Review Paper on Solar e waste recycling

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Abstract

The main objective of this review paper is to deal with found the solar e waste recycling system in current way of traditional landfill practices. Currently PV wastes are ends up with land filling technology. There are various environmental concern due to heavy metal i.e. lead and tin present with solar e waste. To find out the solar e waste, its impact on environment and efficient method of management of solar e waste through various recycling technologies. There are valuable metals like silver and copper also present, which represents optimistic opportunity to recover the same which have intrinsic commercial value. Hence, various methods for recycling of solar e waste are being reviewed here to reduce the environmental impact of end-of-life modules and to recover some of the value from solar e waste. Main objective is to provide the basis for the identification of the recycling solutions that can effectively sustain the increase of the PV market.

Keywords: Solar e waste, environment impacts, recycling method.

I. Introduction

Solar power generation technology give biggest force in current energy requirement on eco friendly basis. It shows biggest market for energy on renewable energy sources. But the solar e waste becomes major concern with end of life of solar modules i.e. 25 – 30 years. Whereas the Indian government is enforced the ambitious solar power programme for country India. The rapid increase of solar energy generation technology gives impact on environment and shows attention on waste create by it and its recycling method instead of traditional land filling option.

Over the past decades, the economic sustainability of photovoltaics has been the subject of numerous studies. Major issue addressed in this context has been the efficient recycling method of solar e waste. In this article, we present a review of the processes proposed over the past two decades to recycle PV panels is presented. In addition to the analysis of the research studies published in scientific articles, a detailed analysis of the patented recycling processes is presented. In order to identify the requirements that recycling processes must satisfy (material recovery rates, types of panels that should be treated) the current legislation regulating the management of PV panels and the evolution of the PV market over the past two decades are preliminarily analysed. Proposed recycling processes are finally compared in terms of their economic sustainability and environmental impact.

The solar photovoltaic (PV) panels waste volume in India is estimated to grow to 200,000 tonnes by 2030 and around 1.8 million tonnes by 2050 as per report by renewable energy consulting firm Bridge to India. India's current solar power target is 100,000 megawatts (100 gigawatts) by 2022, raised from 20,000 MW in June 2015. India has advanced towards this target with the installed solar power capacity 28,180.71 MW in March 2019.

Introduction to Photovoltaic Panel Composition:

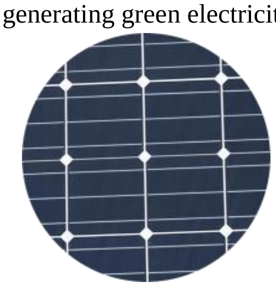
Photovoltaic cells (or solar cells) are devices converting the light energy from any source into electrical energy. In the photovoltaic panel, organic and inorganic components are combined. Through the sketch presented in Fig. 1, the different components of a photovoltaic panel can be recognized. Starting from the bottom, we find the plastic backing (or back-sheet), which is the white surface characteristic of photovoltaic modules, composed by Tedlar (polyvinyl fluoride) and polyethylene terephthalate. Going up we find two sheets of ethylene vinyl acetate (EVA) incorporating the semiconductor, which can vary depending on the type of panel. Finally, a glass layer is found placed on top. All these layers are sandwiched within an aluminium frame to which the junction box is connected. In some cases, an antireflective is added over the glass surface.

Solar Module Parts	Material used
Frame	Aluminium
Module Cover	Glass, Silicon
Solar Cell	Cadmium, tellurium, indium, gallium and Selenium compounds
Solar Cell Coating	Silver, copper, lead, gallium/boron/phosphorous, aluminium
Cell and Module Interconnections	Lead, Copper Tin
Back sheet, Encapsulates	Polymer

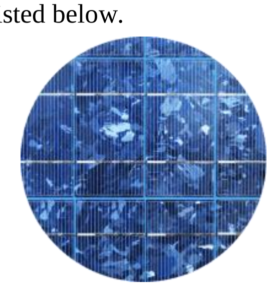
Fig. General structure of a photovoltaic panel.

- **Types of Solar Panels:**

There are different types of solar panels that are used for generating green electricity as listed below.



Monocrystalline Solar Panels



Poly-SI

Thin-Film Solar Cells

Concentrated PV Cell

❖ Discussion on recycling technologies

Photovoltaic systems are becoming increasingly affordable for producing electricity. The total installed capacity of PV systems is estimated around 222GW at the end of 2015. Crystalline-silicon PV technology dominates the market with 85–90% of the share because of its low cost and high efficiency. Off-grid PV systems can be used for both domestic and low energy non-domestic purpose. Globally around 6 million homes were electrified with off grid PV systems till 2015.

Many photovoltaic systems are at their end phase of life cycle and a lot of e-waste will be generated in the coming years. The average lifetime of crystalline silicon photovoltaic module is about 25–30 years. The global cumulative PV panel waste is expected to reach 60 million tons by the end of 2050.

Three different process approaches to PV panel recycling are distinguished and detailed in the remainder of the section: physical treatment and EVA dissolution with organic solvents, thermal treatment, and chemical processes.

▪ Physical Treatment:

In this study the physical treatment are including crushing, Attrition etc. In solar panel recycling the physical process are also known as primary treatment. The solar penal are made by different types of material which are reusable directly So that in physical treatment the dismantling the solar penal and the separate the materials like reusable and recyclable. After dismantling the solar penal the separated recovered materials like solar cells, Plastic, Glass, PCBs are goes to recycling process.

For this process, trial run was taken at one of Gujarat first E waste recycling plant, E coli Waste Management Pvt. Ltd. located at Plot no. 98/99/100, Sabar Industrial Park, Village: Asal, Tal:Bhiloda, Dist:Sabarkantha. The machinery required for dismantling of Solar Penal are magnetic separator, Crusher, Shredder, etc. Results are shown along with results discussion section later on.

▪ Chemical Treatment:

Chemical processes are mainly aimed at the recovery of the module metal fraction. These processes require, as compared to physical treatments, larger costs, becoming economically feasible only if high value metals can be recovered. For example, the treatment for thin film modules is made cost-efficient by the value of the recovered rare elements. Development of chemical processes to recover Ag, Al and the Si wafer in Si type panels.

The process includes the application of HNO_3 to extract Ag, KOH to remove Al metal coatings, and the successive combined application of HNO_3, HF, ethanoic acid and Br to remove the anti reflective layer. Fabricated Pb-free panels by using the wafers recovered from Si-panels.

The Si wafer was immersed into HNO_3 and then KOH solutions to extract Ag and Al, respectively. The anti reflective layer was removed by the application of an etching paste containing H_3PO_4 and by heating.

Leaching of the finer fraction was then performed with 64% nitric acid and subsequent addition of NaCl, allowing obtaining an AgCl precipitate. This process made it possible to concentrate 94% of the silver contained in the modules.

To this purpose, the possibility to recover rare and precious metals can make the chemical treatments cost-efficient,especially if thin film technologies are concerned. Recycling processes targeting the recovery of Ag from Si crystalline panels can also be veryinteresting. The economic feasibility of this route is largely influenced by the year of manufacture of the processed panels, which significantly influence the Ag content.

▪ Thermal treatment:

An effective thermal treatment is represented by delamination. This uses high temperatures to modify the characteristics of the solar modules and decompose EVA, which allows for the subsequent mechanical separation of clean glass and silicon solar cells (Doni and Dughiero, 2012).

An alternative thermal treatment was proposed by Frisson et al. Where the whole panel is introduced in a conveyer belt furnace and EVA is decomposed under nitrogen atmosphere at temperatures around 450 °C. The solar cells recovered by the process lose their efficiency after the treatment and it is necessary to perform a cleaning step before their reutilization. Wang et al. (2012) used a thermal treatment to recycle the materials from silicon based solar modules.

Two heating steps were performed: a first step at 330 °C to separate Tedlar from the module, and second step at 400 °C to burn the EVA and thus recover the glass plate, the cell chips and the ribbons. Doni and Dughiero (2012) proposed an electro-thermal process that heats the core of Si panel samples at temperatures lower than the decomposition temperature of EVA, which allows easily removing the glass fragments. The latter fragments can be directly supplied to glass recycling facilities, whereas the inner part of the samples can be further treated for Si recovery.

Thermal treatments are very effective in removing EVA, which allow recycling up to 90% of PV module components. However, thermal processes are characterized by high energy consumption, which makes questionable the achievement of the economic and environmental sustainability (Tao and Yu, 2015; Xu et al., 2018). A possible approach to enhance the economic and environmental sustainability of processes relying on the thermal degradation of the polymeric PV panel fraction would be the energy recovery by combustion of thermal degradation products. Remarkably, this process route has been almost ignored by previous studies analysing the sustainability of PV panel recycling processes. Marwede et al. (2013), for example, conclude that PV panel pyrolysis is a highly energy demanding process and imposes the recourse to expensive gas treatment technologies.

This is confirmed not only by the available scientific literature but also by the analysis of commercial processes. In the Deutsche Solar process, for example, pyrolysis is performed but the produced gases are condensed and no energy recovery is foreseen (Müller et al., 2005). Only one article on PV panel recycling could be found considering energy recovery by combustion of the pyrolysis products (Frisson et al., 2000). The scarce attention paid to the latter energy recovery strategy may be explained by the formation of fluorine gas during thermal treatment from the back-sheet, which introduces severe technological difficulties to design and operate the post-combustion section. In this sense, processes that consume low energy, for instance, during the heat recovery step are required (IEA, 2018).

- **Combined physical and chemical treatment:**

Several studies have investigated the optimization of the PV panels recycling by combination of different types of treatments.

The different types of photovoltaic panels by a process route including two main steps: a physical treatment (crushing and hammering) and a chemical treatment. According to the trial run, three different fractions were obtained by crushing: an intermediate fraction directly recovered as glass, a coarse fraction mainly composed of Si cells fragments and glass particles glued to EVA, and a finer fraction composed of a glass powder and metals.

Coarse fraction get glass and other components while 3 h chemical treatment of the finer fraction with H2SO4 and H2O2 at 60 °C allowed dissolving metals and thus obtain an additional recoverable glass fraction. The overall process allowed recovering 91% of the treated panels.

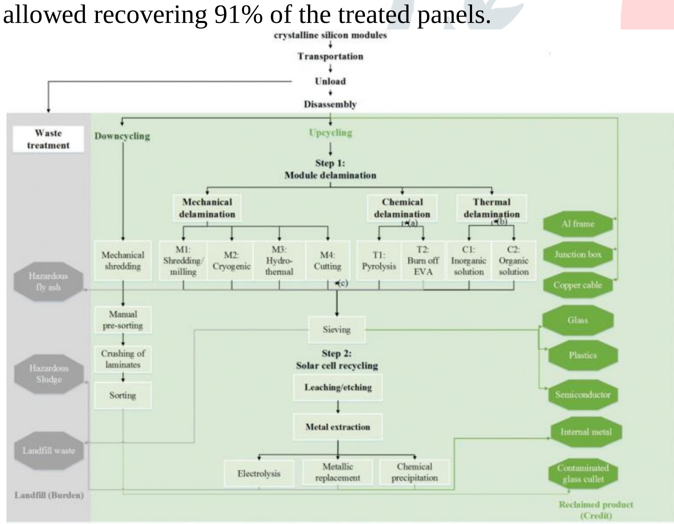


Figure: Feasible Pathway to recycle silicon PV Modules.

- Various other method for recycling of solar e waste are illustrated in Table 1 and 2 as per shown below.

Table 1

Literature

Recycling processes specified by type of treatment and panel treated and expected obtained products.

Treatment	Panel type	Authors	Year	Products
Physical	Si	Doi et al.	2001	Si cell
		Kim and Lee	2012	Si cell
	Thin film	Berger et al.	2010	Glass and enriched In and Te products for new modules
	All types	Granata et al.	2014	Glass, Al frame and fine fraction (to be chemically treated)
Thermal	Si	Frisson et al.	2000	Si cell
		Doni and Dughiero	2012	Glass and Si cell
		Wang et al.	2012	Glass, cell chips and ribbons (to be chemically treated)
Chemical	Si	Klugmann-Radziemska and Ostrowski	2010	Si cell
		Palitzsch and Loser	2011	Silver and poly-aluminum-hydroxide-chloride
		Kuroiwa et al.	2014	Germanium solution
		Yi et al.	2014	Si 99.98% pure
		Dias et al.	2016	AgCl (94%)

		Jung et al.	2016	Glass, Al frame, AgCl (90%), Cu (79%), $Pb(OH)_2$ (93%)
		Shin et al.	2017	Si cell
	CdTe	Fthenakis and Wang	2006	Cd (99.99%), Te
	CIGS	SENSE	2008	Na_2SO_3, gallium oxide and In and Mo precipitate mixture
		Gustafsson et al.	2014	Selenium oxide (99.99% pure)
		Gustafsson et al.	2015	Ga (97%), In (93%)

Table 2			
Patented			
Recycling processes specified by title, year of publication and expected obtained products, according to the PV technology.			
Panel type	Treatment	Patent name	Products
Si	Thermal	Recycling silicon photovoltaic modules	Glass, lead and solar cell
CdTe	Chemical	Recycling of CdTe photovoltaic waste	Glass, CdO and TeO or Te metallic
		Reclaiming metallic material from an article comprising a non-	Glass, $CdCO_3$ and elemental Te
		metallic friable substrate	
		System and method for separating tellurium from cadmium waste	Glass, metallic Cd or $CdSO_4$
		System and process for recovery of cadmium telluride (CdTe)	CdTe
		Recovery processing method of cadmium telluride thin-film solar	Solid mixture containing Cd and Te
CIS/CIGS	Chemical	Recycling of CIS photovoltaic waste	Glass, metallic Cd, CuO, SeO and ZnO/InO mixture
		Method for recovery of copper, indium, gallium and selenium	Elemental Se, metallic Cu and metallic In
Generic	Thermal	Recycling insulating and/or laminated glass panels	Glass and remaining metal parts
		Method for separating the components of a laminated glazing	Solar module component s separated
	Combined	Film removal	Reusable substrate layer
		Process for treating spent photovoltaic panels	Aluminium frame, glass, metallic Te or TeO and Fe,
			Cd and Al precipitate separately

- **Conclusion:**

The rapid increase in the photovoltaic power installed worldwide will cause over the next few decades a dramatic increase in the volume of end-of-life photovoltaic panels. In accordance with the analysis presented in this article, peaks for dismissal of PV panels are expected to occur around the years 2036 and 2045. The improper disposal of these waste fluxes could cause harmful effects to human health and to economy of the manufacture sector by the dispersion of toxic elements and loss of valuable material resources including rare metals, respectively.

Numerous recycling routes have proposed by scientific articles including mechanical, thermal and chemical treatments. Mechanical processes have the advantage of being inexpensive, but they cannot attain the recovery of high value materials, which requires more elaborate treatments. In addition, these processes will be insufficient due to the need to treat and/or dispose toxic elements, which will be required by the future legislation. Proposed thermal processes typically rely on the pyrolysis of plastic panel fraction and it is generally agreed that they are characterized by high energy consumption. Remarkably, only one article could be found considering the possibility to recover energy by the combustion of pyrolysis products. The scarce attention to energy recovery can be explained by the technological difficulties that would be imposed by the treatment of the generated gaseous emissions. Thermal processes are very interesting because they do not generate further waste but produce toxic gas emissions, like fluorine gas. Investigating this issue is therefore deemed fundamental to attain the environmental and economic sustainability of thermal recycling processes. Chemical processes are mainly aimed at the recovery of the module metal fraction and use solvents and other reagents. These processes require larger costs but the purity of the final output materials, especially high value metals, are higher than those obtained from mechanical processes.

Major issue to be investigated is therefore the development of processes allowing for the regeneration of the employed reactants, which could considerably reduce the environmental impact and the processing costs. It is worth remarking that, even considering the negative aspects generated by the recycling of photovoltaic panels, like the expenditure reagents and gas emissions, such processes are still convenient and can be remedied with gas emission filters, reuse of reagents and wastewater treatment.

The energy expenditure in a recycling process is less than that spent in the manufacture of a new panel. Thus, the research on PVP recovery techniques is in constant development, emphasizing that an ideal process is one that results in the treatment of all typologies, since other technologies tend to emerge and share the market with Si technology.

The production of the content of these renewable energy resources consumes a huge amount of energy and emits carbon and GHGs, which have been underestimated while selecting and using. In order to reduce environmental effects of production processes, raw material saving and waste minimization are important factors. This is why recycling PV modules is highly effective to prevent the adverse environmental effects that are coming from raw material production steps. For 1 kW PV module production, it is estimated to release 80,113 kg of CO_2 for subsidizing the raw material. However, compared with fossil-based coal burning systems, for the same amount of electricity power generation, the PV modules production phase emits 3.3% less. Only 65% of this PV module power is assumed to be recycled. As previously mentioned, the major part of the CO_2 emission of the panel production comes from raw materials. Hence, if these metals are regained and reused for panel productions or other applications, from the recycled PV modules. On the one hand, recycling the wastes of PV modules brings waste minimization and raw material saving, but on the other hand it is a great source of carbon release to the atmosphere and so decreases the countries carbon footprint. Today, this release can be observed at a country level, yet, in the years that recycling will be taking place, it is going to be much more important than today because of climate change and increasing levels of industries and population.

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