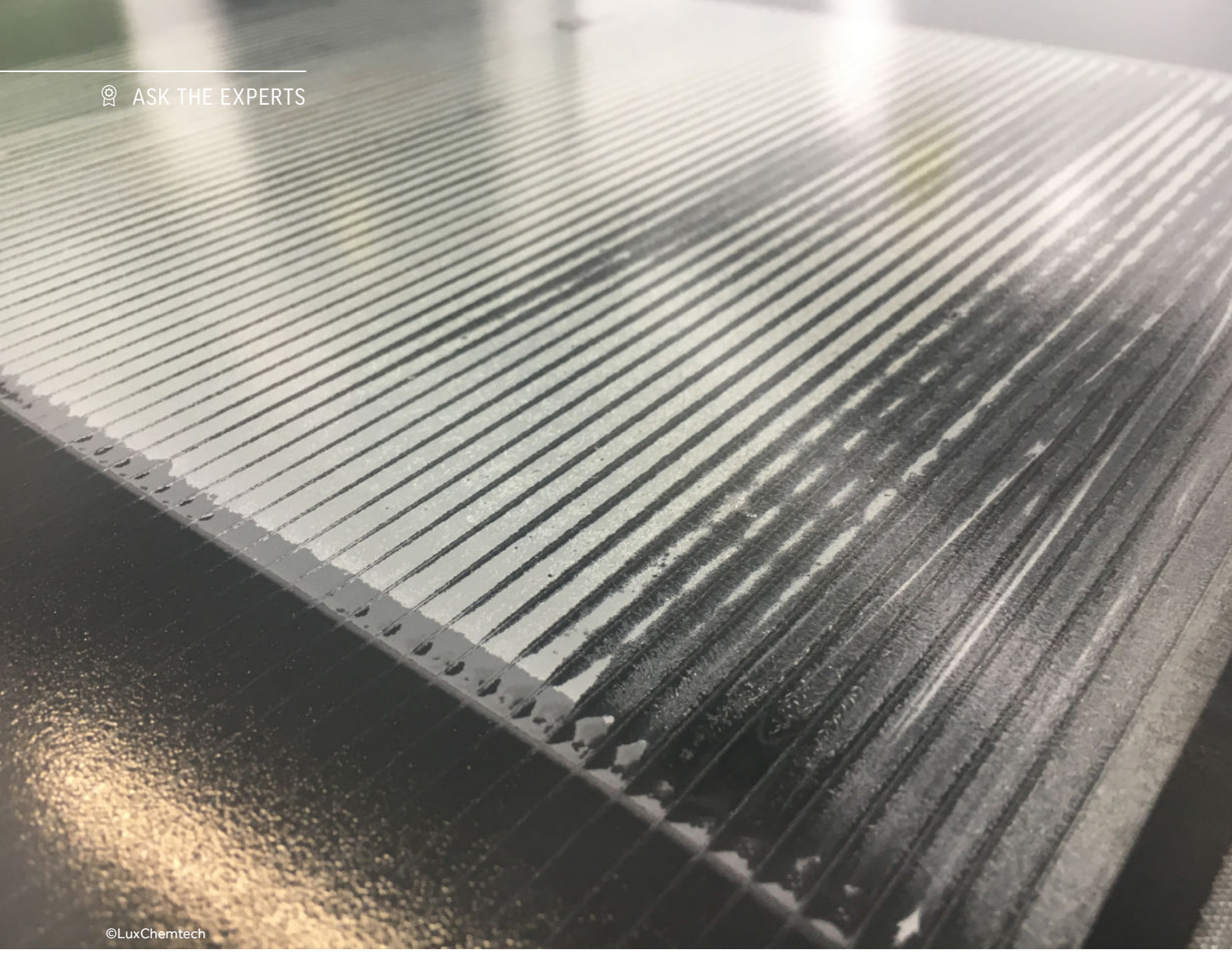


CIGS-module with part of optical treatment

Exploring the potential for PV recycling

The PHOTORAMA project was set up and funded to help support the adoption of sufficient recycling channels for Photovoltaic (PV) products. PES was fortunate enough to speak to some of the key stakeholders in the initiative, to learn more about the possibilities and what the future hopefully holds for PV recycling.

PES: Welcome to PES everyone. We're looking forward to gaining more insight into how PV panel recycling can be improved. Perhaps we can begin with a look at some of the challenges to this. From your perspective, what would you say these are?

Claire Agraffeil, CEA: PV recycling is a young field, mostly because of the unusually long lifetime of the PV devices, which is about 25 to 30 years. The volume of available PV waste is still considered too low to develop a proper business, however it is growing year on year and expected to reach several million tons in the coming decades.

Nowadays, PV waste is either treated through existing or dedicated lines, using mainly shredding/ crushing processes identified as

down-cycling or stored and sometimes landfilled. Considering the current practices, the critical and valuable materials embedded in the PV panels such as silicon, silver, indium, gallium are not recovered and it will dramatically lead to irreversible losses of these precious resources.

The challenges are therefore to avoid mixing materials to preserve their purity as much as possible, while taking into account the mass balance of the different PV waste streams, such as configuration, technologies, size etc. and associated revenues.

PES: This is why the PHOTORAMA project has been set up to help isn't it? What is your approach to meet these challenges? The consortium is made up of 13 organisations, can you briefly tell us about them and how they have been chosen?

CA: Yes, definitely. The PHOTORAMA project has been set up to address the needs and the technical challenges of PV recycling and more globally of PV waste management. Our main target is to demonstrate the potential of up-cycling by implementing new ecosystems of innovation and providing new business perspectives. For that, we are designing and developing robust technological solutions keeping a reasonably fast throughput to produce high-quality, high-purity secondary raw materials.

Yet, we are well aware that to answer the challenge appropriately, we need more than a single strategy, and this is why we are working on extensive and smart technological combinations.

We have built a strong consortium with a comprehensive framework that brings together multiple and diversified competences at all stages of the PV value chain. We gathered academic organisations such as CEA, SINTEF and Idener R&D, equipment manufacturers such as Mondragon Assembly and DFD and industrial end-users such as LuxChemtech, Maltha and RHP technology, to develop strong and marketable technological solutions.

Soren, the eco-organism in charge of the collection phase and Enel Green Power, PV manufacturer are also part of the team to consolidate our circular approach. Economic, environmental and social analysis are continuously carried out by Bifa and ZSI to adjust and strengthen the technical solutions as a multi-level approach to foster a sustainable model. Of particular reliance are dissemination and exploitations activities, managed by ENEA, to develop industrial symbiosis in our consortium and drive to successful commercial opportunities.

PES: Efforts have been made for years to get the problem of future waste volumes under control. You have big plans. What are the special innovations of your approach?

Wolfram Palitzsch, LuxChemtech: Due to the layered structure and the encapsulation of the photoactive elements and power lines, it is a great challenge to design a reasonable recycling treatment. As practice shows, this cannot be achieved with simple shredding processes. We are more likely to pursue the strategy of dismantling in layers. And that with an unmanageable variety of product types. That is why we use the synergies of our partnership and bring interdisciplinary methods together. High-tech products require high-tech recycling.

PES: What is the timeline that you are working to and when do you think we will begin to see changes in the recycling landscape for PV?

Karsten Wambach, bifa: With the completion of the project a commercialisation of the results is intended. Within three years of the end of the project, we expect a further increase in waste volumes and also an impact of the developed technologies on the market.

PES: What role does sustainability play in your processes? With what effort do you want to convert materials from waste into secondary raw materials?

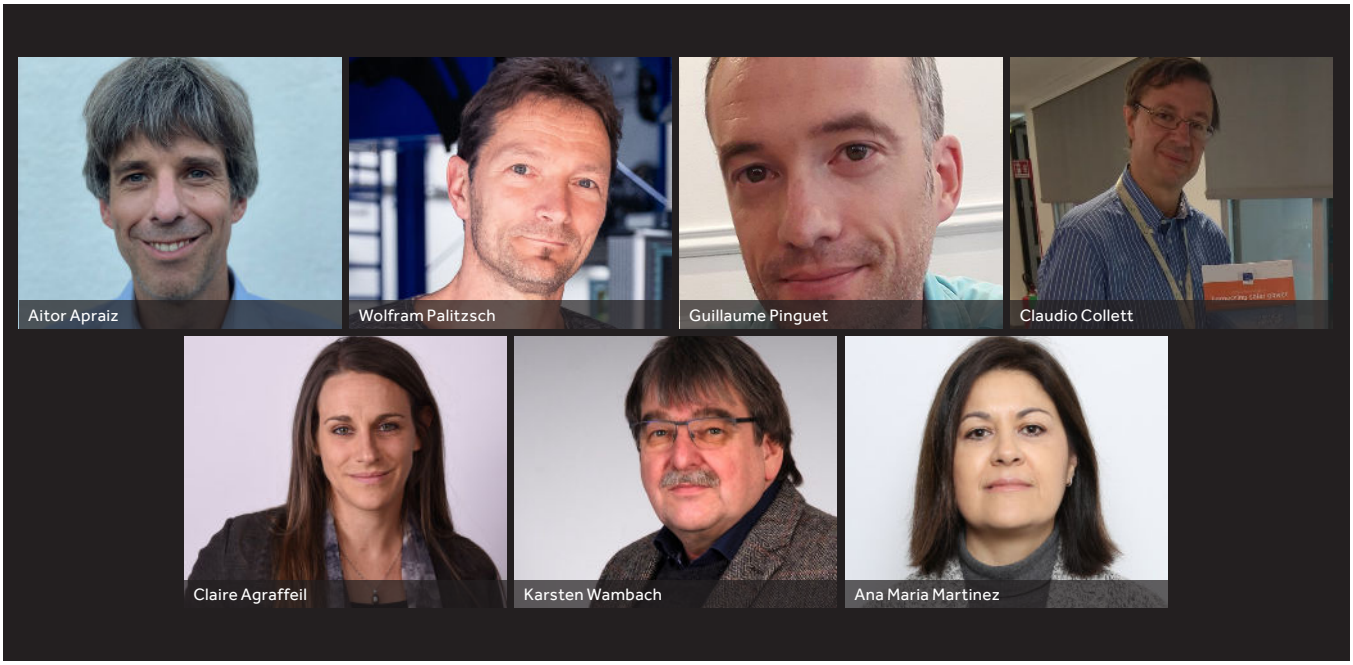
KW: The topic of sustainability and the evaluation of possible solutions are the focus of our work. Therefore, we not only examine the technical aspects of PV recycling, but also evaluate the progress from an ecological perspective, consider aspects of resource and environment protection and give an economic outlook.

The process runs alongside the project and always compares the results achieved with the current status quo in the field of PV recycling. This also includes information and input from different stakeholders and users, via surveys and workshops, with the aim of increasing awareness and the acceptance level of the project and its technical solutions for practice.

PES: What role do manufacturers and PV producers play in this?

Claudio Colletti, Enel Green Power: While the transformation of the energy system will reduce fossil fuel consumption, it will also require the use of up to six times more minerals in 2050 compared to today. The new technologies will in fact require 'traditional' materials such as steel, copper or aluminium, as well as previously less used raw materials, such as critical metals and silicon used in photovoltaic modules.

PV value chain industries are actually committed to significantly reducing resource consumption. Adopting a circular and



sustainable model as an integral part of the energy transition process will allow us to lower our dependence on raw materials, as well as to reduce the waste at the end of life of PV modules.

The PHOTORAMA commitment to a continuous increase in the quality and percentage recovery of process waste from PV End-of-Life is fundamental to ensure an efficient transition to minimise the exploitation of natural resources in accordance with sustainable objectives, ensuring not only the competitiveness of the business model, but also full social and environmental sustainability across the full value chain.

Enel Green Power and other industrial partners in PHOTORAMA are investing in the present innovation project, aiming not only to further increase recycling percentages, reducing the future PV waste, but also to regenerate high-quality, pure materials with high added value, which can be reused in industrial processes and where possible re-injected in the PV value chain itself, thereby reducing the need to extract new natural resources.

PES: There is a general trend to place more value on resource efficiency, especially when it comes to secondary raw materials. Are there any specific sustainability improvement initiatives you have tried or are currently pursuing that you can tell us about?

WP: Yes, of course. And yes, this trend will determine our future. The use of material matter that is present in waste has occupied us for a long time. At the same time, it sounds very simple: use the energy donated by the sun to convert apparently unusable mixtures of substances into usable new mixtures of substances. This can be separating and cleaning to reuse a product for the same purpose. But it can also be further processed into a completely new product.

The main thing is that as much waste as possible can be reused. For pure silicon waste, which is generated right at the beginning of the production chain for photovoltaic modules, we have been doing this successfully for quite some time and in large tonnages. Now we want to do the same for end-of-life PV modules.

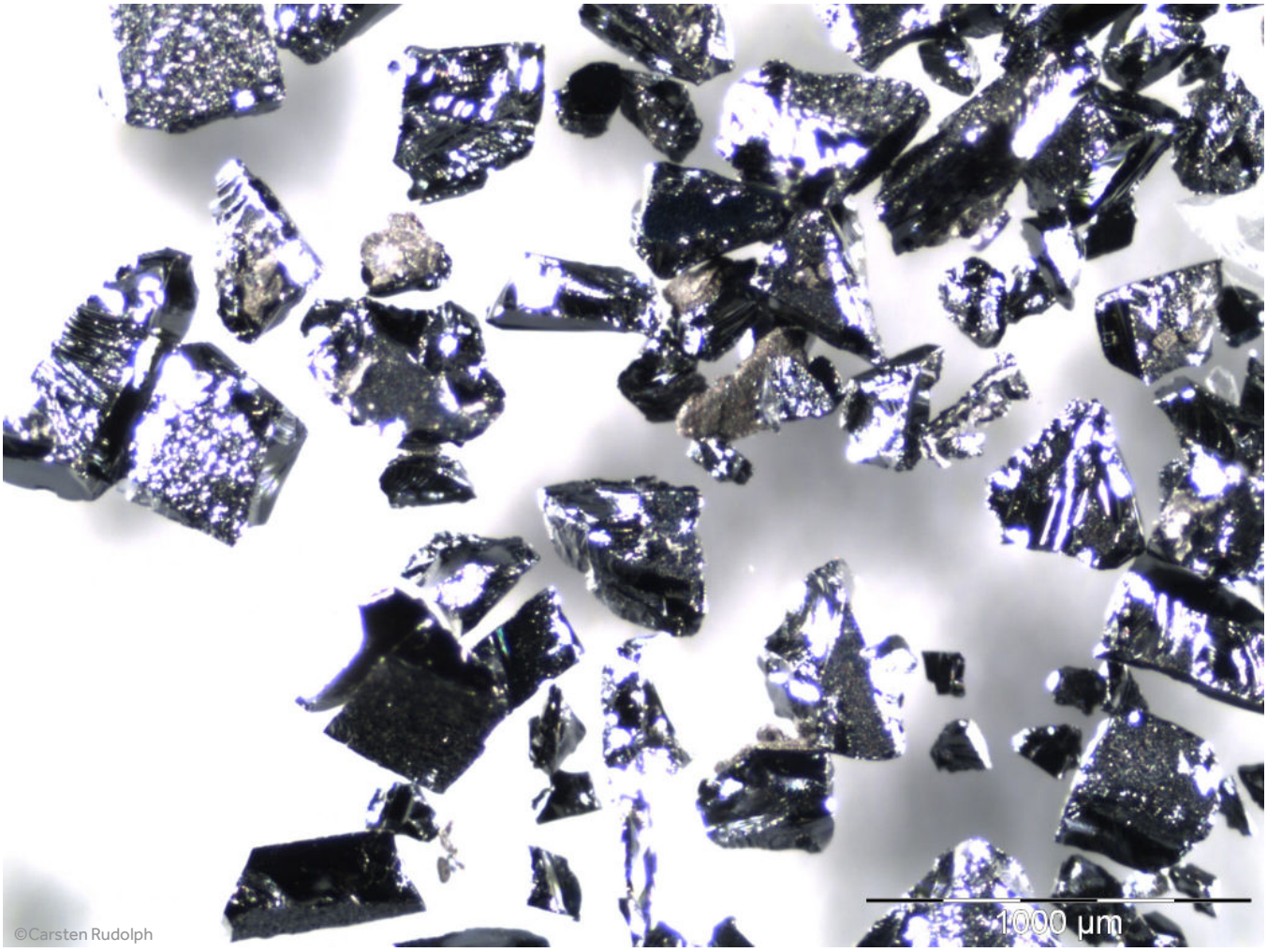
PES: There will no doubt be challenges ahead, not least in terms of technology compared to current recycling practices, is that right?

KW: Yes, it is certainly necessary to solve the technical challenges first and foremost. In addition to general feasibility and process stability, throughput rates in particular still remain a challenge at this stage. Of course, this also has a direct impact on economic competitiveness. For example, in comparison with virgin material production. As long as there are no regulations for the mandatory use of recycled materials, the overall cost of recycling must be lower than the cost of purchasing raw materials from conventional sources.

Another challenge is to meet the quality requirements for the input materials used in production. Even the smallest impurities that cannot be removed in the recycling process can prevent direct recirculation of raw materials.

PES: What do you hope to achieve from the pilot line?

Aitor Apraiz, Mondragon Assembly: For Mondragon assembly, the ramping up of such a pilot line represents a big opportunity to become a key reference on the market for disassembly solutions dedicated to PV recycling. It will allow a real test bench and real evaluation of the technologies for recycling lines.



Isolated silicon grains with silver residues from PV waste material: LuxChemtech

Purified solar glass from thin film PVB

We expect to continue the collaboration with LuxChemtech and the other partners after the project, to further improve the technical performances, but also to deepen the study of the replicability and scalability of the current solutions.

PES: With many PV technologies in use, what kind of waste can be processed with your proposed solutions?

WP: You mean the difference between thin-film photovoltaics and modules based on crystalline silicon? Let's put it this way, a recycling company should be able to process all types. So we analysed the main differences and decided on several key technologies that can be used to process all common PV modules.

The prerequisite for this is, of course, an incoming inspection. It must be known which module is to be assigned to which type. It would be desirable if we could read a kind of product pass. But you have to address that to the manufacturer.

PES: One aspect of recycling for the industry that presents a big challenge is delamination. Are you close to any innovations in technique that might help?

Guillaume Pinguet, DFD: Recycling PV panels is definitely challenging due to their multilayer structure, based on materials that involve physical characteristics that are dramatically different: glass, encapsulating polymer (EVA), cells and electrical contacts, backsheet.

As a result, the efficiency and the robustness of the delamination step is of prominent importance in order to recover items of interest. The PHOTORAMA project enables the development and implementation of novel solutions for this delamination, amongst other the supercritical carbon dioxide technology.

Once the pressure and temperature exceed their critical values, that 73.8bar and 31.1°C, respectively, the carbon dioxide exhibits gas-like diffusion properties and liquid-like densities, noticeably. It implies that supercritical carbon dioxide acts as a solvent in front of solutes that have a low polarity such as fluorinated polymers or EVA.

The solvation power of the supercritical carbon dioxide may be modulated by adjustment of pressure and temperature time. It is able to separate glass and backsheet from EVA layers thanks to a novel foaming process driven by supercritical carbon dioxide. It represents a significant breakthrough towards sustainable solutions due to the nontoxic, inexpensive and reusable character of carbon dioxide.

PES: And for metal recovery from solar cells, is that also a focus?

Ana Maria Martinez, SINTEF: Europe is highly dependent on metal imports, in general, and particularly on precious and critical metals. With the current PV growth projections in the coming years, the demand of metals needed to cover the European demand will be huge. Recovering those metals from PV-waste, including off-spec PV panels, will be a precious material resource, as well as an important step towards circularity.

SINTEF is developing an innovative electrolysis technology that will be able to recover silver metal from c-Si PV panels with a purity of 98-99.9 %. The Ag obtained can be used in PV and other markets. Moreover, the PHOTORAMA project aims at recovering silicon, indium and gallium, those three metals being classified by the European Commission as critical due to their importance in the EU economy and strong dependency on imports.

PES: The consortium includes equipment manufacturers, what are their objectives for entering the very new market of PV recycling?

AA: For us, as equipment supplier, the main objective is to develop a new product line inside the solar business unit. We have developed a very wide catalogue for PV assembly solutions, and this project will allow to further enlarge such a portfolio with disassembly solutions for PV recycling.

Currently there is no such offer for turn-key solutions able to treat and recover PV modules, so we expect to become one of the first providers with a validated solution, which can be widely replicable in several markets.

PES: It's not only research organisations that are important for new developments, your consortium also consists of strong industrial partners. What were your reasons for getting involved in PHOTORAMA?

GP: The PHOTORAMA project gathers the synergistic chain of economic operators needed from the collection of PV panels to the reuse of the related by-products. The project offers the opportunity to build the industrial background of this very new recycling market. Each technical step considered alone within the PHOTORAMA project can by no means tackle the whole PV recycling issues. To elaborate this synergistic chain as well as to develop and implement new industrial applications of the supercritical carbon dioxide technology were key drivers for getting involved in the PHOTORAMA project.

PES: How do you think that the co-operation between the partners and the exchange of ideas can continue to be helpful? What are the main advantages of such partnerships?

CC: A circularity-based business model requires the utmost collaboration between all players involved. That's why we consider it essential the cooperation between organisations who share this vision, involving the full PV supply chains and promoting common initiatives to safeguard natural resources and boost the ecosystem's competitiveness. Indeed, such an approach cannot be found by looking only within a company or its area of activity. Rather it is necessary to explore synergies with other areas that the company has perhaps never interacted with in the past. Adopting a circular approach means decoupling business and resource consumption by reducing the use of finite natural resources, avoiding waste and maintaining the value of goods and materials.

This way we can create environmental benefits not only in terms of reducing emissions throughout the value chain, but also by lowering all kinds of impacts, from the consumption of natural resources, including water, through to waste generation and the loss of biodiversity.

We need to leverage all pillars: reducing the consumption of non-renewable resources and maximising the value of those already in use and of the goods produced, and extending their life by recovering resources at the end of their lifecycle.

Moreover, shifting from a linear model to a circular one, i.e. from a model based on resource extraction, production and consumption that is strongly reliant on automation, to one based on maintaining the value of products and goods through design, repair, service, reverse logistics and recycling, allows for much higher value to be placed on human labour.

PES: At the end of your project, you combine various technologies into a demonstration system. How universal will this system be? What types of end-of-life PV modules can you recycle?

WP: Our focus for this project is on crystalline Si modules and thin-film modules based on CIGS. The previous work shows very good results for these types.

Of course, we also want to transfer the results to CdTe modules, which belong to the family of thin-film modules.

PES: Can your project contribute to a circular economy?

CA: Even though PV waste management remains the weakest spot of the PV value chain, we intend to tackle the challenge with inclusive solutions integrated in a circular model. Today, solar energy is the best candidate to lead the energy transition and must be as such exemplary when it comes to sustainability practices.

While the circular economy is still at the conceptual phase in many sectors, we are demonstrating the reality of the field experience. Indeed, the entropy of the stakeholders in the PV value chain leads to many different individual business drivers and approaches. The challenge is not easy but doable! It is a question of bringing together all the players to define new perspectives and develop common interests in order to collectively achieve economic, environmental and social benefits.

PES: What legal framework would you like to see in order to set up sustainable recycling for the photovoltaic industry? Have you identified barriers?

KM: The existing European WEEE Directive (Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment) and its national implementations regulate, among other things, the prevention, recovery and disposal of waste electrical equipment.

The directive establishes minimum standards for the treatment of waste electrical and electronic equipment in Europe. It is also aimed at manufacturers and includes guidance on sustainable product design. The addition, for example, of a quota for the reuse of secondary materials in the production of new goods could create a compelling case for greater sustainability here.

Another aspect is the shipment of PV modules to non-European countries and the corresponding withdrawal of raw materials from the European economic system. Sound policies shall be developed to ensure proper treatment of PV waste all around the world applying the same standards and realising the extended producer responsibility principle. Stricter export requirements could contribute to more sustainability here in the meantime.

PES: The last Intersolar in Munich showed the potential of photovoltaics and that there could be a renaissance for Europe. It seems that your consortium has come at exactly the right time with its ambitions?

WP: Oh yes, the last Intersolar was encouraging. It was a fantastic trade fair and as exhibitors, we also had many international contacts who asked about the status of innovative recycling concepts.

We were able to arouse interest here and have already met potential customers. Yes, the consortium is active at the right time with the right topic.

We will be present at WCPEC-8 conference https://www.wcpec-8.com/ and Sustainable Energy week, Networking village https://european-sustainable-energy-week.b2match.io/

www.photorama-project.eu

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Participants		
LuxChemtech	Wolfram Palitzsch	PhD, CEO
bifa	Karsten Wambach	Managing Director
Enel Green Power	Claudio Colletti	Innovation Solar Unit Project Owner
Mondragon Assembly	Aitor Apraiz	R&D Project Engineer
DFD	Guillaume Pinguet	PhD, Process Engineer
SINTEF	Ana Maria Martinez	PhD, Senior research scientist
CEA	Claire Agraffeil	PhD, Project Manager and Photorama Coordinator