e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
Volume:06/Issue:07/July-2024 Impact Factor- 7.868 www.irjmets.com

PHOTOVOLTAIC SOLAR MODULE FOR POWER GENERATION AND ITS ASTE MANAGEMENT STUDY-A REVIEW

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ABSTRACT

This review is an overview of the step-wise recycling of crystalline silicon (c-Si) PV modules after End-of-life (EOL) using mechanical, thermal, and chemical routes. Aluminium frames, cables & junction boxes were removed from modules mechanically before further recycling. Encapsulated EVA (ethylene vinyl acetate) & backsheet polymers were primarily removed from the module by chemical route or thermal pyrolysis. As reportedworks of literature, pyrolysis of modules is the most efficient, faster, and less hazardous than chemical processes.After that, they recycled solar cells to recover high-value materials such as Ag, Al, and Si from waste PV cells via a chemical route to facilitate sustainable development for PV industries.

Keywords: Photovoltaic (PV) Module, Recycling, C-Si, And Solar Cells.

I. INTRODUCTION

Harnessing solar energy through the PV module (Photovoltaic effect) to produce electricity has become the fastest-growing sector in the renewable energy production industry [Dias, P, et. al. 2017]. A Typical PV module (fig. 1) consists of Si solar cells connected in rows and columns by solder and interconnects rails. Generally, solar cells are divided into four broad categories silicon-based solar cells, thin film solar cells, perovskite solar cells, tandem solar cells, etc (figure 2 & Table 1) [Dobra, T. et. al.,2022]. The solar cells are encased in an encapsulant (typically Ethylene Vinyl Acetate, EVA) and fused to glass on the front and with a backsheet [Weckend, S, et. al. 2016]. The entire structure is encased in an Aluminum frame. There is a junction box on the backside for making the electrical connections. Photovoltaic modules work for almost 25-30 years before they are no longer usable due to reduced efficiencies [Ambaryan, G. N, et. al. 2019]. Worldwide estimatedsolar energy target by 2050- 4500 TW [Kim, S. W et. al. 2016], and the same tonnage estimated Solar Waste willbe 78 million tons [Sah, D, et. al. 2022] (Figure 3-4). As the installation of PV modules increases exponentially, the End-Of-Life modules are also expected to rise by the same proportion shortly [Wang, X. Et. al. 2022]. Despite the obvious environmental benefits, it is difficult for PV module recycling to be widely accepted due to economicconstraints, namely, the low value of recovered material and high recycling cost [Xu, Y. et. al. 2018]. The lack ofPV-specific disposal guidelines, technical know-how, and intense industrial involvement further add to this burden. Thus, decommissioned panels are primarily being dumped in landfills or, at best, sent to glass recyclers.

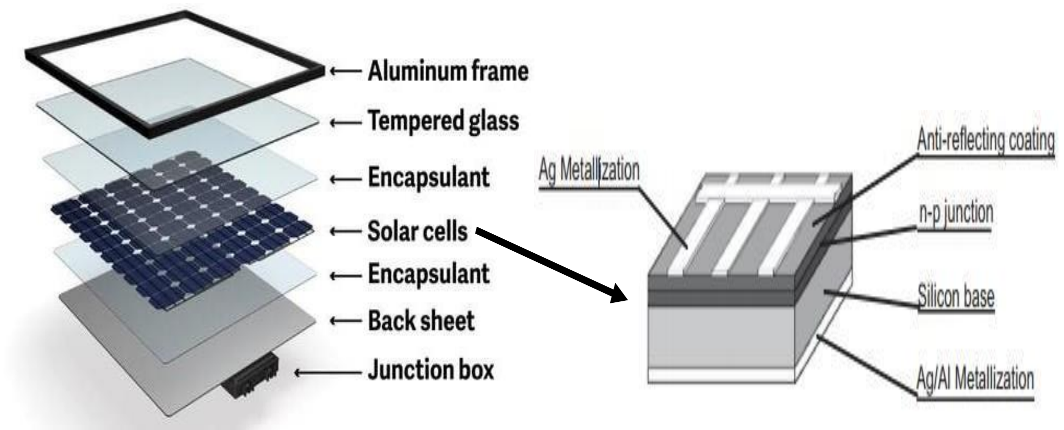

Fig. 1. Solar module basic structure and types of material used in solar cells [Dias, P, et. al. 2017].

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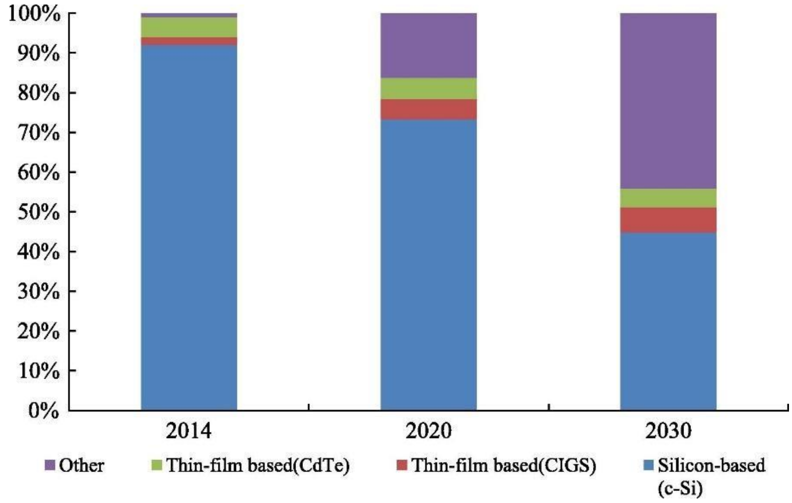

Fig. 2. Market share by different Solar panels [Xu, Y. et. al. 2018]

Table 1. Solar PV panels types

S.No.	Generation of PV panels	Solar PV panel Types
01	1st Generation (c-Si)	Monocrystalline
		Multi-crystalline
02	2nd Generation (Thin Film)	Cadmium telluride (CdTe)
		Copper indium gallium selenide (CIGS)
		Amorphous silicon
03	3rd Generation	Dye-sensitized solar panel
		Organic solar panel
		Hybrid solar panel

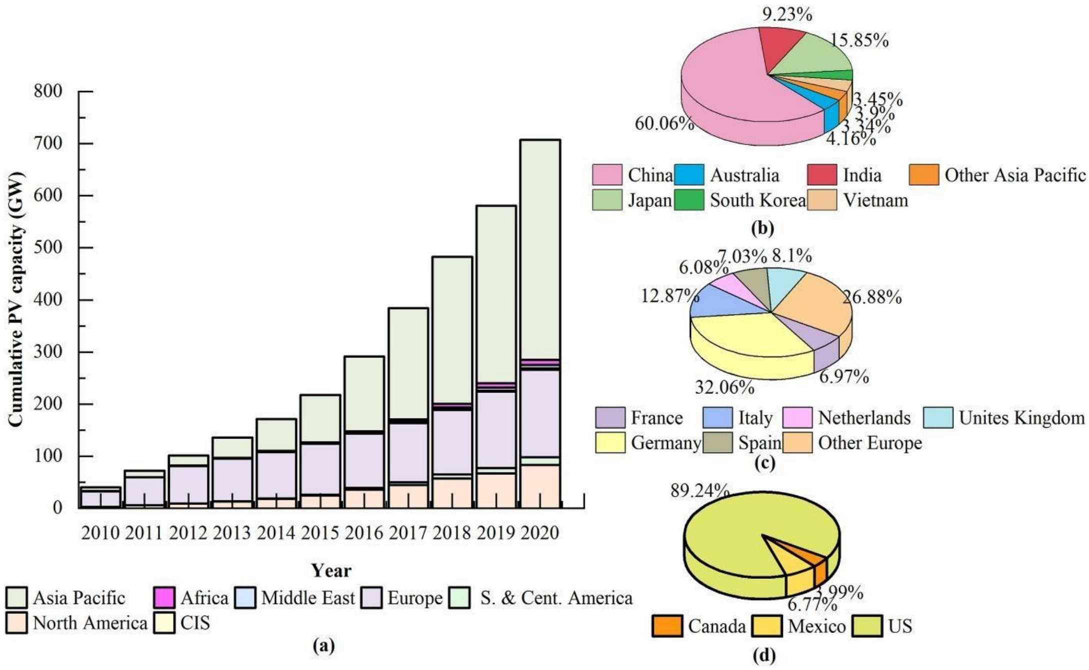

Fig. 3. Globally cumulative installed PV panel capacity (a) Global cumulative installed (b) share in Asia-Pacific in 2020, (c) Share inEurope 2020, (d) Share in North America in 2020 [Wang, X. Et. al. 2022].

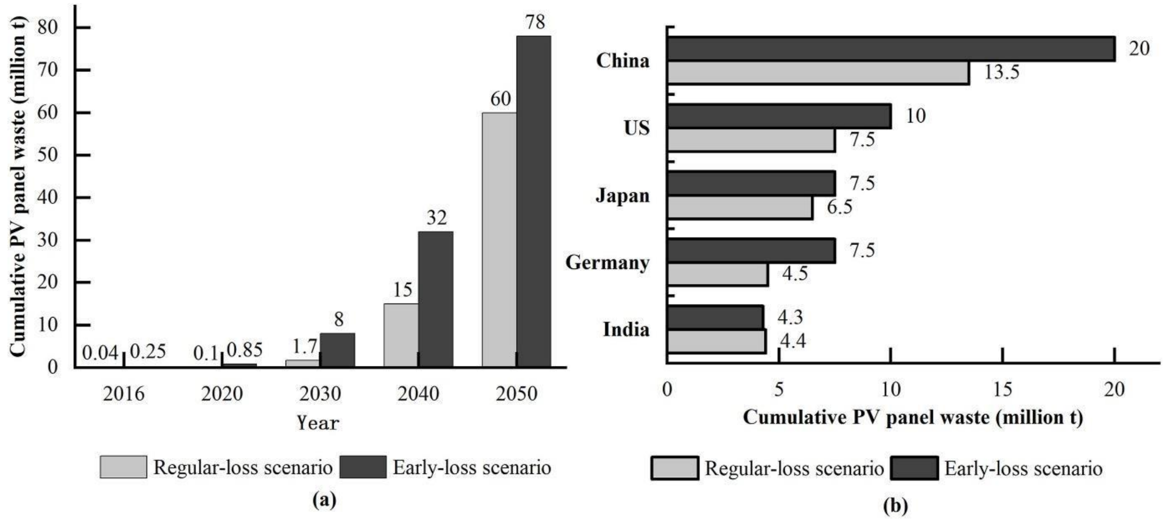

Fig. 4. Estimated cumulative waste of EOL PV panels. (a) Cumulative global waste (million t) of EOL PV panels, (b) Cumulativewaste by the top five countries in 2050. Date source: End-of-Life Management: Solar Photovoltaic Panels (IRENA)

During the thermal treatment (pyrolysis) of Silicon PV solar modules, hazardous byproducts could get released into the environment. In a study reported earlier, the PV module is placed inside a closed furnace and heated at 500°C for pyrolysis, and complete degradation of the encapsulant (EVA) is achieved [9]. Later the trapped gases were analyzed to quantify the release of metals, if any. The results indicate the presence of small amounts of dangerous metals like Pb, Si, Cu, and Ag in the gases evolved during pyrolysis [Fiandra, V et. al. 2019]. Usually, the recycling process for the EOL PV module starts with the manual removal of junction boxes and aluminum frames. After that, the removal/delamination of backsheet and encapsulant from the solar cell and glass plate needs to be done, which is a challenging task. Several routes have been tested and employed in the past for removal of the encapsulant by organic solvent, acetic acid, shockwave recycling and thermal decomposition . In the studies by [Farrell C et al. 2019], in-situ pyrolysis of c-Si solar PV module having EVA and PVDF backsheet was performed in a vacuum atmosphere. The evolved gas was tested using TGA-MS and TGA-FTIR with selected molecular fragments ion intensity spectral signals such as m/z= 43, 44, 2, 13, and 18 corresponding to acetic acid, carbon-di-oxide, hydrogen, carbon-13, and water vapour, respectively to identify the gases evolved during decomposition. Researcher [Wang, R et al. 2019] reported removal of EVA encapsulation of the c-Si PV module by pyrolysis at 500°C. At the end of the pyrolysis, undamaged glass and silicon wafers were obtained, which could be recycled further.

FTIR is a rapid well-proven and unique chemical fingerprint technique to identify organic as well as inorganic entities present in the sample. Researchers [Rathore, N. et. al.2022] used FTIR technique to detect EVA encapsulant and PVF backsheet and different functional group present in the gas evolved during pyrolysis of the PV module. They found that the C-H bond stretches at the absorption bond of 3000-2800 cm^{-1}. Several researchers have reported TGA-MS analysis of PV module pyrolysis [Dias, P et. al. 2018]. However, reports on the product of pyrolysis, reaction mechanics, and evolved gas characteristics have not been found deliberated exhaustively.

II. RECYCLING TECHANIQUES

Recycling combines mechanical, Thermal, and Chemical methods [Dias, P, et. al. 2017]. The processes chosen depend on the requirement of the end products (Figure 5 & Table 2).

The Aluminum frames are removed by mechanical means by physically separating them from the modules. The encapsulants are usually unrecoverable. They are typically pyrolyzed by heating to approximately 500°C. The other option is to dissolve it chemically in organic solvents. The key challenge here is either the generation of gaseous exhaust from polymer pyrolysis or the disposal challenge of large quantities of organic solvents [Weckend, S, et. al. 2016]. Glass removal: The glass used in PV modules is low Fe, Tempered, and Textured Glass. It is the primary recoverable material in a module. Most recycling operations crush the module into small

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pieces of glass with Si and encapsulant stuck to them. Solder is usually removed thermally or chemically. Though Lead-free solders have been developed, the PV modules still use lead-containing solder, especially those expected to come for recycling over the next few decades. Depending on the local legislative requirements, these may need to be recovered. Interconnects are usually quickly recovered once the solder is removed. These can be easily collected and recycled as Al or Cu [Ambaryan, G. N, et. al. 2019].

Silicon recovery: Silicon solar cell recovery depends to a large extent on the preparatory steps as theydetermine if the cell is recoverable intact or in pieces. If the modules are not crushed, it may be possible to obtainintact Si cells. However, these cells are not reusable because the Ag interconnect grids, a Passivation layer, and Al back contacts will likely have been damaged [Sah, D, et. al. 2022]. Generally, it is observed that the PV panelwaste is treated by engaging the Four-R-Principle; R-Reuse (generate a robust secondary market for second-handuse of the panel at lower efficiency and lower power rating below 80%, though), R-Recycle (major components like Aluminium frame, cables, and glass are retrieved intact and are either reused or repurposed), R- Recover (Various physicochemical ways recover valuable materials like Silver, Aluminium, and Silicon) and R-Reduce (the hazardous components from the waste like lead, bismuth, etc. are separated carefully and reduced in volumefor further processing).

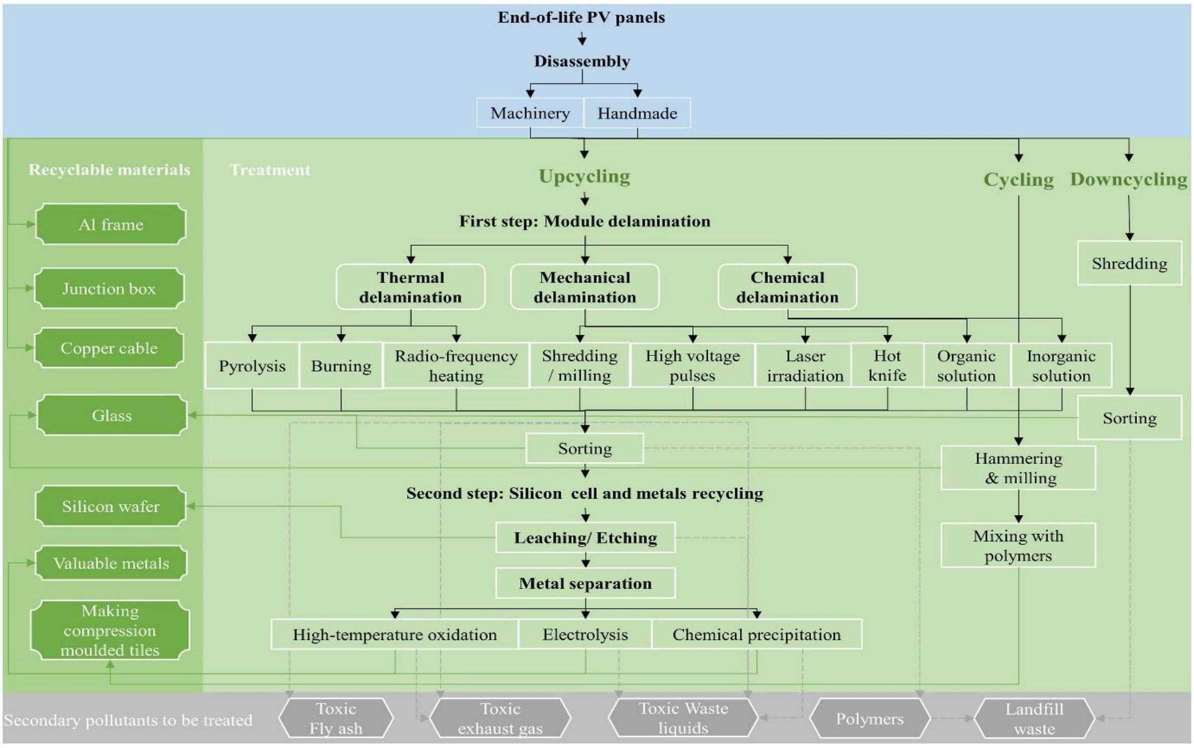

Fig. 5. Possible EOL PV panels recycling strategies and process [7].

Table 2. Various recycling routes of c-Si PV solar modules.

Process	Type of module	Advantage	Disadvantage	Processing time/Scale
Mechanical separation by hotknife/wire cutting[2]	C-Si/ thin film	Cell & glassrecover.	Other separation processes required for the complete removal of EVA	2 to 60 min/one by one
Thermal treatment[4]	C-Si/ thin film	Full EVA, Glass &cell removal	Harmful gas emissions	2 to 5 hr/ Bulk
Organic dissolution[5-6]	C-Si/ thin film	EVA/Backsheet removal	Cell defects,harmful emissions,waste solutiontreatment	6 to 48hr/Bulk

III. CONCLUSION

Following conclusions can be summarized point to point below:

1. This work demonstrates that present past and future challenges and opportunity with solar PV modules.It is possible to recover most of the materials in the c-Si PV modules for reuse and recycling.
2. The development of new generation of solar panel to fulfil the energy demand of society. After EOL the modules need to be proper way to recycle to protect our eco-system and environment.
3. Step-wise sequential recycling of PV modules to minimize the minimum environmental impact and maximum material recovery to facilitate the sustainable development to PV industries.

ACKNOWLEDGEMENT

All authors declare that no conflict of interest of this research work.

IV. REFERENCES

[1] Dias, P., Javimczik, S., Benevit, M., & Veit, H. (2017). Recycling WEEE: Polymer characterization and pyrolysis study for waste of crystalline silicon photovoltaic modules. Waste Management, 60, 716- 722..

[2] Dobra, T., Vollprecht, D., & Pomberger, R. (2022). Thermal delamination of end-of-life crystalline silicon photovoltaic modules. Waste Management & Research, 40(1), 96-103.

[3] Weckend, S., Wade, A., & Heath, G. A. (2016). End of life management: solar photovoltaicpanels (No. NREL/TP-6A20-73852). National Renewable Energy Lab.(NREL), Golden, CO (United States).

[4] Ambaryan, G. N., Vlaskin, M. S., Zhuk, A. Z., & Shkol'nikov, E. I. (2019). Preparation of High- Purity Aluminum Oxide via Mechanochemical Oxidation of Aluminum in a 0.1 M KOH Solution, Followed by Chemical and Heat Treatments. Inorganic Materials, 55, 244-255.

[5] Kim, S. W., Chung, H. E., Kwon, J. H., Yoon, H. G., & Kim, W. (2010). Facile synthesis of silver chloride nanocubes and their derivatives. Bulletin of the Korean Chemical Society, 31(10), 2918-2922.

[6] Sah, D., Lodhi, K., Kant, C., Srivastava, S. K., & Kumar, S. (2022). Extraction and Analysis of Recovered Silver and Silicon from Laboratory Grade Waste Solar Cells. Silicon, 14(15), 9635-9642.

[7] Wang, X., Tian, X., Chen, X., Ren, L., & Geng, C. (2022). A review of end-of-life crystalline silicon solar photovoltaic panel recycling technology. Solar Energy Materials and Solar Cells, 248, 111976.

[8] Xu, Y., Li, J., Tan, Q., Peters, A. L., & Yang, C. (2018). Global status of recycling waste solar panels:A review. Waste management, 75, 450-458.

[9] Fiandra, V., Sannino, L., Andreozzi, C., & Graditi, G. (2019). End-of-life of silicon PV panels: A sustainable materials recovery process. Waste management, 84, 91-101.

[10] Farrell, C., Osman, A. I., Zhang, X., Murphy, A., Doherty, R., Morgan, K., Rooney, D.W., Harrison, J., Coulter, R. and Shen, D. (2019). Assessment of the energy recovery potential of waste Photovoltaic (PV) modules. Scientific reports, 9(1), 1-13.

[11] Wang, R., Song, E., Zhang, C., Zhuang, X., Ma, E., Bai, J., Yuan, W. and Wang, J. (2019). Pyrolysis-based separation mechanism for waste crystalline silicon photovoltaic modules by a two-stage heating treatment. RSC advances, 9(32), 18115-18123.

[12] Rathore, N., & Panwar, N. L. (2022). Strategic overview of management of future solar photovoltaic panel waste generation in the Indian context. Waste Management & Research, 40(5), 504-518.

[13] Dias, P., Schmidt, L., Gomes, L. B., Bettanin, A., Veit, H., & Bernardes, A. M. (2018). Recycling waste crystalline silicon photovoltaic modules by electrostatic separation. Journal of Sustainable Metallurgy, 4, 176-186.