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# **The Dark Side of Solar Power**

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**Summary.** Solar energy is a rapidly growing market, which should be good news

for the environment. Unfortunately there's a catch. The replacement rate of solar panels is faster than expected and given the current very high recycling costs, there's a real danger that all... [more](#)

**It's sunny times for solar** power. In the U.S., home installations of solar panels have fully rebounded from the Covid slump, with analysts predicting more than 19 gigawatts of total capacity installed, compared to 13 gigawatts at the close of 2019. Over the next 10 years, that number may quadruple, according to industry research data. And that's not even taking into consideration the further impact of possible new regulations and incentives launched by the green-friendly Biden administration.

Solar's pandemic-proof performance is due in large part to the Solar Investment Tax Credit, which defrays 26% of solar-related expenses for all residential and commercial customers (just down from 30% during 2006–2019). After 2023, the tax credit will step down to a permanent 10% for commercial installers and will disappear entirely for home buyers. Therefore, sales of solar will probably burn even hotter in the coming months, as buyers race to cash in while they still can.

Tax subsidies are not the only reason for the solar explosion. The conversion efficiency of panels has improved by as much as 0.5% each year for the last 10 years, even as production costs (and thus prices) have sharply declined, thanks to several waves of manufacturing innovation mostly driven by industry-dominant Chinese panel producers. For the end consumer, this amounts to far lower up-front costs per kilowatt of energy generated.

This is all great news, not just for the industry but also for anyone who acknowledges the need to transition from fossil fuels to renewable energy for the sake of our planet's future. But there's a massive caveat that very few are talking about.

## **Panels, Panels Everywhere**

Economic incentives are rapidly aligning to encourage customers to trade their existing panels for newer, cheaper, more efficient models. In an industry where circularity solutions such as recycling remain woefully inadequate, the sheer volume of discarded panels will soon pose a risk of existentially damaging proportions.

To be sure, this is not the story one gets from official industry and government sources. The International Renewable Energy Agency (IRENA)'s official projections assert that "large amounts of annual waste are anticipated by the early 2030s" and could total 78 million tonnes by the year 2050. That's a staggering amount, undoubtedly. But with so many years to prepare, it describes a billion-dollar opportunity for recapture of valuable materials rather than a dire threat. The threat is hidden by the fact that IRENA's predictions are premised upon customers keeping their panels in place for the entirety of their 30-year life cycle. They do not account for the possibility of widespread early replacement.

Our research does. Using real U.S. data, we modeled the incentives affecting consumers' decisions whether to replace under various scenarios. We surmised that three variables were particularly salient in determining replacement decisions:

installation price, compensation rate (i.e., the going rate for solar energy sold to the grid), and module efficiency. If the cost of trading up is low enough, and the efficiency and compensation rate are high enough, we posit that rational consumers will make the switch, regardless of whether their existing panels have lived out a full 30 years.

As an example, consider a hypothetical consumer (call her “Ms. Brown”) living in California who installed solar panels on her home in 2011. Theoretically, she could keep the panels in place for 30 years, i.e., until 2041. At the time of installation, the total cost was \$40,800, 30% of which was tax deductible thanks to the Solar Investment Tax Credit. In 2011, Ms. Brown could expect to generate 12,000 kilowatts of energy through her solar panels, or roughly \$2,100 worth of electricity. In each following year, the efficiency of her panel decreases by approximately one percent due to module degradation.

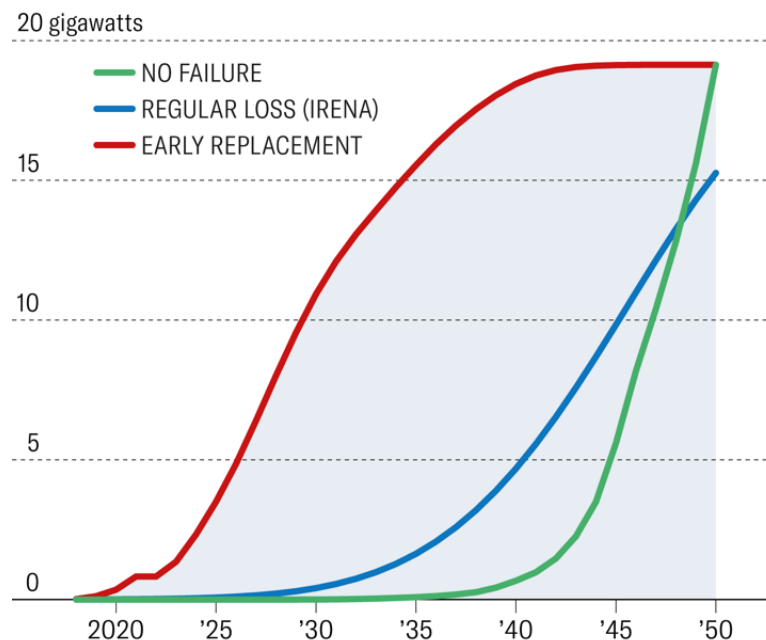
Now imagine that in the year 2026, halfway through the life cycle of her equipment, Ms. Brown starts to look at her solar options again. She’s heard the latest generation of panels are cheaper and more efficient — and when she does her homework, she finds that that is very much the case. Going by actual current projections, the Ms. Brown of 2026 will find that costs associated with buying and installing solar panels have fallen by 70% from where they were in 2011. Moreover, the new-generation panels will yield \$2,800 in annual revenue, \$700 more than her existing setup when it was new. All told, upgrading her panels now rather than waiting another 15 years will increase the net present value (NPV) of her solar rig by more than \$3,000 in 2011 dollars. If Ms. Brown

is a rational actor, she will opt for early replacement. And if she were especially shrewd in money matters, she would have come to that decision even sooner — our calculations for the Ms. Brown scenario show the replacement NPV overtaking that of panel retention starting in 2021.

## The Solar Trash Wave

According to our research, cumulative waste projections will rise far sooner and more sharply than most analysts expect, as the below graph shows. The green “no failure” line tracks the disposal of panels assuming that no faults occur over the 30-year life cycle; the blue line shows the official International Renewable Energy Agency (IRENA) forecast, which allows for some replacements earlier in the life cycle; and the red line represents waste projections predicted by our model.

### Cumulative capacity



Source: International Renewable Energy Agency, Electricity Data Browser, Global Solar Atlas



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If early replacements occur as predicted by our statistical model, they can produce 50 times more waste in just four years than IRENA anticipates. That figure translates to around 315,000 metric tonnes of waste, based on an estimate of 90 tonnes per MW weight-to-power ratio.

Alarming as they are, these stats may not do full justice to the crisis, as our analysis is restricted to residential installations. With commercial and industrial panels added to the picture, the scale of replacements could be much, much larger.

### **The High Cost of Solar Trash**

The industry's current circular capacity is woefully unprepared for the deluge of waste that is likely to come. The financial incentive to invest in recycling has never been very strong in solar. While panels contain small amounts of valuable materials such as silver, they are mostly made of glass, an extremely low-value material. The long life span of solar panels also serves to disincentivize innovation in this area.

As a result, solar's production boom has left its recycling infrastructure in the dust. To give you some indication, First Solar is the sole U.S. panel manufacturer we know of with an up-and-running recycling initiative, which only applies to the company's own products at a global capacity of two million panels per year. With the current capacity, it costs an estimated \$20–\$30 to recycle one panel. Sending that same panel to a landfill would cost a mere \$1–\$2.

The direct cost of recycling is only part of the end-of-life burden, however. Panels are delicate, bulky pieces of equipment usually installed on rooftops in the residential context. Specialized labor is required to detach and remove them, lest they shatter to smithereens before they make it onto the truck. In addition, some governments may classify solar panels as hazardous waste, due to the small amounts of heavy metals (cadmium, lead, etc.) they contain. This classification carries with it a string of expensive restrictions — hazardous waste can only be transported at designated times and via select routes, etc.

The totality of these unforeseen costs could crush industry competitiveness. If we plot future installations according to a logistic growth curve capped at 700 GW by 2050 (NREL's estimated ceiling for the U.S. residential market) alongside the early-replacement curve, we see the volume of waste surpassing that of new installations by the year 2031. By 2035, discarded panels would outweigh new units sold by 2.56 times. In turn, this would catapult the LCOE (levelized cost of energy, a measure of the overall cost of an energy-producing asset over its lifetime) to four times the current projection. The economics of solar — so bright-seeming from the vantage point of 2021 — would darken quickly as the industry sinks under the weight of its own trash.

### **Who Pays the Bill?**

It will almost certainly fall to regulators to decide who will bear the cleanup costs. As waste from the first wave of early replacements piles up in the next few years, the U.S. government — starting with the states, but surely escalating to the federal level — will introduce solar panel recycling legislation.

Conceivably, future regulations in the U.S. will follow the model of the European Union's WEEE Directive, a legal framework for the recycling and disposal of electronic waste throughout EU member states. The U.S. states that have enacted electronics-recycling legislation have mostly cleaved to the WEEE model. (The Directive was amended in 2014 to include solar panels.) In the EU, recycling responsibilities for past (historic) waste have been apportioned to manufacturers based on current market share.

A first step to forestalling disaster may be for solar panel producers to start lobbying for similar legislation in the United States immediately, instead of waiting for solar panels to start clogging landfills. In our experience drafting and implementing the revision of the original WEEE Directive in the late 2000s, we found one of the biggest challenges in those early years was assigning responsibility for the vast amount of accumulated waste generated by companies no longer in the electronics business (so-called orphan waste).

In the case of solar, the problem is made even thornier by new rules out of Beijing that shave subsidies for solar panel producers while increasing mandatory competitive bidding for new solar projects. In an industry dominated by Chinese players, this ramps up the uncertainty factor. With reduced support from the central government, it's possible that some Chinese producers may fall out of the market. One of the reasons to push legislation now rather than later is to ensure that the responsibility for recycling the imminent first wave of waste is shared fairly by makers of the



equipment concerned. If legislation comes too late, the remaining players may be forced to deal with the expensive mess that erstwhile Chinese producers left behind.

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But first and foremost, the required solar panel recycling capacity has to be built, as part of a comprehensive end-of-life infrastructure also encompassing uninstallation, transportation, and (in the meantime) adequate storage facilities for solar waste. If even the most optimistic of our early-replacement forecasts are accurate, there may not be enough time for companies to accomplish this alone. Government subsidies are probably the only way to quickly develop capacity commensurate to the magnitude of the looming waste problem. Corporate lobbyists can make a convincing case for government intervention, centered on the idea that waste is a negative externality of the rapid innovation necessary for widespread adoption of new energy technologies such as solar. The cost of creating end-of-life infrastructure for solar, therefore, is an inescapable part of the R&D package that goes along with supporting green energy.

## It's Not Just Solar

The same problem is looming for other renewable-energy technologies. For example, barring a major increase in processing capability, experts expect that more than 720,000 tons worth of gargantuan wind-turbine blades will end up in U.S. landfills over the next 20 years. According to prevailing estimates, only five percent of electric-vehicle batteries are currently recycled — a lag that automakers are racing to rectify as sales figures for electric cars continue to rise as much as 40% year-on-year. The only essential difference between these green technologies and solar panels is that the latter doubles as a revenue-generating engine for the consumer. Two separate profit-seeking actors — panel producers and the end consumer — thus must be satisfied in order for adoption to occur at scale.

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None of this should raise serious doubts about the future or necessity of renewables. The science is indisputable: Continuing to rely on fossil fuels to the extent we currently do will bequeath a damaged if not dying planet to future generations. Compared with all we stand to gain or lose, the four decades or so it will likely take for the economics of solar to stabilize to the point that consumers won't feel compelled to cut short the life cycle of their panels seems decidedly small. But that lofty purpose doesn't make the shift to renewable energy any easier in reality. Of all sectors, sustainable technology can least afford to be shortsighted about the waste it creates. A strategy for entering the circular economy is absolutely essential — and the sooner, the better.

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