

Recycling of solar photovoltaic modules

The growth of solar energy

Solar is one of the cheapest sources of energy as the sun is abundant in all corners of the globe. Energy gov'n. reports that around 173,000 terawatts of solar power constantly reaches the earth. In just 90 minutes, enough sunlight reaches the earth to power every home and business in the world for a full year.

The first solar cell was built in the 1950s. Since then, the solar industry has boomed. Most recently, homes across the globe are installing solar panels in yards and on rooftops to help power appliances, electronic devices, and energy grids across the country. From homeowner installations to large solar farms, solar energy is taking off.

But there is a problem that's just starting to gain attention. It is estimated that by 2050, China and the US will have the largest amounts of end-of-life solar panels. Perhaps more worrisome are reports that photovoltaic (PV) modules will account for more than 10% of electronic waste within the next 30 years.

Most solar panels only have a lifespan of 25 to 30 years. As time goes on, solar energy production slows down and the panel is no longer viable. As the solar industry started booming in the early-2000s, people are starting to consider what happens next?

At this point, recycling is the only option. It is also a newer process for many recycling facilities and residential solar installers.

Classification of solar panels

Solar panels can be classified into three generations:

- Crystalline silicon (c-Si) (mono-crystalline/poly-crystalline);
- Thin-film (amorphous silicon, cadmium telluride, and copper indium gallium selenide, CIGS); and
- Concentrator photovoltaics (organic, dye-sensitized, and hybrid).

Crystalline (mono- and poly-) silicon solar panels have higher conversion effi-



NANDU SAROLKAR

Sarvesh Engineering, Pune
E-mail: sarvesh.e@gmail.com

ciency than thin-film solar cells. Therefore, these are currently the most widely used. While crystalline silicon panels hold a 95% market share of worldwide PV production, thin films solar panels account for ~4.5%. Third-generation solar panels have not yet been commercialised on a large scale.

Solar panels contain valuable materials such as silicon, silver, aluminium, copper, and gallium, as well as hazardous materials such as lead and cadmium, which are harmful to humans. From an economic perspective, it is quite significant to recycle valuable materials that can ensure the sustainability of the supply chain in the long term. Moreover, from the environmental protection aspect, recycling of solar panels not only prevents the release of hazardous substances from the waste streams, but also reduces the greenhouse gas emissions related to the production of virgin PV modules.

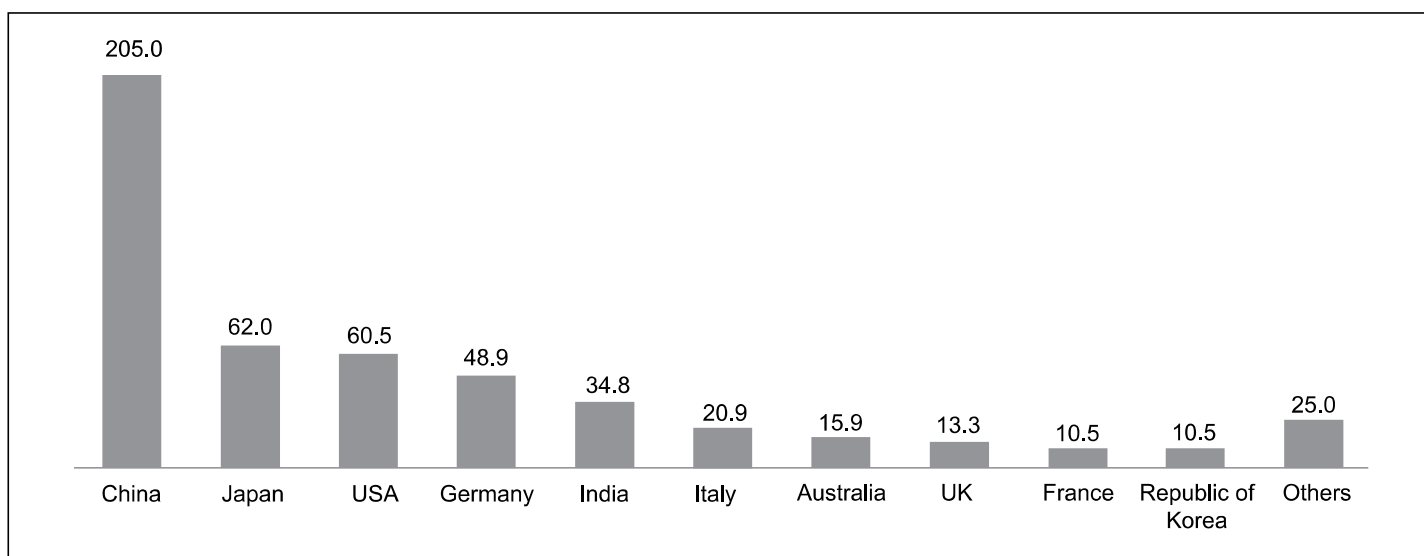


Fig. 1: Cumulative solar installed capacity by 2019; top 10 countries

Source: IRENA, FutureBridge Analysis

Waste generation

Most waste is typically generated during four primary life cycle phases of solar panels:

- Panel production;
- Panel transportation;
- Panel installation; and
- End-of-life disposal of the solar panel.

Waste generated during production is easily managed; collected and treated by waste treatment contractors or manufacturers themselves.

Solar panel waste streams will increase alongside worldwide PV deployment. Global cumulative PV deployment accelerated after 2010 and has grown exponentially, to reach 586-GW in 2019. The major global PV leaders today include China (205-GW of cumulative installed capacity), Japan (62-GW), the US (60.5-GW), Germany (48.9-GW), and India (34.8-GW).

Considering the worldwide surge in PV deployment since 2010 and an average lifetime of 25 years for solar panels, waste volumes are certain to increase more rapidly after 2030, from 1.35-mt in 2030 to 12.3-mt in 2040. By 2030, the top three solar panel waste countries are expected to be Germany (400,000-tonnes), China (200,000-tonnes), and Japan (200,000-tonnes), but the picture will change by 2040, by which time China is predicted to have accumulated the largest amount of waste (2.8-mt), followed by Germany (2.2-mt) and Japan (1.8-mt).

Recycling overview

As pointed out earlier, c-Si solar technology represents most of the solar panel market. This type of panel is constructed with an aluminium frame, glass, copper wire, polymer layers and a back sheet, silicon solar cells, and a plastic junction box. The

polymer layers seal the panel from exposure to weather, but can make recycling and panel disassembling difficult, as high temperatures are often required to loosen the adhesive.

Many of these components can be recycled. Glass composes most of the weight of a solar panel (about 75%), and glass recycling is already a well-established industry. Other materials that are easily recyclable include the aluminium frame, copper wire, and plastic junction box.

Other materials located within the solar cells may be more difficult to recycle. Silver and internal copper are valuable, but panels typically contain very small amounts of these materials. Toxic metals like lead and cadmium may also be present.

Solar panels may contain critical materials, including aluminium, tin,

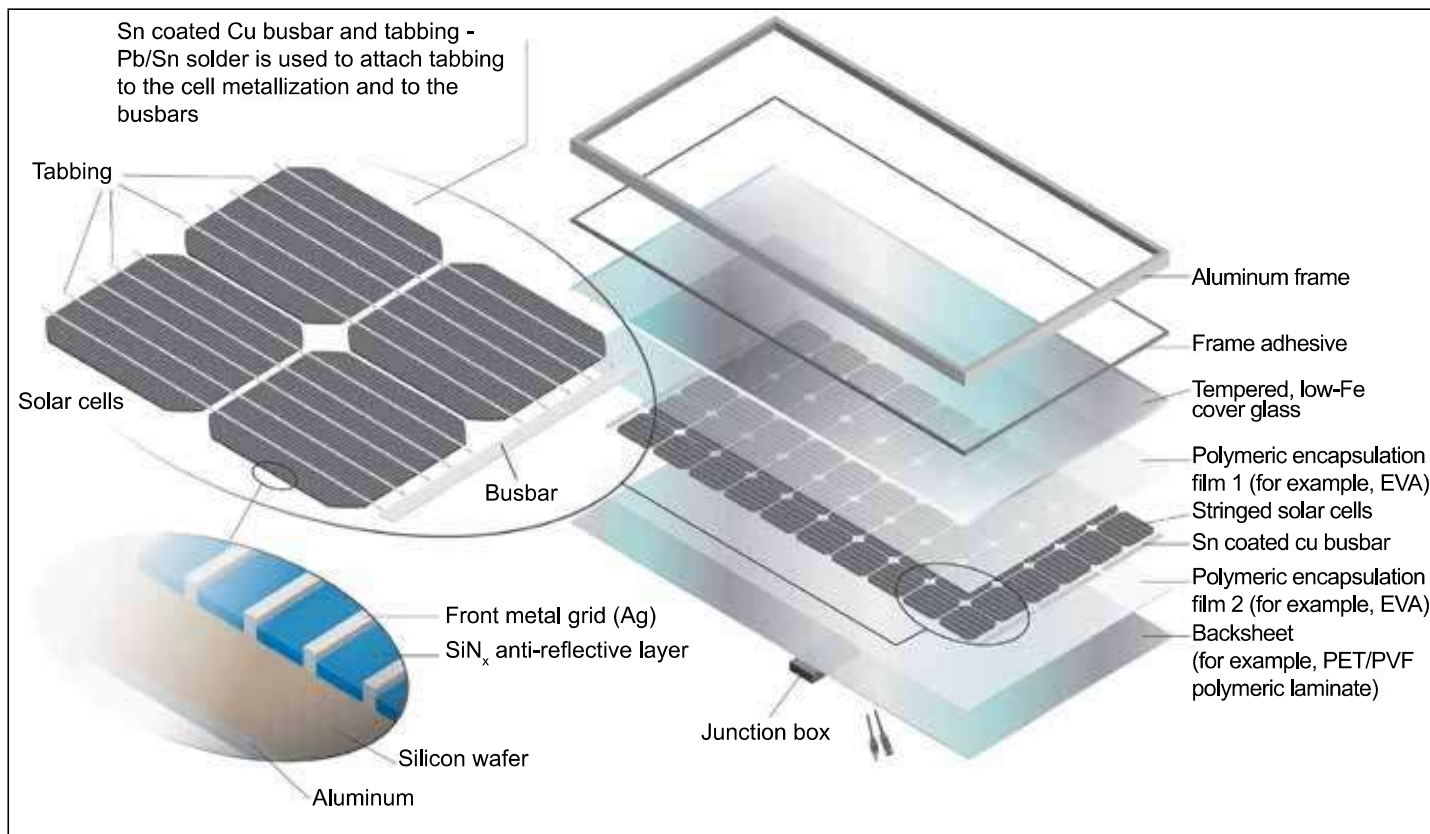


Fig. 2: Construction of a crystalline silicon solar panel

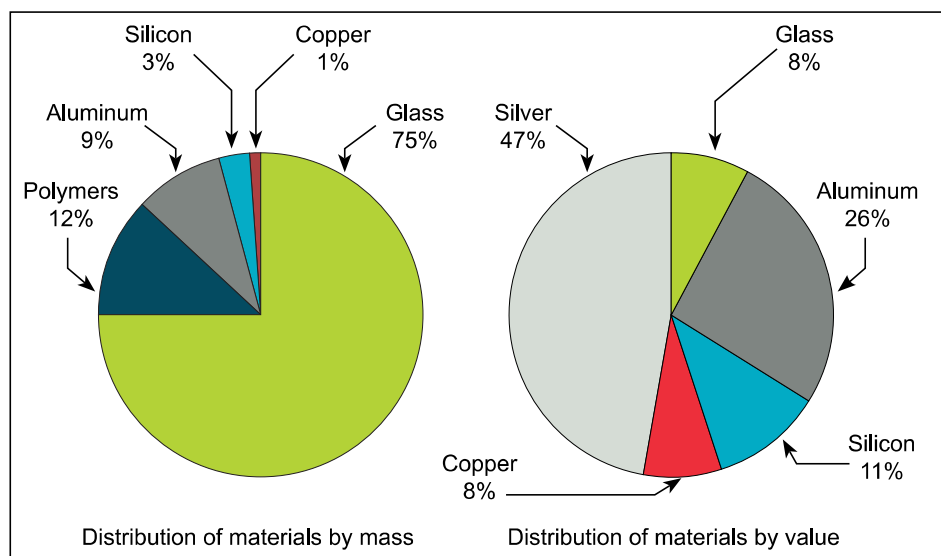


Fig. 3: Materials in a typical silicon PV cell

Source: Martin Bellman/Icarus

Note: Silver is less than 1% of the mass

tellurium, and antimony, as well as gallium and indium in some thin-film modules. Other components of a solar power system may include inverters, racking, and battery backup systems, which may also be recycled. Inverters may be recycled with electronic waste, and racking may be recycled

with similar scrap metals. Battery-based grid energy storage systems may be handled with current battery recycling programs.

In a typical c-Si PV module approximately 75% of the total weight is from the module surface (glass);

10% from polymer (encapsulant and back-sheet foil); 8% from aluminium (mostly the frame); 5% from the silicon (solar cells); 1% from copper (interconnectors); and less than 0.1% from silver (contact lines) and other metals (mostly tin and lead). The rest of the components have an even smaller percentage of the module weight.

Recycling process

An ideal recycling system would recover as much material from solar panels as possible. There are different methods to recycle solar panels, which can include some or all of the following three steps:

1. Removal of the frame and junction box;
2. Separation of the glass and the silicon wafer through thermal, mechanical or chemical processes; and/or
3. Separation and purification of the silicon cells and specialty metals (e.g., silver, tin, lead, copper)

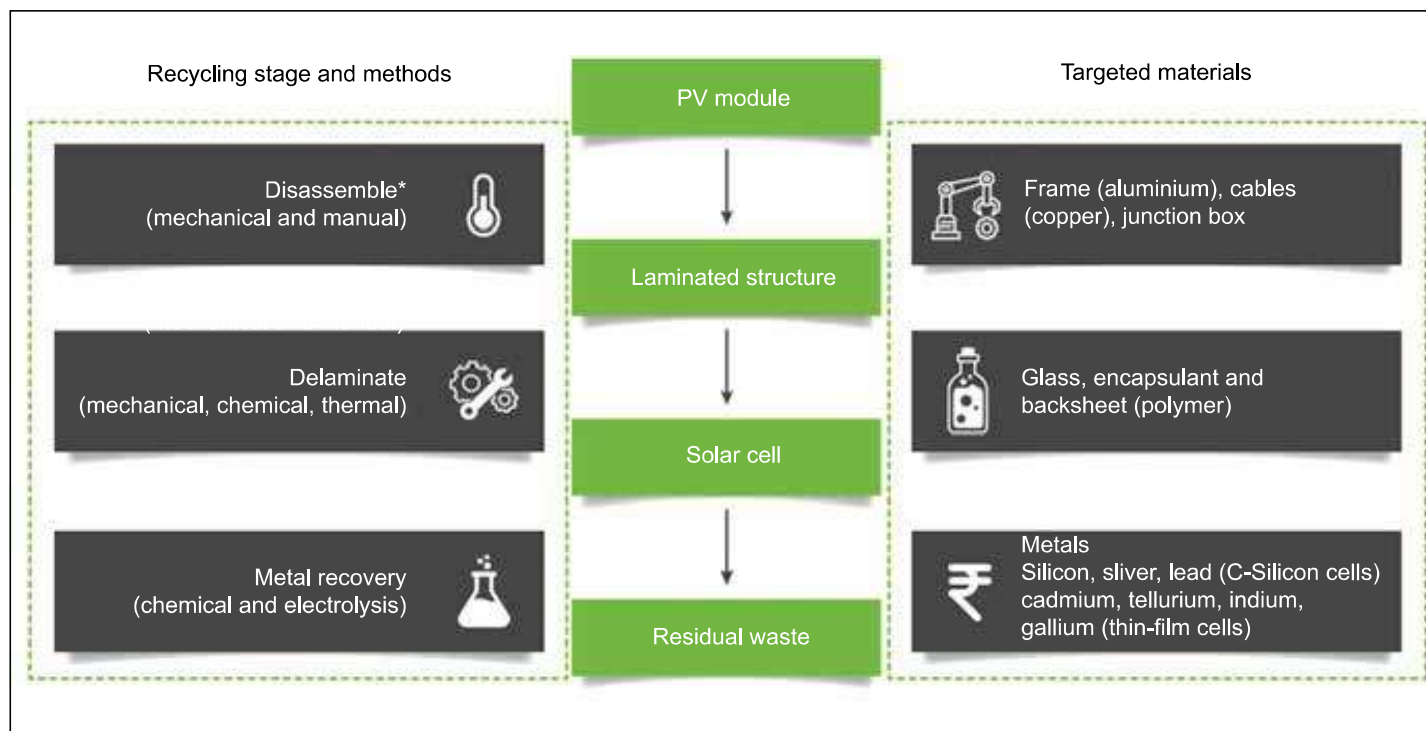


Fig. 4: Multiple stages of a PV recycling system

*: Not applicable for thin-film modules

through chemical and electrical techniques.

The solar panel recycling industry is new and growing, with researchers examining how to commercialize recycling to economically recover most of the components of a solar panel. But it is not yet happening on a large scale.

Recycling is already established in the glass, metals, and electronics industries, which can accommodate solar panels and other solar power system components. These processes typically involve crushing, shredding, and milling, usually after removal of the frame and junction box. In these processes, glass, aluminium, and copper may be recovered and the other materials, including the silicon solar cells, may be incinerated.

Thin film cadmium-telluride panels, which represent a small part of the solar market, undergo a different recycling process. At least one US manufacturer runs dedicated recycling facilities for thin film panels, which recover the semiconductor material (cadmium and tellurium), in addition to glass and copper.

PV panels continue to produce energy even after the guaranteed 25 years, even if their yield is reduced by ~15%. It is therefore not certain that once the guaranteed period has elapsed, the plant is to be disposed of: replacement should be spoken of only when this brings real economic convenience, i.e., when the maintenance cost exceeds the production profit.

PV module recycling is a multistep process, involving dismantling, delamination, and metal recovery. Some recycling techniques like chemical delamination yield undamaged solar cells, which could be reused directly or with little refurbishing. Mechan-

ical and combustion delamination, on the contrary, yield damaged solar cells that need to be treated electrochemically or metallurgically to recover the metals.

In total, 94% of panel components can be recovered, the remaining 6%, in the form of dust, is captured by filters and sometimes used as a substitute for sand in the construction industry.

Economic aspects

The extraction of secondary raw material from end-of-life PV modules, if made in an efficient way, can make them available to the market again. These PV modules represent a large stock of embodied raw materials, which can be recovered and become available for other uses or even for solar cells again.

The International Technology Roadmap for Photovoltaic (ITRPV) predicts that by 2030, the total material value recovered from PV recycling can reach \$450-mn. With this amount it is possible to produce 60-mn PV modules (18-GW), which would be approximately 33% of the 2015 production. Up to 30,000-tonnes of silicon can theoretically be recovered in 2030, which is the amount of silicon needed to produce approximately 45-mn new modules. Considering current polysilicon prices of \$20/kg and a recovery rate from commercial recycling processes of 70%, this is equivalent to \$380-mn.

Environmental aspects

An environmental study made for the European Full Recovery End-of-Life Photovoltaic (FRELP) project showed that environmental impacts from c-Si recycling processes come from plastic incineration and some chemical and mechanical treatments (sieving, acid leaching, electrolysis, and neutralization) for the recovery

of metals. Additionally, before the recycled silicon from solar cells can be used again, further chemical treatment is necessary, as well as for silver and aluminium. The chemical treatments have the potential of producing environmental impacts. Besides, it is important to note that no process can recycle 100% of recovered materials from solar modules yet.

Nevertheless, for the c-Si recycling process it has been shown that there is a significant decrease in Global Warming Potential impacts (up to 20% compared to the process of making cells), and for CdTe modules, there is an environmental benefit from the glass and copper recycling.

When comparing c-Si recycling and landfill end-of-life scenarios it was found that the environmental impacts from the recycling process are lower than for landfill, assuming that the recycled resources go back to PV cells and modules manufacturing. These results considered that the recycling process involving dismantling, remelting, thermal and chemical treatments.

How are other countries handling solar waste?

Except for the European Union (EU), no country in the world has passed laws/regulations on solar panel waste recycling to tackle the impending sharp increase in end-of-life PV modules. In Europe, solar panels are officially regarded as Waste Electrical and Electronic Equipment (WEEE) by the European Commission, which means that solar panels waste must be collected and recycled in an appropriate way.

The EU directive established recycling targets in terms of module weight and also expresses the intention to increase the collection rates to allow the

progressive recycling of more material and less to be landfilled. Even with targets aiming for 65% recycling product weight, some of the current studied recycling processes can recycle over 80% of the weight of a PV module. However, there is still incentive to improve, considering that most of the weight is from glass and frame, which are relatively easy to remove.

The WEEE Directive imposes responsibility for the disposal of waste on the manufacturers or distributors who introduce or install such equipment for the first time. PV manufacturers are solely responsible for the collection, handling and treatment of modules at the end of their life cycle.

The UK also has an industry-managed “take-back and recycling scheme”, where all PV producers will need to register and submit data related to products used for the residential solar market (B2C) and non-residential market.

While there are no federal statutes or regulations in the US, there are some States who have proactively defined policies to address end-of-life PV module management. Washington and California have come up with extended producer responsibility (EPR) regulations. Washington now requires PV module manufacturers to finance the take-back and reuse or recycling of PV modules sold within or into the State at no cost to the end-user. In addition, New Jersey and North Carolina passed legislation in 2019 to study and explore PV module management options that can help in forming future legislations.

The federal government in Australia has acknowledged the concern and announced \$2-mn grant as part of the National Product Stewardship Investment Fund to develop and implement

an industry-led product stewardship scheme for PV systems. It is expected that the scheme will encourage shared responsibility throughout the supply chain to manage the impacts of PV modules through their life cycle and support the development of an efficient and innovative domestic PV recycling industry.

Countries such as Japan and South Korea have already indicated their resolve to come up with dedicated legislation to address the PV waste problem.

Indian scenario

India does not have a solar waste management policy, but it does have ambitious solar power installation targets. The nation is currently hosting 42 solar parks with total installed capacity exceeding 35.7-GW last year.

Solar waste – the electronic waste generated by discarded solar panels – is sold as scrap in the country. It can increase by at least 4-5 fold by the next decade. India should focus its attention on drafting comprehensive rules to deal with this solar waste. It is likely that India will be faced with solar waste problems by the end of this decade, and solar waste will end up being the most prevalent form of waste in landfills soon.

The two most popular PV module technologies in India are C-Si and thin-film (mainly CdTe), with 93% and 7% market shares respectively. Both the technologies can have a recovery rate of 85-90%.

Why are we not recycling more?

The large cost gap between recycling and discarding panels in landfills points to an unpleasant truth: Recycling a solar panel cost between \$20 and \$30, according to the National Renewable Energy Laboratory (NREL),

in USA; sending it to a landfill costs just \$1-2.

There are no rules and regulation for recycling end-of-life solar panels in India, and society here is not yet geared up for recycling, as there are many constraints. For one, waste collection is mostly done by rag pickers or in the unorganized sector and the recycling industry is not yet developed. Majority of the waste is recycled in a crude way, by small scale industries. There is a need to develop the recycling industry in India as a prime business, to save on scarce resources. Specially for end-of-life solar panel recycling the required infrastructure and technology is not yet available. The little recycling that is done is to recover aluminium and glass.

One way to keep solar panels out of landfills is through panel reuse, either by direct reuse or after refurbishment. When reused, solar panels get a second life, generating clean energy at a different location. The secondary market has not yet gained traction even in the US, and regulatory considerations include electrical grid interconnection regulations, and fire, building and electrical codes that must be examined when planning for solar panel reuse. However, there are many beneficial ways solar panels could be reused in situations where they are not connected to the electrical grid, including electric bike or vehicle charging stations, or other remote locations.

Establishing a solar module recycling system in India

The technical feasibility of the plant currently looks good. As for economic viability, transportation is a considerable cost, especially when panel waste is collected from other parts of India. If transportation costs are managed in the long term, we can

have a much better, financially viable business model.

Right now, PV recycling is a very grey area: There are doubts like whether it fits under e-waste or will there be a separate regulation for it. The aim should be to have a commercially, financially, and technically viable system, as well as SOPs, and the right kind of stakeholders.

Recently, a start-up formed by Ankit Kapasi and Kishore Ganeshan, from Sofies India, have started working on a project, funded by Signify Foundation based in Netherlands, and Doen Foundation, Poseidon Solar as technology partner. A pilot project, having a capacity of 2.5-tpd (tonnes per day), has been installed at Gummidipoondi in Tamil Nadu, which is likely to be upgraded to higher capacity of 150-200 tpd soon. The company is currently doing mechanical recycling of solar modules.

How can India manage PV module waste better?

Experts in the industry have studied the Indian and international policy landscape of PV module waste management to outline some immediate interventions needed in India, and given recommendations. These are guided by a thorough review of the recycling processes and globally implemented regulatory and voluntary mechanisms to manage PV module waste.

Currently, recycling cannot be considered the economically favourable option, so economic incentives are required. Among the valuable materials in the panel, silicon presents the best opportunity, given its considerably larger fraction and its ultra-high purity (99.9999%). The solar grade silicon from PV waste can be recovered for second-use applications in solar panels or repurposed for value-added

application as in the anode of lithium-ion batteries.

Currently, the technology for solar module recycling is not available in India and the equipment is not manufactured locally. If the equipment were made locally the cost can come down by about 30-35%. The technology required is not rocket science, and is a combination of different technologies, which are already available in India, so what we need to do is integrate the technologies.

Environmental disposal and recycling of solar waste should be made part of the power purchase agreement SECI/DISCOMS/government sign with project developers.

Ban on landfills is also needed, as solar panel waste is harmful to the environment, as it contains toxic metals and minerals that may seep into the ground.

Chemical Weekly | Import-Export Data Market Surveys | Directories Business Forums | Expositions

The only organisation in India catering exclusively to the needs of the entire chemical industry

Contact:

SEVAK PUBLICATIONS PVT. LTD.

602-B, Godrej Coliseum, K.J. Somaiya Hospital Road,
Behind Everard Nagar, Sion (E),
Mumbai 400 022.

Phone: +91-22-24044471 / 72

Email: admin@chemicalweekly.com