

# Is a solar circular economy on the horizon?

**Recycling** | The solar industry's manufacturing footprint, and indeed the projects themselves, are becoming ever larger, with more panels and other associated equipment being packaged and shipped globally. Now, as Emilie Oxel O'Leary, CEO at Green Clean Solar explains, the industry is getting serious on its end of life obligations and establishing a true circular economy



Credit: Green Clean Solar.

**Panels aren't the only recycling consideration for developers, with shipping materials also posing issues.**

utility-scale projects with a higher rate of expected broken panels per install. Utilities are also commencing more decommissioning projects requiring responsible waste diversion and management. As more aggressive weather systems impact solar farms and natural disasters cause damage to panels and racking systems, recycling effort demand is expected to increase.

## Current status quo in solar's circular economy

The solar circular economy is waiting in the wings worldwide as we wrap up the era of status quo landfilling for solar panels and packaging materials. Especially for more extensive commercial, industrial, and utility installs, filling roll-off bins with broken panels and leftover packaging, all destined for the landfill, will soon no longer be the norm. Depending on the recycling outfit, waste diversion for panels can sometimes cost more than a landfill dump. Still, with discussion and movement toward standard practice for EOL panels, costs will be driven downward. The EU, in particular, has been a tremendous example of what's possible when we enact actionable recycling mandates for solar panels.

The EU has primarily led the solar circular economy, with some international companies and non-profits taking the lead. Other countries are now following suit in preparation for an onslaught of first-wave EOL. For example, the US and China had little or no mention of solar PV recycling and material recovery efforts before 2022, and here's where they're at now.

## Asia & Australia

A 2021 report from the Global Energy Interconnection Development and Cooperation Organization estimated that China may witness 1.05 million tonnes of retired components and solar panels entering

**E**xpanding solar power production is key to reducing emissions worldwide. The International Energy Agency initially predicted that global solar energy would reach 550TWh in 2030 - that capacity was reached and beat as of 2018.

With greater heights in solar installation come greater needs for efficient and effective waste management of panels and installation by-products. As a rapidly scaling industry, it is inevitable that solar stakeholders begin taking end of life (EOL) panel waste seriously. As of early 2022, we're beginning to see more global leaders address EOL panels as worldwide waste streams brace themselves for the influx.

## First wave generation and early EOL

We have about ten more years before we begin to see the first genuine wave of EOL panels. EOL panels have yet to be data-tracked, and waste has not been well documented thus far, making it challenging to know the exact reasons early EOL is taking place beyond breakage. The lack of EOL data is expected to change as major bodies in the US, Asia and Australia have

officially expressed formal research plans, albeit well behind the actionable efforts of the European Union.

The first wave of installed solar panels is warranted to perform about 20-35 years. Currently, there are varying factors that contribute to early EOL for some of these panels. The most common reasons include:

- expected percent breakage during shipping or installation
- manufacturing serial defects
- aging systems
- extreme weather damage
- early upgrades for better efficiency
- tax policies
- installation errors
- high-temperature rooftop and early degradation

These factors highlight our need to implement waste management protocols and cost-effective recycling solutions now, both from a manufacturer responsibility perspective and legislation to help streamline protocols and lower recycling costs.

What we're seeing now is a great need for cost-effective solutions that include logistics and cleanup support, especially for

the waste stream by 2025. In February, China's policymakers formally addressed the impending renewable energy waste management need with new policy plans to develop technologies for reuse and recycling.

In particular, the Chinese policy aims for "cross-sector utilisation" of materials such as silicon recovered from solar panels to be used in other non-solar sector electronics and components. As far as it's understood, this is the first time the Chinese government has addressed the issue as an urgent matter requiring new technologies and directives for waste management and encompassing solar panels, wind turbines, and EV batteries. China, Japan, and Korea contributed to the rush in 178-plus filed patents aimed to solve module recyclability, focusing primarily on crystalline silicon (c-Si) technology.

Australia has also chosen early 2022 to announce shifts to deal with solar panel waste. So far, efforts have varied across regions, with some considering solar panels e-waste. As it stands, the solar recycling services in Australia can only recover about 17% of the materials from a panel, leaving the remaining 83%, including glass, silicon, and polymer back sheeting on the market for export or headed to the landfill.

#### European Union

Since 2012, EOL solar panels have been under the scope of the Waste from Electrical and Electronic Equipment in the EU (WEEE). WEEE regulations require 85% collection and 80% recycling of the materials used in PV panels. The policy uses a fund or tax incentive for the repair, reuse, or refurbishment of panels. It includes right to repair laws and enlists policies to minimise new fossil fuel infrastructures. These measures, which have been in place for about a decade now, have effectively lowered the costs of recycling to create a profitable solar recycling market.

The EU's solar panel recycling body, PV Cycle, has been widely used to fulfill WEEE compliance. The EU has been a worldwide beacon for EOL solar panel handling and recycling legislation.

#### Africa

As solar power scales in Sub-Saharan Africa, various African countries' EOL solar PV standards are starting to be addressed. The topic has been discussed in research and best practices in Ghana and South Africa.

In Ghana, a hybrid public-private strategy focuses on technical solutions and delivers clear roles to all actors, including government, business, and end-users. The goal of Ghana's EOL plan is to achieve reduction, reuse, repair, and recycling that will benefit all stakeholders and promote education around sustainability and lifecycle knowledge on solar panels.

#### North America

There is no set national law for recycling solar panels thus far. The US's closest to a national directive is the Department of Energy's Solar Energy Technologies Office (SETO) Photovoltaics End-of-Life Action Plan, released in March 2022. SETO outlined an 18-page Action Plan aiming to better understand the state of EOL panels through the development of a database that tracks materials, quantity, age, location, cause of EOL, and handling methods for modules. In addition the directive aims to reduce panel recycling costs by more than half by 2030.

Currently, costs are on average US\$15 - \$45 to recycle one module, with the more well-known and mainstream PV recycling companies charging upwards of US\$58 per panel at the higher end. It will be key to drive these costs down as landfill fees average about US\$1 - \$5 per module. The National Renewable Energy Laboratory (NREL) has suggested that we could have a profitable solar module recycling industry by 2032, with a US\$10 - 18 per panel subsidy. These combined figures would result in the goals of SETO to reach a US\$3 per panel recycling rate by 2030.

California leads the US by categorising all solar panels as universal waste, the first in the country to do so. Listing panels as such reduces the management burden and facilitates the recycling of the panels by necessary means. The mandate started on 1 January 2021, and declared that decommissioned solar panels would be regulated like other universal waste, including batteries, cathode ray tubes, mercury-containing equipment, electronic devices, and lamps.

#### Canada

Canada's Ministry of Environment and Climate Change Strategy announced a recycling guide; however, facilities are too limited in scope to actualise solar panel recycling under current circumstances. For now, manufacturers can become members of the PV Cycle to support recycling efforts.

#### South America

Brazil's massive electronics industry has paved the way for panel recycling which has launched in 2021 by SunR. For Brazil, it's not so much the recycling capabilities; those are in place, and recycling is much more cost-effective than incineration or landfilling. The larger issue is logistics in getting panels to the proper recycling facilities.

The company estimates that for every 500,000 tons of panels installed, about 40,000 tons of materials are discarded, putting the value of this market at around US\$3.8million.

#### What percentage of panels go to landfills?

Solar Panel recycling laws and rates vary from region to region across the globe. One of the highest known recycling rates is within the EU.

#### Europe

According to PV Cycle, the EU is hovering at a 94.7% recovery rate of crystalline silicon-based PV modules, which exceeds WEEE's recovery rate directive of 85%. In 2008, the first full-scale solar panel recycling plant opened in France, which handles large-scale quantities of PV panels for the region. PV Cycle has partnered with solar manufacturers under the EU WEEE regulations and offers manufacturers that operate within the region recycling and compliance support.

#### North America

Panel recycling rates in the US are around 10%, leaving the remaining 90% destined for landfills, according to estimates from NREL.

#### Worldwide

The global e-waste recycling rate is estimated to be around 17.4% - that is collected and recycled properly. With looming waste recovery from the solar sector, if mandates and incentives are put in place and panels are officially designated as e-waste worldwide, solar panel recycling rates can begin having a global framework and likely a higher recycling rate than the global e-waste rates.

#### What can be recycled, and what is recycled?

By mass, the ratio of each panel is about 70% glass, 15% aluminum, 10% silicon, silver, indium, gallium account for 4%, and other rare metals account for about

1%. Around 99% of PV materials are non-hazardous, and about 95% of the materials are recoverable using currently available technologies. Recyclable parts of panels, installation materials, and packaging include:

- aluminum frame
- copper wire
- plastic junction box
- ground mounts
- trackers
- wiring
- inverters
- racking
- battery backup systems
- wood crates
- cardboard

When it comes to panels, the general process for recycling them should aim to recover as much material as possible. While there is no standardised process yet, there are three core phases for recovering as much material as possible from each panel.

**Phase 1:** Frame and junction box removal

**Phase 2:** Chemical, thermal, or mechanical separation of the silicon wafer from the glass

**Phase 3:** Chemical and electrical methods for separating and purifying silicon cells and metals (copper, lead, tin, silver)

These materials aren't the only things that need recycling. Tons of wood crates, plastic, and cardboard at a rate of about 40 pounds per pallet require diversion and management protocols.

### How is the industry ramping up its efforts to boost recycling?

Panel recycling efforts across the solar industry have been sporadic, with some proactive manufacturers taking charge, others beginning research and a large majority waiting until guidelines, subsidies, and mandates move forward on recycling plans. We are witnessing a transition toward a circular solar economy thanks to varying degrees of effort and action.

### Producer responsibility

Responsibility on the part of solar manufacturers is currently voluntary, and those who are acting ahead of the mandate curve are developing a model for improving their environmental and customer relations now. Early waste diversion adoption is helping these manufacturers remain relevant to their customers, especially ESG-minded businesses.

A handful of these manufacturers in the solar industry are gearing up efforts

for boosting the recovery of solar materials. One manufacturer, in particular, has already established a producer responsibility model. First Solar is one of the premier manufacturers with a recycling program integrated into its contracts. Recovery is performed with a takeback approach; broken or unusable panels are sent back to the manufacturer. The company reports a 90% reuse rate for semiconductors and a 90% reuse rate for glass - materials are reimplemented into manufacturing new panels.

There are also racking companies exploring the best practices for their product and packaging supply chains. As ESG reporting becomes increasingly important and tied to both solar installs and waste - tracking recycling metrics on solar is becoming more pressing on the producer end.

### ESG reporting pressures

While most manufacturers are still on the sidelines, legislation and ESG reporting are quickly putting manufacturers in a reactive position when it comes to producer responsibility. The proactive manufacturers, implementing recycling and take-back efforts, are getting ahead of best practices.

Responsible solar manufacturers delivering solutions to their customers for material recovery and waste diversion are quickly gaining leverage. ESG reporting encompasses the adoption of solar panels to combat carbon emissions; historically, solar energy installation and waste reporting were not mentioned in the same categories. Now that reporting and verifiable metrics are the expected environmental norm, waste outcomes of every advancement must be addressed. We're seeing these reports more and more, and the data must incorporate waste reduction efforts, validated by recycling reports and receipts from the recycling plant.

### New markets for secondary solar products

Depending on the quality of a panel at EOL, it can be reused as a whole or for parts, refurbished, or recycled, and any materials that cannot be treated under one of these conditions can either be stored until future needs or solutions arise, or sent to the landfill as a last resort.

Solar panels that are decommissioned early or can be refurbished or repaired have an opportunity to be resold at a discounted rate for things like community solar projects or anywhere where solar costs have held people back from imple-

menting solar. A solar panel refurbishment market is ramping up efforts; research and development have been going on since around 2017. Grants have been issued in the US for developing a full-functioning submarket for second-hand panels, parts, and components.

One of these organisations is EnergyBin, which in 2017 received federal funding to build a feasibility case for an online marketplace that supplied overstocked and hard-to-find components and decommissioned materials for the solar industry.

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Energy Bin operates as a member platform dedicated to moving otherwise warehoused items and getting them back on the market to decrease costs for engineering, procurement, construction, manufacturers, distributors and other firms to sell overstock.

### Designing for end of life

Ultimately we will need to see actionable measures for increasing global recycling and refurbishing infrastructure coupled with better design on the front end and optimised supply chain choices to create a lasting circular economy for the solar industry. This direction is inevitable, and it's apparent that the solar industry wants to do the right thing and scale toward a decarbonised future. There are a lot of improvements to make, and the efforts and acknowledgments that have been made public by large countries and organisations are a sneak peek of the recovery efforts in the works. Within the next 10 years, we will see a solar industry that treats panels and packaging materials in a cradle-to-cradle manner. Now is the time for solar industry leaders to roll up their sleeves and get us there. ■

### Author

Emilie Oxel O'Leary is the CEO/Owner of Green Clean Solar, based in Marietta, Georgia. She has a strong passion and expertise in the solar industry, focusing on waste management and landfill diversion services while building a diverse workforce.

