SOLARCYCLE

Rethinking Solar's Second Life

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What's the Question?

At SOLARCYCLE, our mission is to close the loop on the circular solar economy and extract the greatest value from end of life (EOL) panels with the highest environmental integrity. Because sustainability is at the core of what we do, we are constantly evaluating our environmental impact, looking at things like resource depletion, pollution, and climate change. We're known for our advanced solar panel recycling services, but we also offer reuse solutions and even reuse panels ourselves.

Beyond our current service offerings, we're investing in advanced R&D to truly close the loop. We've demonstrated a proof-of-concept solar panel made with 50% recycled glass from end-of-life solar panels, and envision a future panel produced with even greater recycled content on domestic, circular manufacturing lines.

Thousands of decommissioned panels arrive daily at our facilities. The reasons for decommissioning a panel are numerous, and include repowering, hail/storm damage, manufacturing defects, warranty returns, and construction breakage, among others.

A question we've been asking ourselves is: When a solar panel is decommissioned, can recycling ever be a more climate-friendly solution than reuse?

We all remember the classic "Reduce, Reuse, Recycle" from school. Under the "3 R's" hierarchy, we are told we should always attempt to reuse before recycling, though recycling is better than tossing something in the trash.

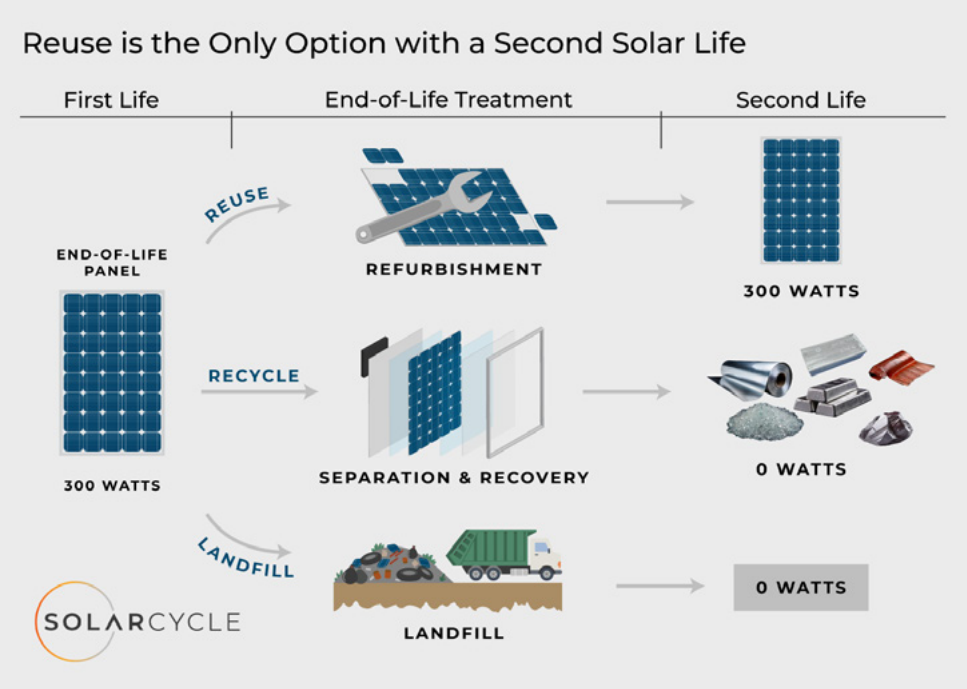
In the solar waste industry, we've historically upheld this maxim as an infallible rule of thumb. But should we?

It's not a simple question. First, we have to consider whether we even can reuse an EOL panel – its physical condition, power output, market demand, regulatory requirements, and more. We've also discussed the many social and moral complexities of a flawed and unregulated reuse market.

Putting all that aside, let's imagine there are no barriers to reuse at scale. Solar panels are unique in the world of waste products due to the emissions-free energy they produce. What does this mean? In terms of climate impact, they will continue to generate more carbon benefit as long as they are connected to a grid. As such, there is an opportunity cost of carbon associated with not reconnecting a decommissioned, but still functional panel to the grid.

The natural conclusion would follow that the traditional "reuse before recycling" hierarchy holds true on climate impact. Via recycle, an EOL panel generates a one-time carbon benefit when metals are recovered, by displacing the carbon-intensive

Figure 1. Reuse is the Only Option with a Second Solar Power Life



production of virgin materials. Via reuse, an EOL panel gets a second solar power life. In its second life, the panel generates continuous future carbon benefits, year after year.

However, solar panels are also unique in the world of waste products due to the pace at which the technology has advanced. Every year manufacturers produce modules with greater power output, fewer energy-intensive materials, and via a more efficient production process. This is known as the consumption per power (CPP), coined by a team of researchers a few years ago.

Yet, individual products are warrantied for decades of use. Thus, there is a major inconsistency between the material and operational durability of solar panels versus their technological durability (i.e., ability to maintain their up-to-datedness). It's in discrepancies that we find exceptions to rules.

Knowing what we now know, we return to our original question and update it: Can recycling enable a more climate-friendly solution than reuse for decommissioned panels? Can the opportunity cost of carbon from foregoing reuse be recouped if we can give a second solar life to recycled panel materials via truly circular manufacturing?

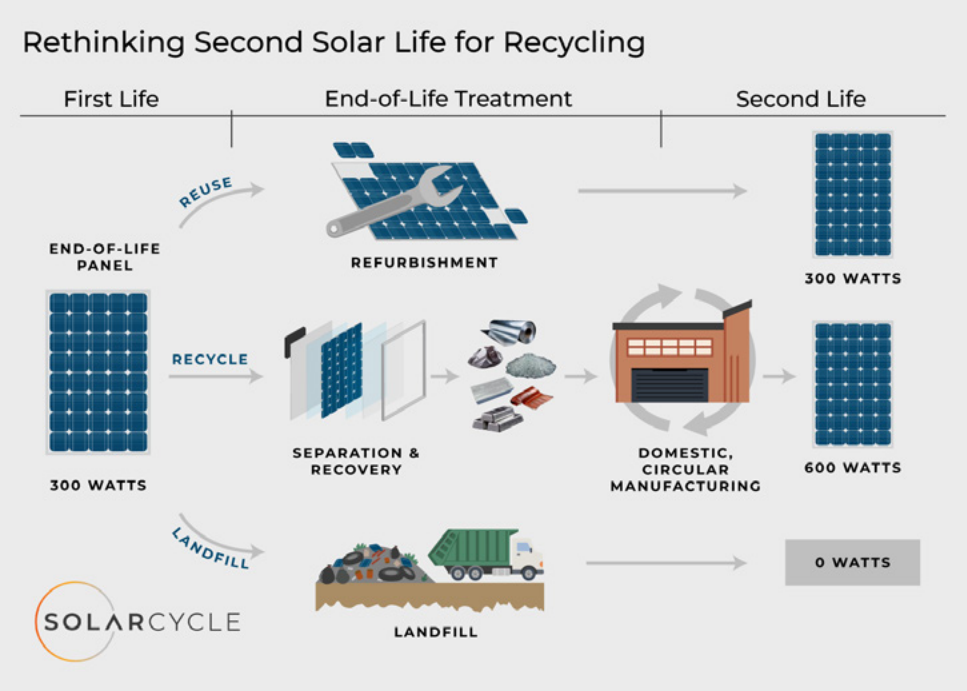
To answer our question, we turned to Life Cycle Assessment (LCA) – a tool that helps

us quantify the environmental impact of different choices across a product's life cycle. In this case, we modeled and compared two scenarios:

1. Reusing a typical EOL solar panel as-is.
2. Recycling that same panel on a SOLARCYCLE advanced recycling line and then using the recovered materials to manufacture a new, more efficient one.

The results might surprise you.

Figure 2. Rethinking a Second Solar Power Life for Recycling



How We Did It

LCA is a structured approach used to evaluate the environmental impacts of a product or process across its entire life cycle. Designing an LCA involves defining the system and scope, compiling a detailed inventory of inputs and outputs, and assessing potential environmental impacts, typically across a range of impact categories, using standardized methods.[1]

[1] Per ISO 14040 and 14044.

We modeled EOL scenarios for a 375-watt peak (Wp) monofacial crystalline silicon (c-Si) solar module – the average of the panels we installed in our own on-site second-life 500KW system – for both refurbishment (reuse) and recycling treatment methods. For the newly manufactured panel, we assumed a rated power of 600 Wp, which can be commonly found amongst utility-grade monofacial products available in the market today. We then conducted a sensitivity analysis on a range of other panel wattages. Domestic manufacturing was modeled using the U.S. weighted-average pathway presented in research by the National Renewable Energy Lab[2] (NREL). We scaled the NREL results for this case study using a combination of wattage, area, and average composition.

Altogether, our analysis used:

- SOLARCYCLE's internal, primary data for our own reuse and recycling program LCAs
- NREL's LCA data for modern solar module manufacturing
- Average panel composition data from SOLARCYCLE's comprehensive and proprietary database
- Assumptions that all activities (reuse, recycling, manufacturing, and operation) occur in the U.S. in 2024

To ensure an apples-to-apples comparison when working with LCAs from multiple sources with differing impact assessment categories, we focus on the climate change impact (i.e., global warming potential) category in this analysis.

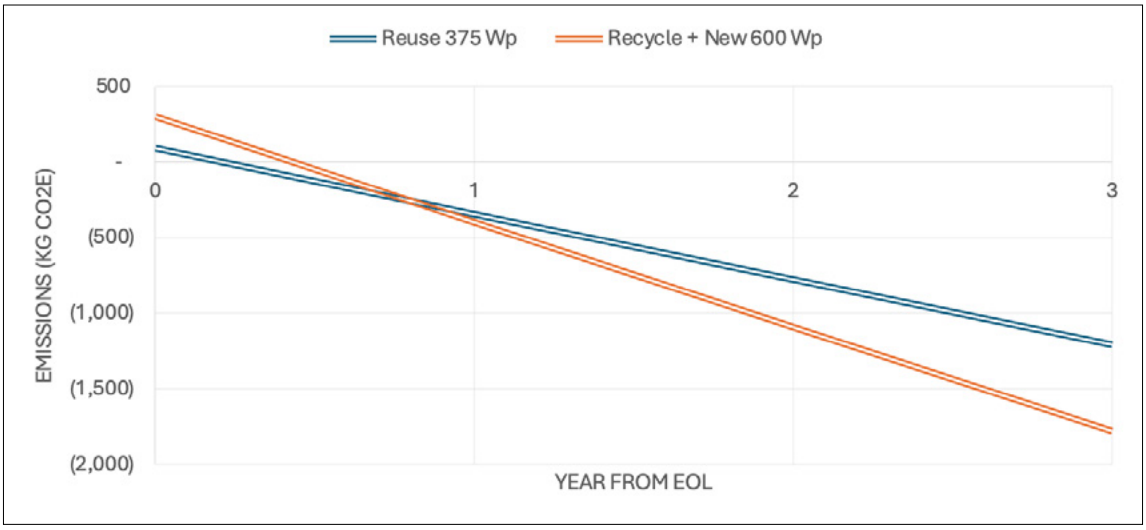
Our goal was to identify the "carbon overtake" moment – or the day, month, or year in which the newly manufactured panel produces enough carbon-free electricity to neutralize its own life cycle emissions and surpasses the amount of electricity, and equivalent avoided greenhouse gas (GHG) emissions, the reused panel has been simultaneously producing.

What We Found

The results were unexpected: the newly manufactured 600 Wp panel can catch up to and overtake the net carbon benefit of the reused panel in just 10 months of operation. Even looking at the lowest rated power (400 Wp) and highest material intensities (e.g., kg silver/Wp) in our sensitivity range – it takes 6 years for the new panel to catch up to the net carbon benefit of reuse.

[2] Renamed "National Laboratory of the Rockies" on December 1, 2025. However, the referenced study was published under the former name.

Figure 3. Carbon Overtake for 600 Wp Recycle + Manufacture Case Study



While benefits may not necessarily be realized within the short term (i.e., 2-5 years), all overtake periods fall well within the average manufacturer's warranty for a new panel (20-30 years), meaning that under standard conditions, overtake is merely a question of "when" not "if".

The Future Opportunity, The Future Necessity

The waste hierarchy taught us to reuse before we recycle, but in the fast-evolving world of solar and recycling technology, that guidance needs a refresh. By using LCA to compare a realistic – if not quite yet realized – future case in which a decommissioned panel is efficiently recycled and manufactured into a new, circular panel versus reused, we've unlocked a paradigm.

Now, the imperative is to establish these ideal conditions for circular solar: scaling advanced recycling operations, connecting the secondary supply chain and creating low-carbon production capacity.

We'll be the first to admit that this study is a thought experiment. It doesn't acknowledge the very real economic pressures facing solar asset managers around decommissioning and the reality that we, the industry, have yet to fully recycle an EOL panel into a new one. But with EOL panel waste projected to reach 54 to 160 million metric tons by 2050, we think it's critical to invest in advanced solar recycling now – to drive down recycling costs and drive forward innovation – before waste hits crisis levels. We envision a closed-loop future for solar and we're trying to build it.