Solar

Solar Panel Recycling and Disposal

Solar panels—primarily composed of non-hazardous materials—present minimal risks to the environment and human health, and their disposal and recycling processes can recover more than 90% of materials, maximizing resource efficiency.

Key Takeaways

1. **Low Risk:** Solar panels present minimal risks to the environment or human health, even in the event of breakage.
2. **Recycling Potential:** Advanced recycling technologies can currently recover more than 90% of the materials by weight in a typical solar panel, including valuable materials like glass and aluminum.
3. **Safe Disposal:** Solar panels are primarily made of non-hazardous materials and can be safely disposed of in municipal landfills if panels pass the Toxicity Characteristic Leaching Procedure (TCLP) or are known to be non-hazardous through process knowledge.
4. **Extended Lifespan:** Solar panels often continue to operate after their warranty period, allowing for reuse or refurbishment before recycling.

Background

Solar energy plays a vital role in the American energy portfolio, with utility-scale solar energy growing exponentially due to rapid technology improvements. Installed solar capacity in the U.S. is more than 100 gigawatts (GW) of power—enough to power 22 million homes.[1]

According to the U.S. Department of Energy, utility-scale solar deployment will need to grow at an accelerated pace—at least four times its current rate—to meet 40% of the nation's electricity needs by 2035.[2] This makes effective end-of-life management of solar panels, through safe disposal and recycling, a critical part of the energy transition.

Solar Panel Design & Public Safety

Solar panels are designed to be durable and long-lasting, with most manufacturers offering 25-year warranties.[3] Most of a solar panel's weight (over 75%) is glass, and aluminum is used for the frames. Silicon or other semiconductor materials are used in the power-generating solar cells. The most common types of modules also use small amounts of silver or other metals to connect the cells to each other. Most of these materials are non-hazardous.

In the event of breakage or fire, solar panels present a low risk to the general public or human health.[4,5,6] Panels are designed to withstand harsh environmental conditions and extreme weather events.

Safe Disposal of Solar Panels

Crystalline silicon and thin film cadmium telluride (CdTe) modules—the two most common types of modules in the U.S.—have minimal hazardous materials. In some cases, damaged or decommissioned solar panels may be safely disposed of in municipal landfills if they pass the **Toxicity Characteristic Leaching Procedure (TCLP)**—which is used to determine whether waste is hazardous or non-hazardous under federal regulations—or the panels are known to be non-hazardous through process knowledge.[7,8]

Damaged solar panels are quickly and easily removed by asset owners when they reach their end of life or are otherwise rendered nonfunctional.

Extending Solar Panel Lifespan

After a panel's useful life, it may continue to operate, albeit at reduced efficiency. A study from the National Renewable Energy Laboratory (NREL) calculated that typical PV panels lose approximately 0.2–1.0% efficiency per year, meaning that **by its twentieth year, a typical module can operate at 85-90% of its original output**.[9]

Undamaged solar panels can be refurbished and reused in other applications can be a viable strategy for renewable energy deployment in lower income communities, but should be carefully managed to avoid creating disposal challenges.[10,11]

Maximizing Recycling & Resource Recovery

The recycling potential of solar panels is significant. According to the DOE's Solar Energy Technologies Office, 95% of the materials in solar panels are recyclable. The bulk of a solar panel's weight (about 90%) is glass and aluminum.[12] The remaining PV system materials include steel for racking, piles, and trackers; copper and aluminum for wiring; and plastics for electronics and wire housing. All of these materials are commonly recyclable in the U.S.[13]

The U.S. Environmental Protection Agency (EPA) notes that many solar panels may contain materials deemed critical to national security such as tin and aluminum.[14]

The Expanding Solar Recycling Market

As the solar industry grows, so does the potential value of these recyclable materials. The solar panel recycling industry is growing rapidly as more facilities reach the end of their operational life in the next decade and beyond.

By 2030, it is estimated that the cumulative value of recoverable materials from decommissioned solar panels will be approximately **$450 million**.[15] By 2050, this figure is expected to increase exponentially to **$15 billion**, enough to produce two billion new solar panels.[16]

According to a recently published study by the International Energy Agency (IEA),[17] six recyclers—five European recyclers and one U.S. recycler with global operations—indicated having a combined solar recycling capacity of between **1,000 tons to 50,000 tons per year**. The study also notes companies are scaling up innovative technologies to improve the economic value of recycling through improvements in yield and quality.

- Actual recycling rates may be significantly higher, as more than 30 U.S. recyclers accept PV panels or materials from recycled panels (such as silicon scrap or metals from the PV system), according to the Electric Power Research Institute (EPRI).[18]

The solar industry, research organizations, government agencies, and other stakeholder groups are taking steps to increase solar panel recycling and apply technological advances for alternative uses for the decommissioned panels and materials. Several crystalline silicon and thin film PV recyclers operate in the US.[19] One manufacturer creates a closed-loop system through operation of a high-value recycling process which provides semiconductor recovery for use in new panels.[20]

As technological innovations continue to grow, the price of recycling will fall, and the rate of recycling will increase.

Landfill Disposal & Waste Comparison

When recycling is not feasible, solar panels that pass the TCLP may be safely disposed of in municipal landfills under federal regulations (though many states have regulations restricting the disposal of panels).

While the contribution of solar panels to overall waste streams is expected to grow, it will remain a small fraction compared to other waste types. For example, by 2050, solar panel waste is expected to total **54–160 million metric tons**, compared to **70,350 million metric tons** of municipal waste and **12,355 million metric tons** of plastic waste.[21]

As waste diversion efforts increase in the U.S., solar recycling will likely become more common.

For more information on the contents of solar panels, see "Solar Panels and Your Community."

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