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Solar Panels Life After Death – An Overview on Solar Panel Recycling Methods and Imminent Business Opportunities

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Abstract**—** *The energy harvested from the sun is said to be clean form of energy. The world relies on the energy generated from solar energy to address the growing power demand and to address the climate change (Surender Rangaraju, 2021). Solar panels can have a maximum life of 20 to 25 years and beyond this the solar panels becomes waste and if not discarded properly it can release toxic substance that can be dangerous and pollute the environment. The solar panels must handle and recycled properly after their end of life in order to make the entire life cycle of generating clean energy meaningful. In this paper we will focus on the various approach for recycling solar panel and their effectiveness.*

I. INTRODUCTION

Solar panel recycling is still in its inception, but as the solar business expands, recycling methods will play an increasingly significant role. Solar panels have a 30-year life expectancy. With the growing number of solar panels supplied and installed globally each year, it'll only be a matter of time until large numbers of panels reach the end of their useful lives and must be discarded (Marsh, 2021). By 2030, it is projected that the global volume of solar module trash would have reached 8 million tonnes. With 400 gigawatts (GWdc) of photovoltaic (PV) modules deployed worldwide, end-of-life management is critical for all PV technologies to guarantee that clean energy solutions are a long-term part of the energy economy (Solar Energy industries Association, 2021).

A key challenge is using discarded solar modules into the circular economic paradigm. The presence of potentially dangerous elements, a high cost of recycling, and poor commodity prices are all obstacles. The Industrial Technology Research Institute (ITRI) created the "Easy-Dismantled PV Module" and redesigned the solar module with the help of the Ministry of Economic Affairs' Department of Industrial Technology (DoIT). In the upstream production end of the solar module value chain, ITRI introduced easy-to-dismantle materials and novel structural designs, enabling the complete dismantling of discarded solar panels and substantially boosting the value of solar module recycling (Industrial Technology Research Institute, 2021).

Fig. 1. Recuperation of ultra-pure silicon and other metals from solar panel's end of life Source: (ROSI – Return of Silicon, 2021)

According to Research and Markets, the market for solar panels and their recycled parts might increase at a rate of over 18 percent per year by 2027, reaching a value of over $100 million. According to the MIT Technology Review, with the volume of decommissioned cells reaching 80 million metric tons and the materials used in solar panels might be worth $2 billion per year by 2050 (Robare, 2021). However, because recycling is currently not a financially viable alternative, economic incentives are necessary to speed this shift. Given its significantly bigger proportion and ultra-high purity (99.9999 percent or six nines/6N), silicon gives the best possibility among the panel's valued constituents. Solar-grade silicon from PV waste may be recycled for use in solar panels or reprocessed as a value-added component in the anode of Lithium-ion batteries with in 3b generation.

If hazardous compounds found in solar panel's end-of-life condition are discharged into the environment, they can cause substantial pollution and health problems. To complete the energy cycle, the solar panel industry's next main objective is to safely dispose or salvage of end-of-life items. However, re-use or value-added recovery/re-purposing is preferred over recycling in the waste management hierarchy.

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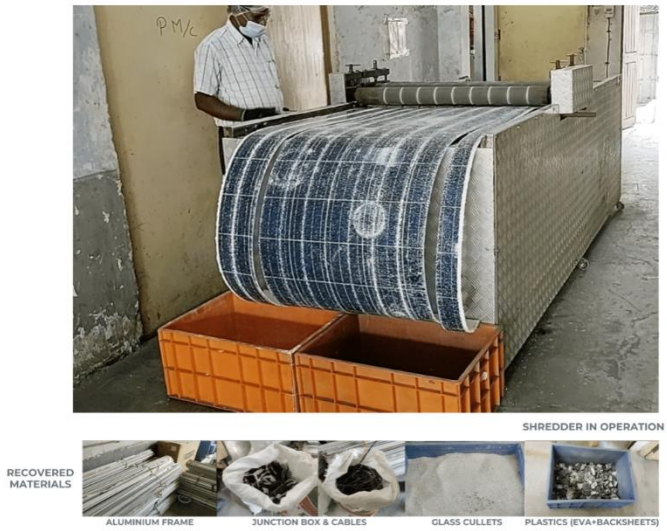

Fig. 2. At the SWAP Pilot facility in Gummudipoondi, Tamilnadu, the Waste PV cells are reprocessed (Gupta, 2020)

Glass (75%) accounts for the majority of the overall weight of a standard crystalline silicon PV module, followed by polymer -10%, aluminum - 8%, silicon - 5%, copper -1%, and minor quantities of silver, tin, lead, and other metals and components. Lead and tin, if leached into soil and groundwater, are hazardous to human health and the environment, but copper, silver, and silicon, if recovered properly, can be valuable. To avoid contamination and collect the valuable elements included in the panel, the disposal option should be completely replaced by recycling (Mahdokht Shaibani, 2020).

Fig. 3. Metals like copper, aluminum, silicon are extracted from silicon panels (Milbank, 2019)

II. Waste Disposal of Solar Panel

PV panel trash is still classified as normal garbage under regulatory guidelines. PV panels are classified as e-waste under the EU's Waste Electrical and Electronic Equipment (WEEE) Directive, which is the only exception. This regulation, in addition to other legislative frameworks, governs the handling of PV panel waste. In order to ensure that solar panels do not become a burden on the environment, solar cell producers are required by law to meet strict regulatory criteria and recycling norms. That's when solar panel recycling solutions began to emerge. Photovoltaic manufacturers teamed together with government agencies to devise a few strategies for dealing with solar waste (Vekony, 2021).

Solar waste is produced by cells that have reached the end of their useful life as well as cells that have been damaged in natural catastrophes. Several solar systems in Puerto Rico were devastated by Hurricane Maria in 2017, resulting in tonnes of garbage as panels were crushed by strong winds or flying debris, or uprooted from their housings and became debris itself. The Debris Materials such as glass and aluminium are used to make solar cells. They're simple to recycle. It may even be able to repurpose cells that have reached the end of their useful life. The remaining of the cell is made up of the photovoltaic materials, as well as the semiconductors and other components required to generate a meaningful electric current.

Fig. 4. solar panel facility in Humacao, eastern Puerto Rico was wrecked (BloombergNEF, 2017).

According to Waste Dive, recycling a solar panel presently costs $20-$30, but the reclaimed materials are only worth $3-$4, posing a significant roadblock to keeping them out of dumpsites. Some companies are emphasizing reuse, recovering usable panels and selling them to customers that can't afford new ones. One issue is that solar panels are often classified as hazardous trash by authorities, which increases the cost of recycling significantly. Another issue is that many solar panels are not constructed with recycling in mind, despite the fact that the European Union compels solar cell manufacturers to make solar cells that are 85 percent recyclable. Photovoltaic reusing has a lot of promise and can play a vital role in developing a renewable energy "ecosphere." Businesses should not miss out on this chance (Robare, 2021).

III. Process Involved in Solar Panel Recycling

Glass, plastic, and aluminium are the primary components of silicon solar modules, all of which are widely recycled. Despite the modules' recyclability, the material separation process is time-consuming and needs sophisticated technology. The following are the key steps in effectively recycling a silicon module:

1. Taking off the aluminium frame which is 100 percent reusable.
2. Using a conveyor belt to separate the glass which is 95 percent reusable.
3. At 500 degrees Celsius, thermal processing takes place. This permits little plastic components to evaporate and the

cells to be separated more easily. Silicon wafers are etched away and melted into reusable slabs which is 85 percent reusable (Cedgreentech, 2021).

3.a Mechanical Recycling Technique

For entire solar modules, the mechanical recycling process is utilized. Mechanical and hydrometallurgical processing are the most common types of recycling. PV modules are pulverized in a crusher before being shredded into desirable bits of 4 to 5 mm in size. In this method, the PV module's lamination is harmed. Because of the milling cutter's size, the glass is separated from bigger parts of the laminate film. In the vibrating network, the remaining pieces of the laminate sheet are separated from the glass particles. After that, the separated glass is cleaned.

3.b Thermal Recycling Technique

The Solar panel was placed in a vessel and heated to above 420 degrees Celsius. The temperature rises at a rate of almost 20 degrees Celsius every minute. The photovoltaic module is heated for 25 minutes in the furnace. The plastic materials evaporates, separating the PV cells from the glass. Although the recycling process is energy intensive, up to 85% of recovered cells may be reused, reducing the manufacturing energy consumption of new PV modules by up to 70%. Because of its simplicity and great efficiency, this process may be utilized for commercial PV module recycling with better outcomes than the chemical method. The generation of emission gases during thermal evaporation of the EVA copolymer is a drawback of thermal recycling.

3.c Chemical Recycling Technique

Monocrystalline solar cells are generally selected for chemical recycling. The components of the broken PV cells might be removed using chemical methods. Unfortunately, the chemical method's efficiency was insufficient. The reason for this was the etchant's comparatively long action period and the expensive value of the solvents. One solar cell takes over twenty minutes of chemical treatment. This approach is not appropriate for large-scale commercial use. The most difficult part was determining the proper etching solution composition, concentration, and procedure temperature (Dávid Strachala, 2017).

IV. Approaches to PV Waste Management on a Global Level

US Market forecasts for PV panels and recycling

In the United States, large-scale PV installations has only developed in the last ten years. As a result, end-of-life PV waste quantities in the United States are predicted to remain modest at 6,500-24,000 tons by the end of 2016. Cumulative waste is expected to reach between 170,000 and 1 million tons in 2030, then more than double to 7.5-10 million tons in 2050. In the United States, there are no photo - voltaic waste laws or regulations governing the collection and recycling of end-of-life PV panels. Several PV industry players have offered to collect and recycle end-of-life PV panels on a provisional basis. For example, commercial-scale recycling facility in Ohio with a daily capacity of 30 tons. A corporate social responsibility committee of the US Solar Energy Industries Association monitors progress in PV recycling.

CHINA Market forecasts for PV panels and recycling

China installed 15 GW of PV in 2015, exceeding its 10-GW yearly growth target for the second year in a row and maintaining its position as the world's largest PV market. The National Energy Administration released its 13th Solar Energy National Plan 2016-2020 in December 2015.By 2020, the key short-term objectives outlined are 150 GW of cumulative PV installation. There will be 70 GW of distributed PV and 80 GW of large-scale ground-mounted PV in this project panel waste streams are expected to be 8,000-100,000 tons in 2020, according to this analysis. By 2030, this is expected to rise to between 200,000 and 1.5 million tons, then to 13.5-19.9 million tons by 2050.

China's National High-tech R&D Programme PV Recycling and Safety Disposal Research funded research on PV recycling technologies, concentrating on two recycling processes for c-Si PV. Physical or thermal recycling is used in these procedures. Crushing, cryogenic grinding, and separation are among the procedures used in the physical approach to produce aluminium, glass material, copper, ethylene-vinyl-acetate and back sheet particles, as well as a silicon powder combination. The recycling rate is around 90% by mass, however due to its poor purity, silicon cannot be recycled for use in the PV sector. The clean cell detritus in the thermal approach passes through a thermal procedure before being employed in chemical studies to recycle silicon, silver, and aluminium.

JAPAN Market forecasts for PV panels and recycling

Japan has been a pioneer in the field of photovoltaics, providing significant R&D for decades and housing some of the world's major producers. By 2016, total waste might be between 7,000 and 35,000 tons, growing to between 200,000 and 1 million tons by 2030. According to the scenarios included in this analysis, it might reach 6.5-7.6 million tonnes by 2050. Because there are no special plans in place in Japan for dealing with end-of-life PV panels, they are likely to be treated similarly to other industrial wastes.

PV panels will be removed from buildings or installation locations and transferred to waste treatment centers. PV panel components will be separated as much as possible there, with precious materials being collected and repurposed. Recoverable metals, for example, will be shipped to refineries and recycled as secondary metals. Glass cullet is made from glass that can be separated while retaining a high level of purity. Materials that are difficult to separate, reclaim, or recycle will be disposed of in landfills.

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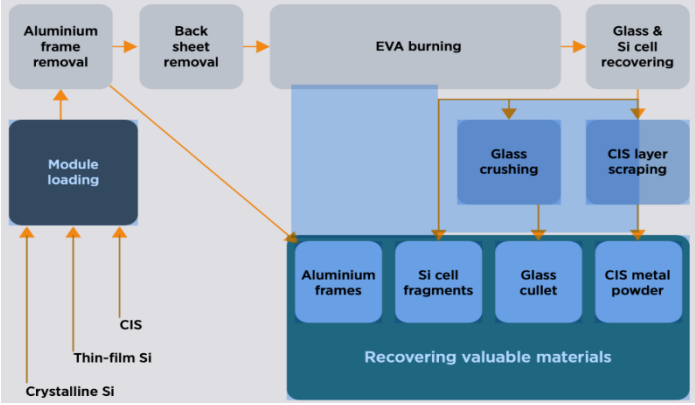

Fig. 5. PV panel recycling technology developed by the Foundation for Advancement of International Science (FAIS) (IRENA: Stephanie Weckend IEA-PVPS: Andreas Wade, 2016).

GERMANY Market forecasts for PV panels and recycling

Germany's end-of-life PV panel waste levels are estimated to range from 3,500 to 70,000 tons by 2016. This is mostly owing to the amount of PV capacity it has already installed. Depending on the situation chosen, the figure fluctuates. The regular-loss and early-loss scenarios predict 400,000 t to 1 million t and 4.3-4.4 million tons in 2030 and 2050, respectively.

The producer must now determine the Level 1 obligation. For example, run its own collection and recycling system. In either case, the costs of collecting and recycling all B2C-business to consumer waste in a specific product category are shared among all registered market participants in proportion to the volume collected. This ensures that historic waste (or orphan waste in the case of products produced by now-defunct manufacturers) is collected and treated. Those volumes will be deducted from the remaining fraction if a producer can show that it collected and recycled its share on its own.

Germany has also designated PV panels as a separate collection category, ensuring that waste panels are collected and treated separately at municipal collection locations. For B2C items currently on the market, each manufacturer must additionally verify that adequate Level 2 funding is available. If the joint Level 1 system continues to function, this will happen spontaneously. Last-man-standing insurance, on the other hand, must provide funding if all manufacturers of a certain product category go out of business. All Level 1 participants pay a yearly fee for insurance that ensures costs are met in the event that all market participants go out of business. This premium is usually negligible since the chances of all market participants vanishing are extremely unlikely (IRENA: Stephanie Weckend IEA-PVPS: Andreas Wade, 2016).

V. Demand for Rise in Solar Panel Recyclying Market

In 2018, First Solar began offering a commercially viable recycling option for photovoltaic (PV) power plants and modules. This would allow owners to satisfy their module EOL obligations in a cost-effective and responsible manner. Power plant operators may maximize their return on capital and total financial returns by taking advantage of a competitive and flexible recycling service.

Total worldwide energy consumption is anticipated to rise by 28% from 575 quadrillion British Thermal Units (BTUs) in 2015 to 736 quadrillion BTUs in 2040, according to the International Energy Outlook 2017. As a result, throughout the projected period, rising worldwide power consumption is likely to generate new possibilities for the global solar panel recycling market. Because of the increased attention on the impact of climate change and the long-term viability of fossil fuels, demand for renewable energy has been rising in the worldwide power generating mix. In comparison to 2000, the percentage of renewable energy sources (including hydropower) in the worldwide power generating mix increased by 26% in 2018.

The need for energy is increasing as the world's population grows, the industrial sector expands, and infrastructure construction activities increase. Energy demand has been rising as countries' economies have developed and their living standards have improved. Due to the introduction of rigorous government laws regulating greenhouse gas emissions, businesses are focusing on creating low-cost renewable energy generation methods. Companies will be able to invest in the building-integrated photovoltaic (BIPV) business in the near future due to rapid growth in the construction sector (Transparency market research, 2020).

VI. The Recycling of Solar Panel – A Multibillion Dollar Industry

According to recent research, the total annual recycled product value of crystalline silicon solar panels would reach $12 billion by 2035.The business opportunities opened as crystalline solar panels are made up mostly of aluminium, glass, and silicon, and over 90% of the weight of a panel may be recycled into further modules or other items. PV Cycle report said that its Collective Scheme and Individual System have gathered over 2,900 tonnes of end-of-life modules. PV Cycle presently includes more than 200 solar panel manufacturers, including Suntech, REC, AUO, and Hanwha Solar One.

The value per watt of a recycled PV module will reach $0.58 by 2025, rising to $1.21 per watt in 2035, according to the paper "Solar Module Recycling - A Necessary Step to Maximize Environmental Benefits of Solar PV Industry." According to Global Data, the increasing recycled mass of solar panel glass and aluminium, as well as predicted market price fluctuations of crystalline modules, would be important contributors driving up recycled product value. The overall recycled product value of crystalline modules is predicted to rise from $122 million in 2025 to $12 billion by 2035, according to Global Data. Solar panel recycling appears to be a successful business. According to a recent estimate from Global Data, the quantity of trash generated by end-of-life crystalline modules is predicted to reach 19,475 tonnes by 2025, rising to 1,098,282 tonnes by 2035.

PV recycling will become an emerging sector in the next 15 years as a result of this tremendous development (Energy matters, 2012).

VII. Conclusion

As the coal crisis increasing, the energy demand increases and the government from various countries took an initiative to reduce the emission of greenhouse effect and to satisfy the needs all over the world which paved a way for installation of many solar panels with storage technology provide green energy. However these panels are need to be prolong but life expectancy is about 30 years with a 20% reduction in power capacity may occur during the life of solar panels. The highest decline in efficiency during the first 10 and 12 years is 10%, and when you reach 25 years, it is 20% (Vekony, 2021).Regardless of the decreasing in efficiency of these panels become a PV waste and since it contains metals like Lead and Tin which is hazardous to the human health and affect the ecosystem. It is necessary to recycle the solar panels and extract the raw materials like silicon, aluminium, copper, polymer etc. The reusage of these solar panel provide a huge opportunity in recycle market and expected to have a higher demand on further year.

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