieving 100 GW by March 2022.

While solar installations are growing at a robust rate, little attention has so far been paid to module recycling in India. We estimate that annual PV module waste volume will grow to 200,000 tonnes by 2030 and around 1.8 million tonnes by 2050. Cumulative waste volume is expected to touch 18 million tonnes by 2050.

Figure 1: Estimated annual PV module waste generation in India, thousand tonnes



Source: IRENA and IEA-PVPS; BRIDGE TO INDIA research

Notes:

1. We have conservatively assumed average annual solar capacity addition of 13 GW until 2025 to estimate waste volume. This is much lower than the Government of India's targets for the sector.
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3. 'BRIDGE TO INDIA – Early loss' scenario assumes higher than average global early life losses (as assumed by IRENA and IEA-PVPS)[4] based on higher incidence of poor quality and site accidents in India.

[4] End-of-life management, solar photovoltaic panels, (2016) http://iea-pvps.org/fileadmin/dam/public/report/technical/IRENA_IEAPVPS_End-of-Life_Solar_PV_Panels_2016.pdf

To justify its green energy claims, the solar industry needs to adopt a closed loop life-cycle management approach

Management of module waste is a challenge because of use of potentially hazardous materials in manufacturing and lack of suitable recycling infrastructure. To justify its green energy claims, the solar industry needs to adopt a closed loop life-cycle management approach to address critical issues such as environmental impact of module manufacturing and end-of-life recycling.

Figure 1.2 Environmental impact of solar value chain in India

MANUFACTURING

- High energy consumption
- Use of environmentally harmful materials such as lead, copper, tin and halogenated polymers

POWER GENERATION

- No emissions

END-OF-LIFE TREATMENT

- Lack of technical standards for safe disposal and recycling
- No operational infrastructure
- Low awareness regarding hazards of improper disposal

Source: BRIDGE TO INDIA research

Solar modules use potentially hazardous materials including lead compounds, polymers and cadmium compounds

Solar modules use potentially hazardous materials including lead compounds, polymers and cadmium compounds. If disposed of in an uncontrolled way, potential leaching of those hazardous materials at end-of-life can have negative environmental and health impacts. Leaching of lead has huge environmental impact—loss in biodiversity, decreased growth and reproductive rates in plants and animals, and several other health hazards—adverse impact on kidney function, nervous, immune, reproductive and cardiovascular systems.[5] Cadmium is a carcinogen with high toxicity as well as high accumulation potential in humans.[6]

Uncontrolled burning of fluoro-backsheets poses a significant health and environmental risk

The polymer fraction, which constitutes backsheet and encapsulants, consists mainly of fluorinated and cross-linked plastics. This fraction cannot be recovered and is typically incinerated. Uncontrolled burning of fluoro-backsheets poses a significant health and environmental risk due to formation of highly corrosive gases at the incineration stage. If landfilled inappropriately, waste and waste constituents can find ways into soil and water, resulting in potentially damaging impact on the eco-system.

Issues pertaining to use of materials in module manufacturing, responsibility for waste collection and disposal, recycling standards and impact of waste on the environment have not been explored in sufficient detail in India. This report aims to examine the relevant issues in detail, understand current global practices in solar module waste management and way forward for India.

[5] Heavy metal pollution and human biotoxic effects, Duruibe et al. (2007)

[6] Report on carcinogens, fourteenth edition, U.S. Department of Health and Human Services (2016)

2. PV module technologies

Crystalline silicon (c-Si) module technology has dominated installations in the Indian solar market, accounting for a 93% market share as at the end of December 2018. Thin-film solar modules, mainly cadmium telluride (CdTe), account for the remaining 7% share.

2.1 Module composition

A c-Si PV module consists of an assembly of solar cells, packaged into a protective multi-layered structure comprising five main components—a front cover, electrical circuit interconnecting solar cells, an envelope of two encapsulant layers protecting solar cells and a back cover (backsheet or tempered glass). Additionally, metal frames are used for supporting the panel structure.

c-Si modules are essentially made up of glass, metal, silicon and polymer fractions - glass and aluminium constitute more than 80% of the total weight

By way of material composition, a module is essentially made up of glass, metal, silicon and polymer fractions. Glass and aluminium constitute more than 80% of the total weight of a c-Si module. Other metals include lead, copper and tin. Tin and solders containing lead are used as standard interconnection technology for solar cells and modules. Copper is used in cables as well as a part of paste used for coating on cells.

The figures below provide current material and value composition of each of the two types of modules.

Figure 2.1: Material composition of c-Si solar modules, %

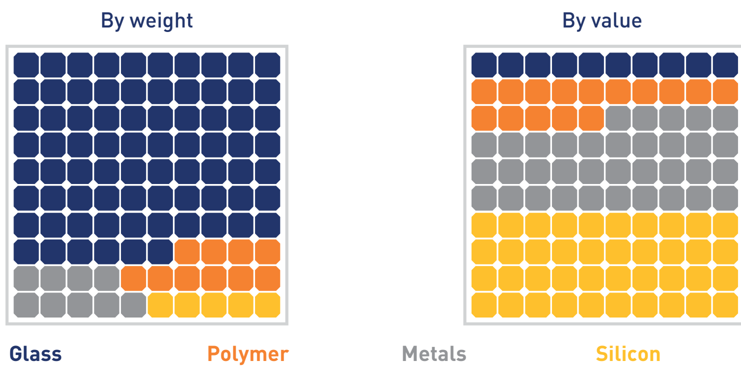
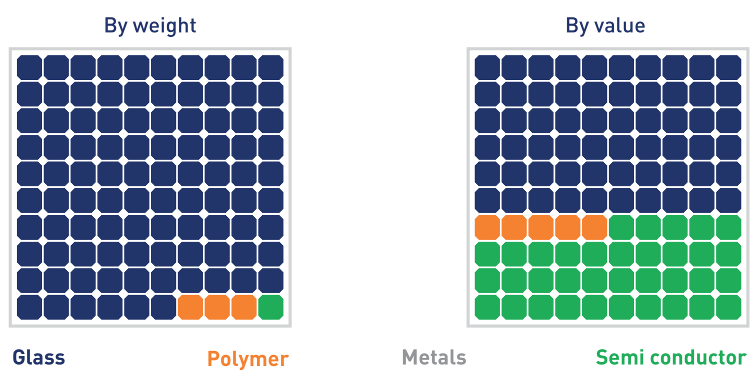


Figure 2.2: Material composition of thin-film solar modules, %



Source: IRENA and IEA-PVPS; BRIDGE TO INDIA research

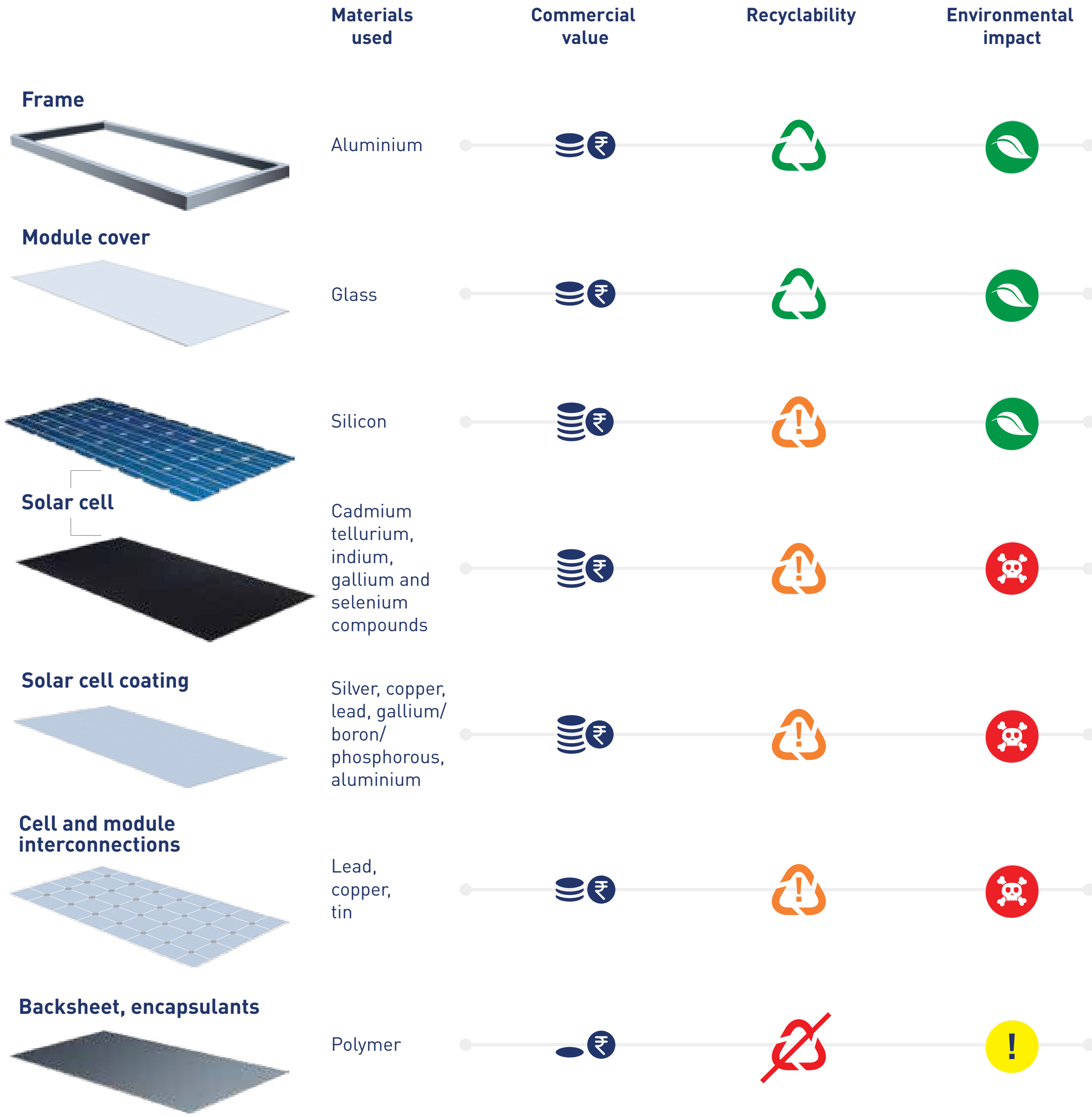
Note: Semi-conductor material includes compounds of cadmium, tellurium, indium, selenium and gallium.

2.2 Waste classification

Solar module waste can be classified on the basis of its environmental impact, recyclability as well as commercial value. Classification with regards to environmental impact is based on the definition of hazardous waste provided by Hazardous and Other Wastes (Management and Transboundary Movement) Rules 2016 of Ministry of Environment, Forest and Climate Change, Government of India. As per these rules, hazardous waste is defined as any waste which by reason of its physical, chemical, biological, reactive, toxic, flammable, explosive or corrosive characteristics causes danger or is likely to cause danger to health or environment.

Photograph by REC

Figure 2.3: Solar module composition and waste classification



Source: BRIDGE TO INDIA research

3. PV waste recycling

PV recycling is still at a nascent stage globally. Most countries classify PV waste as general industrial or e-waste. Even in Europe, which has specific regulations for PV waste, most of the waste is currently sent to conventional laminated glass and metal recyclers. There are dedicated recycling facilities for thin-film modules in some countries, but a first-of-its-kind c-Si module recycling facility has become operational only recently (July 2018) in France by Veolia.

3.1 Conventional recycling technologies

Most conventional glass and metal recyclers use mechanical processes for separating laminated structures of modules

Most conventional glass and metal recyclers globally use mechanical processes for separating laminated structures of c-Si modules. This includes manual or automated removal of aluminium and copper from module frame and junction box respectively, followed by use of crushers, sieves, magnets, eddy-current devices and inductive and optical sorters to obtain glass and polymer fractions.

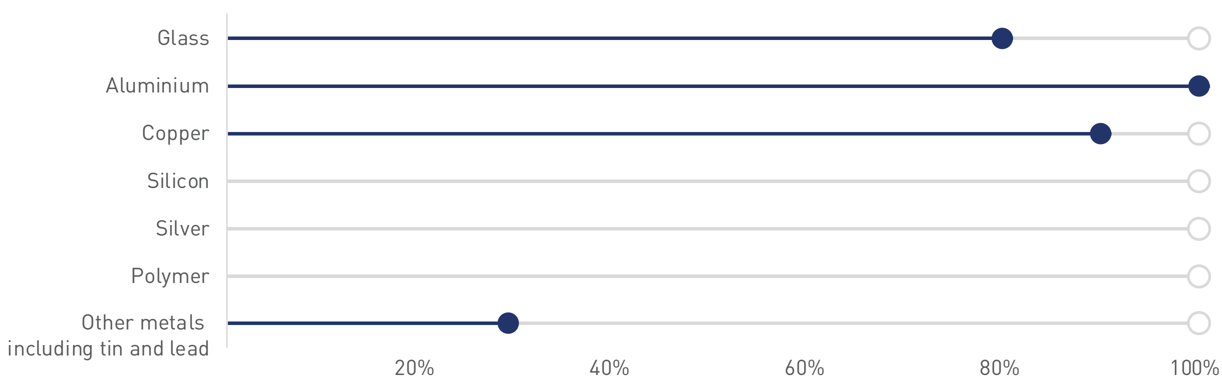
The metal fraction is sent to metal recyclers for smelting. The glass fraction remains contaminated with bits of silicon, polymers and metals. The low-quality glass is unfit to be used in manufacturing of new modules and finds use in low value glass fibre manufacturing for construction industry. Purification of glass requires a mix of thermal and chemical processes that is usually not part of conventional glass recycling plants.

The polymer fraction comprises mainly a mix of plastics along with small traces of metals, silicon and glass. In countries without a specific regulation for PV recycling or incineration, this fraction is either sent to the landfill or is incinerated. This raises a serious environmental threat as incineration of polymers leads to harmful greenhouse gas emissions. Once waste volumes become large, incineration of polymers in conventional incinerators will not be possible due to corrosive emissions caused by halogens.[7] Use of specialised incinerators is likely to increase the total cost of recycling by 10-15%.

Conventional recycling is able to recover 70-80% of the raw materials by module's weight

Conventional recycling is able to recover 70-80% of the raw materials by weight of a c-Si module. Majority of the recycled and recovered material consists of glass, followed by aluminium and copper. The following figure shows the percentage of input materials recovered from conventional recycling.

Figure 3.1: Raw materials recovered by conventional recycling



Source: BRIDGE TO INDIA research

[7] Life cycle inventory of current photovoltaic module recycling processes in Europe; IEA-PVPS (2017)

Most of the high value materials including silver and solar-grade silicon and environmentally hazardous elements including lead and polymers are not recovered in the conventional recycling process.

Most of the high value and environmentally hazardous elements are not recovered through the conventional recycling process

However, ongoing technological improvements are aimed at reducing use of high value materials like silver and silicon to cut production cost. Silicon content in c-Si modules has already reduced from 7g/ Wp in 2010 to 5g/ Wp in 2017. Manufacturers are also trying to reduce the silver content. The content of silver remaining on cell after processing is expected to be reduced by 50% in the next ten years.[8]

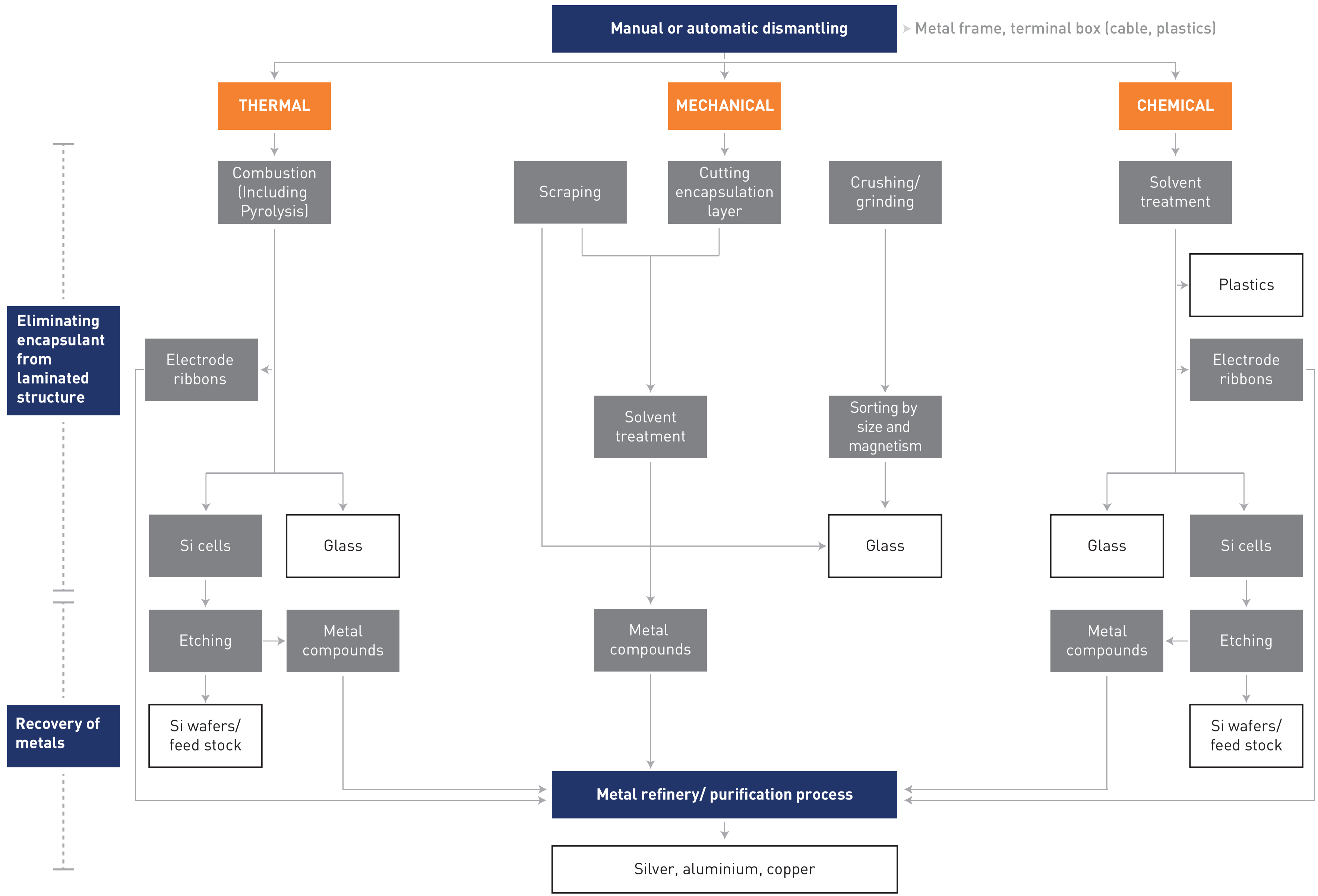
3.2 Advanced recycling technologies

Advanced or specialised PV recycling uses a mix of mechanical, thermal and chemical processes to recover most materials including glass, aluminium, copper, silicon, silver, lead and tin. The polymer fraction, 8-10% by weight, still remains unrecoverable and must be landfilled and/ or incinerated.

Photograph by First Solar

[8] International Technology Roadmap for Photovoltaic (2018), ninth edition http://www.itrpv.net/.cm4all/uproc.php/0/ITRPV%20Ninth%20Edition%202018%20including%20maturity%20report%2020180904.pdf?cdp=a&_=165a39bbf90

Figure 3.2: Processes used in advanced recycling technologies



Source: IEA PVPS; BRIDGE TO INDIA research

Up to 90-92% of the PV waste is estimated to be recovered using advanced recycling technologies

As specialised PV waste recycling is still very uncommon, there is insufficient data on exact recovery of materials. However, scientific studies show that up to 90-92% of the PV waste is recoverable.

3.3 Commercial viability

Solar module recycling is still not commercially attractive and is a net cost for the industry. Cost of recycling is estimated to vary between USD 250-300/ tonne in Europe and the US. Transportation cost can add 60-100% to this cost depending on distance. By comparison, the value of recovered materials is estimated to be only about USD 45-130/ tonne depending on the recycling technology used.

Technological advancements are underway to enhance recovery of high value materials and reduce processing cost

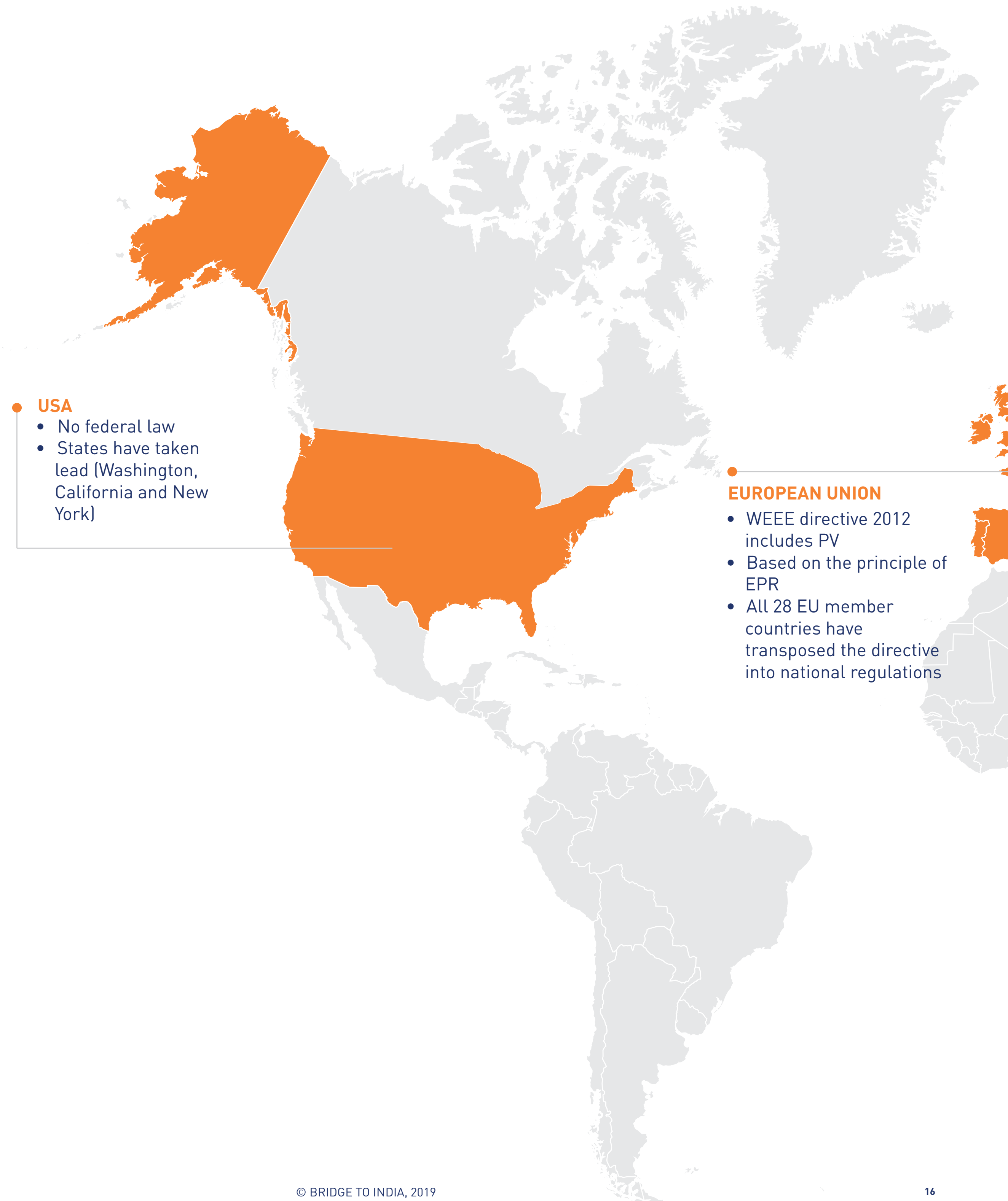
However, various technological advancements are underway to: i) enhance recovery of high value solar grade silicon, glass and silver; and ii) to reduce processing cost. With solar module waste quantities reaching a substantial level in 2030, commercial viability of recycling is expected to improve substantially.

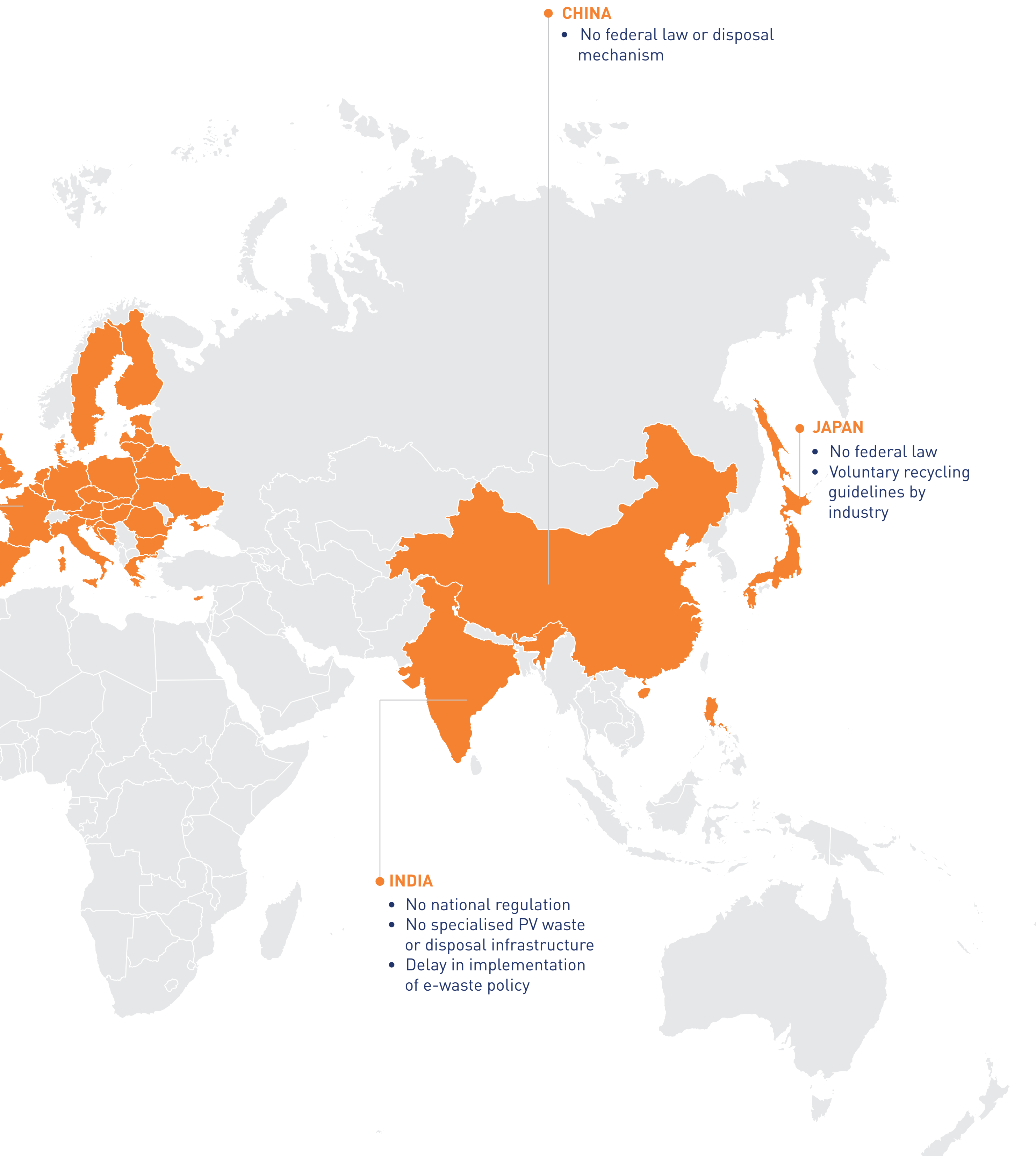
Photograph by First Solar

4. International regulatory framework

Countries with large solar installations are China, India, USA, Japan and Germany. Today, only countries in the EU have adequate regulations in place to manage PV module waste.

Figure 4.1: Regulations for PV recycling around the world




CHINA
• No federal law or disposal mechanism
JAPAN
• No federal law
• Voluntary recycling guidelines by industry
INDIA
• No national regulation
• No specialised PV waste or disposal infrastructure
• Delay in implementation of e-waste policy

4.1 European Union

The EU's WEEE directive, based on the EPR concept, mandates all member states to implement a regulation for setting up tracking, collection and waste treatment mechanisms

The EU's Waste Electrical and Electronic Equipment (WEEE) directive was formulated in 2002 and revised in 2012 to include module waste management. It mandates all member states to implement legally binding regulatory framework for setting up tracking, collection and treatment mechanisms for module waste. The regulation addresses: i) liability; ii) collection, recovery and recycling targets; iii) treatment requirements; and iv) information dissemination to ensure consumer awareness.

The regulation is based on the concept of Extended Producer Responsibility (EPR). Producers are responsible for tracking and financing the management of their waste streams. They can choose to comply independently or as part of collective initiatives. Cost of compliance is based on the type of end-consumers.

B2B (commercial consumers)
Producers have the option to share recycling responsibility and cost with consumers by mutual agreement.

B2C (residential and other non-commercial consumers)
Producers retain complete responsibility for all end-of-life waste management. They can opt for multiple types of financing to ensure this:

i. Pay-as-you-go (PAYG): Cost of collection and recycling is borne by the producer.

ii. Last-man-standing insurance: This product is part of collective recycling programs. It covers the costs of collection and recycling if all producers disappear from the market by the time the product's end of life is reached.

iii. Joint-and-several liability: Producers agree to jointly accept the liabilities for waste collection and recycling (see Box: Implementation of WEEE directive in Germany).

iv. Pay-as-you-put (PAYP): The producers set aside an estimated cost for collection and recycling waste at the time of sale.

Progressively stricter compliance targets have been set under the WEEE directive.

Table 4.1: Targets for e-waste collection, recovery and recycling in the EU

Directive	Period	Collection	Recovery	Recycling
WEEE 2002	2003-12	4 kg/ inhabitant/ year	75%	65%
WEEE 2012	2012-16	4 kg/ inhabitant/ year	75%	65%
	2016-18	45% (by mass) by market-share in the 3 preceding years	80%	70%
	2018 and Beyond	65% (by mass) by market-share in the 3 preceding years or 85% of waste generated	85%	80%

Source: IRENA, BRIDGE TO INIDA research

Another EU directive (Waste Framework, 2008) specifies processes and minimum standards for treatment of specific types of e-waste including PV modules.[9] In 2017, the European Standards Organisation (ESO) published technical and operational standards to be followed for collection, transport, re-use and treatment of module waste under the WEEE directive.[10] The producers are also required to inform consumers clearly regarding means of disposal and return/collection mechanisms to ensure that e-waste is not inadvertently disposed of with general waste.

We highlight Germany as an example of how the WEEE Directive and the module waste management models have been implemented (see Box: Implementation of WEEE directive in Germany).

Other regulations

In addition to WEEE directive, the EU also has separate waste management requirements for incineration

In addition to WEEE directive, the EU also has separate waste management requirements for incineration. It specifies that input material to the incineration plants should have halogen concentration less than 1% measured as chlorine. Higher halogen concentration can lead to corrosive emissions and require specialized incinerators.[11] These norms are met today as the volume of incinerated polymer fraction of PV waste forms only a small part of the total input into the incinerator. However, they may pose problems when waste volumes increase.

Further tightening of norms

The EU has an eco-design directive, a policy instrument to reduce environmental impact of energy-related products throughout their lifecycle

The European Standards Organization (ESO) is developing separate standards to enable 'high-value' recycling. The recommendations are likely to be published in 2019. The EU also has an Eco-design Directive 2009, a policy instrument to reduce environmental impact of energy-related products throughout their lifecycle.[12] As part of this directive, a research committee is developing a "preparatory study on sustainable product-policy instruments for solar photovoltaic modules, inverters and systems."[13,14] The committee is likely to recommend norms for ensuring sustainable design and material use during the manufacturing of panels. The report and its recommendations are expected to be submitted to the European Commission in mid-2019. Signs of tightening norms have already led to producers and their suppliers taking proactive steps to develop modules with the end-of-life in mind (see Box: Module material composition and design changes with end-of-life in mind).

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[9] Waste Framework Directive, 2008, European Commission https://eurlex.europa.eu/legalcontent/EN/TXT/PDF/?uri=CELEX:32008L0098&from=EN

[10] European Standards for Waste Electrical and Electronic Equipment (WEEE), 2018 , CENELEC https://www.cencenelec.eu/news/publications/publications/weee-brochure.pdf

[11] Life Cycle Inventory of Current Photovoltaic Module Recycling Processes in Europe, 2017, IEA-Photovoltaic Power Systems Program http://www.iea-pvps.org/index.php?id=460&eID=dam_frontend_push&docID=4239

[12] Eco-design Directive, 2009, European Commission https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32009L0125

[13] Solar Photovoltaic modules, inverters and systems, Joint Research Centre, European Commission http://susproc.jrc.ec.europa.eu/solar_photovoltaics/index.html

[14] Draft-Task 5, Environmental and economic assessment of base cases Preparatory study for solar photovoltaic modules, inverters and systems, 2018, Joint Research Centre, European Commission http://susproc.jrc.ec.europa.eu/solar_photovoltaics/docs/DraftReport_Task5.pdf

Implementation of WEEE directive in Germany

In 2015, Germany incorporated the WEEE directive into national law by revising its existing e-waste regulation, 'Electrical and Electronic Equipment Act' of 2005. However, Germany had already initiated voluntary collection and recycling of modules before the WEEE 2012 regulation came into place. Its producers have established a National Register for Waste Electrical Equipment (Stiftung Elektro-Altgerate Register or Stiftung EAR) in response to the 2002 WEEE directive. Additional voluntary initiatives by producers have been undertaken through PV CYCLE, a member-based organisation that enables collective or custom-made PV waste management solutions. This infrastructure for collection and disposal has now been modified to suit the new regulatory requirements.

Operations: The regulations define two categories of consumers and take-back systems:

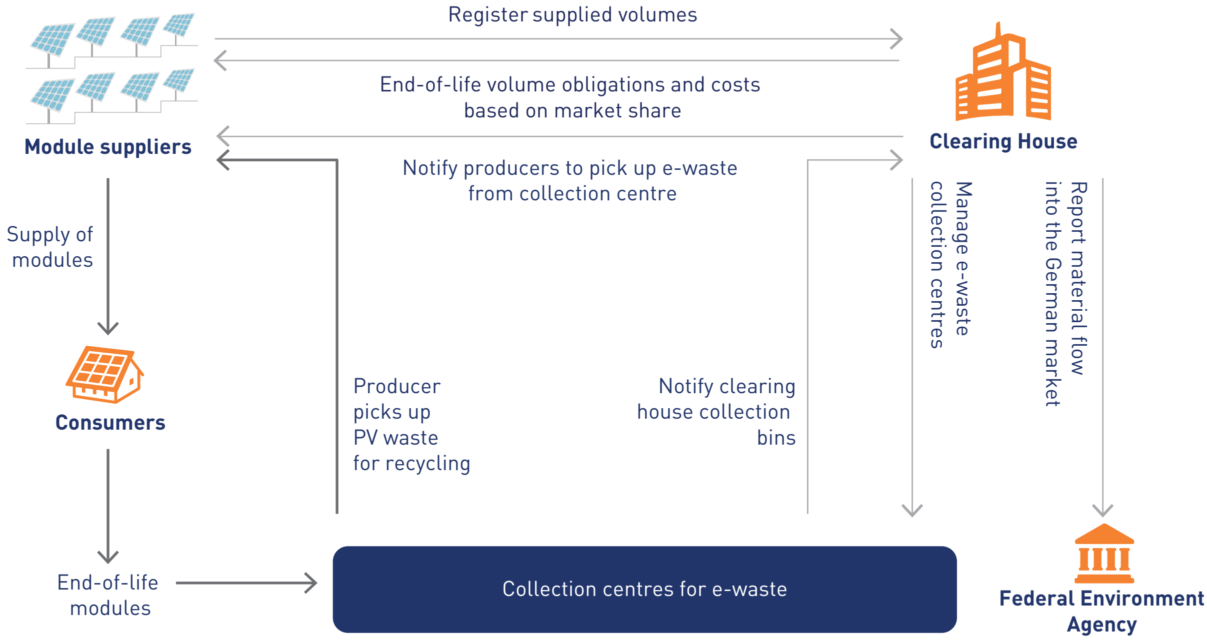
B2B sales: The Producers need to reach a mutual agreement with the consumers for compliance - types of agreements can include upfront recycling payments, recycling service contracts, outsourcing to third-party etc. The consumers may also opt to use the same mechanism as a B2C consumer (outlined below).

B2C sales: PV waste is deposited in 700 collection centres set up around Germany and managed by Stiftung EAR, clearing house.

PV waste reporting, collection and co-ordination: Stiftung-EAR tracks and co-ordinates waste collection and reporting to ensure compliance by producers. A producer registers the volume of modules sold with Stiftung-EAR, which in turn calculates the volume of e-waste required to be treated by the producer. At an appropriate time, it notifies the respective producer for waste collection. The producers or their service providers ensure it is picked up for recycling within 24 hours of notification. As the modules waste picked up by the producer are from historic installations, the mechanism ensures that these historic waste streams do not go into a regulatory 'no-man's land'.

Financing: Germany's financing mechanism is a combination of PAYG and last-man-standing schemes. The producers pay a registration fee – calculated based on total weight of panels sold, cost of recycling and the presumed rate of return of PV waste – to Stiftung-EAR. Producers also agree to cover future waste streams and pay an annual insurance premium to this effect. Finally, producers are also responsible for the cost of logistics and recycling.

Figure 4.2: Implementation of WEEE mechanism in Germany



Source: BRIDGE TO INDIA research

4.2 USA

There are no federal regulations for module waste management in the US but regulatory initiatives are being undertaken at the state-level

There are no federal regulations for module waste management in the US. However, regulatory initiatives are being undertaken at the state-level to manage it. Washington was the first state to pass a solar stewardship bill mandating manufacturers to submit a plan to recycle their end-of-life modules by January 2021.[15] California and New York are also in the process of passing bills to hold manufacturers responsible for module waste and prevent their disposal in landfills.[16,17] The limitation with these state-level regulations is that waste can be transported to neighbouring states with no regulations.

There are several voluntary initiatives, both individual and collective, in place. The most well-known of these includes First Solar, a thin-film module producer.

First Solar's recycling initiatives

First Solar introduced a pre-funded, take-back model in 2005. The company has established dedicated recycling facilities in the US, Germany, Malaysia and Vietnam. It budgeted recycling cost of USD 0.04/ Wp as part of the module cost historically but has made this cost optional since 2012. The company continues different versions of its take-back program in the EU, modified to suit country specific-regulations.

[15] House Bill Report ESSB 5939, 2017, Washington State Legislature http://lawfilesext.leg.wa.gov/biennium/2017-18/Pdf/Bill%20Reports/House/5939-S.E%20HBR%20APH%2017%20E3.pdf

[16] Photovoltaic Modules (PV modules)-Universal Waste Management Regulations, California Department of Toxic Substances Control, https://www.dtsc.ca.gov/HazardousWaste/PVRegs.cfm

[17] Senate Bill S2837B, 2017, The New York Senate, https://www.nysenate.gov/legislation/bills/2017/s2837

The Solar Energy Industry Association is attempting initiatives like the old, voluntary PV CYCLE model of Europe through its PV Recycling Working Group.[18]

The American National Standards Institute, a private sector voluntary standardization system, has established 'NSF/ANSI 457-2017: Sustainability leadership standard for Photo Voltaic modules'. The standard addresses performance across seven categories - substances, materials use, life cycle assessment, energy efficiency & water use, end-of-life management & design for recycling, product packaging, and corporate responsibility.[19]

4.3 Japan

While there are no national regulations in Japan, voluntary guidelines to ensure proper recycling of modules are in place

There are no national regulations in Japan regarding module waste management. However, voluntary guidelines to ensure proper recycling of solar PV modules have been issued by the Japan Photovoltaic Energy Association (JPEA). Additionally, there have been extensive R&D initiatives by New Energy and Industrial Technology Development Organization (NEDO), a national research facility, towards developing cost-effective recycling solutions.

4.4 China

China's 13th five-year plan (2016-2020) states that the principle of EPR will be imposed on waste treatment in general but a regulatory framework specific to module waste is yet to be adopted. China's regulations for e-waste management have been effective since 2011 but PV modules are not classified as e-waste.

Module material composition and design changes with end-of-life in mind[20]

Tightening regulations on recycling in Europe have spurred module manufacturers and suppliers to make changes to module technology with end-of-life waste management in mind.

REC: The Norwegian manufacturer introduced lead-free modules in 2012. In 2018, it introduced a silicon recovery process (specific to its own modules) to extract solar grade silicon from PV waste.

APOLLON SOLAR: The company has a patented glass-glass module technology with no encapsulation, soldering or lamination requirement which makes it one of the most efficient design for recycling.

DSM: The Netherlands-based company is the first supplier of co-extruded polymer backsheets that are halogen (fluoride) free and are 100% recyclable. This reduces possible problems during incineration.

[18] SEIA National PV recycling program
https://www.seia.org/initiatives/seia-national-pv-recycling-program

[19] Read more at the ANSI Blog: Solar Photovoltaic Modules – Sustainability Leadership Objectives
https://blog.ansi.org/?p=156999

[20] Draft-Task 4 Report, Technical analysis including end-of-life, 2018, Preparatory study for solar photovoltaic modules, inverters and systems, 2018, Joint Research Centre, European Commission
http://susproc.jrc.ec.europa.eu/solar_photovoltaics/docs/DraftReport_Task4.pdf

5. India status

MNRE's bidding guidelines place the onus of waste disposal on the developers in accordance with the e-waste rules but these rules do not cover PV modules

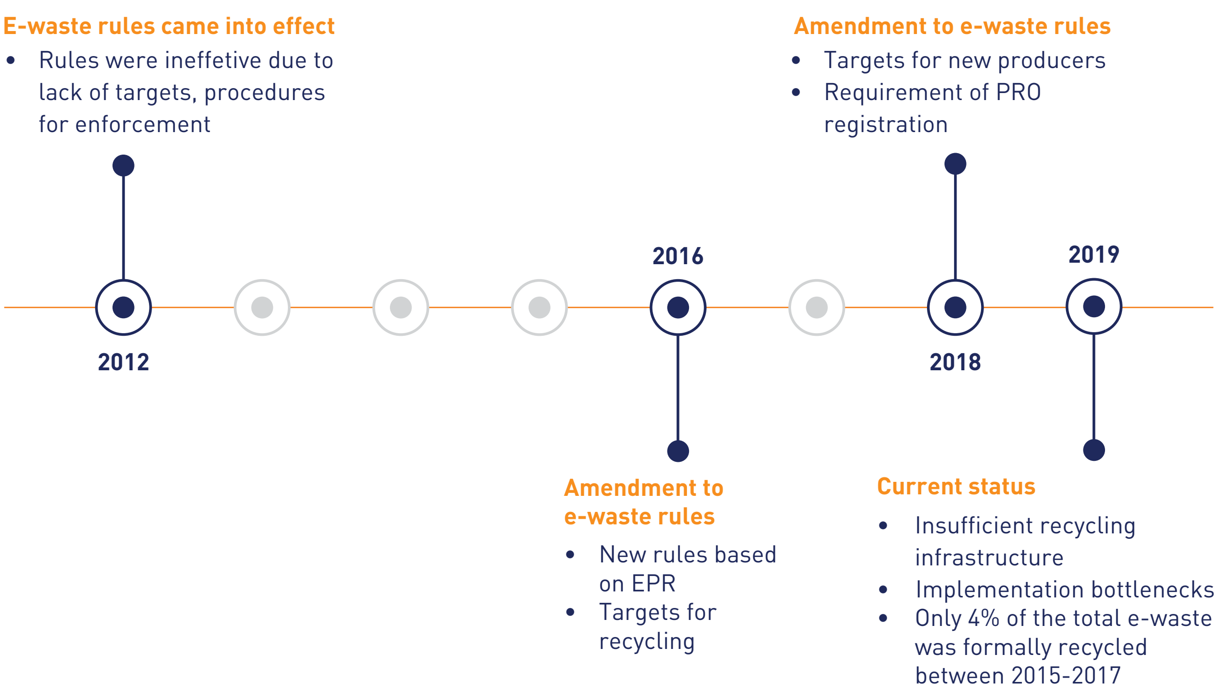
There is no specific regulation for solar module waste disposal or recycling in India. The only reference to recycling is found in MNRE's guidelines for setting up grid-connected solar power plants. The guidelines place the onus of disposal of module waste on the developers and state that "the developers will ensure that all solar PV modules collected from their plant after their end-of-life are disposed-off in accordance with the 'E-waste (Management and Handling) Rules' notified by the central government as amended from time to time." Bizarrely, the e-waste rules do not cover module waste. There is therefore no specific mechanism or standard for module waste disposal in India.

5.1 E-waste management policy

India is estimated to have generated around 1.8 million tonnes of e-waste in 2016. This waste is expected to grow at 30% annually.[21] E-waste (Management and handling) Rules were first notified in 2011 and then revamped in 2016 by the Ministry of Environment, Forests and Climate Change.[22] The new rules are based on the principle of EPR with responsibilities and liabilities being laid out for various categories of producers (manufacturer, distributer, dealer, re-furbisher etc.). The rules allow producers to use several instruments to ensure compliance: i) PROs, ii) e-waste exchanges, and iii) deposit refund scheme where consumers pay a deposit that is withheld until they return the product for disposal.

Producers are also tasked with creating awareness about recycling options and ensuring consumers do not dispose their e-waste as normal waste by marking the products with a "crossed-out bin symbol".

Figure 5.1: Evolution of e-waste regulations in India



[21] Report E-waste management: generation; collection and recycling, 2018, https://cdn.downtoearth.org.in/library/0.00599000_1527080032_e-waste-report-for-hc-final.pdf

[22] E-Waste (Management) Rules, 2016. http://www.moef.gov.in/sites/default/files/EWM%20Rules%202016%20english%2023.03.2016.pdf

Every producer has individual collection targets based on sales volumes and product lifespan. The targets are defined only for collection and channelling of e-waste to recyclers and not for actual recycling or recovery. Collection target was set at 20% for the first two years increasingly progressively to 70% by 2023. The target for the first year (2016-17) was revised downward later to 10% to give more time for compliance.

5.2 Recycling capacity

India is under-prepared to deal with rising e-waste volumes given low targets, poor enforcement and insufficient disposal facilities

Data from the Central Pollution Control Board (CPCB) shows that installed capacity of registered e-waste recyclers/ dismantlers in the country is only about 0.4 million tonnes per annum, 22% of the estimated e-waste volume. But we understand that actual capacity is even lesser as many facilities exist only on paper.

Low targets, poor enforcement and insufficient disposal facilities mean that India is grossly under-prepared to deal with rising e-waste volumes. It is estimated that less than 4% of the estimated e-waste generated in the country was sent to formal, registered recyclers between 2015-17.[23]

Photograph by REC

[23] Report E-waste management: generation; collection and recycling, 2018
https://cdn.downtoearth.org.in/library/0.00599000_1527080032_e-waste-report-for-hc-final.pdf

6. Conclusion

PV waste is rising rapidly and India needs to be prepared for it. The EU offers an effective international benchmark. Its stringent approach is bearing desired results in the market place. We expect PV waste regulations to tighten globally over time.

Existing e-waste rules offer a tentative first step in introducing rules for PV waste treatment

Indian government should take urgent action for PV waste management. Existing e-waste rules offer a tentative first step in introducing rules for PV waste treatment. It is imperative that policy makers and private stakeholders act proactively and in concert for long-term growth of the sector.

Our suggestions for way forward for India to tackle the imminent PV waste problem are as follows:

Regulatory framework

- Mandate module manufacturers to use environmentally sustainable design and materials with end-of-life in mind (similar to eco-design initiatives of the EU);
- Specify liability and responsibility of each stakeholder for waste management and treatment;
- Lay down standards for PV waste collection, treatment and disposal;
- Strengthen Producers Responsibility Organisations (PRO) to handle PV waste;
- Promote use of sustainable materials and module design in bidding specifications;

Financing

- Lay down a collective compliance scheme based on a combination of PAYG and, joint and several liability principles;
- Encourage mutual recycling responsibility agreements between module suppliers, project developers and power purchasers;

Operational infrastructure

- Undertake regular surveys of recycling facilities to understand technology and capacity levels;
- Identify investment and technical requirements for dedicated PV recycling facilities focusing on high-value recovery;