

SOLAR PANELS RECYCLING

Reduce-Reuse-Recycle Waste
from Solar PV Panels

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Abstract

The rapid adoption of solar energy has led to an increase in solar panel installations worldwide, raising concerns about their end-of-life disposal and environmental impact. Solar panels, primarily composed of glass (76%), aluminium (8%), silicon (5%), plastic (10%) and various metals (1%), have a lifespan of 25 to 30 years. The International Renewable Energy Agency estimated there to be about 78 million metric tons of waste in the world by 2050. By 2030, it is estimated that the world will have accumulated about 8 million metric tons of PV panel waste.

As more panels reach the end of their operational life, recycling becomes essential to manage waste and recover valuable materials. Recycling techniques like thermal, mechanical, and chemical processes are employed to recover high-purity silicon, silver, copper, and other metals. Recycling not only reduces the environmental burden but also provides a sustainable supply of raw materials, contributing to the circular economy.

Recycling of solar panels currently stands only at about 10%, with the remaining 90% ending up in landfills. As of 2022, the installed capacity of solar panels globally was 100 GW. Projections indicate total installations to grow to about 1600 GW by 2030. In the coming years, as a significant portion of these panels reach the end of their lifecycle, a substantial opportunity will be presented to manufactures and businesses to explore recycling and reuse options.

In this study, we explore the current percentage of solar panels installations around the world, different recycling methods, probable value generation after recycling and how organizations benefit by working on different factors like adoption and innovation in recycling methods, modern designs for solar Photovoltaic (PV) panels, initiation of new industrial growth, employment and promote sustainable practices.



Fig 1

Introduction

Solar panels with System of Photovoltaic (PV) modules include several hazardous materials, with the amount and type of chemicals used depending on the type of cells used in the modules. Once PV modules reached the end of their operational life, they are classified as waste. If disposed improperly in landfills without sufficient treatment, they can pose significant environmental and human health risks. This could occur through the release of hazardous metals, such as lead and cadmium or through the loss of conventional resources such as glass, aluminium, and rare metals.

The development of PV-specific collection and recycling regulations, including recycling and treatment standards for PV modules, will help to consistently, efficiently, and sustainably, deal with increasing waste volumes. Recycling of solar panels will help reduce the adverse environmental impacts by avoiding landfills, reducing electronic waste, creating energy saving options and economic opportunities while manufacturing new panels.

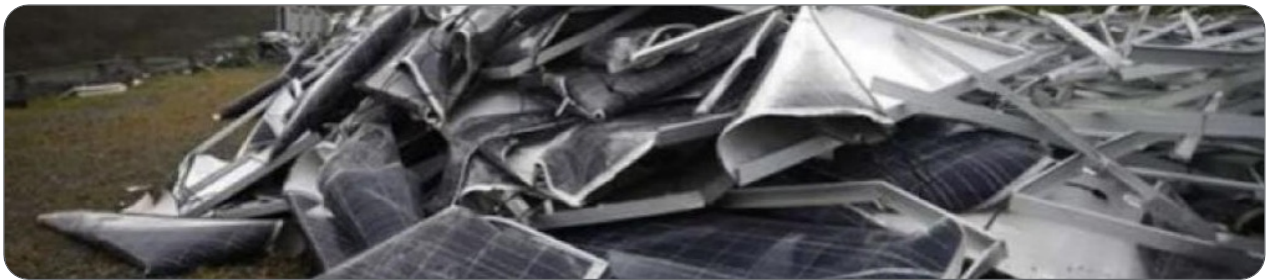


Fig 2

Source: <https://www.cleanfuture.co.in/2020/04/03/panel-recycling-for-99-recovery/>

Background

A photovoltaic system consists of one or more solar panels, a power inverter that converts DC electricity to alternating current (AC) electricity, and sometimes other components such as controllers, meters, and trackers. A photovoltaic system can be used to provide electricity for off-grid applications, such as remote homes or cabins, or to feed electricity into the grid and earn credits or payments from the utility company.

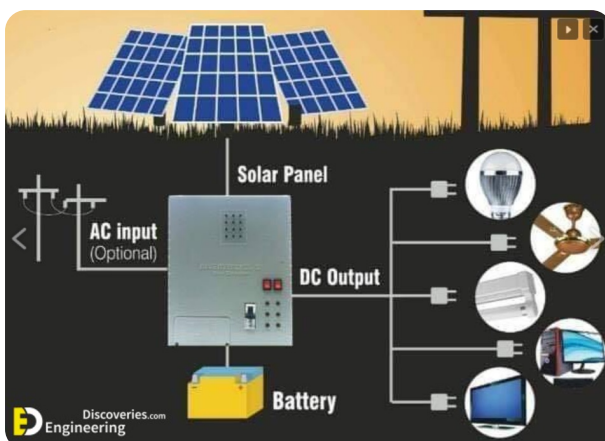


Fig 3- Generation of Solar Energy

Source: <https://engineeringdiscoveries.com/solar-power-plant-main-components-working-advantages-and-disadvantages/>

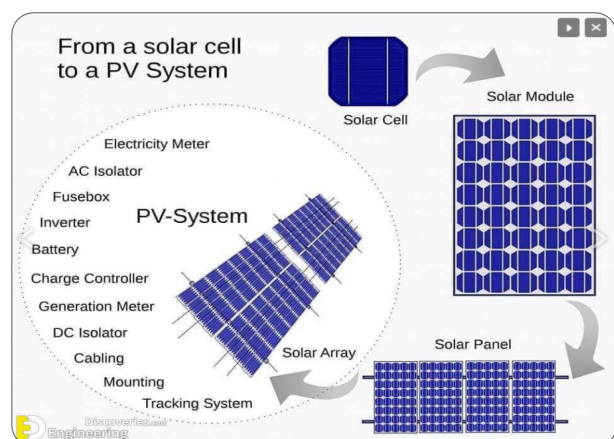


Fig 4- Solar Cells to PV System

Solar Cell/Panels Details

Generally, one solar cell size ranges from 0.5 inches to 4.0 inches, which generates a power output of 1 to 2 watts. Power generation capacity of solar panels such as small solar panels ranges between 50W to 100W; with standard solar panels generating between 200W-500W and, big solar panel systems having multiple panels connected to form a PV system generating about 1KW to 10KW of power.

Power generated by solar panels depends on the type of panel used and the sun's position in the sky. On an average, 300W to 400W solar panels can generate 0.9KWH to 1.8KWH assuming 4 to 6 hours of the sun's location.

Generally, a residence with 4 to 5 members should install a 2KW to 3KW grid connected solar system to meet their power requirements with surplus power being supplied back to the grid so as to reduce the load and receive credits in monthly consumption.

Solar PV Panel Types

Silicon Solar Panels (Mono & Poly Crystalline)

Crystalline-silicon solar panels contain solar cells made from a crystal silicon structure. These solar panels typically contain smaller amounts of valuable metals embedded within the panel, including silver and copper. Crystalline-silicon solar panels are efficient, cost effective, and have prolonged lifetimes, with modules expected to last for 25 years or longer.



Fig 5- Monocrystalline PV Solar Cell Panels



Fig 6- Rows Array Polycrystalline Silicon Solar Panels

Monocrystalline Solar Panels



A monocrystalline solar panel is made from monocrystalline solar cells or "wafers." Monocrystalline wafers are made from a single silicon crystal formed into a cylindrical silicon ingot. These panels are considered a premium solar product due to higher efficiencies and sleeker aesthetics.

Polycrystalline Solar Panels



Polycrystalline solar panels, also known as multi-crystalline panels, are a common type of solar panel used in residential and commercial settings. They are made up of multiple silicon crystal fragments. This manufacturing distinction gives polycrystalline panels a unique appearance that resembles a mosaic of different shades of blue.

Thin Film Solar Panels

Thin-film solar cells contain thin layers of semiconductor material, such as cadmium telluride (CdTe) or copper indium gallium di selenide (CIGS), layered on a supporting material such as glass, plastic, or metal. CdTe is the second-most common PV material after silicon, and cells can be made using low-cost manufacturing processes, but their efficiencies are not as high as silicon solar PV.

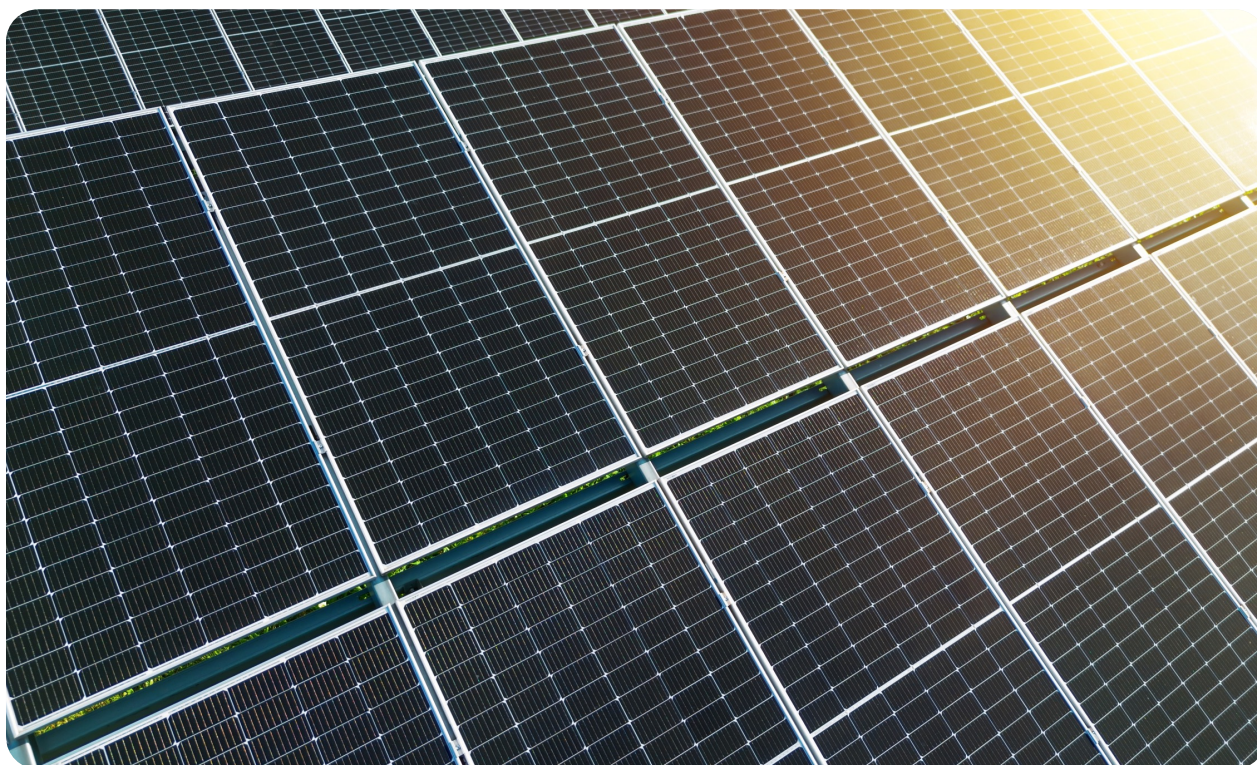


Fig 7- Thin-film solar batteries

Contents of Solar PV Panels

Solar Cells

These are semiconductor devices that convert sunlight into direct current electricity when photons from sunlight knock electrons free from atoms in the semiconductor material.



Junction Box

The junction box contains electrical connections and is mounted on the back side of the solar panels. It serves as the connection point for wiring that carries the generated electricity from the solar panels to an external system.



Encapsulant & Back Sheet

The protective material used to encapsulate the solar cells to protect from moisture and mechanical damage.



Connector Cables

Connector cables are used to link the solar panels to an electrical system.



Front Glass

A tempered glass covering that protects the solar cells and allows sunlight to pass through them. Its designed as durable and transparent to maximize the amount of sunlight reaching the solar cells.



Frame Sealant

A sealant is applied around the edges of the solar panel frame to provide weatherproofing and prevent moisture ingress, maintaining the panel's integrity over its operational lifetime.



Frame

The aluminium frame provides structural support for the solar panels and helps to protect from mechanical stresses.

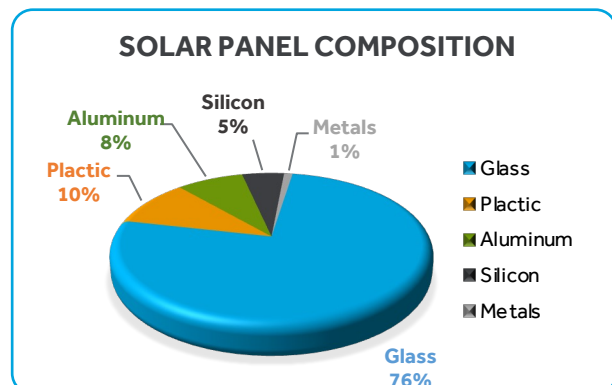
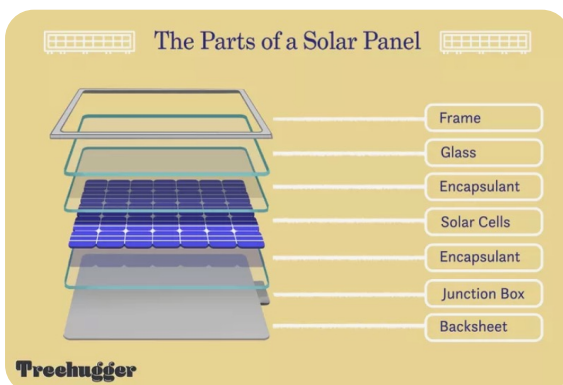


Fig 8 & 9- What Are Solar Panels Made Of? The Parts of a Solar Panel

Source: <https://www.treehugger.com/what-are-solar-panels-made-of-5179704>

Life Cycle Details of PV Panels

Solar panels naturally experience a decline in efficiency due to exposure to sunlight, temperature fluctuations, humidity, mechanical stress, the quality of manufacturing and materials used. Other factors such as dirt, debris, foreign objects, cracks etc can also decrease the efficiency of solar panels. On an average, most solar panels have a yearly degradation rate of about 0.5% to 0.8%.

EOL solar panels are considered rich waste because they have valuable metals, e.g., silver, aluminium, copper, tin, and silicon. The recovery of such valuable metals or materials has positive impacts on both environmental and economic viewpoints. Further, this contributes to energy saving, the availability of valuable materials and actively addresses the issue of electronic waste management.

Solar PV Panels Installations

As of 2022, the total energy generated from solar PV installations was more than 1000 GW worldwide. Countries like China, the USA, Australia, India, Germany, and the UK play a significant role in solar energy generation.

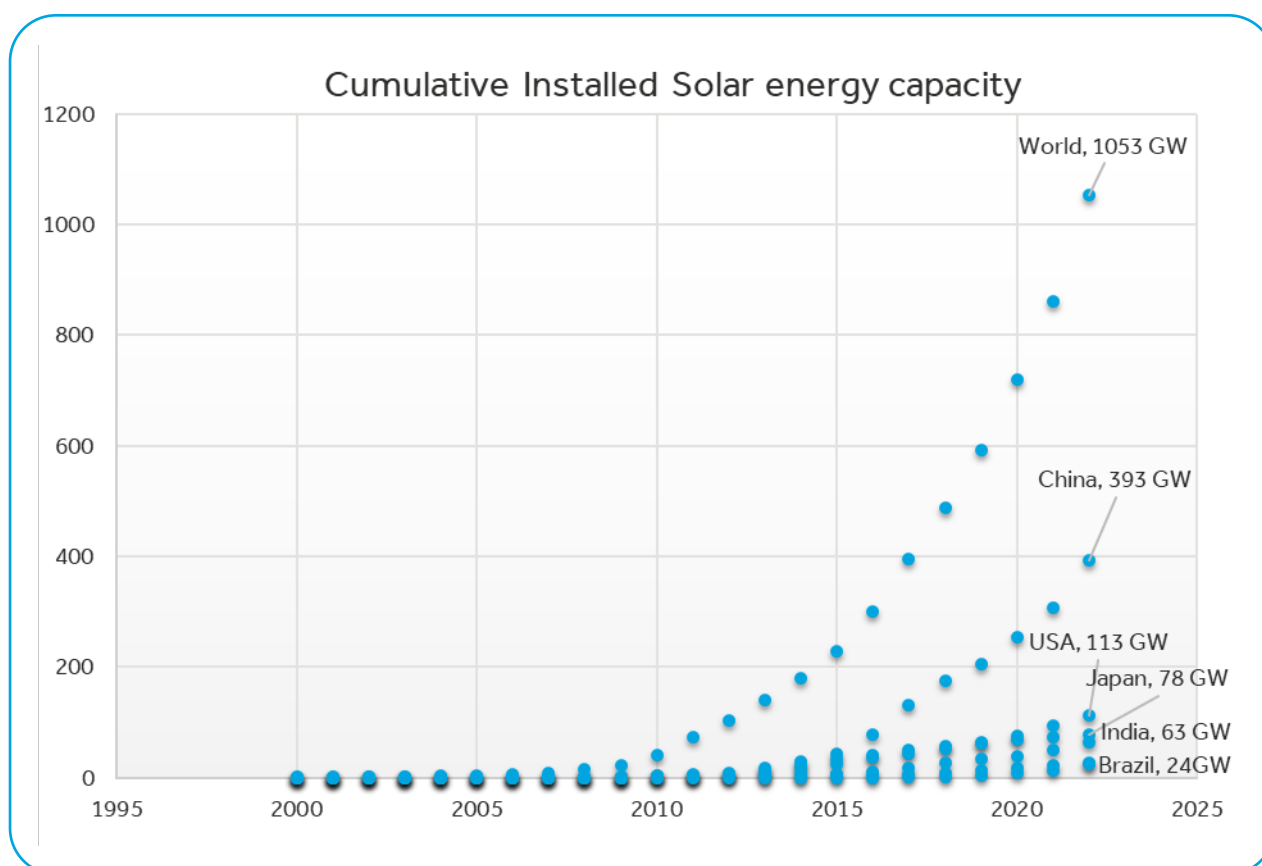


Fig 10 -Installed solar energy capacity

Source: <https://ourworldindata.org/grapher/installed-solar-pv-capacity>

Industry Challenges

Solar Panels Waste

Solar photovoltaic panels, whose operating life is 20 to 30 years, lose productivity over time. The International Renewable Energy Agency estimated that there would be about 78 million metric tons of waste in the world by 2050. In 2030, it is estimated that the world will have accumulated about 1.7 million metric tons of PV panel waste.

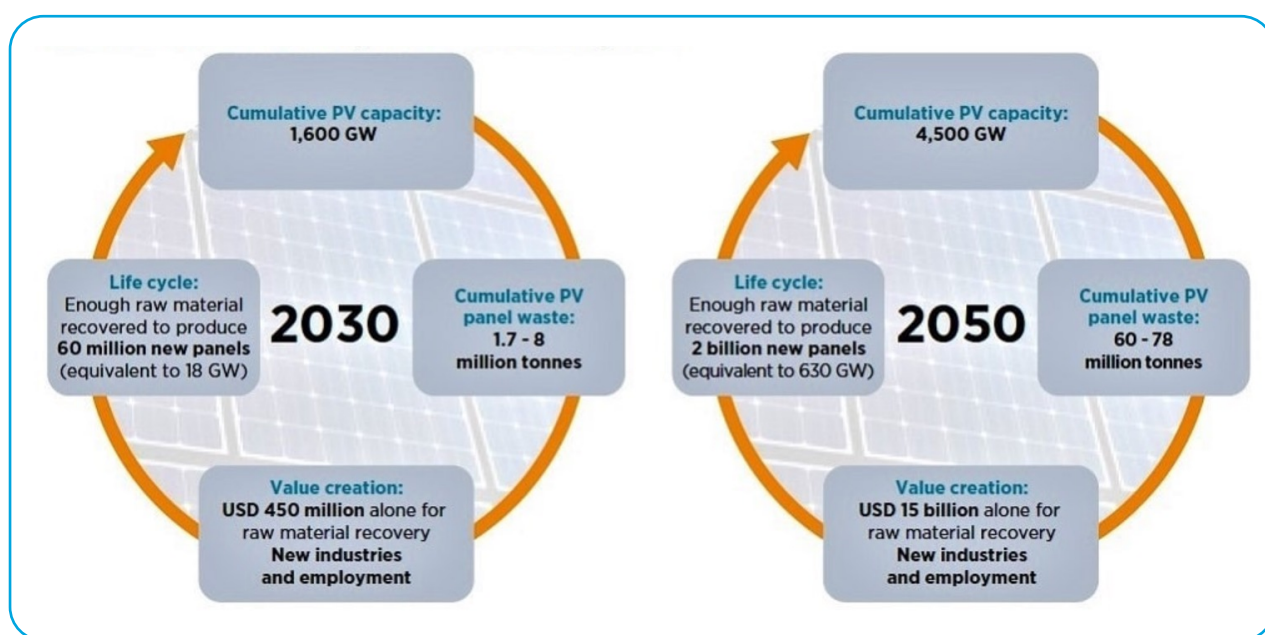


Fig 11 - Potential value creation through PV end-of-life management

Source: <https://avenston.com/en/articles/solar-second-life/>



Recycling PV Panels

Solar energy is the fastest-growing renewable energy source and is projected to continue to accelerate, driven by the global shift away from fossil fuel dependency and the increasing adoption of clean energy solutions to mitigate climate change. Historically, decommissioned solar panels mostly went to landfills. However, given the current advancements about 95% of the materials' value can be recycled to recover and reused.

“Estimated 78 million tons of solar panel waste expected by 2050, recycling is necessary to mitigate the negative environmental impact of this rapidly growing industry”. Currently, average landfill disposal costs can range from \$5 to \$20 per panel. This can go down as low as \$1 when compared to recycling cost, which can range from \$10 to \$40 per panel depending on type, installations, technology/method, and other aspects of the panel.

Solar panels recycling- Reduces hazardous landfill waste, helps reclaim valuable materials, creates employment opportunities, supports local economies, and cuts down costs of a new installation.

The value of recoverable materials **which would be enough to power 630 GW with 2 billion solar panels by 2050.** Globally, it is expected that end-of-life (EOL) solar panels will drive the solar panel recycling business in the next 10-20 years.

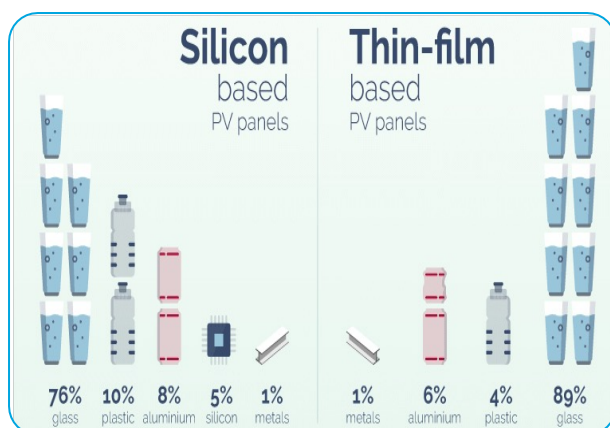


Fig 12 - Recycling:
A Solar Panel's Life after Death

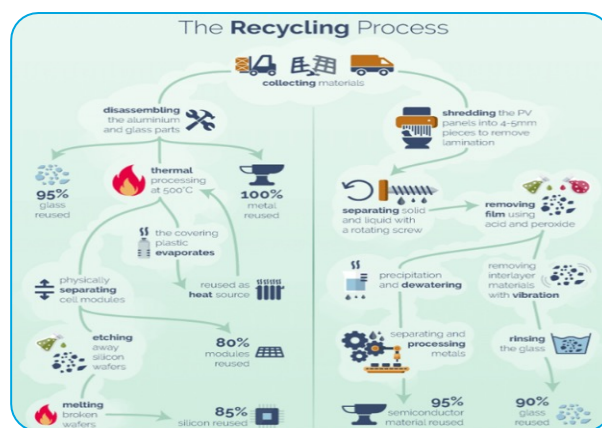


Fig 13 - The Importance of Recycling
in the Energy Transition

Source: <https://www.greenmatch.co.uk/blog/2017/10/the-opportunities-of-solar-panel-recycling>



Recycling Methods

Solar panels consist of materials like glass, aluminium frames, copper wires, plastic junction boxes, and other metals with silicon. Once panels come to the end of the lifecycle, 95% of the solar panel materials can be reused or recycled. Recycling can be performed by using mechanical, thermal, and chemical methods to remove the materials.

Mechanical Recycling- Separation of materials using shredders, sieves, and magnets for sorting and recycling the varied materials. During this process, the solar PV module is crushed before glass is recovered through separation or other methods. This is an advantageous process as glass can be recovered without the use of chemicals or high temperatures. Another process includes hot-wire cutting to remove glass without shredding the solar panel. This approach recovers the solar wafer with minimal damage and does not require the use of chemicals or high temperatures. Mechanical recycling involves the following steps-

01 Disassembly



Mechanical recycling begins with disassembling the solar panels, separating components such as the aluminium frame, glass, copper wiring, and plastic junction box.

02 Shredding



The separated components are then shredded into smaller pieces using specialized equipment. This process helps break down the materials for further processing.

03 Separation of Materials



After shredding, various techniques, such as screening, air classification, and magnetic separation, are used to separate the materials, isolating glass, aluminium, and other valuable materials from the shredded components.

04 Recovery of Materials



After the materials are separated, valuable components such as aluminium, glass, and copper are recovered through further refining and processing of the separated materials.

Thermal Recycling- This method involves heating solar panels to a high temperature, melting down the glass, plastic to recover valuable materials. The metal frame can be separated using magnets. During thermal recycling, solar modules withstand temperatures ranging from 450 degrees Celsius to 650 degrees Celsius so as to facilitate the burning of the Ethyl vinyl acetate (EVA) layer off the solar wafer. At such high temperatures, a 91% recovery rate for clean glass can be expected for recycling. Using this method produces emissions and chemical compounds, including methane, carbon monoxide, and hydrogen fluoride.

Another approach can be Electrothermal Heating which can reduce emissions and yield clean glass. However, the electrothermal process cracks the solar wafer and requires additional processes to recover raw materials.

The Thermal recycling process involves the following steps



Thermal Decomposition

This process involves heating the solar panels in a low-oxygen environment to break them down into smaller components for the recovery of valuable materials such as silicon cells, metals, and glass.



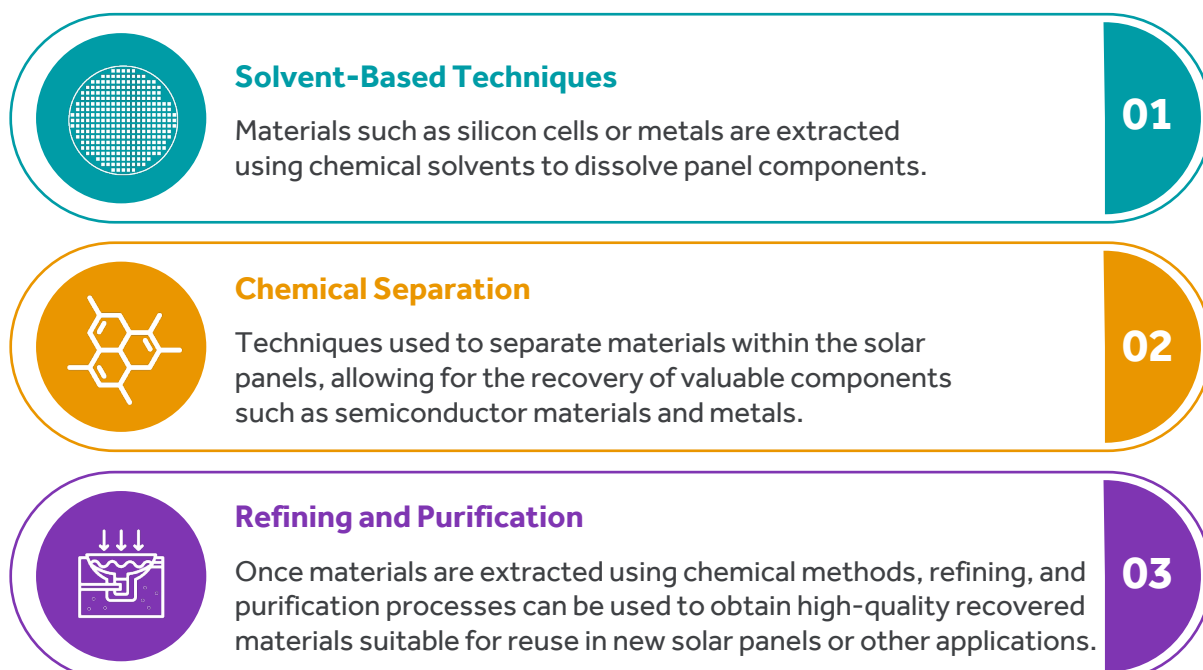
High-Temperature Treatment

Solar panels are subjected to high-temperature treatment to break down the polymer layers and other non-metallic components. This helps in separating the materials for further processing.



Chemical Recycling- Use of chemical solvents or acids to break down the solar panel components into individual materials that can be recovered and recycled. When solar PV panels are chemically recycled, various acids and chemicals are employed to extract and purify valuable metals from the solar wafer. While these chemical processes effectively recover high-value minerals, the chemicals and acids involved in this process are hazardous, making it difficult to implement chemical recycling on a commercial scale.

Chemical recycling involves below steps



While a combination of the above processes is necessary to recycle a solar PV panel, each process has its unique limitations. Scientists and governing bodies are exploring different materials and manufacturing methods for solar PV panels with the aim of streamlining and simplifying the recycling process.

Simultaneously, keeping the focus on material choices during the production process can potentially reduce waste generated by solar PV panels when they reach the end of their life cycle.

Challenges for Recycling

There are global efforts to improve solar panel recycling, including the creation of industry associations such as PV Cycle in Europe and the Solar Energy Industries Association, that enact regulations and policies to encourage solar panel recycling and reducing waste. Key stakeholders such as solar panel manufacturers, recyclers, and consumers all play a role in promoting sustainability in the industry. Major challenges such as complex material composition, hazardous materials, lack of standardization, economic viability, volume and collection needs to be addressed.

Cyient Capability and New Business Opportunities

Innovation & Technology Development-

Innovations in existing recycling methods and separation methods will be helpful to recover the valuable materials easily. Using modular design principles and methods for easier disassemble will be helpful for replacing any specific part instead of replacing entire solar panel from the location. Existing solar panels can also be used for a second life in rural and underdeveloped areas for energy storage systems.

Technologies like AI can be implemented for material sorting improving the efficiency of the recycling facilities and adopting AI modules for preventive maintenance.

Sustainability- Promoting innovation-driven research into new recycling methods, supporting recycling facilities with renewable energy resources and providing funding or tax benefits to recycling facilities will help reduce, reuse and recycling of the solar panels.



Conclusion

Solar panel recycling is a crucial aspect of sustainable energy practices, aiming to mitigate the environmental impact of photovoltaic (PV) technology. Mechanical, chemical, and thermal recycling methods will help to recover the valuable materials from the existing solar panels, reduce the electronic waste and helps to reduce environment impacts. Continuous improvement in recycling methods, use of digital technologies for new recycling methods will help to reduce the solar panels waste.

Several challenges including the development of efficient and cost-effective recycling technologies, as well as the establishment of comprehensive collection and recycling infrastructure. Collaborative initiatives among industry stakeholders, policymakers, and environmental organizations are essential to overcoming these challenges and promoting sustainable practices.

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Dnyandeo Baburao Shinde is a seasoned GIS professional with expertise in the Utilities domain, technical certification in ArcGIS Utility Network Associate 2024 currently serving as a Subject Matter Expert for Utilities in the Competency Development Team. With extensive experience in GIS projects, including data conversion, migration, and conflation for utilities, he brings deep knowledge in project management, execution, and data analysis. Dnyandeo is also adept at delivering technical training on industry-leading tools such as Esri UNM, ArcGIS Pro, Smallworld, ArcMap, AutoCAD, and QGIS, showcasing his proficiency in driving technical excellence and upskilling teams.



About Cyient

Cyient (Estd: 1991, NSE: CYIENT) partners with over 300 customers, including 40% of the top 100 global innovators of 2023, to deliver intelligent engineering and technology solutions for creating a digital, autonomous, and sustainable future. As a company, Cyient is committed to designing a culturally inclusive, socially responsible, and environmentally sustainable Tomorrow Together with our stakeholders.

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