# Innovations in recycling boost photovoltaic sustainability

The PHOTORAMA project addresses the impending wave of end of life photovoltaic modules by developing innovative recycling technologies. By classifying and processing various module types, the consortium aims to recover valuable materials like silicon and silver, significantly reducing waste and promoting sustainability in the photovoltaic industry. Their efforts have now been rewarded with the European Sustainable Energy Award.

The PHOTORAMA project is a consortium of 12 European companies and research organizations that aims to make a joint contribution to increasing resource efficiency and sustainability in photovoltaics. By exploiting all existing synergies, the project is now in a position to close material cycles for the photovoltaic industry. For this, the consortium received the European Sustainable Energy Award in June this year.

The EUSEW Innovation Award recognizes outstanding ongoing or EU funded projects that show an original and innovative path towards the clean energy transition and tangible results.

There is an invisible tidal wave of end of life photovoltaic modules from homeowners and power plants coming our way in the next few years. Of course, that is the expectation if modules are expected to last 25 years, but it is not the reality. Simply shifting installation forecast graphs by 25 years is not enough to determine a point in time for repowering.

First, demand side participants are known to have purchased lower grade B or C modules at a lower price despite visible defects. Second, one should also consider the huge technical improvements in the products in terms of their efficiency, which is driving many power plant operators to repower.

This and many other reasons explain the increased demand for recycling that we are seeing. For example, photovoltaic modules installed for ten years or less are starting to fail and exhibit delamination, hot spots, separated cells, etc. Some manufacturers


Image 1: Project coordinators Claire Agraffeil (CEA INES) and Manfred Spiesberger (ZSI)

have disappeared from the market. Replacing defective modules may not be seamless, even if warranties are honored. There is no reason to throw away these obsolete devices. We simply can no longer afford to do without the materials and values contained in the products.

The approach of the PHOTORAMA project to solving current problems for the recycling of photovoltaic modules is both unique and universal. The sheer number of module types used presents a recycling company with extreme challenges. A database reveals over 105,000 different module types that are currently in use. Since treatment should be simple and available for as many different PV types as possible, a robust technology must be used that can process various types. As a rule, however, the focus and practices are currently on shredding and sorting processes.

Certainly, this aids in addressing disposal needs. Glass, metal frames, and cable scrap are effectively collected and recycled. However, a PV module comprises more than just these components, and the additional materials hold significant value. For a particular type of module, the consortium found that the glass, aluminum frame, and cables with connection boxes constitute about 84.5% of the module's mass, but they only represent around 40% of the total value of the pure materials in the module.

In contrast, the 2.5% corresponding to silicon and the 0.03% silver alone account for around 60% of the value, as seen in image 2.

It is therefore clear that photovoltaic modules must be processed to separate and prepare as many materials as possible for sale. However, technology alone is not sufficient. For industrial scale operations to be viable, the process must also be economical. The values mentioned above can only be realized if the required purity for the markets is achieved. Thus, we have focused on a step by step dismantling of the modules.

Image 2: From left: 6 g silver, 0.05 kg copper, 0.5 kg silicon, 2kg foils, 14.5 kg glass

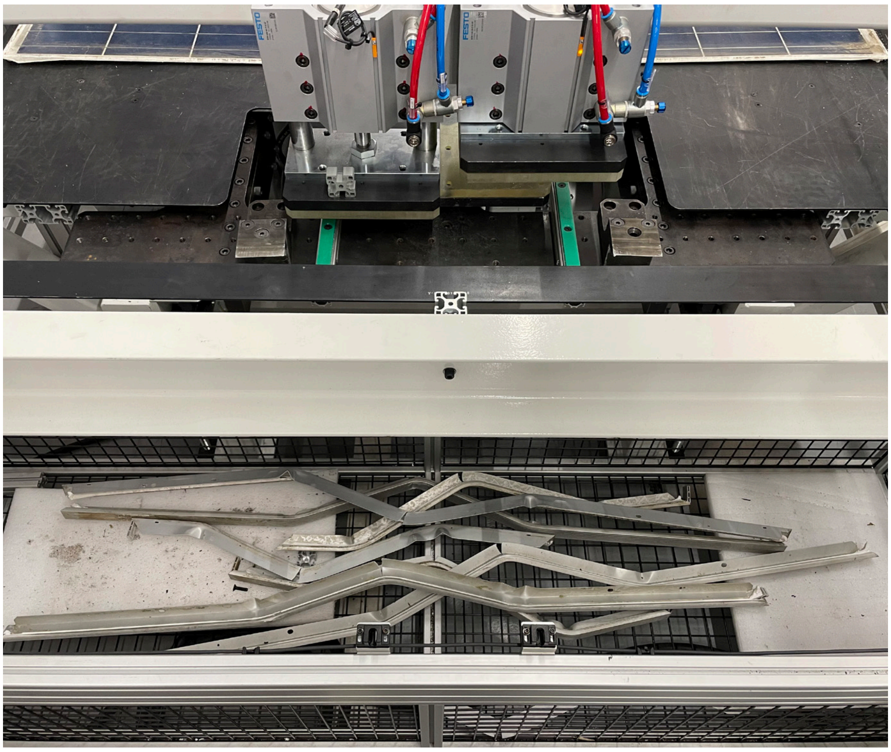

Image 3: Frame parts after treatment

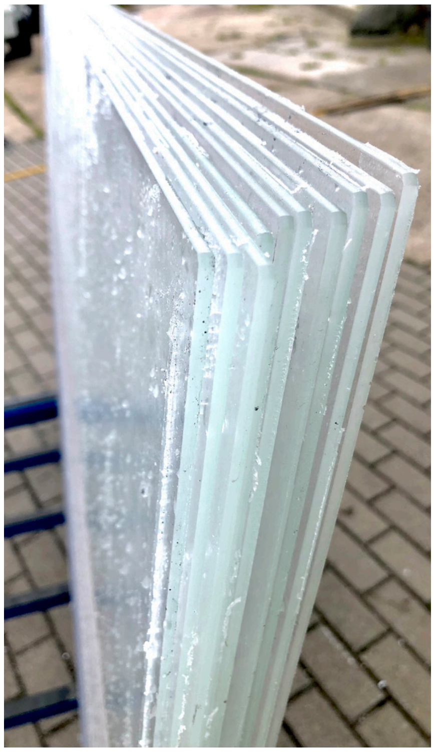

Image 4: Glass panes after water jet treatment

At the beginning of our process, data must be collected. Classifying PV modules into thin film and silicon based modules is the first step. Non destructive analysis helps to distinguish between the different cell systems, such as CdTe, CIGS, Si ALBSF, SI HJT and so on. This is important for preparing campaigns to keep the materials separate for subsequent chemical treatment. For the Si modules, a distinction is also made between single glass and double glass modules.

The connection boxes with the connection cables and plugs are removed from all modules using a flexible, simple system. The frames must then be removed from framed modules. Both machines were developed and built by our partner, Mondragon Assembly.

The challenge of completing this pre treatment without breaking the glass was successfully accomplished, as seen in image 3. For deframed modules, the next step follows immediately. A water jet process developed by partner LuxChemtech and implemented by Mondragon Assembly is now used to separate all layers of the module, resulting in pure glass panes, as shown in image 4.

The attentive reader will ask how one could treat a double glass module with the water jet system. For this type of module, a system for separating the rear glass using a wire saw was developed in collaboration between CEA, Mondragon Assembly, and LuxChemtech. In this process, a 'single glass' module, which is necessary for water jet processing, is essentially made from a double glass module. This follows the steps described above.

In this process, the individual layers of the complex composite are separated using a special nozzle technique. This allows for the detachment of the plastic layers, cells, and finally the glass. The copper containing connecting lines are very clean and can be directly recycled. At this stage, we obtain high purity glass, which is evaluated by our glass specialist, Maltha. Image 5 shows the PV glass running over the line at Maltha in Lommel.

Why is the focus of the glass so important? Through recycling, the Flat Glass Sector's European operations save almost 300,000 metric tonnes of raw materials per year,

Image 5: Glass from Photorama treatment at the industrial line at Maltha

thereby avoiding 70,000 metric tonnes of $CO_2$ emissions. And a lot of energy is saved, since the melting point of glass cullet is much lower than the raw material mixture consisting of sand, limestone, and other mineral additives.

Finally, we take care of the blasted material and use the different densities to harvest the pure cell material on a so called wet separation table. This contains silicon and the respective contacts. Now we have to continue working with chemical methods.

For the respective thin film PV modules, which are usually double glass modules, flashes of light are used to weaken the connection between the corresponding photoactive layers and the glass. The demo plant is shown in image 6. Finally, these modules can be opened up as a whole, and a chemical treatment is carried out that can dissolve the compound semiconductors and contact metals.

HSEQ is also of increasing importance worldwide. That is another reason why the consortium relies on environmentally friendly methods. Using light and water for a unique recycling process. In addition, biodegradable substances play a major role in hydrometallurgy, because health is one of the most important assets.

In this context, two partners, CEA and SINTEF, successfully developed a highly environmentally friendly silver extraction process and implemented it with LuxChemtech in a demonstration plant. This method eliminates the need for nitric acid, which releases NOx, to dissolve silver from the metal fractions.

The new leaching process uses the principle of selective dissolution of silver (Ag) to Ag(I) ions by using FeCl3 as an oxidant in a deep eutectic solvent (DES). The resulting silver containing solution is then sent directly to an

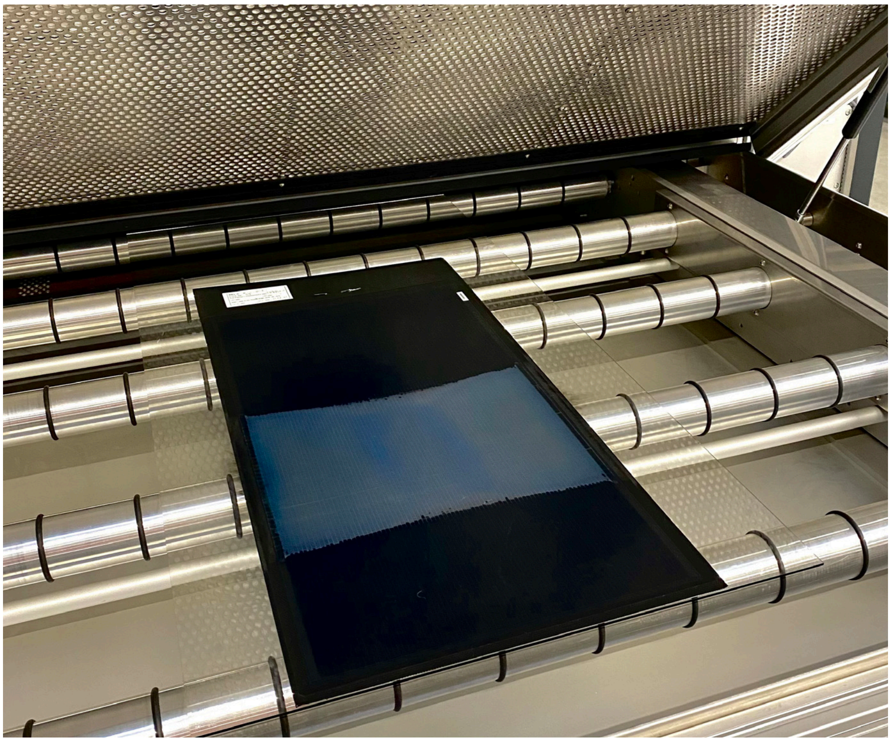

Image 6: Treated area in the centre of a CIGS module


Image 7: Test equipment at Sintef for electrowinning of silver

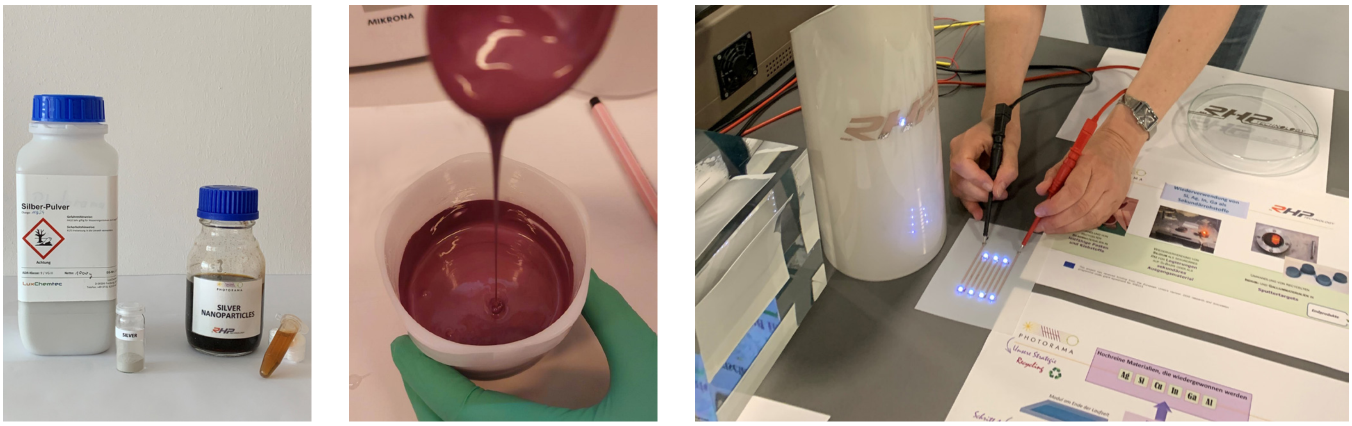


Image 8: Transformation of recycled silver into high value products, such as conductive pastes, silver nanoparticles and nanowires

electrolysis cell, where the silver is extracted by electrowinning from the DES electrolyte, as shown in image 7.

The semiconductor elements are extracted from the thin film modules in a similarly environmentally friendly way. A process by LuxChemtech is used here, which uses biodegradable methylsulfonic acid. Here, too, a solution is prepared and then electrochemically processed.

Secondary raw materials obtained from the recycling process are transformed into new products and reinjected into the value chain. The project partner RHP-Technology GmbH develops high value products based on recycled materials, such as silver based conductive pastes, see image 8, for PV and electronic industry, high performance silicon based alloys, as well as In and Ga sputtering targets for thin film deposition.

Naturally, these efforts collectively enhance opportunities for successful international cooperation. One proposed innovation is the demonstration of a semi industrial recycling plant to evaluate the feasibility of recycling and reusing module materials through newly developed recycling steps. The consortium, drawing on its extensive experience in recycling, is prepared to host a public event at the demo site in Germany in April 2025.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958223.