



SOLAR TECHNOLOGY

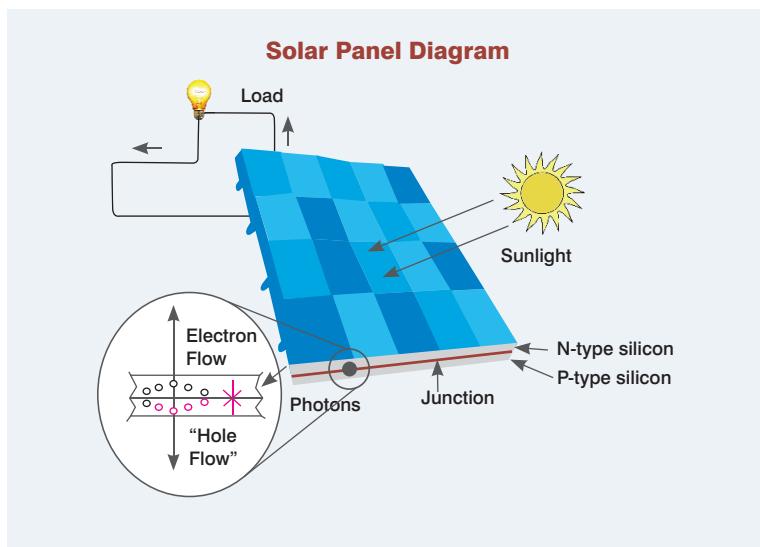
SOLAR ENERGY IS CONSIDERED AS A CLEAN AND GREEN TECHNOLOGY, BUT IS THERE A NON-SUNNY SIDE HERE? LET'S FIND OUT MORE...

India is the fourth largest primary energy consumer, after China, USA and Russia and accounts for more than 4.6 % of total global annual energy consumption. The increasing demand for energy in the country has been putting pressure on its supply sources. According to the International Energy Agency, currently coal accounts for about 40% of India's total energy consumption, oil for about 24%, and natural gas for 6%. Developing countries like India need energy security and the expectations that the conventional energy sources can fulfill that are dwindling. With the supply of non-renewable sources like coal and oil being limited in the country coupled with growing dependence on imports to meet the existent demands, the country is looking at renewable sources of energy like never before. Also, as the science on climate change and its impacts are becoming clearer and more urgent, governments are increasingly looking for ways to reduce their greenhouse gas emissions. Renewable provide a local source of energy which is considered clean and seems like a hope for the future.

To meet the energy demand in coming years, Indian government has put its focus towards renewable sources. Although the country has wide renewable energy sources, solar energy in particular has been in limelight, because India's potential for receiving solar energy is around 5000 trillion KWh yearly¹. In 2010, Ministry of New and Renewable Energy (MNRE) launched the Jawaharlal Nehru National Solar Mission (JNNSM), which has been the key-driver of the growth of the Indian solar industry. Though solar

technology was not very common and affordable few years back, recent technology advancement has changed the entire scenario. New technologies are lowering costs and are now being increasingly looked as a viable option in the country.

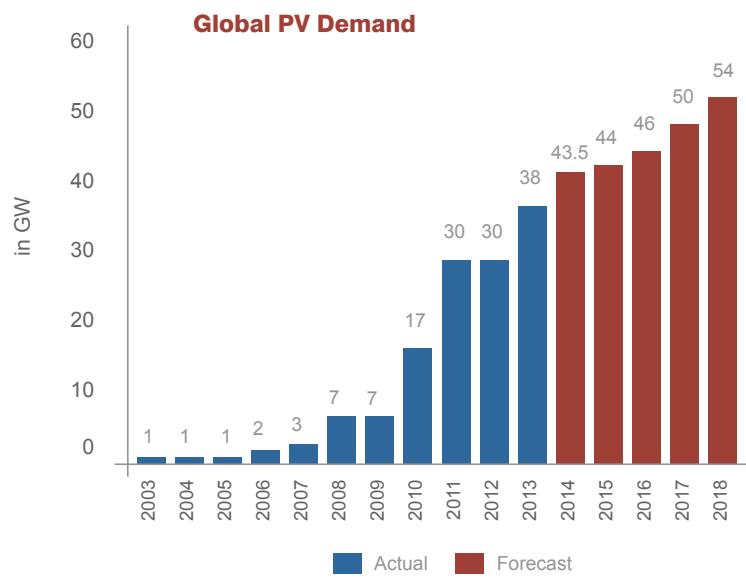
Solar energy has now become an essential part of the global move toward clean energy and it will play an essential role in meeting the energy demand challenges in future. Thus it is critical that the growing solar photovoltaic industry is truly safe and sustainable. But as the sector expands, little attention is being paid to the potential environmental and health costs of this technology. Is this technology completely safe and clean? Or do we need to look at it more closely? The answer probably lies in knowing and understanding the risks and look for solutions if needed.



¹ Ministry of New and Renewable Energy- <http://www.mnre.gov.in/related-links/grid-connected/solar/>

SOLAR TECHNOLOGY

Solar power is the conversion of sunlight into electricity. Solar power technology is primarily of two types – solar photovoltaic (PV) and solar thermal. Photovoltaic (PV) energy production is the more widely used one and its production has been doubling every 2 years, increasing by an average of 48% each year since 2002², making it the world's fastest-growing energy technology. The demand for PV is



also expected to grow exponentially in the coming years, with average global demand predicted to be touching 54 GW in 2018. At the end of 2013 the cumulative photovoltaic capacity around the world reached more than 138 GW, compared to 2.6 GW in 2003 and is expected to reach around 275 GW by 2018³.

Solar cells or photovoltaic cells (PV), the basic component of photovoltaic technology, are solid state semiconductor devices that convert sunlight into electricity using the photovoltaic effect. Typically a number of individual cells are connected together to form modules, or solar panels. In order to provide electrical insulation and protect against environmental corrosion, the solar cells are encased in a transparent material referred to as an encapsulant. To provide structural integrity the solar cells are mounted on top of a rigid flat surface or substrate. A transparent cover film, commonly glass, further protects these components from the elements.

Several types of semiconductor materials are used to manufacture solar cells but the most common material is crystalline silicon.

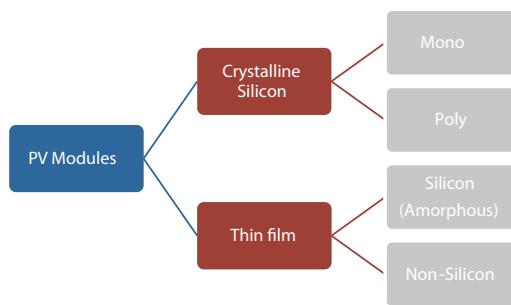
A typical PV panel, which is made up of solar modules can operate for up to 10 years at 90% of its rated power capacity and for up to 25 years at 80% of its rated power capacity.

Based on technology, there are mainly two types of PV Modules. These are:

- **Crystalline silicon (c-Si) PV:** There are two sub-categories i.e. Mono crystalline and Poly crystalline
- **Thin film-silicon and non-silicon:** Non silicon thin films are of different types, like Cadmium Telluride, Copper indium gallium selenide and Di-sensitized

GROWTH OF SOLAR TECHNOLOGY IN INDIA

India has huge potential for solar PV. With about 300 clear sunny days in a year in most parts, India's theoretical solar power reception on only its land area, is about 5000 Petawatt-hours per year (PWh/yr) (i.e. 5,000 trillion kWh/yr or about 600,000 GW).

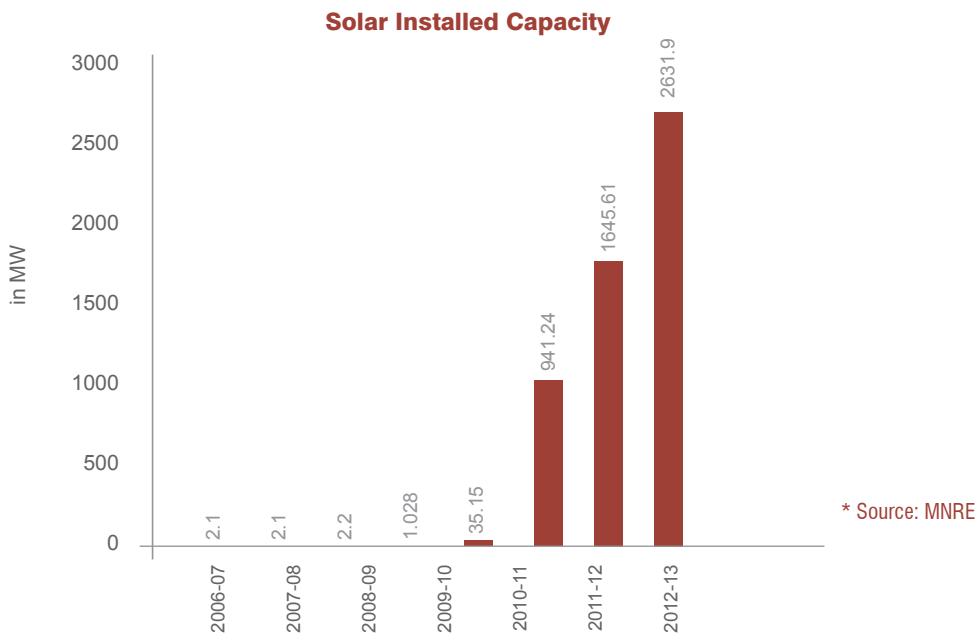


With the increasing thrust in this area, the solar capacity has shown major jump in the last few years. From 2.1 MW in 2006-07, it is currently at 2632 MW. The country added almost 950 MW of solar power capacity between April 2013 and March 2014. According to MNRE, India's cumulative solar power capacity is expected to be 31729 MW by 2020. This indicates that the dependence on solar energy will increase substantially in near future.

Much of this installed capacity is from Solar PV cells.

² <http://www.aire.net.au/faq>

³ Global Market Outlook for Photovoltaics 2014-2018, June 2013



Solar energy systems provide significant environmental benefits in comparison to the conventional energy sources. Regardless of the technology used, PV electricity generation is considered a zero-emissions process because it does not produce noise, toxic air pollutants, or greenhouse gases (GHGs). However, there are issues of concern if we look at it from the life cycle perspective, especially at the widely used PV technology. Today's most commonly used solar technology is silicon-based solar PV, which is based on silicon semiconductors and uses manufacturing processes and materials similar to those of the microelectronics industry and therefore presents many of the same challenges as E-waste⁴.

There are many hazardous materials used during the manufacturing of the various categories of PV cells. Few types have been discussed below with their material composition:

CRYSTALLINE SILICON PV

As mentioned above, the most common PV technology uses crystalline silicon and the production process begins with the mining of silica, found in the environment as sand or quartz. The raw material is then refined in industrial furnaces to remove impurities to produce metallurgical grade silicon (~98% pure silicon). The metallurgical grade silicon is then further refined to produce high purity poly-silicon for use in the solar and semiconductor industry. Next,

the poly-silicon is used to grow monocrystalline rods or ingots. These ingots are then shaped and sawn into very thin wafers. The wafers are then manufactured into solar cells and assembled into photovoltaic modules ready for installation.

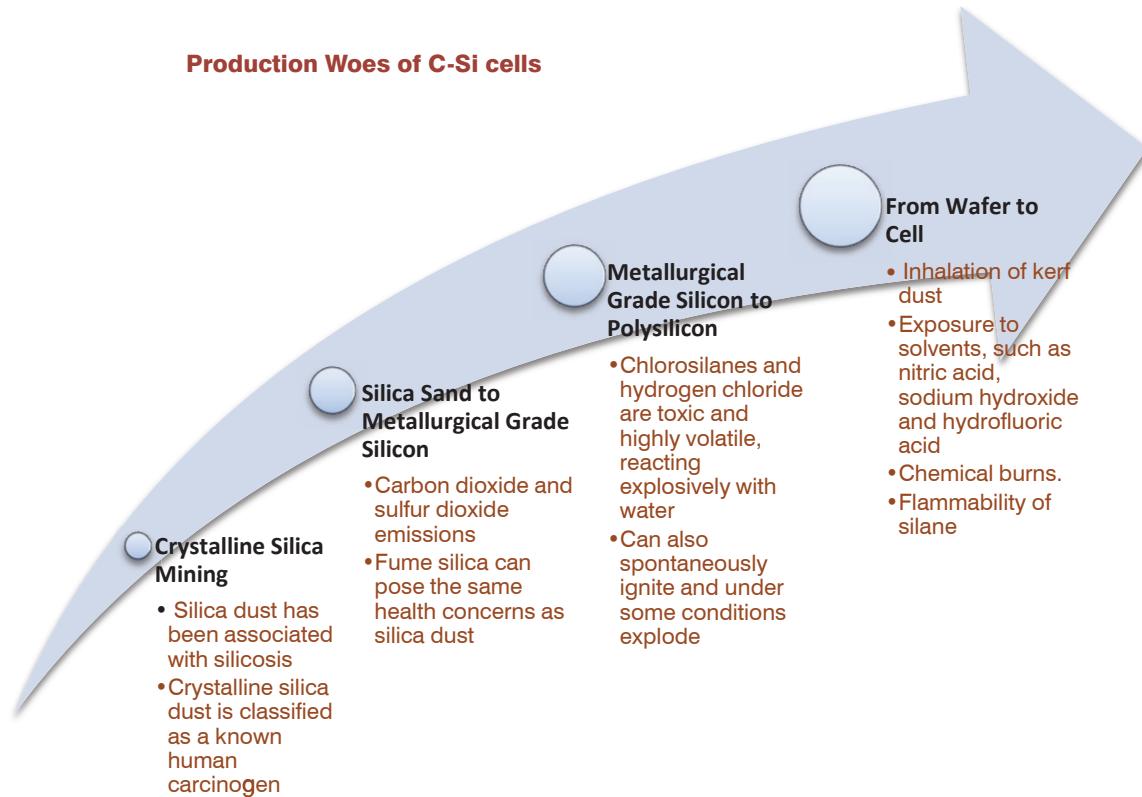
A potentially harmful by-product associated with the mining and processing of silica sand is *crystalline silica dust*. Silica dust has been associated with silicosis, a lung disease where scar tissue forms in the lungs and reduces the ability to breath. Crystalline silica dust is classified as a known human carcinogen by the International Agency for Research on Cancer.

The high temperatures required for c-Si production make it an extremely energy-intensive and expensive process, and also produces large amounts of waste. As much as 80% of the initial metallurgical grade silicon is lost in the process.

- **Silicon Dust:** During the manufacturing of Crystalline Silicon PV, silicon dust is produced which is also called as Kerf. This is produced due to cutting of c-Si wafers or plates. In this process approx. 50% of the silicon is lost in the air and water which is used to rinse them. The silicon particulate matter produced due to this not only causes risk to production workers but also those who clean and maintain equipment.
- **Silane gas:** It is one of the most significant hazards in the c-Si production because of its explosive nature. Accidental leakage of this

4 Toward a Just and Sustainable Solar Energy Industry- A SVTC paper, January 2009

Production Woes of C-Si cells



gas can pose potential threats to the workers involved in this process.

- **Silicon tetrachloride (SiCl_4):** It is formed due to the production of silane and trichlorosilane. It is extremely toxic and reacts violently with water. It can cause skin burns and irritation in eyes, skin and respiratory organs. Although it can be easily recovered and reused as an input for silane production, in places with little or no environmental regulation, silicon tetrachloride can constitute an extreme environmental hazard.
- **Sulfur hexafluoride (SF_6):** It is used to clean the reactors used in silicon production. According to IPCC, it is considered as the most potent greenhouse gas per molecule. One ton of this gas is equivalent to 25000 tons of CO_2 .
- **Sulfur Dioxide (SO_2):** Sulfur hexafluoride reacts with silicon to produce this gas. It can cause acid rain which is one of the biggest environmental threats.
- **NaOH & KOH:** Large quantities of sodium hydroxide (NaOH) are used to remove the sawing damage on the silicon wafer surfaces. In some cases, potassium hydroxide (KOH) is used instead. These caustic chemicals are dangerous to the eyes, lungs, and skin.
- **Toxic phosphine (PH_3) or arsine (AsH_3) gas:** It is used in the doping of the semiconductor material. Though these are used in small quantities, inadequate containment or accidental release poses occupational risks.
- **Lead:** It is often used in solar PV electronic circuits for wiring, solder-coated copper strips, and some lead-based printing pastes. 80% of lead emissions of production are released during material processing related to solar glass manufacturing and soldering.
- **Brominated flame retardants (BFRs):** Polybrominated biphenyls (PBBs) and Polybrominateddiphenylethers (PBDEs) are used in solar panel inverters as flame retardants. They are carcinogenic and are described as endocrine disruptors.
- **Hexavalent chromium (Cr VI):** It is used for coating solar panels to help them absorb solar radiation and it is a carcinogen.

In addition to the chemicals used by all crystalline silicon cell production, additional chemicals used to manufacture mono c-Si solar cells include ammonium fluoride, nitrogen, oxygen, phosphorous, phosphorous oxychloride and tin. Like most industrial chemicals, these materials require special han-

dling and operating standards to prevent workplace hazards or exposure to toxics.

THIN FILM

Since solar is relatively new technology and hence there are many developments on this front. Unfortunately, many of these new technologies use toxic, explosive, corrosive, or potentially carcinogenic materials. Thin film silicon, which is a fast growing segment, reduces the volume of material needed by spraying a thin layer of silicon on to a surface. Since the material used is less, it has the potential to reduce impacts and waste. But the active semiconductor materials in thin-film technology contain cadmium, telluride, and selenium. Multi-junction panels contain arsenic compounds. These are known toxins.

Amorphous Silicon (a-Si) Thin Film

Few of the chemicals or gases are common as above like silane/chlorosilane gas, NaOH, BFR's. But there are various other dangerous chemicals being used in the manufacturing process of a-Si thin film:

- **Hydrogen, methane and germane gas:** These gasses are used either as a doping agent or mixed with silicon to form alloys to coat the thin film. Methane is used to remove the extra hydrogen. All are highly explosive and flammable gases. Methane is a potential greenhouse gas threat if released into the environment. All three gasses pose occupational and health hazard to workers.
- **Acids (HCl, HF, H₃PO₄):** These are used to etch or clean wafers and known as occupational hazards to workers.
- **Silicon and Germane Tetra fluoride:** These tetra fluorides emit toxic fumes when heated.

Cadmium Telluride (CdTe) Thin Film

The CdTe thin film cells use various compounds of cadmium in its entire manufacturing process. Various cadmium compounds used are cadmium telluride, cadmium sulfate (CdSO₄), cadmium chloride (CdCl₂), cadmium sulfide (CdS). The major reason of concern in this case is cadmium.

END OF LIFE SOLAR PANELS

Solar technology uses diverse variety of cells. Out of many varieties only three has been mentioned in this section. There are cells which are dye-sensitized and others which use nano-particles. Solar being relatively new, not all the PV technologies have been analyzed and hence we face the threat of unknown.

Solar PV technology is expected to grow exponentially in India in the coming years. Like any other consumer product, solar panels have a limited shelf life (around 25 years) and disposing of old panels will eventually come into play. A recent increase in solar energy systems, especially large centralized installations, underscores the urgency of understanding their environmental interactions. Also, with domestic adoption of the technology getting popular, the solar panels are becoming geographically dispersed, which would lead to dispersed waste generation. What happens to the obsolete panels after they are decommissioned? Is there a danger, considering that there are toxic materials present? Is there a valuable resource there which can be recovered?

Solar PV Panels contain toxics materials and the obsolete or end-of-life panels can pose risks to human health and the environment if not handled well. Exposure by humans and other species to the toxic substances in 'intact' solar panels is minimal, because other inert materials encapsulate the chemicals. But like most trash, the solar panels will be abandoned in landfills or in a developing country like India recycled by the informal sector with little or no safeguards, potentially causing pollution and contamination of environmental resources. Much like e-waste, solar panels will create a toxic pile if they are improperly recycled off or disposed off in landfills.

If PV products are disposed of on or in land, they can break and release toxic chemicals into soil and groundwater, potentially contaminating our environment. The end-of-life impacts of the materials or chemicals contained are well established. For example, heavy metals, such as cadmium in CdTe cells and lead in crystalline silicon panels, can filter out of the waste. Studies have demonstrated that when thin-film cells containing CdTe are exposed to water; the CdTe dissolves, increasing the risk of leaching



cadmium. Approximately 4.6g of cadmium is contained in an average CdTe panel (weight of 12 kg).

Tests have also shown lead to leach from crystalline silicon panels. Approximately 12.67g of lead is contained in an average c-Si panel (weight about 22 kg). Once in soil and water, cadmium and lead can mobilize and spread beyond the dumping area. The contaminants can then accumulate in plants and animals and poison the food supply.

Studies have also pointed out risks with end-of-life of cells like Copper Indium Selenide (CIS) and Copper Indium Gallium Selenide (CIGS). Selenium is a regulated substance that bio-accumulates in food webs and forms compounds such as hydrogen selenide, which is considered highly toxic and carcinogenic by the EPA. CIGS has toxicity levels similar to CIS with the addition of gallium. These also use cadmium sulfide (CdS) as a buffer layer, so cadmium is also a potential hazard. In addition, cadmium telluride (CdTe) is often used as a buffer material in these modules, which introduces the CdTe toxicity.

Like e-waste, solar panels pose future recycling challenges due to complexity of its composition. But these can be recycled safely. To avoid a repeat of the e-waste crisis, we need to ensure that decommissioned solar PV products are recycled responsibly and do not enter the informal waste stream. Proper decommissioning and recycling of solar panels both ensures that potentially harmful materials are not released into the environment and reduces the need for virgin raw materials.

If solar panel waste is not recycled, it will also amount to loss of valuable resources. It not only contains conventional resources like glass, aluminium, etc., but also contains precious and rare metals like silver, indium, gallium and germanium.

Rare metals	Type of cells
Silver	Crystalline Silicon
Indium	Amorphous Silicon, CIS, CIGS
Gallium	CIGS, CPV and emerging technologies
Germanium	Amorphous Silicon, CPV and emerging technology

Source: Study on Photovoltaic Panels supplementing the impact assessment for a recast of the WEEE Directive, April 2011

Though the quantity of Solar panel waste is probably negligible currently, the waste is going to see exponential rise in coming years as we are seeing a massive growth in the installation of solar panels now. Hence, disposal must be carefully handled to avoid contamination from the enclosed chemicals.

LEGAL FRAMEWORK

INTERNATIONAL FRAMEWORK

The PV industry continues to push its credentials as a technology that addresses one of the fundamental challenges of climate change. However to make solar technology truly green, industry must reduce and eventually eliminate the use of toxic materials and develop environmentally sustainable practices. In addition to toxic chemicals, panels also contain valuable materials like glass, aluminum, semiconductor materials etc. which could be recovered and reused. Solar panels must be designed in way which is easy to recycle and which reduces impact on environment. Internationally, many countries have already taken steps to handle the end of life solar panel waste. Few of the initiatives are listed below:

Regulation in US on Solar PV

- In the USA, there is yet no nation-wide established legislation or recycling scheme for solar panels. End-of-life treatment of solar PV products is governed by the Federal Resource Conservation and Recovery Act (RCRA) and various local state policies. As a prerequisite to be governed by RCRA, solar panels must be defined and classified as hazardous waste, a

condition to be met by failing the Toxicity Characteristics Leach Procedure test (TCLP test), however most panels usually pass TCLP and are therefore not subject to RCRA. If solar panels are determined to be hazardous waste, RCRA could be used to regulate their handling, recycling, reuse, storage, treatment, and disposal.

Regulation is European Union

- Originally notified in 2003, the Waste Electrical and Electronic Equipment Directive (WEEE) regulates the treatment of electrical and electronic waste at the end of their life cycle. The directive has been amended twice (“recasted”) in 2008 and 2012, resulting into an enlarged scope to include many new additional products. Photovoltaic (PV) panels were introduced in the revision of 2012.
- WEEE set the fundamental legal rules and obligation for collecting and recycling photovoltaic panels in the European Union, including setting minimum collection and recovery targets. Up to this day, WEEE does not cover the disposal of solar thermal modules. The WEEE legislation has set up the minimum rules and targets for the disposal of photovoltaic modules across EU Member States. However, each European country has to transform this EU legislation into national law and can further refine or strengthen the rules behind the collection and recycling process.
- The UK, Bulgaria, the Netherlands and Luxembourg are the only countries to have transposed the Directive before the official deadline. The adopted national WEEE law applies to the local Producers right after its transposition.
- It is mandatory for PV module Producers to comply with WEEE, notwithstanding whether the country they operate in has already laid out other set of rules, such as energy relating legislation.

KEY RECOMMENDATIONS

- Reduction and elimination in the use of materials those are hazardous to human health and to the environment.
- Workers and communities are not exposed to harmful materials in the manufacturing, use, disposal, and recycling of PV products.
- Solar PV manufacturers implement programs to take back decommissioned solar panels and recycle the panels responsibly.
- Legal framework to address solar panel waste

INDIAN FRAMEWORK

India currently lacks any framework on solar panel waste. It is not included in the E-waste Management and Handling Rules 2011.

CONCLUSION

Solar photovoltaic (PV) technology has developed rapidly in the last decade or so in India and is being regarded as a part of the solution to the country energy crisis. It is also being considered as a sustainable energy source, thereby addressing global climate challenges. The industry's exponential growth and its use of new and increasingly complex materials raise serious health and environmental issues, both in product manufacturing and throughout product lifecycles.

A major concern is the fate of millions of PV panels currently in use, which will start appearing in the waste stream soon. The unorganized sector involved in waste management in India will pick up the new stream of waste as well, but the big question is whether they will be able to recover resources optimally and do it in a way which is environment friendly. For solar to be truly green and clean technology, it is important to focus on the reduction and elimination in the use of toxic materials and management of end-of-life. Similar to E-waste, Extended Producers Responsibility is being increasingly seen as the way ahead for managing of Solar panel waste. The industry in India must also work towards adopting sustainable technology and take on the responsibility for the lifecycle impacts of their products. It is also important that adequate legislation is introduced in the country before there are large quantities of PV panels contaminating our environment and poisoning health of millions.

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