



SUSTAINABLE SOLAR — EUROPE 2024

Session 8: Closing the Circularity Loop: Research and Innovation Challenges for PV Recycling

12 December 2024

Session 8: Closing the Circularity Loop: Research and Innovation Challenges for PV Recycling



**Pietro Giovanni
Cerchier**

CEO,
9-Tech



**Rune
Søndena**

Senior Scientist,
IFE



**Alejandra
Galarza**

Research Engineer LCA
and Recyclability,
IPVF



**Cumar
Luxsacumar Sivakanesar**

President,
SiPOW



**Claire
Morin**

Junior Project Officer,
SolarPower Europe



Pietro Giovanni Cerchier

CEO,
9-Tech

SUSTAINABLE
SOLAR _____
EUROPE 2024

EVERPV project: advances on upcycling technologies

12.12.2024

Pietro Giovanni Cerchier
CEO 9-Tech

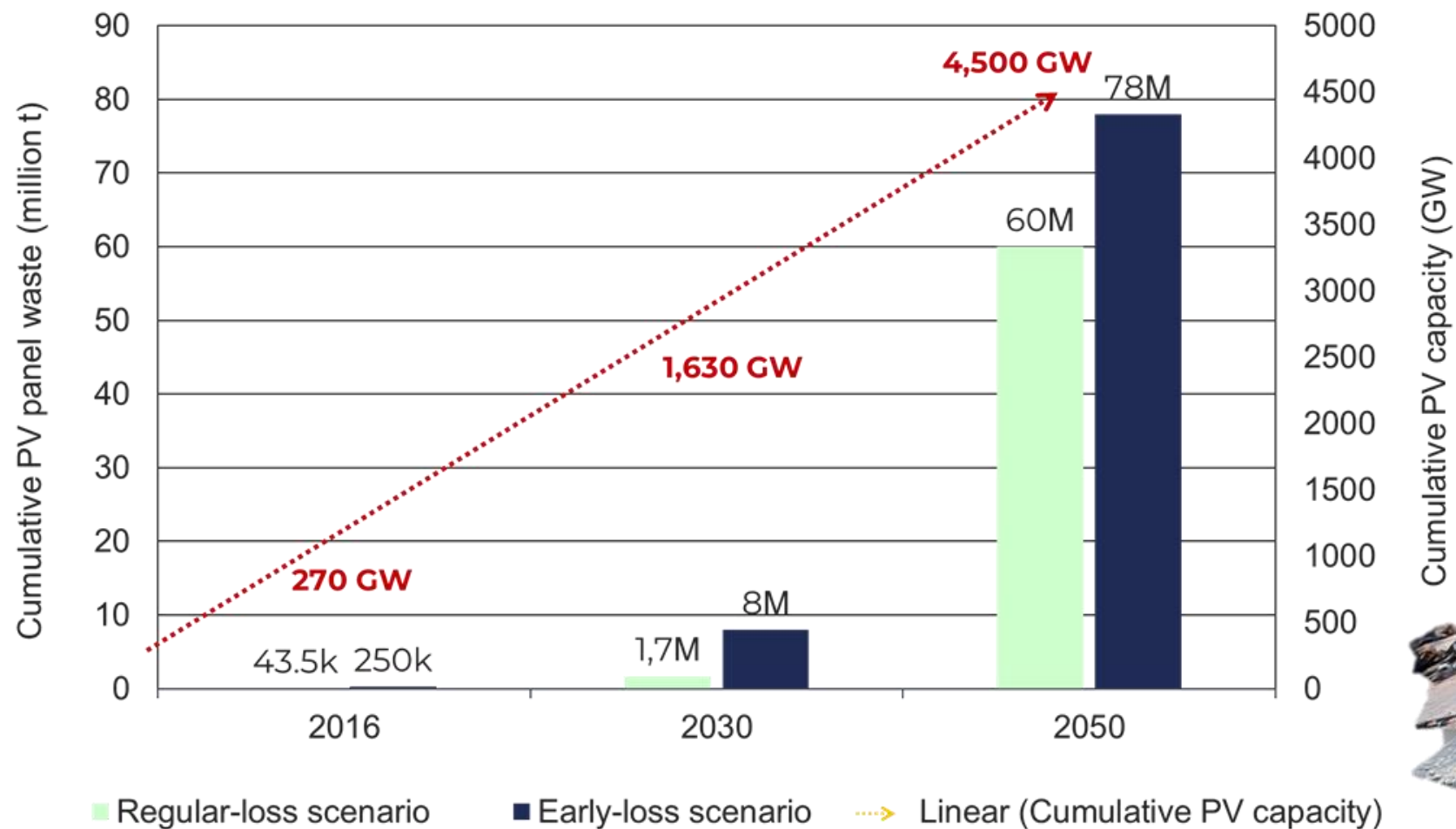


**Funded by
the European Union**

Funded by the European Union under Grant Agreement No 101122208. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.



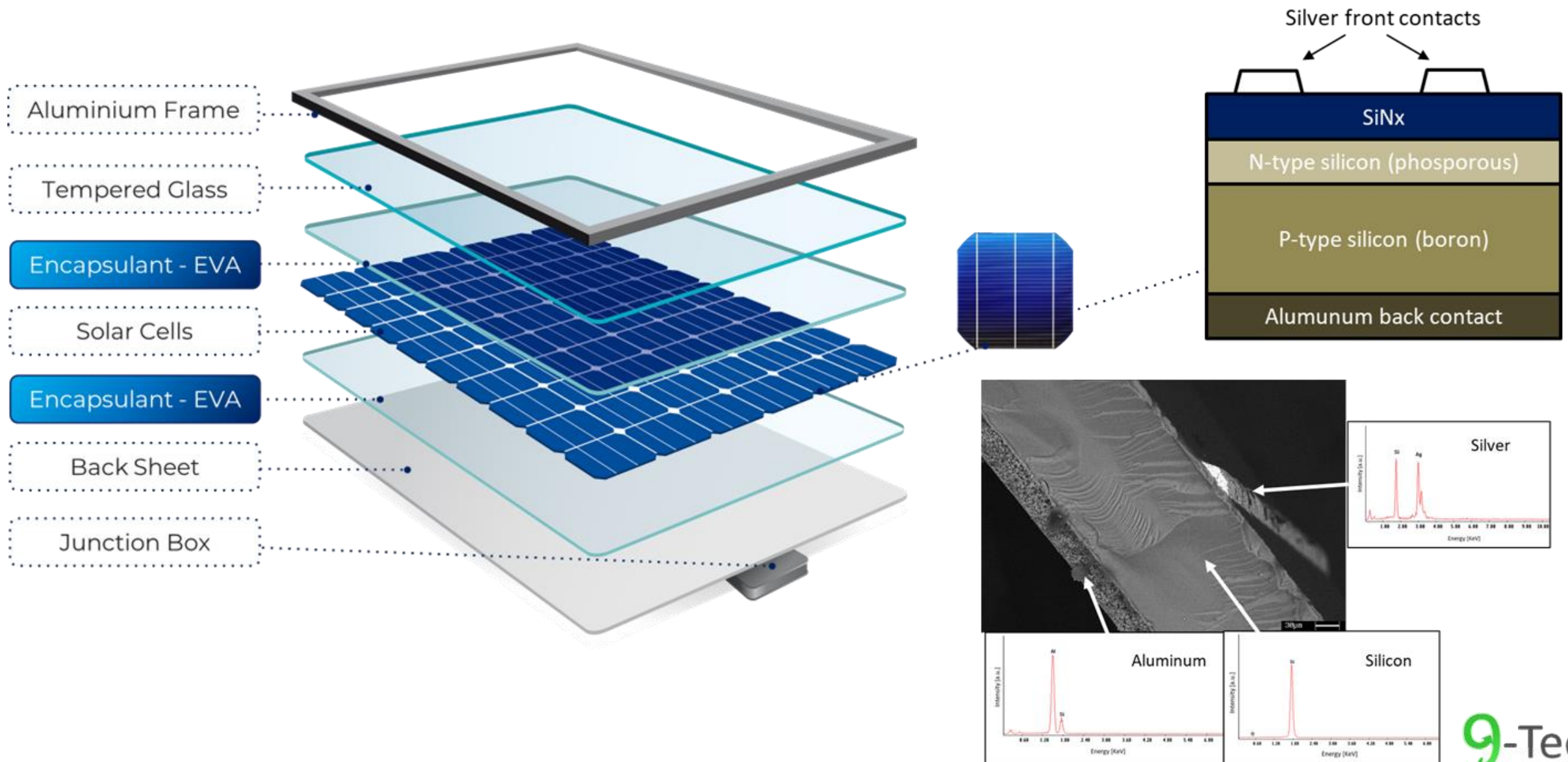
PV waste forecast



**78M tons of PV waste
by 2050
(10M in EU)**



Photovoltaic (PV) technology



9-Tech

9-Tech is a start-up of engineers and researchers that studies and builds prototypes, in particular develops plants to **recycle electronic waste**.



Team



Pietrogianni
Cerchier
CEO



Francesco
Miserocchi
CTO



Rosa
Lubrano
CFO



Alberto
Nalon
CMO



Luca
Pezzato
CSO



Francesco
Nisato
Design & construction
of prototypes



Nicola
Levorato
President of the board



Margherita
Turatello
Administrative



Marco
Sinico
Marketing and comms



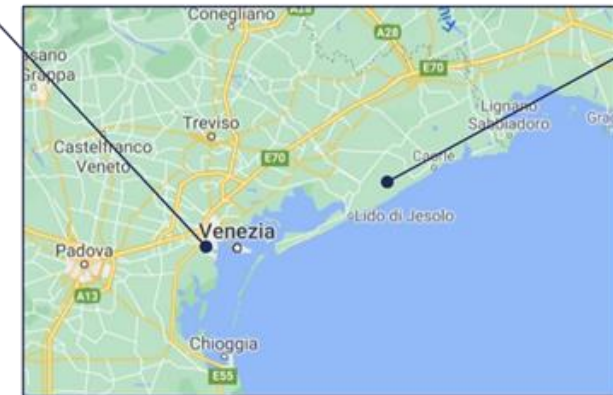
Vittorio
Cerchier
Project
Manager

Facilities

Fusina (VE)
Pilot plant & Labs

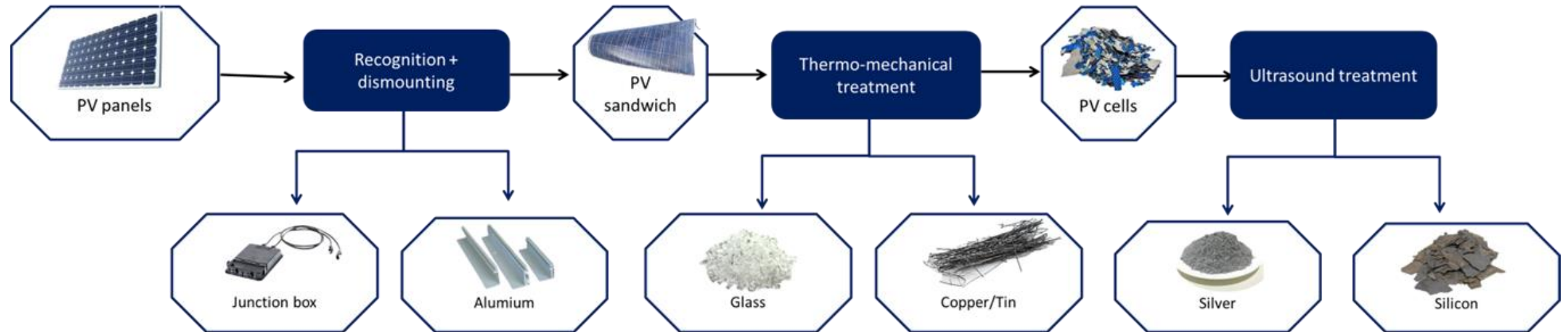


Eraclea (VE)
Headquarter
& Workshop



9-Tech solution

9-Tech developed a process for thermo-mechanical recycling of PV panels that aim to valorise all inorganic materials.



9-Tech pilot plant



PV panels treatment showed good recovery yield (~87%) and purity of raw materials suitable for re-use in other applications.

Moreover the process showed low energy consumption, comparable with those of mechanical treatments.



Aluminum



Junction boxes



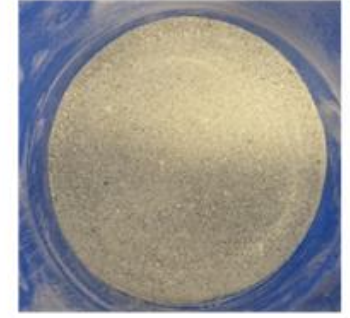
Glass



Copper



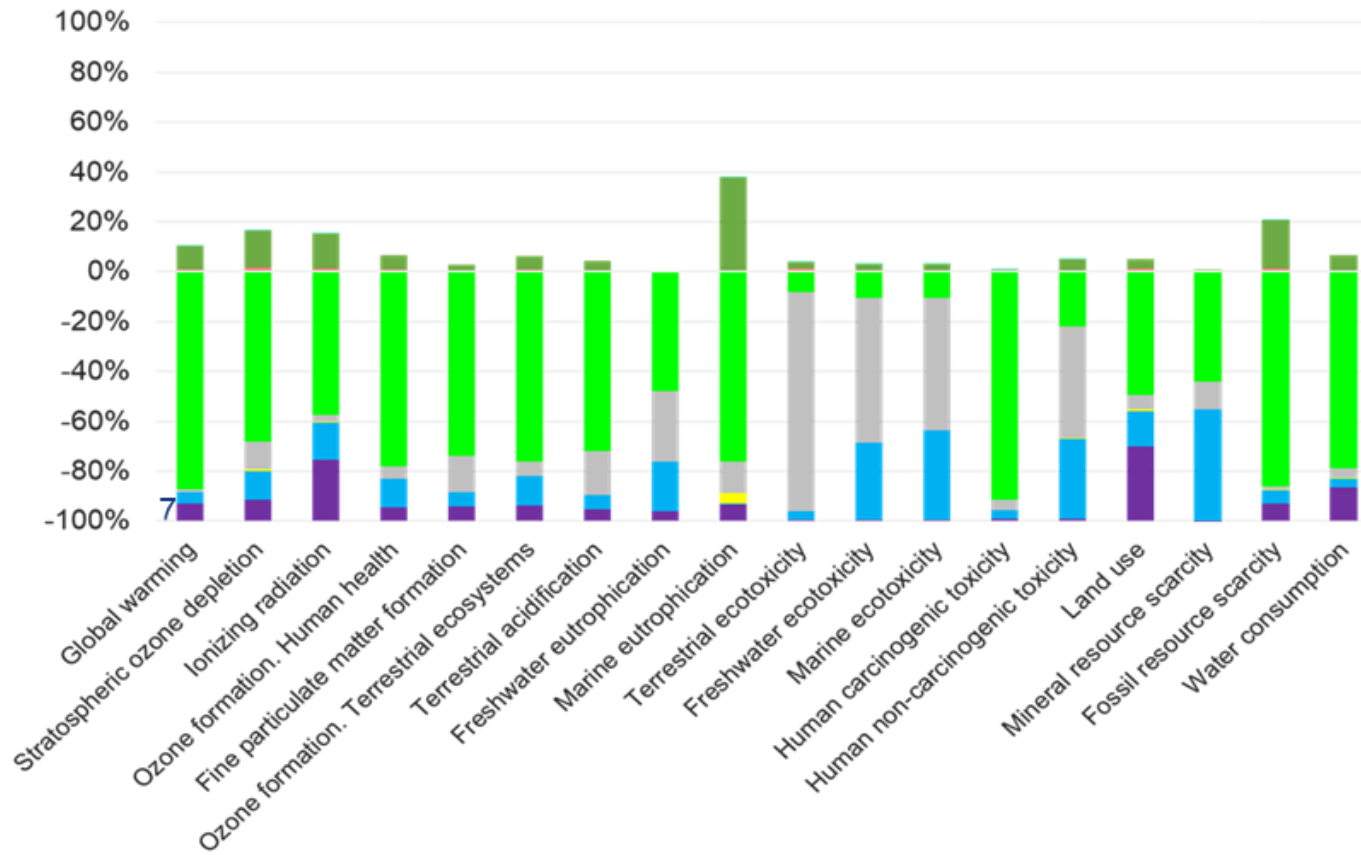
PV cells



Powder

Enviromental impact

The environmental impact was determined with LCA and proved that the process is environmentally advantageous.



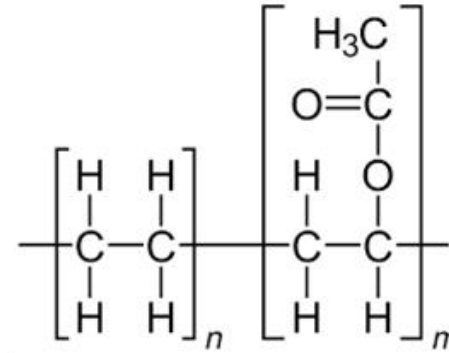
→ The process can be further improved with plastic recovery

Ref.: Mazzi A., Barbiero C., Miserocchi F., Nisato F., Tassinato G., Cerchier P. (2024). Life cycle assessment of Al-Cu-Ag-Si recycling process from photovoltaic waste. *Resources, Conservation and Recycling* 211.

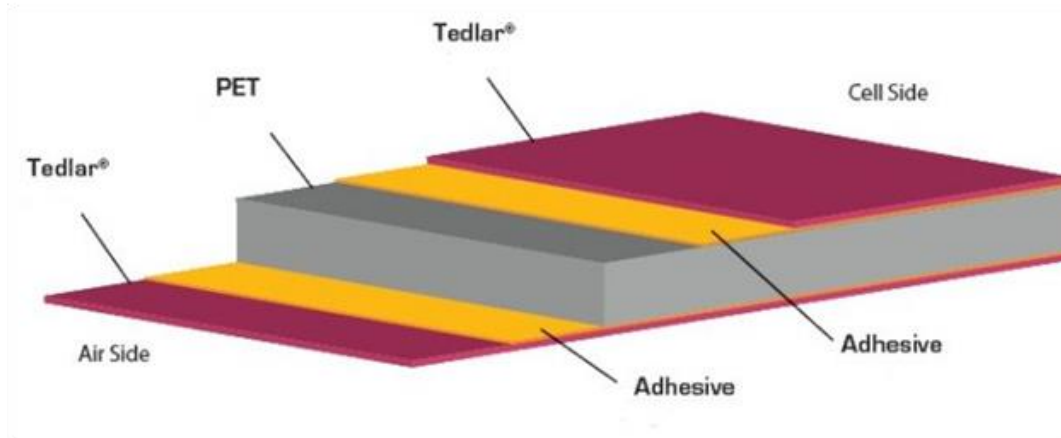
How to improve the process?

Two types of plastic:

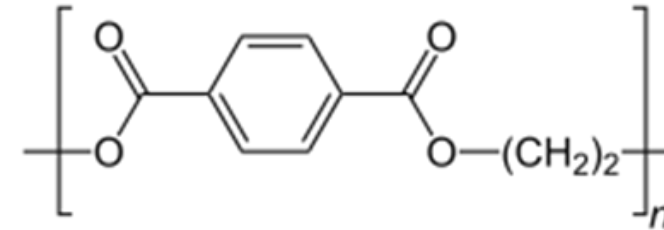
- **Encapsulant** → Typically EVA



- **Backsheet**

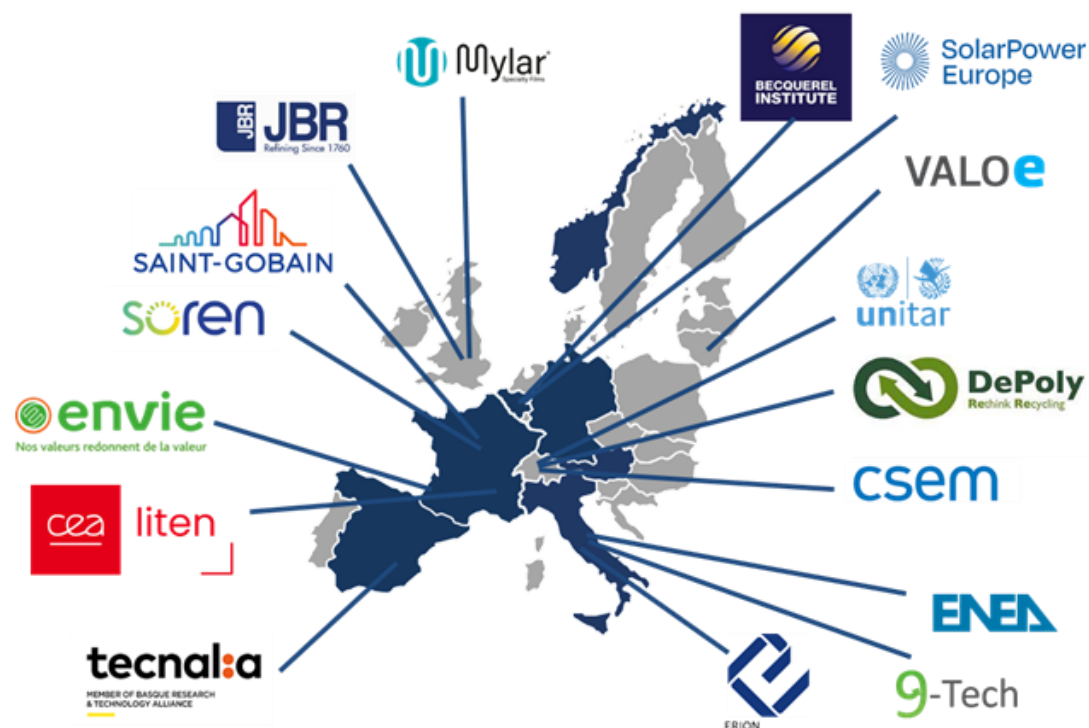


PET can be easily recycled



EVERPV Project

Call: HORIZON-CL5-2022-D3-03 / Sustainable, secure and competitive energy supply



Project Duration: 01st of September 2023 - 01st of September 2026 (36 months)

Funded by: European Climate, Infrastructure and Environment Executive Agency (CINEA)

Coordinator: CEA (French Alternative Energies and Atomic Energy Commission)

Contacts: jeremie.aime@cea.fr



EVERPV objectives

Main objective:

Provide Europe with efficient and sustainable technologies for the recovery, from end-of-life PV panels, of high purity and high integrity material, components qualified to be reused in several applications, including the PV industry.



- Develop two delamination technologies to TRL 7 to recover glass, metal and polymer fractions
- Recover:
 - Glass
 - Silver
 - PET
 - Fluorinated polymers
 - EVA
- LCA & cost, social studies



Glass :

Goal for recycling : < 1% impurities

Goal for recovery : Flat glass manufacturing using % of recycled glass



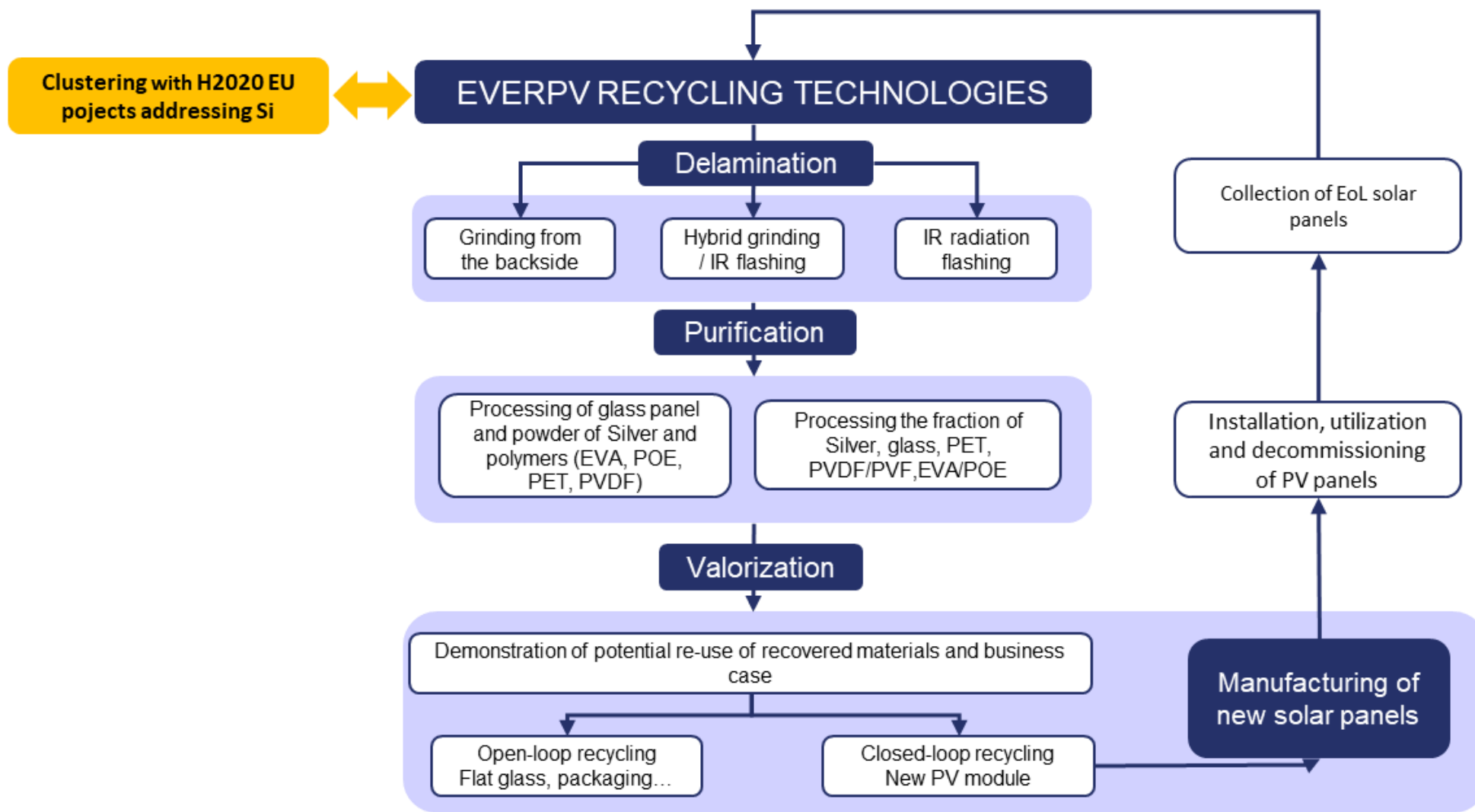
Polymers :

Goal for recycling : separate the fluoropolymers from others

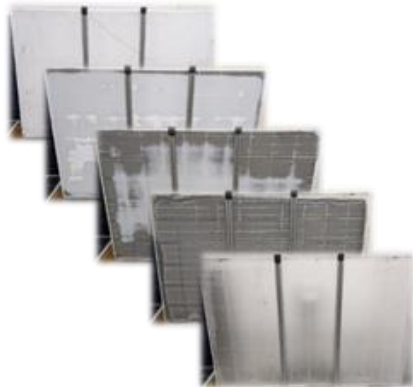
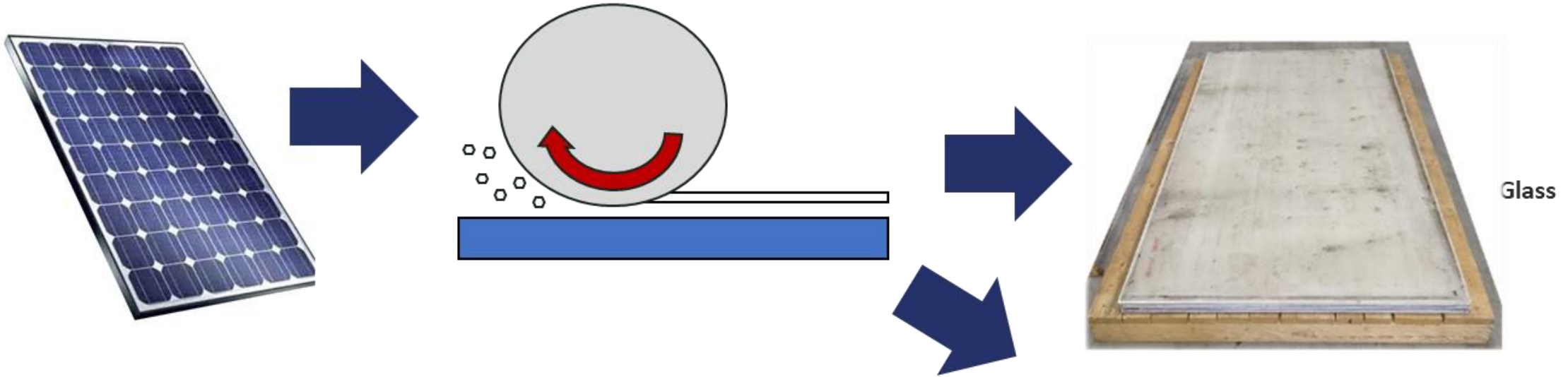
Goal for recovery :

- Pyrolysis → « oil residue » to re-manufacture polymers
- Energy generation (downcycling)
- Chemical processes to recycle PET and fluoropolymers of backsheet and encapsulant

EVERPV concept



CEA grinding process

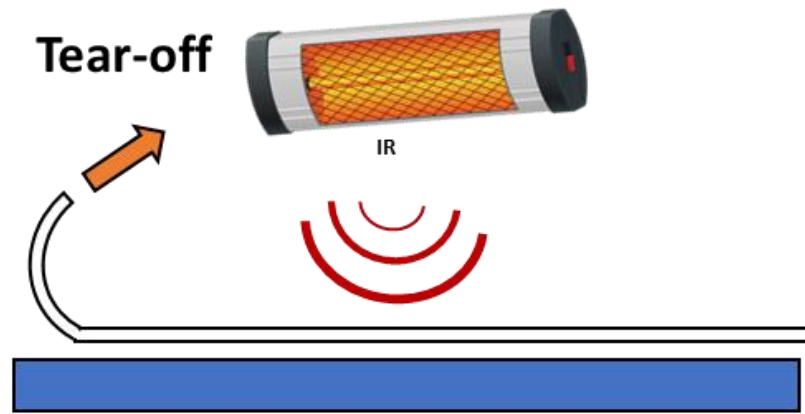


5 fractions are recovered:

1. Backsheet
2. Back side of EVA
3. Cells
4. Front side of EVA
5. Cu Ribbons

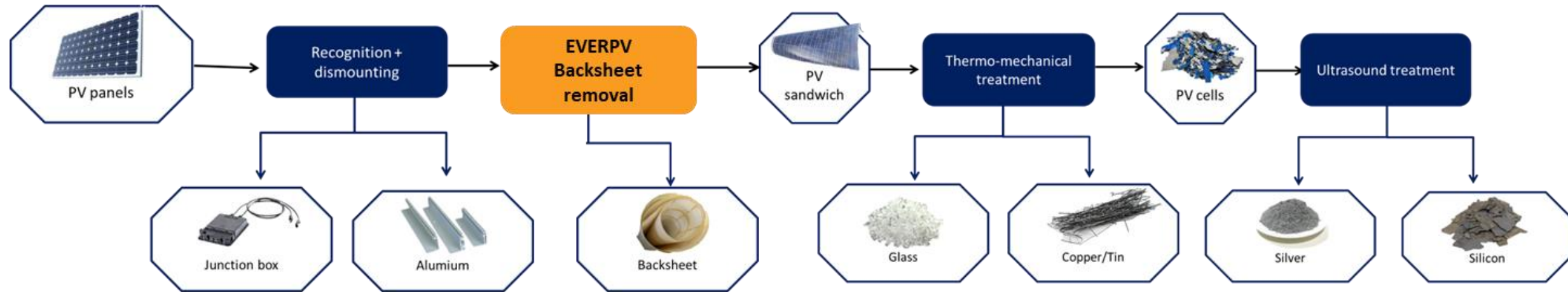


ENEA thermo-mechanical Infra Red based technology

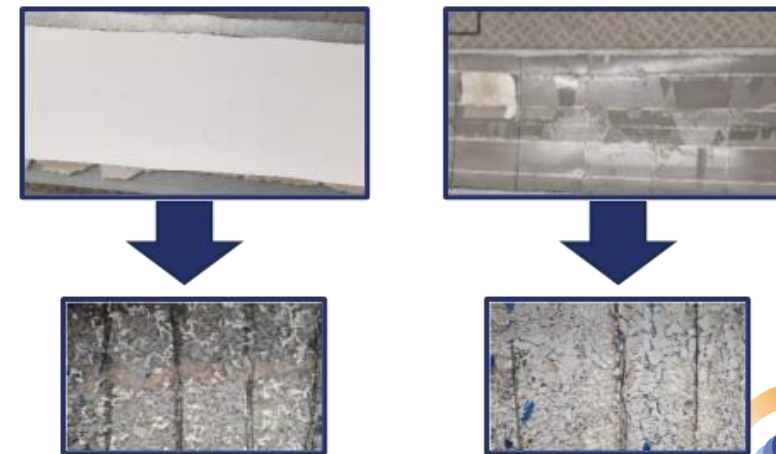


Backsheet foils

EVERPV impact on 9-Tech process



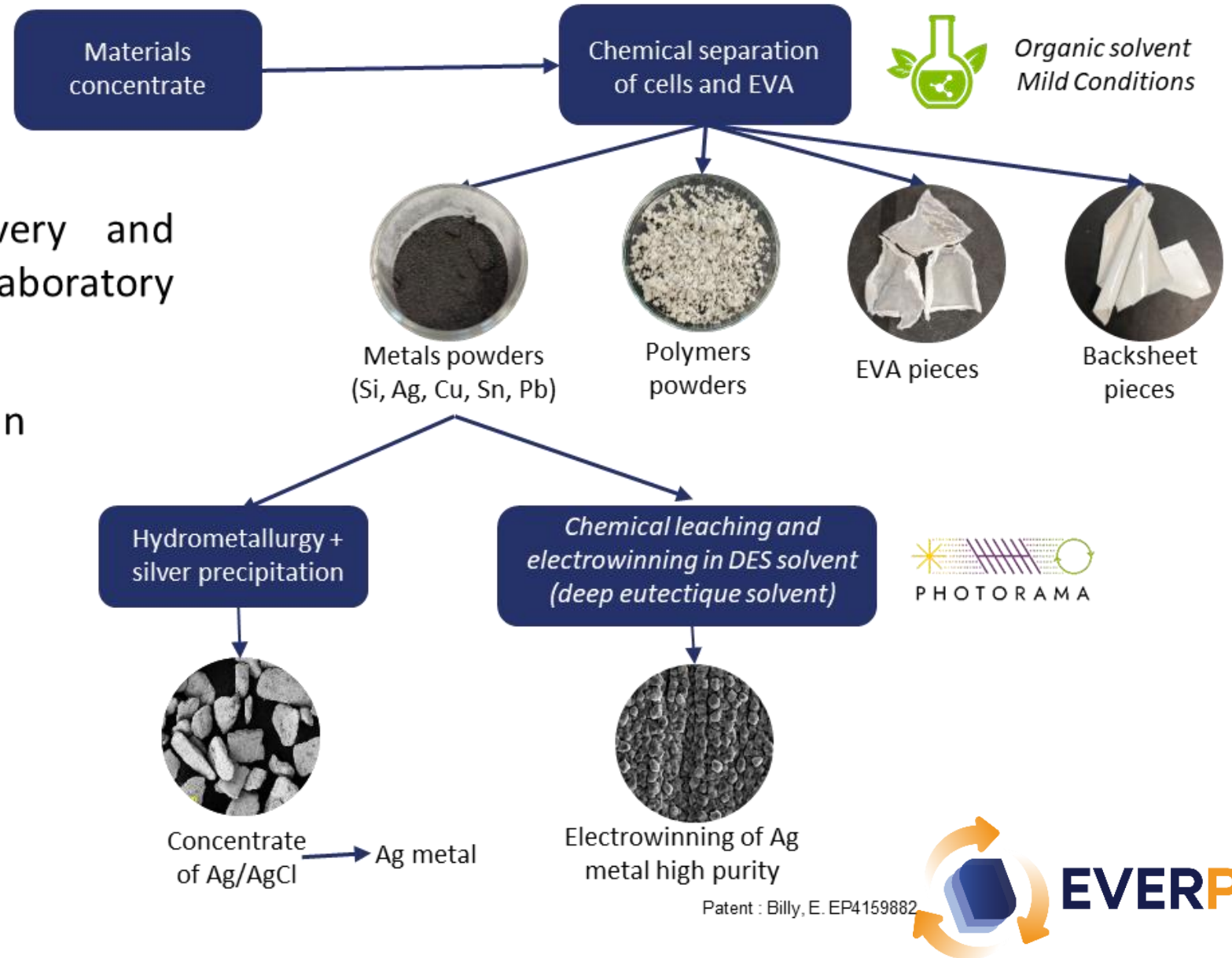
- 👍 less contamination of the material
- 👍 less contaminants in the fumes
- 👍 less CO₂ production
- 👎 decrease in the heating power for the furnace and thus potentially less energy recovery.



EVERPV purification

Silver and polymers recovery and purification demonstrated at laboratory scale.

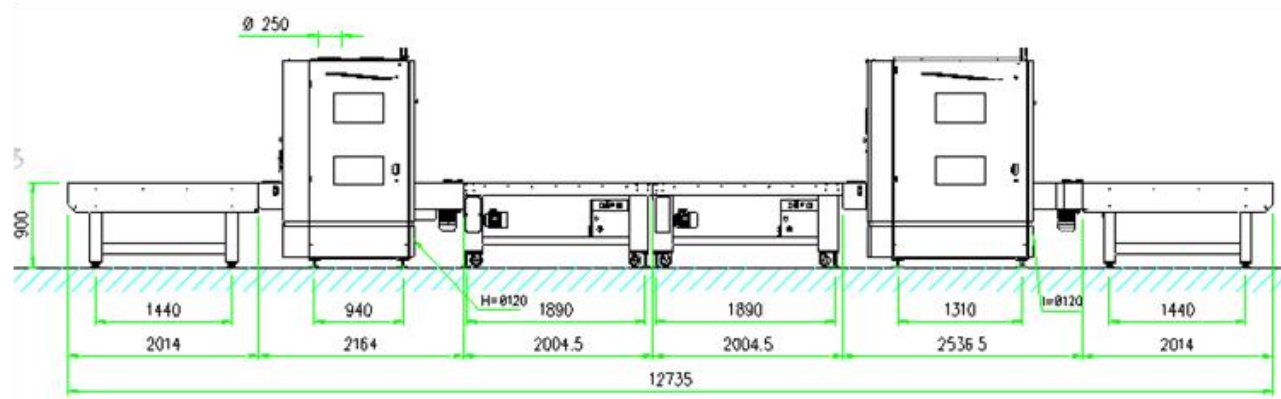
The processes will be scaled up in 2025.



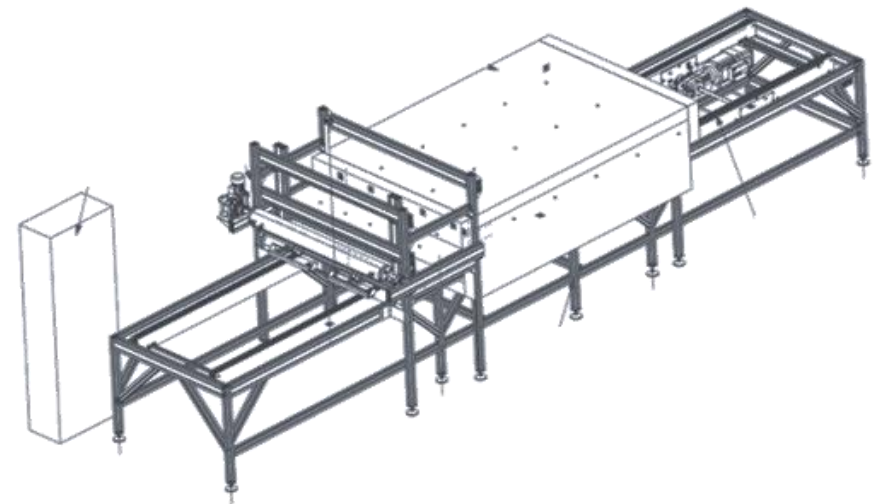
EVERPV perspectives for 2025



Upscale to TRL7 CEA grinding process in France



Upscale to TRL7 ENEA IR process in Italy



Conclusion

- 9-Tech solution is thermal+mechanical+ultrasound treatment and it seems promising in terms of recovery CRMs and environmental impact.
- EVERPV is horizon Europe that aims to improve the recycling of PV panels by studying 2 technologies: CEA grinding and ENEA IR delamination.
- These technologies can be used as pre-treatment for backsheer removal in 9-Tech process with several advantages.
- EVERPV also demonstrated at lab scale polymers and silver recovery.
- Two TRL7 plants for delamination will be realized in 2025.



Thank you for attention

Contacts: info@9tech.it



Funded by
the European Union

Funded by the European Union under Grant Agreement No 101122208. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.





Rune Søndenå

Senior Scientist,
IFE

SUSTAINABLE
SOLAR _____
EUROPE 2024



Reintegration of photovoltaic panel waste back into manufacturing of high value products

Carlos Escudero, Duygu Yilmaz, Helge Malmbeek, and
Rune Søndenå

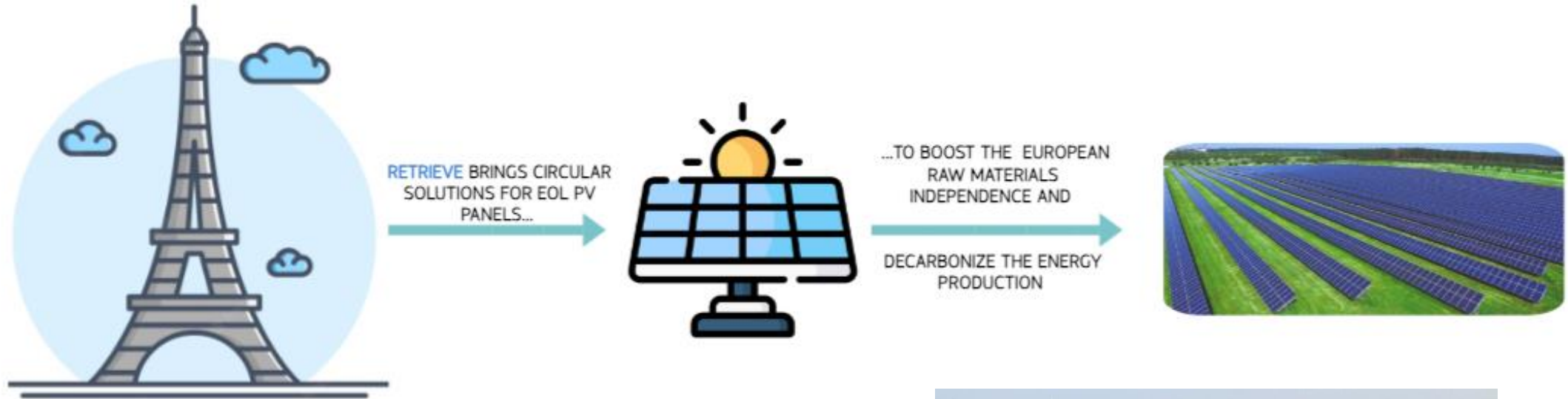
Institute for Energy Technology (IFE)

12/12/2024



This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement No 101122332.

Positioning the problem, part I: the “waste”

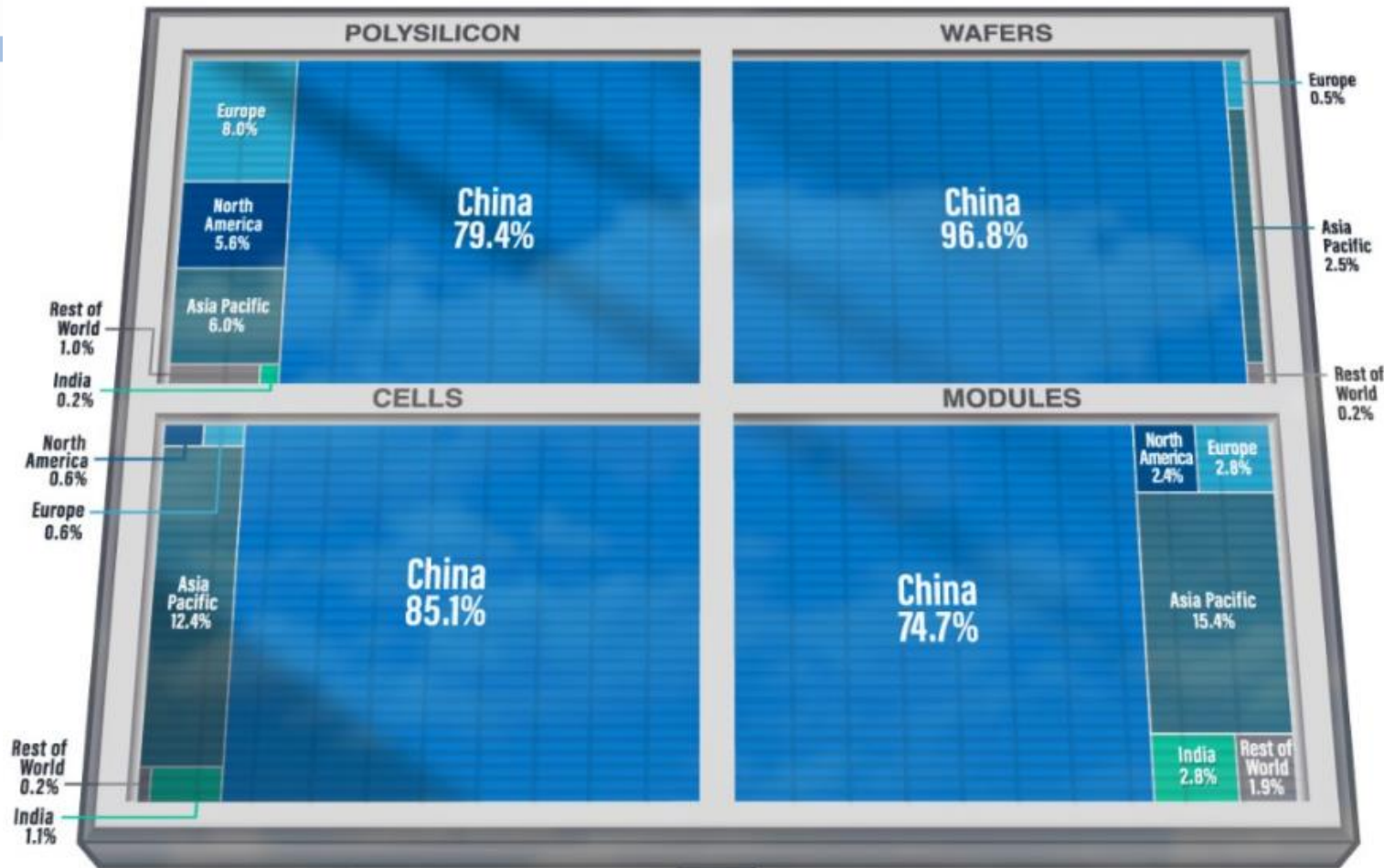


By the year 2050, the equivalent to 700 Eiffel Towers per year in the World will be End of Life PV panels waste



This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement No 101122332.

Positioning the problem part II: external dependence



China made up 55% of global solar panel manufacturing capacity in 2010, with its share rising to 84% in 2021.



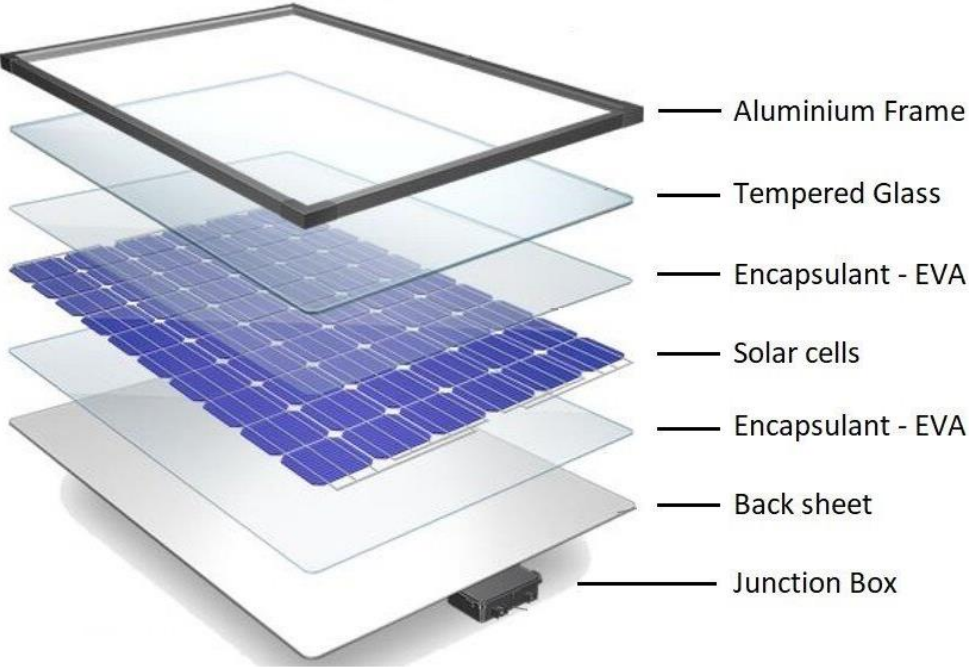
The total value of global solar PV related trade increased by more than 70% YoY to reach over \$40B in 2021.



This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement No 101122332.

Manufacturing capacity by component, country/region (2021, Source: IEA and Visualcapitalist).

Solar panels are not waste



	Quantitat per tona residu
Glass	700 - 750 kg
Aluminium	100 - 150 kg
Silicon	25 - 50 kg
Copper	5 - 10 kg
Silver	0.5 - 1 kg
Tin	0.5 - 1 kg
Plastic	Rest

Source: Fraunhofer ISE, 2020.

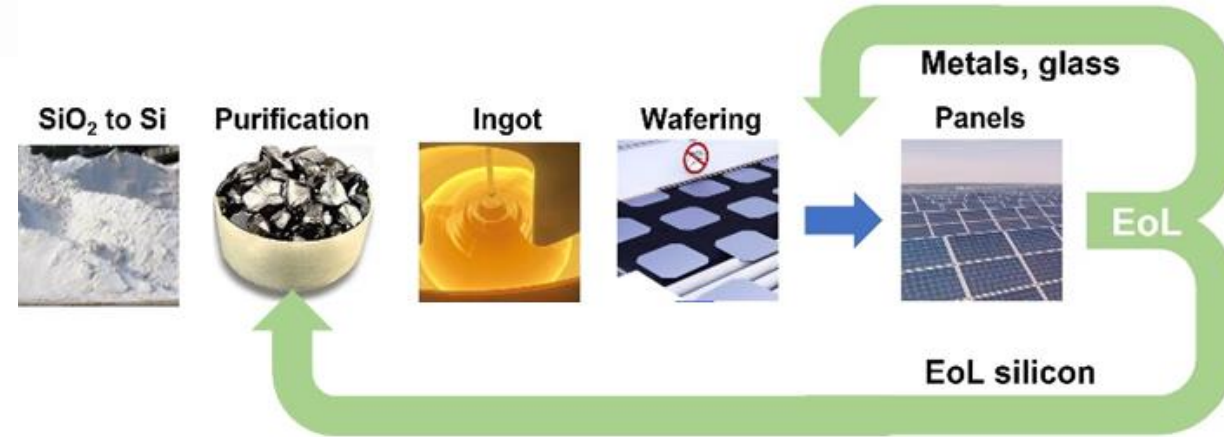


This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement No 101122332.

The solutions and impacts of RETRIEVE



RETRIEVE increases the circularity of the PV recycling sector bringing new processes and advanced technologies for materials' recovery.



1. Develop scrapping processes that allow the different components to be more effectively separated.
2. 95% of the materials will be purified and will again meet the manufacturing specifications of the photovoltaic module.
3. Integrate 99% of the glass and 98% of the silicon in the manufacture of the first panels with fully recycled materials "Made in Europe"
4. Recover 99% of the silver and eliminate the toxicity of the residual effluents.
5. Demonstrate the valorization of residual plastic with integrated CO₂ capture.
6. Develop business models and commercial exploitation adapted to the "secondary raw materials" generated.

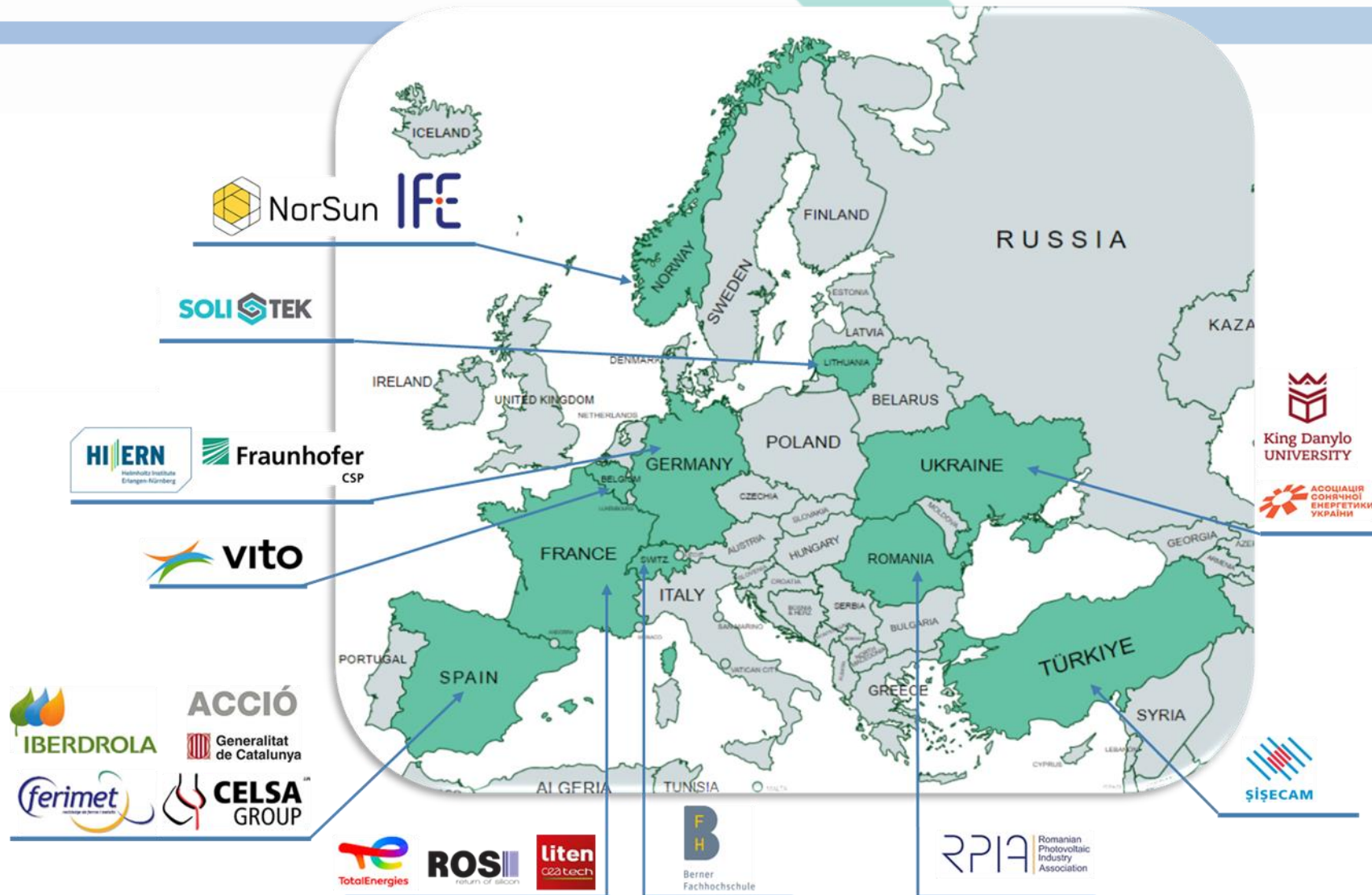


Solitec



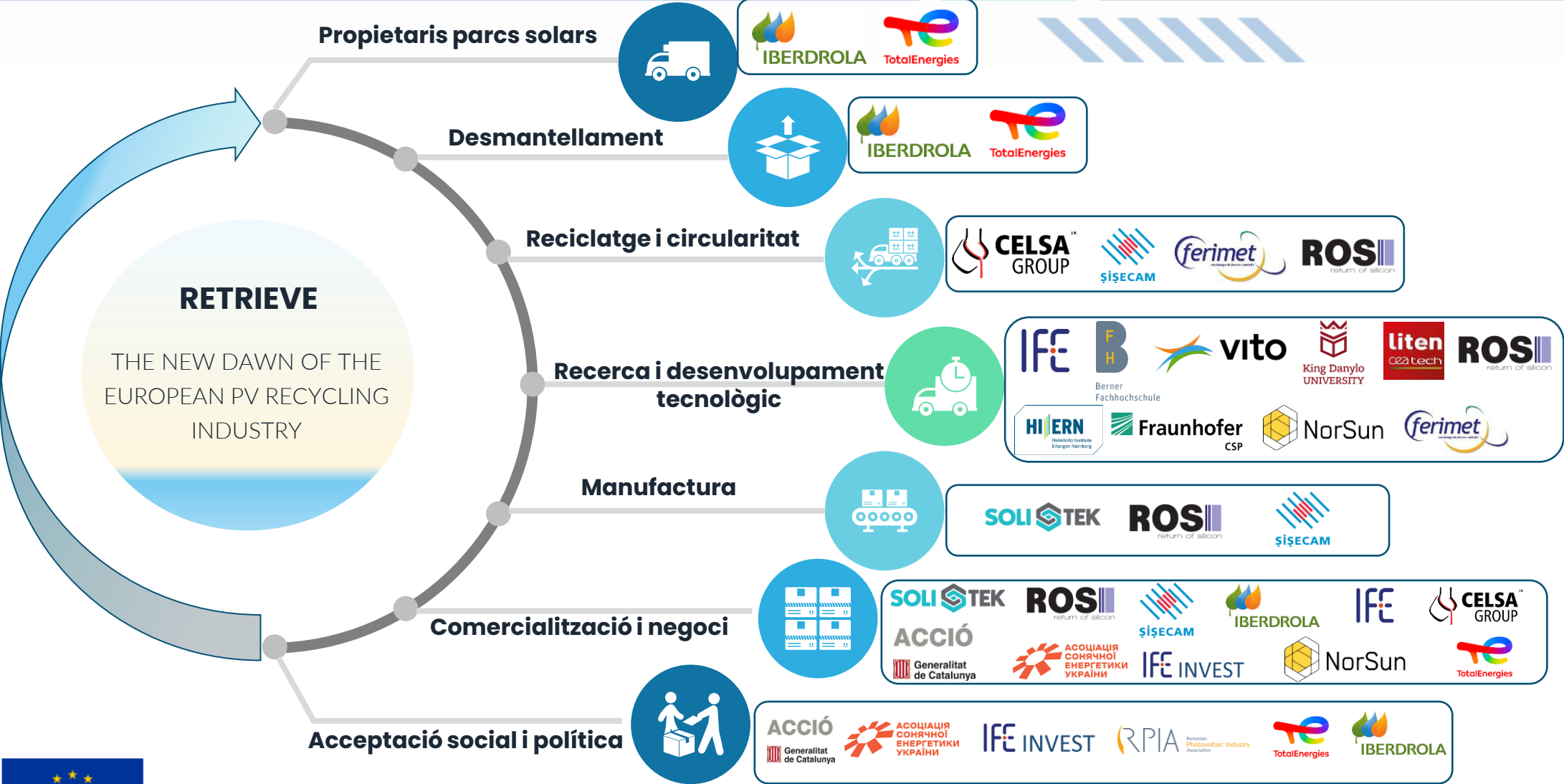
This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement No 101122332.

Our partners



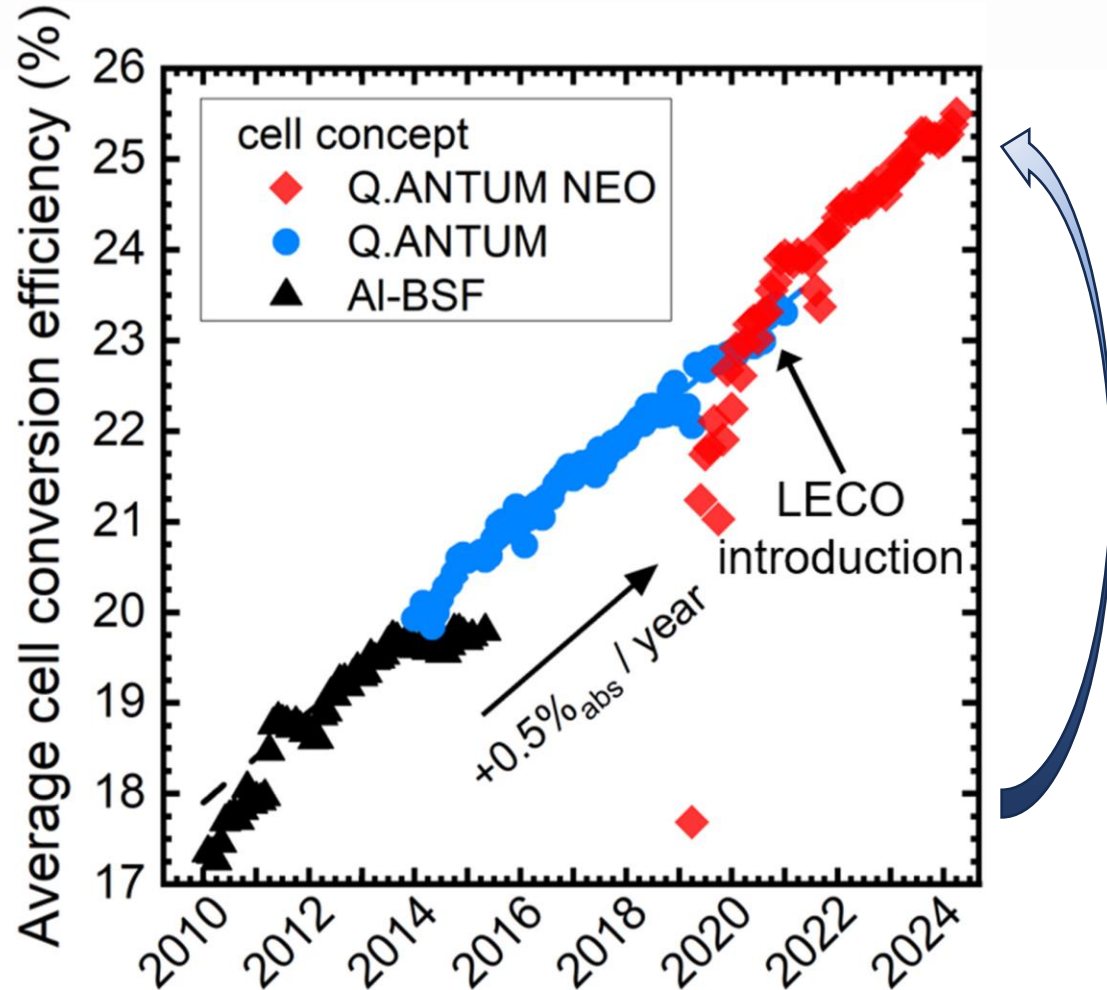
This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement No 101122332.

Our fully circular value chain



This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement No 101122332.

Technical solutions: Silicon



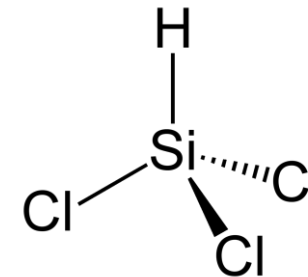
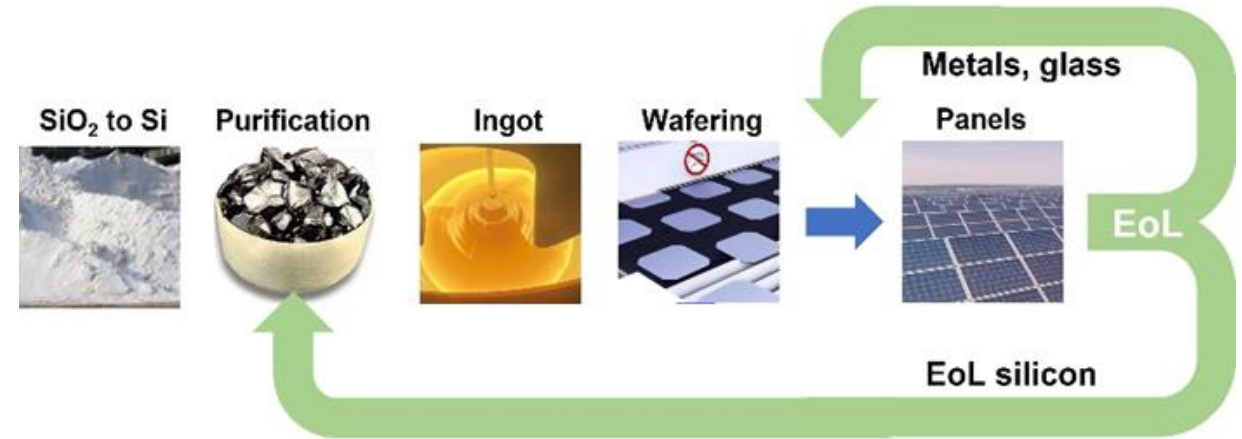
- The learning curve at Hanwha Q cells
- The evolution of solar cell architectures
 - AI-BSF → PERC → TOPCon
- Increased purity/quality demand for the raw material

A. Mette, et al. (Hanwha Q Cells) SEMSC 277 (2024) 113110

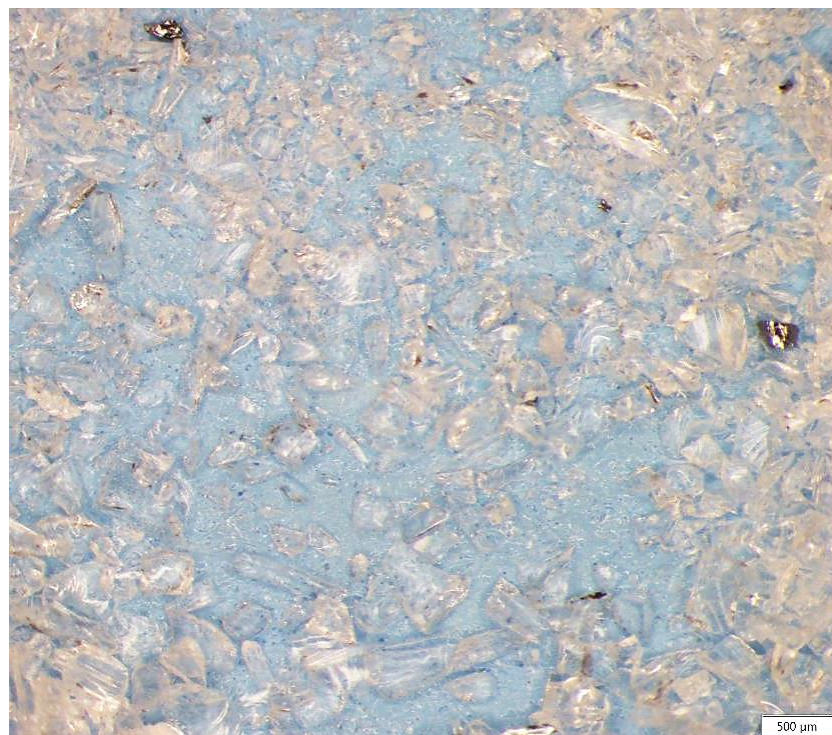


This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement No 101122332.

- Rapid shifts in the PV industry
 - The multicrystalline market disappeared virtually overnight
 - Gallium replacing boron as a p-type dopant
 - **Recently: n-type replacing p-type as the dominant technology**
 - Alternative doping species
 - Handling boron is challenging
- Purification is needed



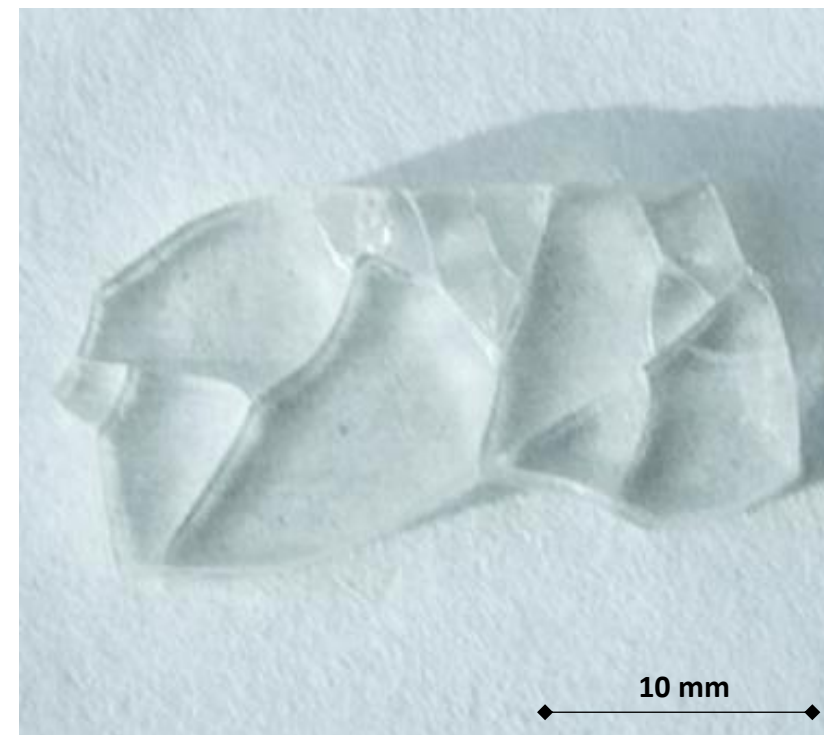
Technical solutions: Glass



Fine



Coarse



Hot knife

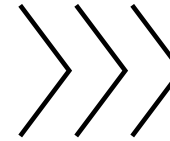
Technical solutions: Glass



Glass Cullet:
fine <1 mm

Glass Cullet:
medium ~ 4 mm

Glass Cullet:
coarse > 4mm



Technical solutions: Glass Cullet size vs. bubble formation

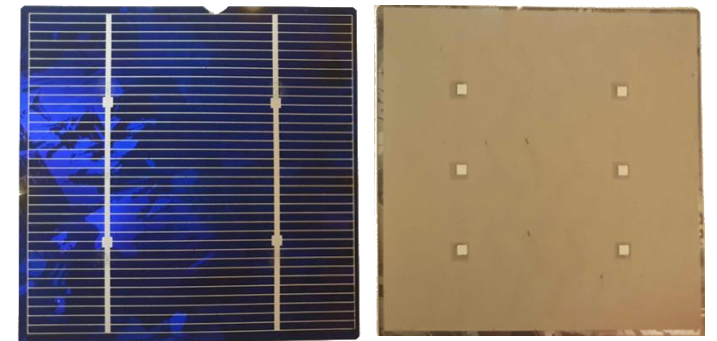
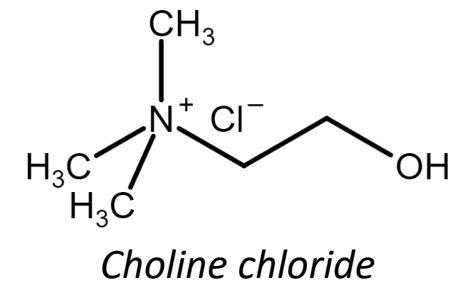
Glass Cullet: fine <1mm

Glass Cullet: medium ~ 4mm

Glass Cullet: coarse >4mm



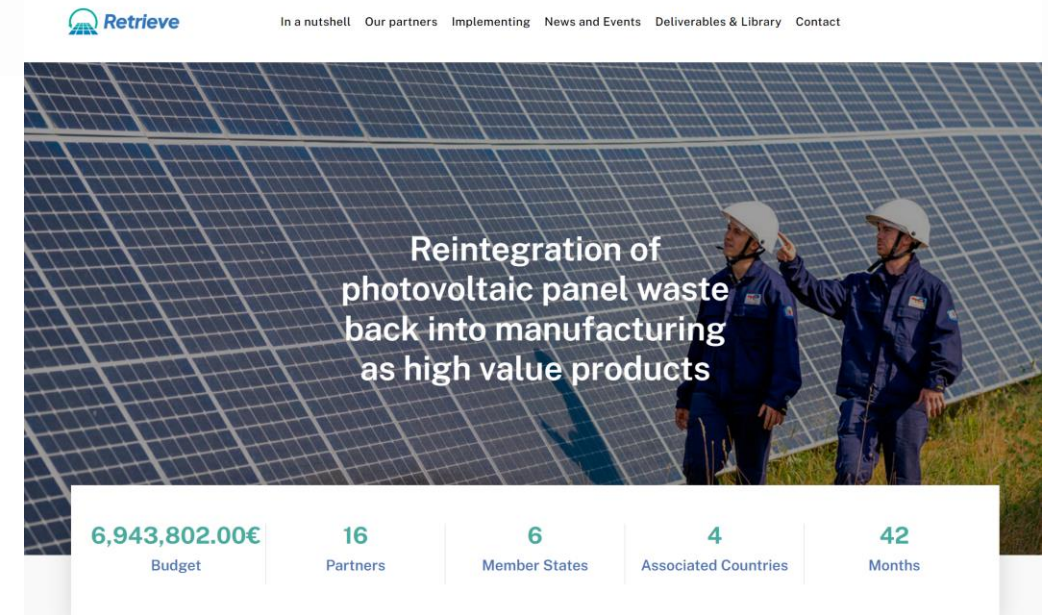
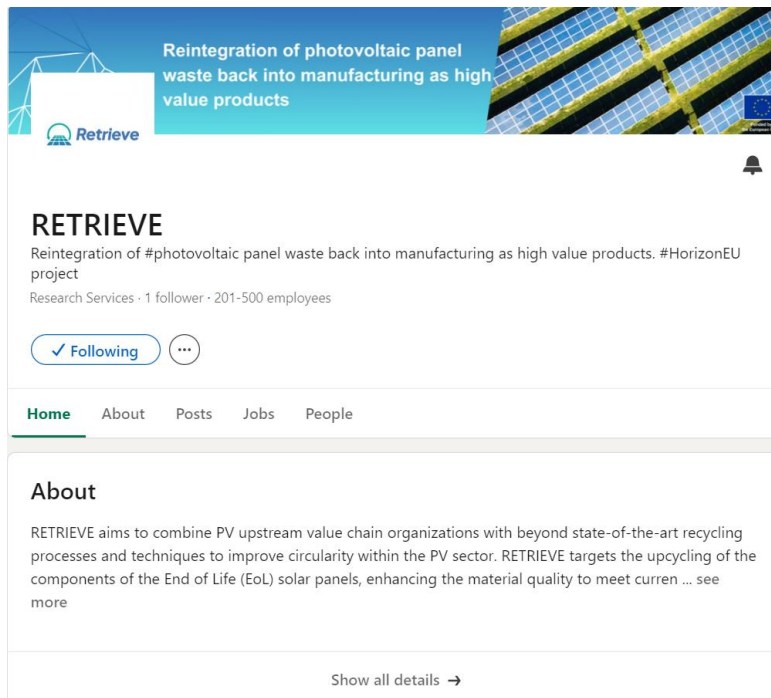
- Ag recovery:
 - Conventional method:
 - Inorganic acids (e.g. HF, HCl, HNO₃)
 - HNO₃ (5N): 1.88 USD/kg solar cell (Reference)
 - Less hazardous & more environment-friendly chemicals:
 - AlCl₃/H₂O: 1.63 USD/kg solar cell
 - FeCl₃/H₂O: 1.65 USD/kg solar cell
 - Ch.Cl/H₂O: 17.52 USD/kg solar cell



RETRIEVE in SoMe



- Web: <https://www.retrieveproject.eu/>



- LinkedIn: [@retrieveproject](https://www.linkedin.com/company/retrieveproject)



This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement No 101122332.



Alejandra Galarza

Research Engineer LCA and
Recyclability,
IPVF

SUSTAINABLE
SOLAR _____
EUROPE 2024

QUASAR Europe Horizon Project



*Eco-efficiency gains of more than 70%
in the PV End-of-Life (EOL) supply chain*

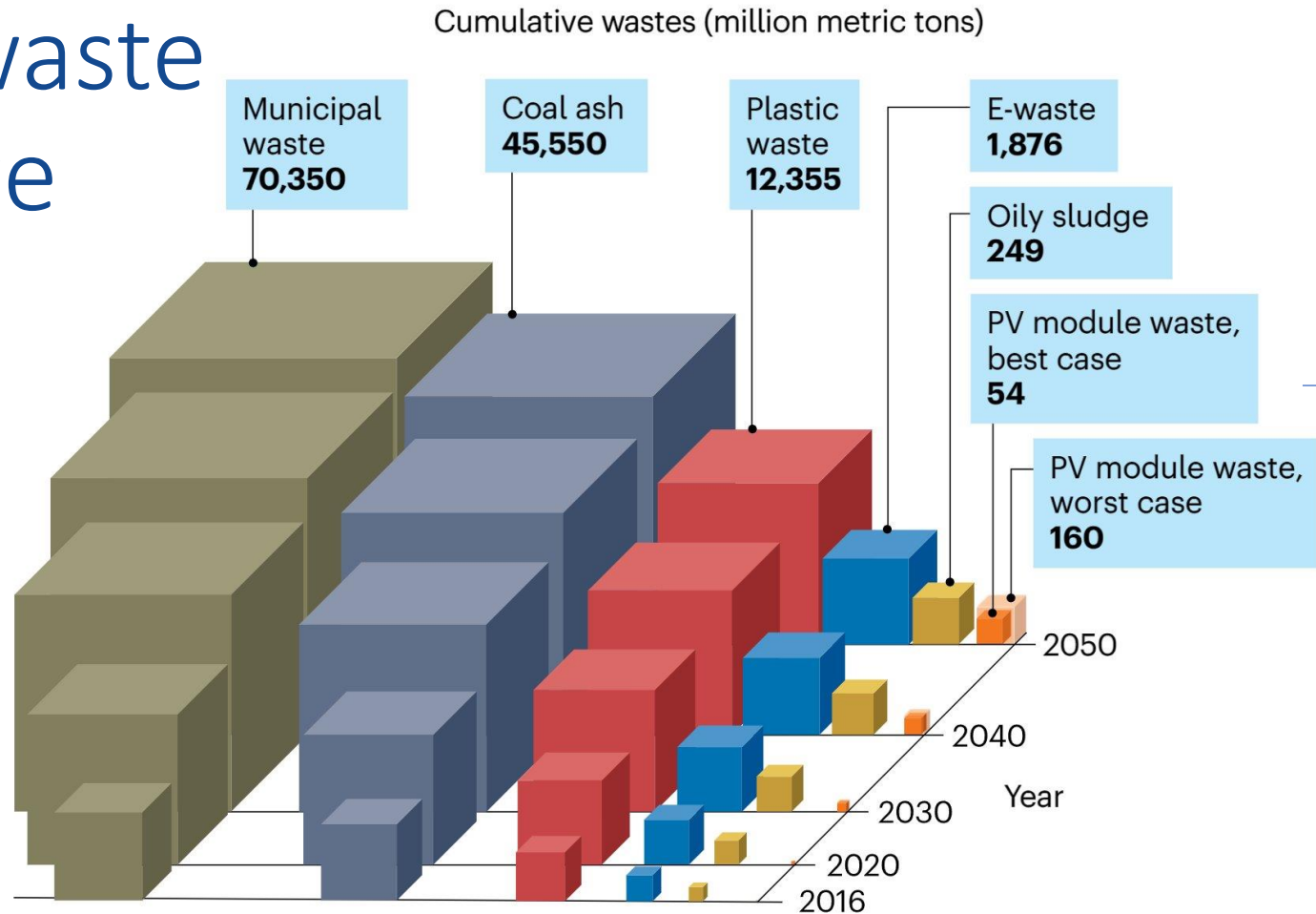


Outline

1. Background
2. Who we are
3. Challenges addressed
4. Roadmap and objectives
5. Project news



Global waste challenge



Low volumes **IF** we compare to others wastes

But...

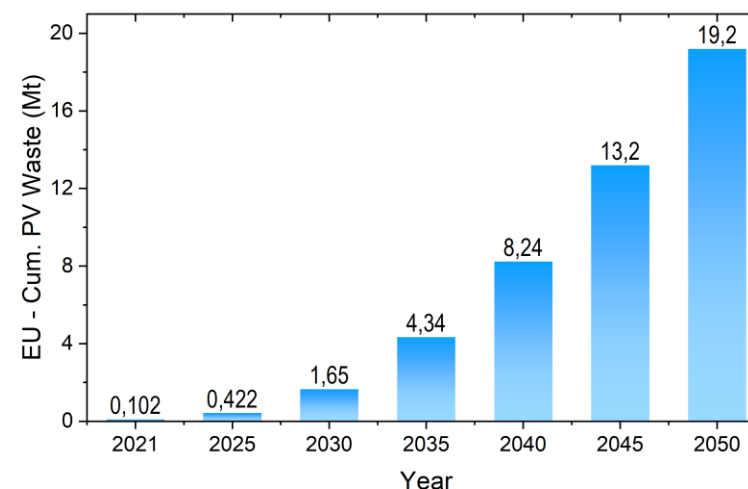
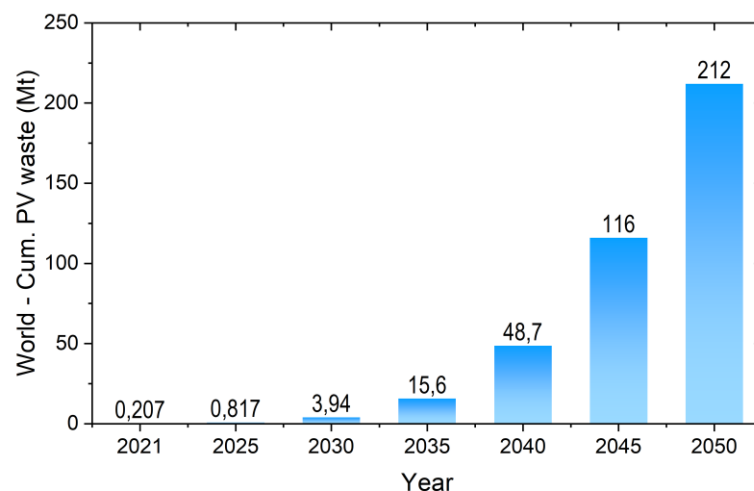
Important quantities of **key materials** could be recovered

■ Municipal waste (ref. 17)
■ Coal ash (ref. 6)
■ Plastic waste (ref. 18)
■ E-waste (ref. 19)

■ Oily sludge (ref. 20)
■ PV module waste (ref. 4)
■ Worst case
■ Best case

Mirletz, H., Hieslmair, H., Ovaite, S. et al. Unfounded concerns about photovoltaic module toxicity and waste are slowing decarbonization. *Nat. Phys.* 19, 1376–1378 (2023).
<https://doi.org/10.1038/s41567-023-02230-0>.

PV Modules – From waste to resource



Cumulated PV waste forecast in Mt (l. world, r. EU) based on PV market growth data IRENA to meet 1.5°C target

Systematic collection of modules
+
Recycling rate of 85%



Could provide resources of the PV-industry's demand:

- *up to 7% during 2031 – 2040*
- *up to 20% during 2041 – 2050*

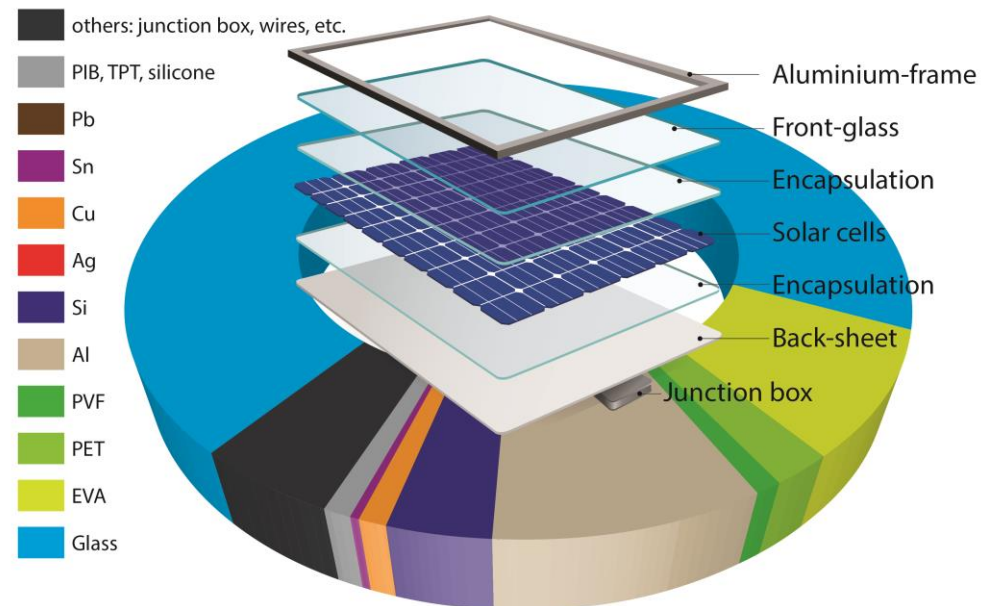
- ✓ *Glass*
- ✓ *Aluminium*
- ✓ *Copper*
- ✓ *Silver*

PV Modules – a multilayer material sandwich



PV products can be classified into three main product groups:

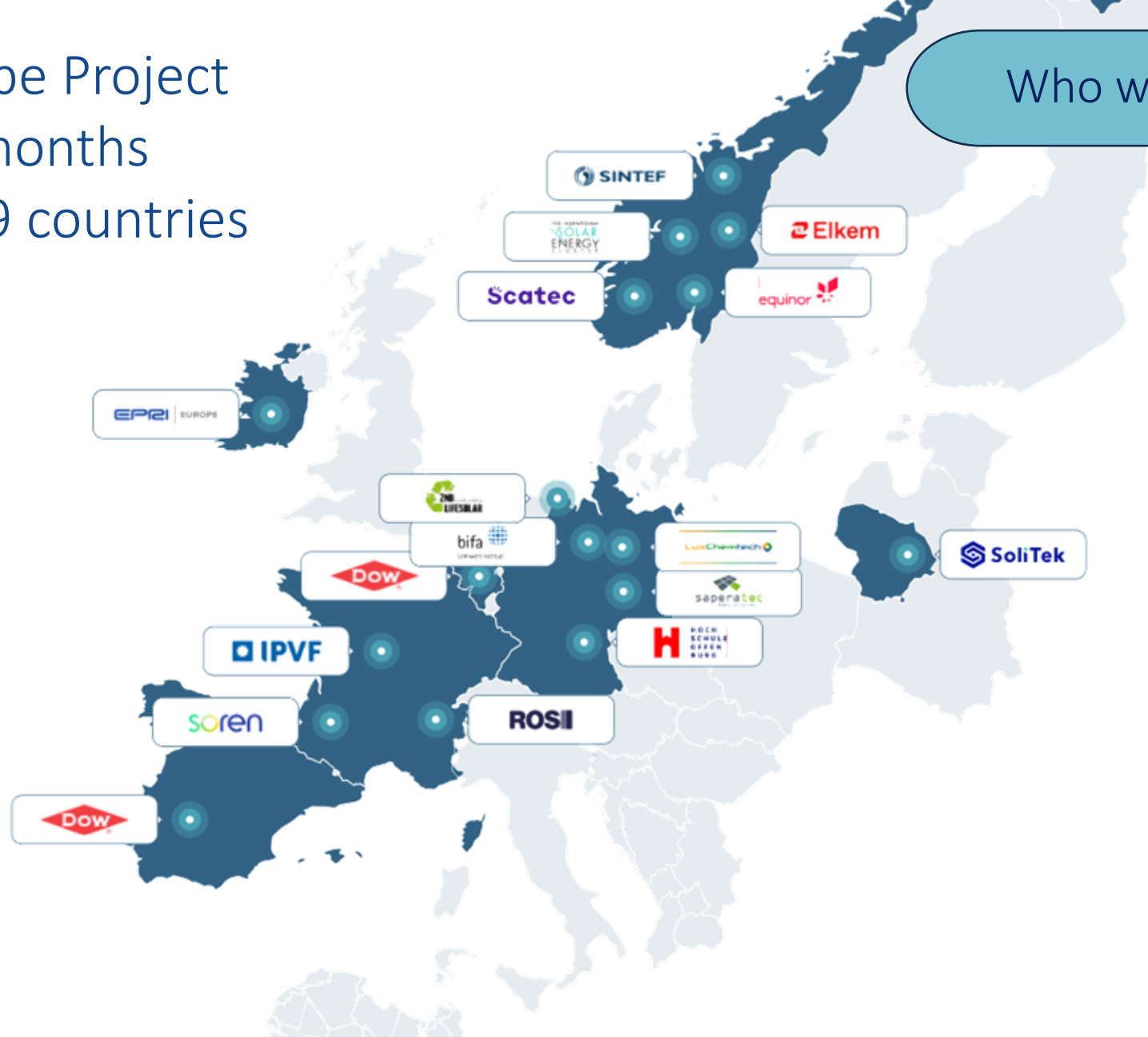
- **Silicon-based** → 97% market share
- **Thin films** → 2% market share (CdTe, CIGS)
- **Others** → < 1% market share (concentrating PV, organic PV, advanced crystalline silicon)



QUASAR

- Horizon Europe Project
- 7.1 M€ - 51 months
- 19 partners, 9 countries

Who we are



PV-module recycling is of **complex nature**



Upscale and demonstrate two emerging recycling technologies



Input streams are currently relatively **low**



Set up a systematic collection and management methodology and decision tools for EOL-PV-modules



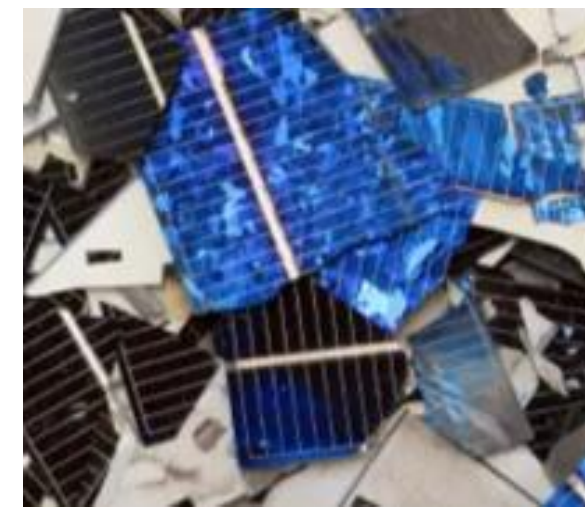
The supply chain needs to be **further diversified**



Accelerate EOL decision-making by delivering a digital product passport



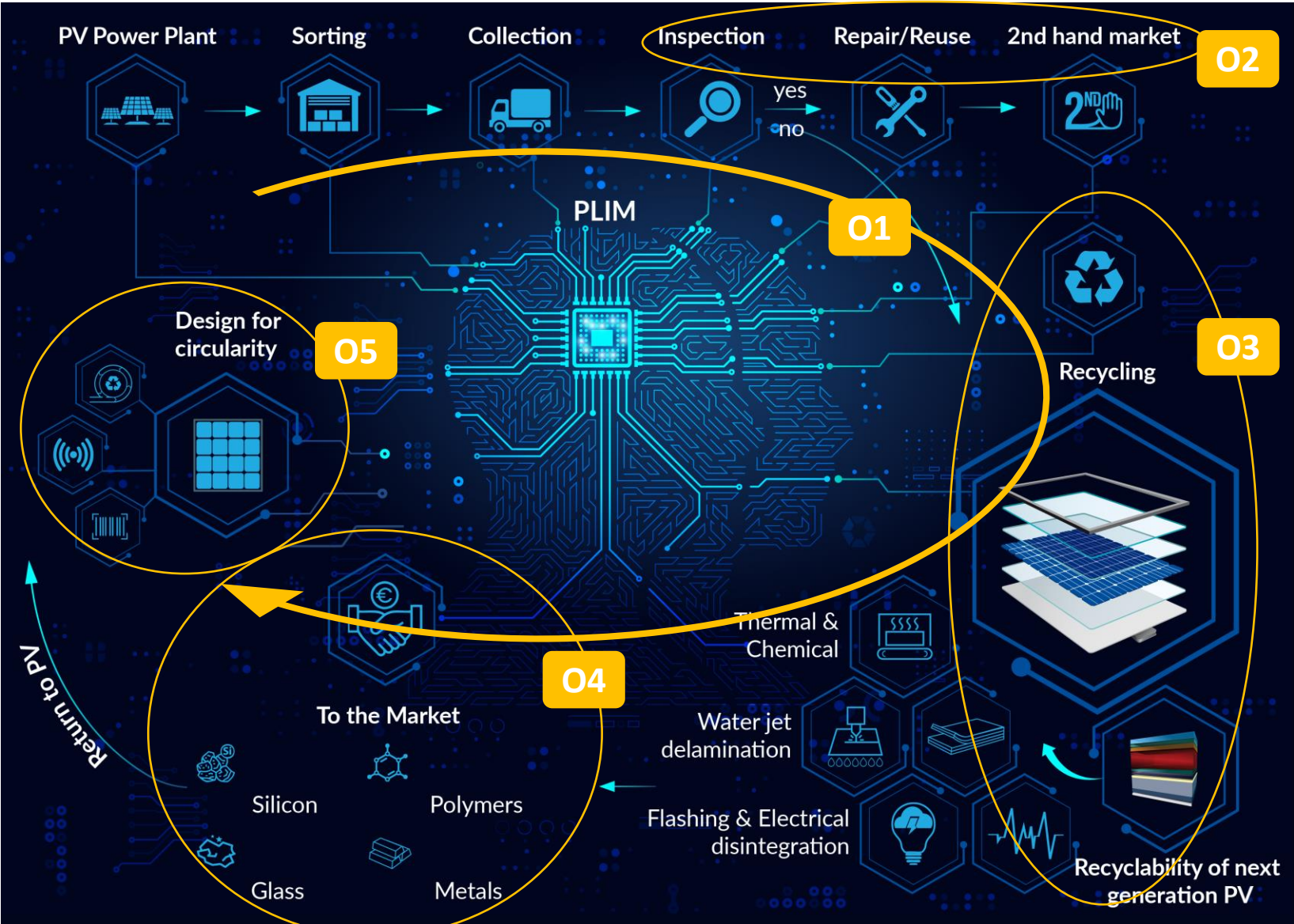
Revenues depend on the recovery of **homogeneous** and **high-purity** fractions
high-value materials



Profitable recycling that enables circular use & resource efficiency of valuable raw materials.



Approach



O1 – Cost-efficient and transparent management for the entire EoL supply chain

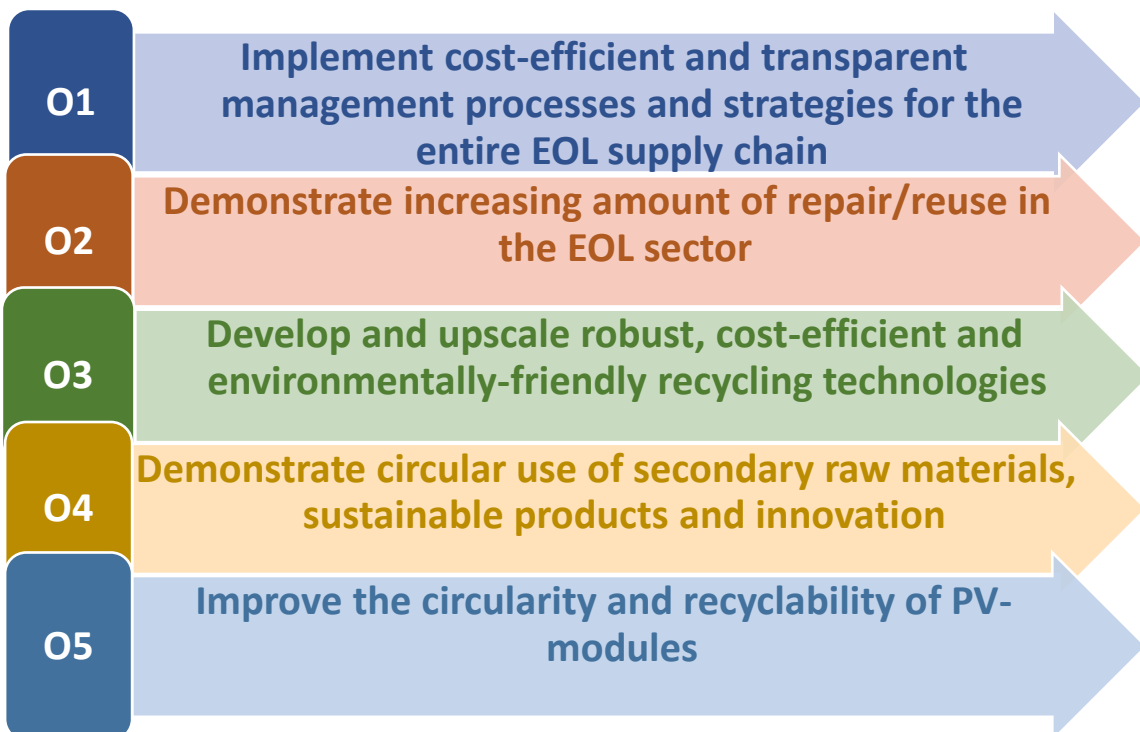
O2 – Promote reuse and repair in the PV industry

O3 – Develop and upscale robust, cost effective and environmentally friendly recycling processes

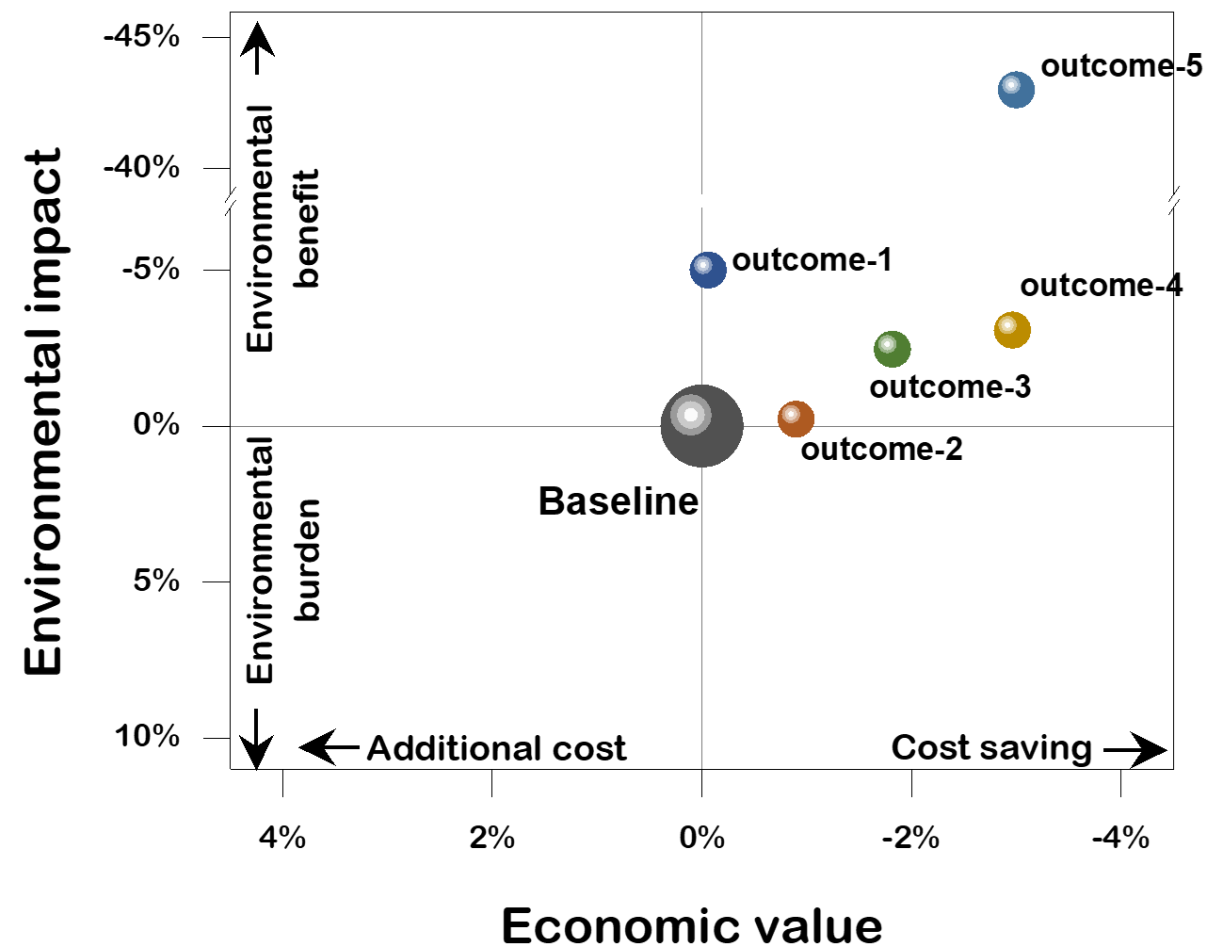
O4 – Demonstrate circular use of secondary raw materials

05 – Promote circularity by increasing traceability





$$\text{Eco-efficiency} = \sum_{i=1}^5 \left(\frac{\text{Environmental burden}}{\text{Economic impact}} \right)_i > 70\%$$



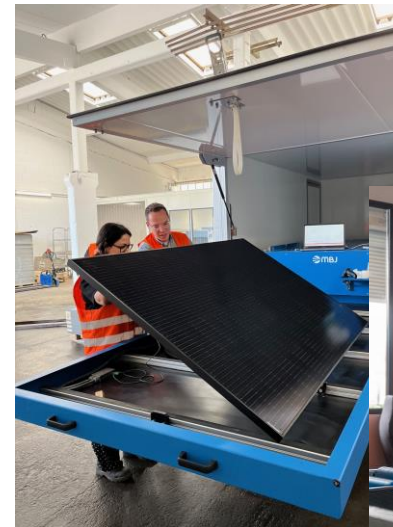
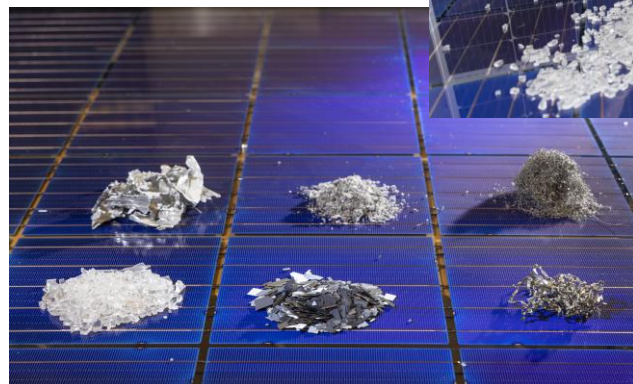
Our aim

Eco-efficiency gains of more than 70% in the PV EOL supply chain

- Reduction of decommissioning costs by 20%
- Module inspection costs < 5€/module
- Module repair costs < 7.5€/module
- Recycling treatment capacity 10,000 t/year
- Recycling rates for silicon, silver, polymers and glass up to 70-90%
- Revenue from recycled materials > 300-500 €/t



Some news ...



Help us shaping
the PV future!



Your invitation to complete the
QUASAR Survey

Contribute to the development of the
end-of-life PV technology



<https://s2survey.net/quasar/>

Stay tuned for updates!




www.quasar-project.eu



Thank you

Website
<https://quasar-project.eu>

 quasar-eu-project



This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101122298 "QUASAR".

Cumar Luxsacumar Sivakanesar

President,
SiPOW



SUSTAINABLE
SOLAR _____
EUROPE 2024

FORESI PRESENTATION AT SUSTAINABLE SOLAR EUROPE

December, 2024 – FORESi Coordinator Team

Luxsacumar Sivakanesar



FOstering a Recycled European Silicon Supply



FOstering a Recycled European Silicon supply (2024 – 2026). This project has received funding from the European Union's Horizon Programme under grant agreement No. 101138503 / Coordinator: SiPow AS (Norway)

FORESi CO-FUNDING

Shining a light on Europe's
photovoltaic panel recycling

Granting Authority: HaDEA
(European Health and Digital Executive Agency)

Horizon Europe: Pillar II, cluster 4: Digital, Industry and Space
Topic: HORIZON-CL4-2023-RESILIENCE-01-05 - Recycling
technologies for critical raw materials from EoL products (IA)

<https://cordis.europa.eu/project/id/101138503>

Project Information

FORESi

Grant agreement ID: 101138503

DOI

[10.3030/101138503](https://doi.org/10.3030/101138503) 

EC signature date

7 December 2023

Start date

1 January 2024

End date

31 December 2026

Funded under

Digital, Industry and Space

Total cost


€ 9 034 111,25

EU contribution

€ 6 999 848,75

Coordinated by

SIPOW AS

 Norway



Growing Need for PV Recycling Activities

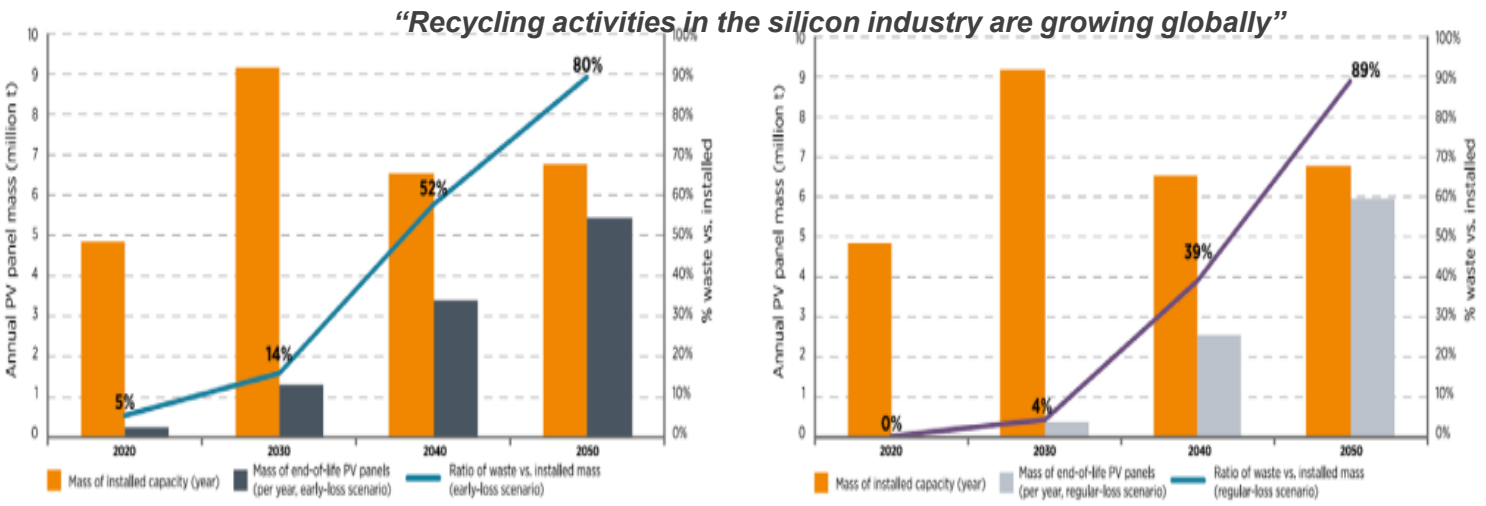
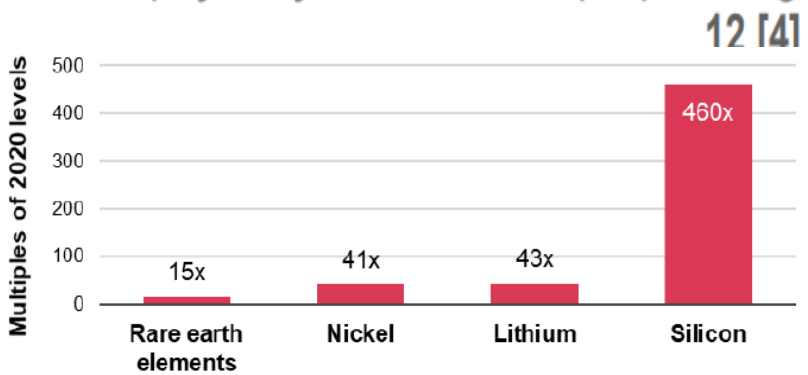


Fig. 1-5 Annually installed and end-of-life PV modules 2020-2050 (in % waste vs. t installed) by early-loss scenario (left) and regular-loss scenario (right) by IRENA/Task



Source: IEA, The role of critical minerals in clean energy transitions, IEA, 2022.



PRIMARY GOAL OF THE PROJECT



What is FORESi : 6 innovations

FORESi will demonstrate 6 different innovations,
each of them covering one part of the PV recycling value chain.

FOstering a Recycled European Silicon supply:



- ➔ Recovery of end-of-life PV panels
- ➔ Testing for reuse or repair
- ➔ Dismantling
- ➔ Extraction of Silicon
- ➔ Purification of Silicon
- ➔ New production of silicon for batteries and solar applications





Energy Capacity

Silicon based anode materials for LIBs has Energy Capacity 10 times higher than traditional graphite anode

Environment

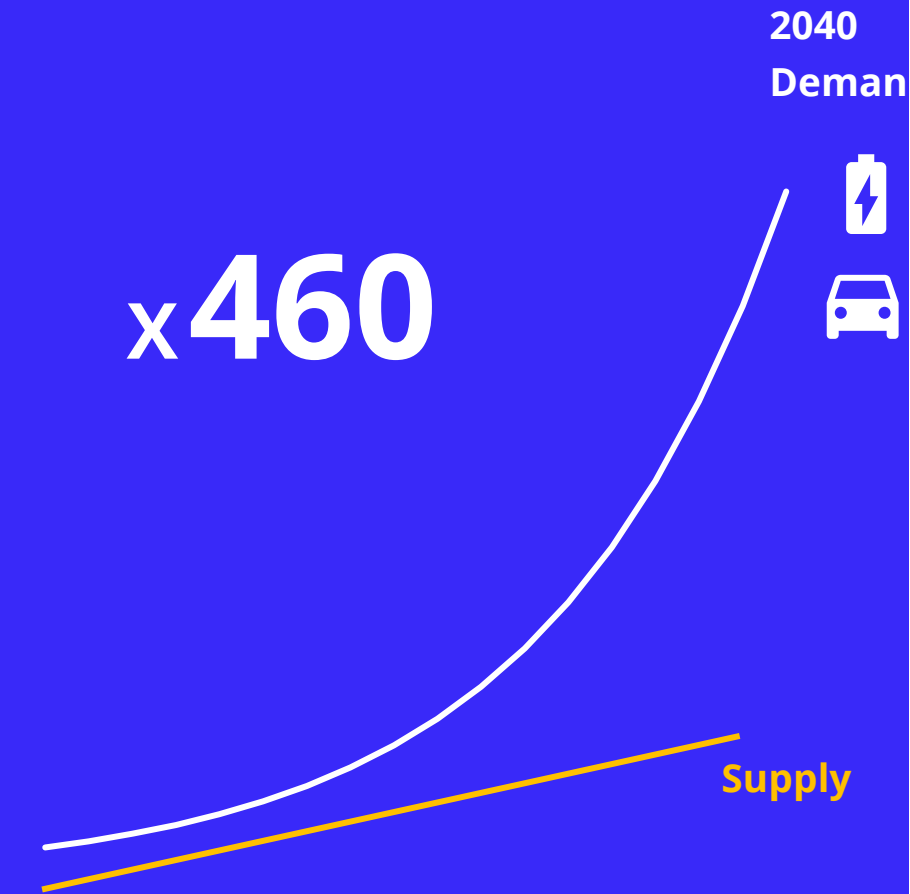
Purification of silicon recovered from End of Life solar panels Has almost zero impact compared to conventional methods

Cost

Production method is very energy efficient, hence reducing costs per kWh, with high RoI



Monocrystalline Silicon supply gap



EV Li-Ion commitments driving exponential growth

Problem:
Producers unable to bridge gap



Too Expensive

Mining and refining leads to high commercial price



Material Scarcity

Silicon Raw Materials becoming increasing scarce, and controlled outside Europe



High Carbon Footprint

Extractive mining has huge CO2 impact



THE PROJECT COORDINATOR

SiPOW...IN A NUTSHELL

SiPow, a spin-off of NanoPow AS, resulted from collaboration among experts in silicon recycling, Waste of Electric and Electronic Equipment (WEEE) photovoltaic, Nanosilicon production, and Battery Manufacturing. Over two decades, SiPow developed a method for producing crystalline nano-silicon powder for lithium-ion battery anodes. Their purified silicon enhances anode performance with ultrahigh specific capacities, surpassing traditional graphite anodes by tenfold. SiPow is revolutionizing the pure silicon market with breakthrough purification solutions and processes facilitating the trade of recovered raw material.

Methodology and Ambition

SiPow's purification process targets economic viability at an industrial scale, handling waste scraps from various PV technologies. SiPow's goal is to: 1) purchase low-purity recycled silicon from WEEE and WEEE photovoltaic recyclers; 2) purify silicon to meet market demand purity levels; and 3) supply purified silicon to users like nano silicon and lithium battery manufacturers. The innovative purification method is expected to reduce energy harvesting and costs with raw silicon from WEEE photovoltaic. SiPow's monocrystalline Pure Silicon aligns with industry demands, offering high energy capacity for new lithium battery-powered products, environmentally friendly solutions to limit CO2 emissions, and a high Return on Investment (RoI) for efficient energy independence.



Green Solutions

SiPow stands at the forefront of pure silicon production from reclaimed raw materials, championing true circular economy models globally.



Industrial Scale

SiPow pioneers cutting-edge disruptive technologies to achieve unparalleled purity levels of silicon recovered from end-of-life products, enabling large-scale industrial applications.



Highest RoI

SiPow facilitates global material exchange through its extensive network of raw material traders, addressing market needs with innovative models while minimizing energy consumption in the process.



10X Better

With innovative approaches, SiPow effectively fills market gaps and enables the international exchange of superior materials, offering performance levels ten times better than conventional solutions.



<https://www.sipow.no/>



FOstering a Recycled European Silicon supply (2024 – 2026).

This project has received funding from the European Union's Horizon Programme under grant agreement No. 101138503 / Coordinator: SiPow AS (Norway)

THE COORDINATION TEAM

MANAGEMENT



Sivakanesar Luxsacumar

Chairman

Serial Entrepreneur and Investor, with 25+ years in International Business with 10+ Start-up companies, Papers in International Scientific Journals; 3 patents.

✉ cumar@sipow.no



Francescantonio Della Rosa, Ph.D.

Chief Executive Officer / CEO

Serial Entrepreneur and Investor, with 25+ years in International Business, Awarded worldwide for Business and Research achievements.

✉ fdr@sipow.no



Monika Pilz, Ph.D.

International Projects Coordinator

Senior Research Scientist with strong academic and industrial background in management of EU projects and scientific Consortia.

✉ monika@sipow.no



<https://www.sipow.no/>



FOstering a Recycled European Silicon supply (2024 – 2026).

This project has received funding from the European Union's Horizon Programme under grant agreement No. 101138503 / Coordinator: SiPow AS (Norway)



PARTNER CONSORTIUM

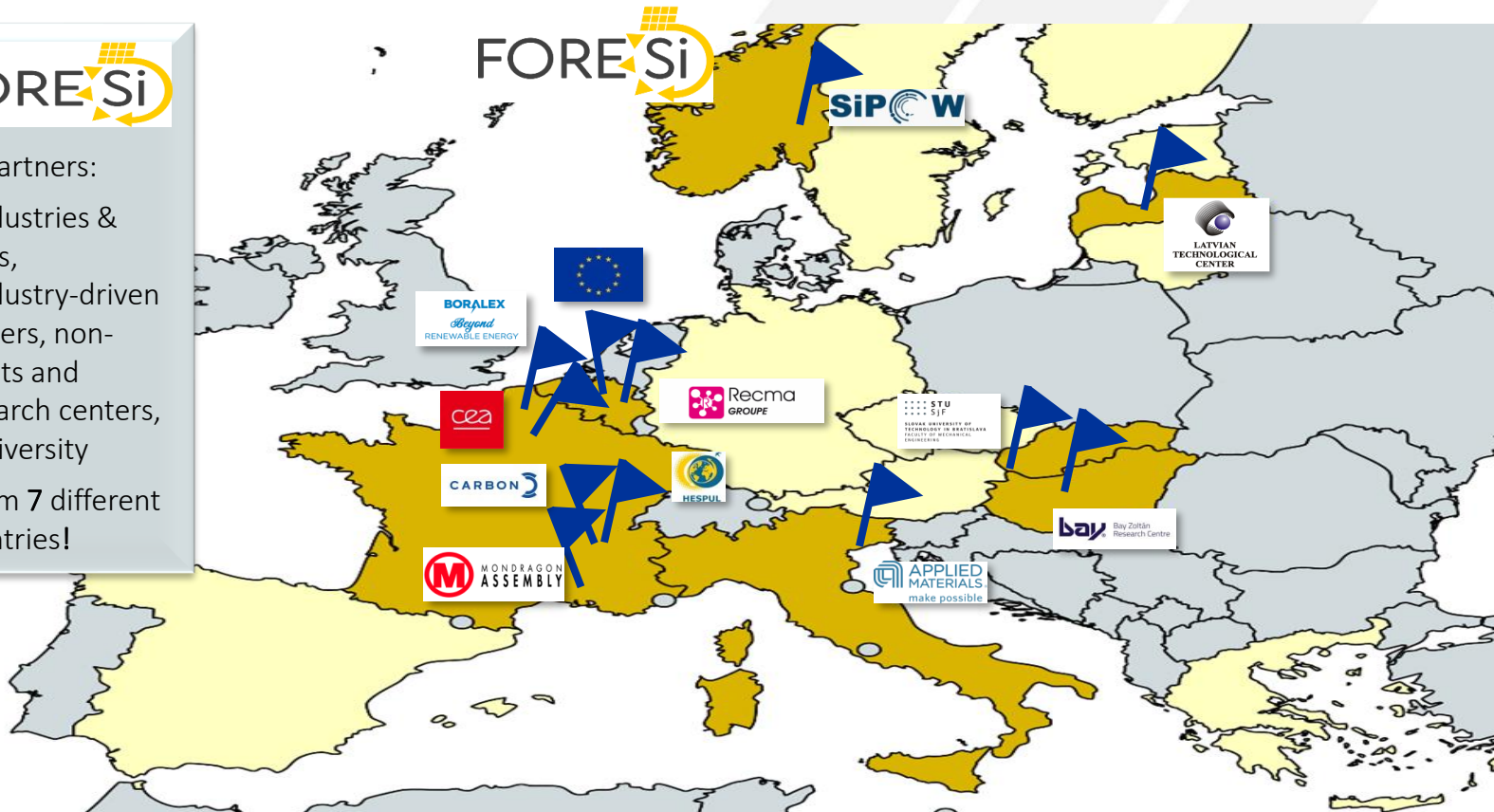
11 entities including 6 industries & SMEs, 4 industry-driven clusters, non-profits and research centers, and 1 university - from 7 different countries:



FORESI IN EUROPE

FORESi

11 partners:
6 industries & SMEs,
4 industry-driven clusters, non-profits and research centers,
1 university
- from 7 different countries!



GA, Annex 1, Part B, page 36



FORESI AMBITION

FORESi will deliver the design of an optimised recycling turnkey factory of end-of-life PV panels by end of 2026.



- Paving the way for a **European industrial mass production of recycled Silicon.**

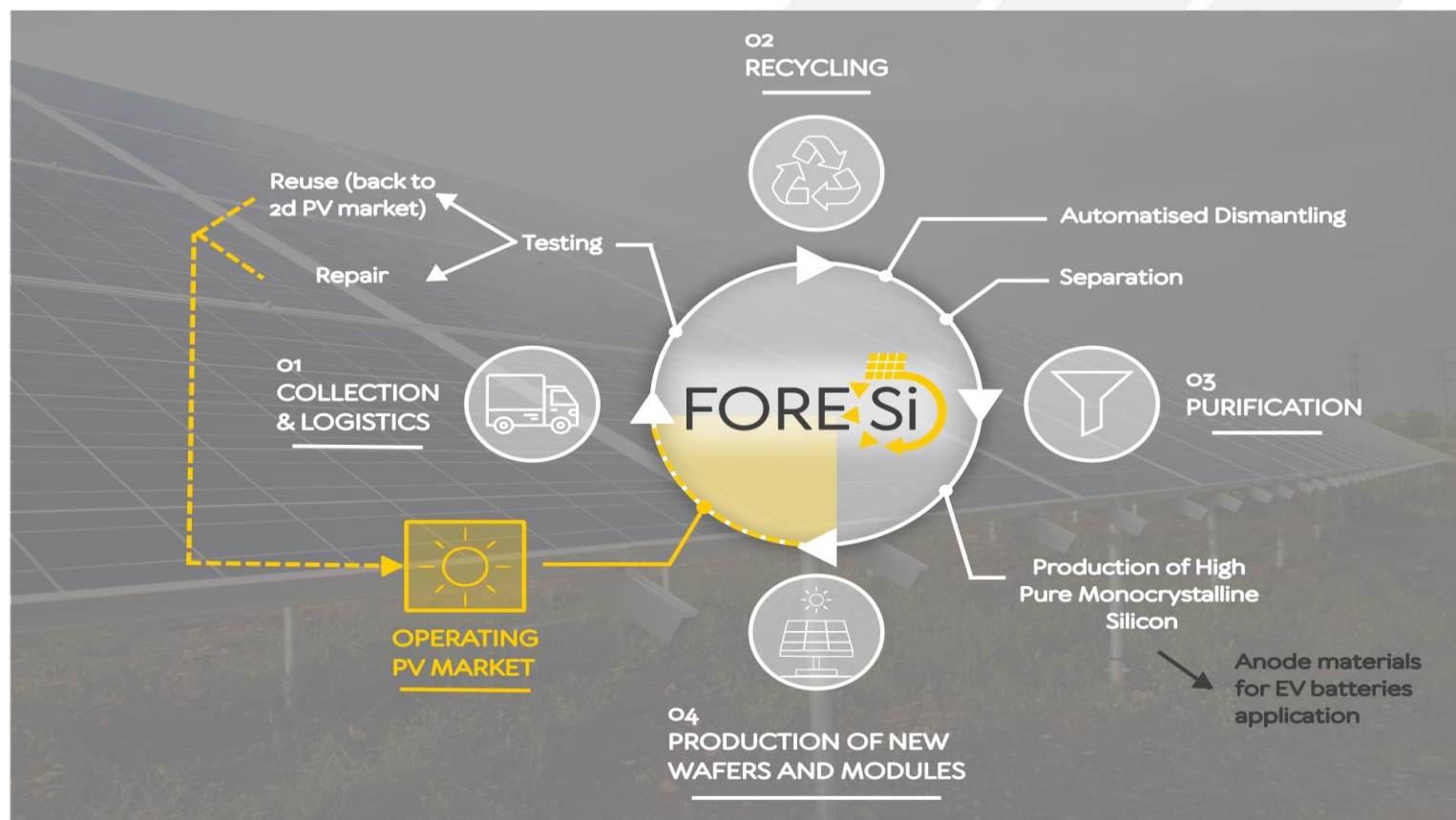


7 SPECIFIC OBJECTIVES

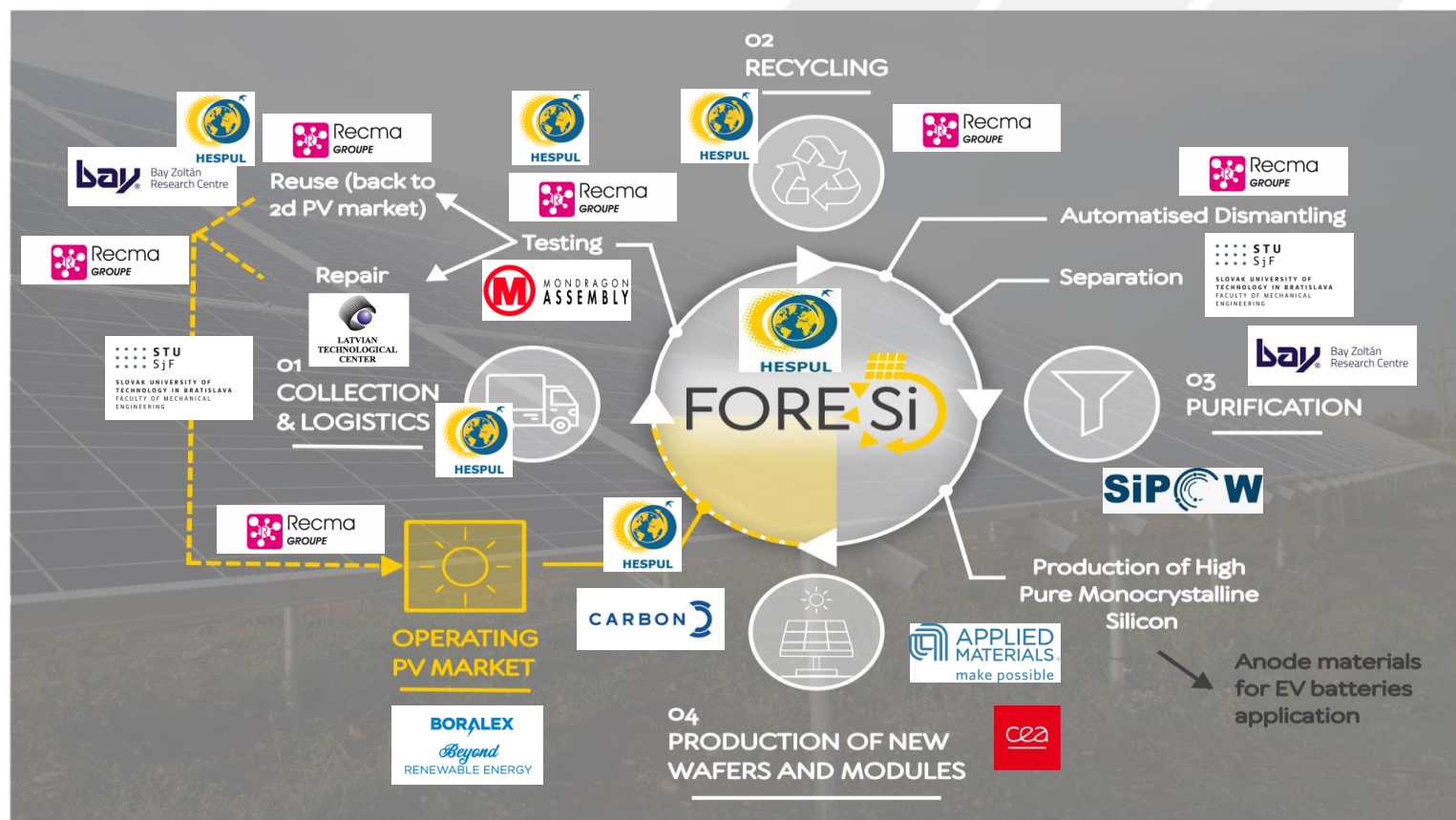
SO1	Develop and demonstrate new processes for PV logistics collection, reuse and repair at EU level.
SO2	Demonstrate a fully automatised dismantling machine and a novel sustainable chemical process to recycle end-of-life PV modules, targeting at least a 95% recovery rate.
SO3	Demonstrate at industrial level a new purification process of silicon from different waste scraps in order to produce High Pure Monocrystalline Silicon.
SO4	Demonstrate the circularity potential of the PV value chain by producing new solar cells with up to 15% upcycled Silicon from end-of-life PV modules.
SO5	Assess and define the optimal parameters to reach the highest economic, technical, social and environmental positive impact along the recycling value chain.
SO6	Provide a design of a PV recycling turnkey factory together with EU policy recommendations to increase the sustainability and future resilience of the European Silicon PV value chain.
SO7	Ensure the scale-up of FORESi innovations on the long run through realistic exploitation strategies, inter-cluster cooperation and stakeholder's engagement.



THE FORESI - CONCEPT



THE FORESI - CONCEPT



FORESi

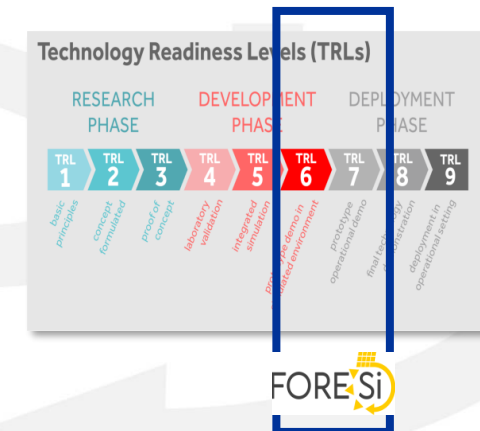
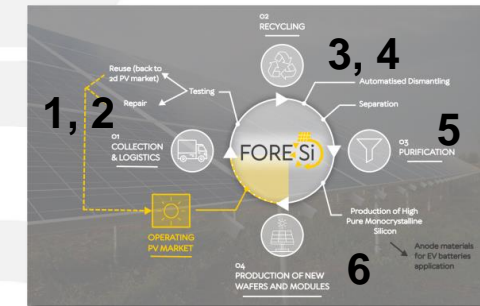


F0stering a Recycled European Silicon supply (2024 – 2026).

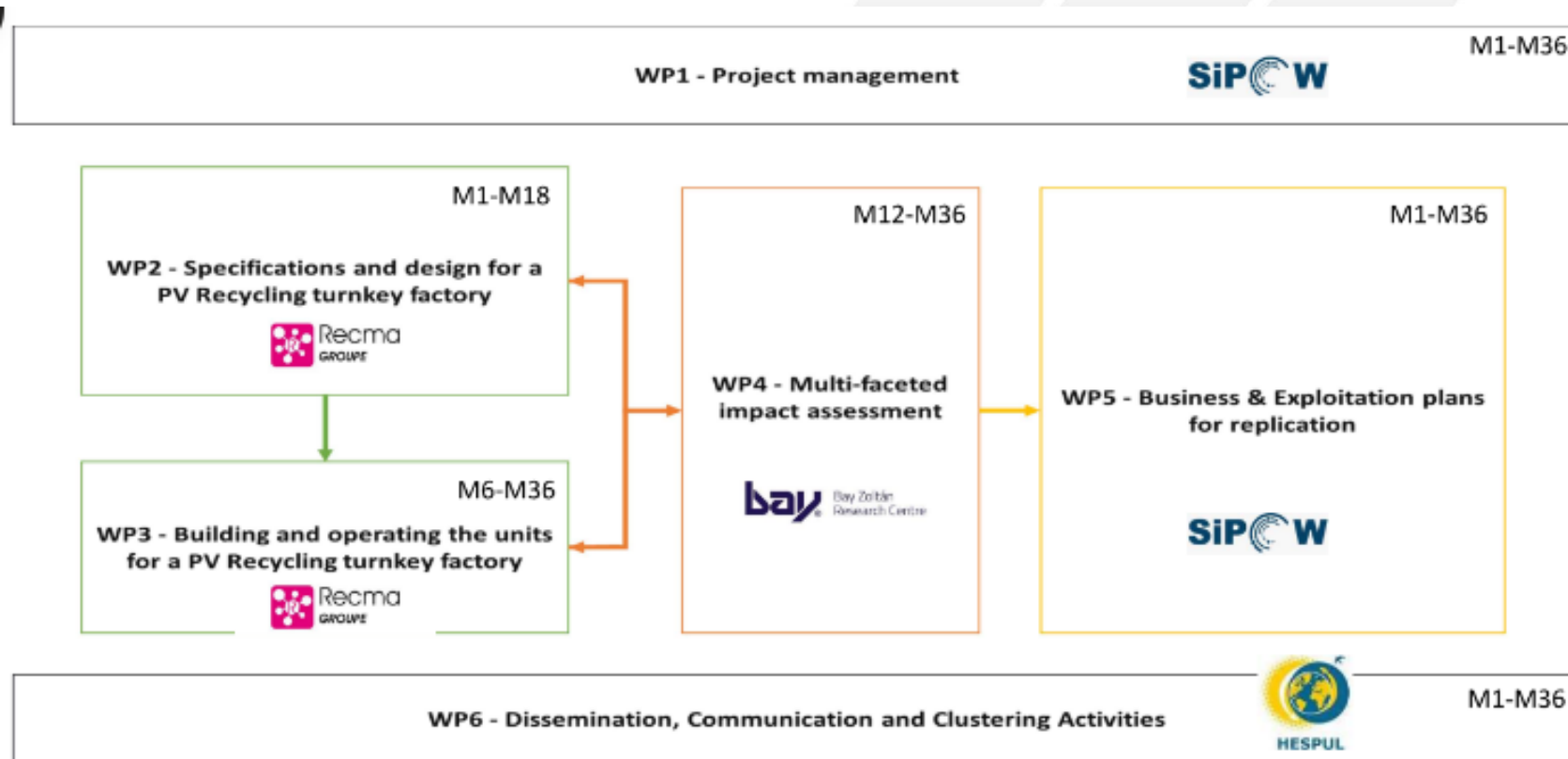
This project has received funding from the European Union's Horizon Programme under grant agreement No. 101138503 / Coordinator: SiPow AS (Norway)

6 FORESi - INNOVATIONS

1	PV Collection Logistics platform
2	PV Testing Process to Reuse and Repair EoL PV modules
3	Fully automatised Dismantling Technology for EoL modules
4	Chemical Separation technology for Glass/Si laminate
5	Industrial Purification process from different EoL waste scraps to highly Pure Silicon
6	Circular solar cells and modules with 15% recycled Silicon from EoL PV modules



FORESI WP structure





Credit photo : Adobe Stock

www.foresi.eu

Thank you!
cumar@sipow.no



Fostering a Recycled European Silicon supply (2024 – 2026).

This project has received funding from the European Union's Horizon Programme under grant agreement No. 101138503 / Coordinator: SiPow AS (Norway)

This project has received funding from the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.



Panel discussion



**Pietro Giovanni
Cerchier**

CEO,
9-Tech



**Rune
Søndenå**

Senior Scientist,
IFE



**Alejandra
Galarza**

Research Engineer LCA
and Recyclability,
IPVF



**Cumar
Luxsacumar Sivakanesar**

President,
SiPOW



**Claire
Morin**

Junior Project Officer,
SolarPower Europe

SUSTAINABLE
SOLAR_____

EUROPE 2024

THANK YOU



Solar Promotion GmbH

Kiehnlestraße 16
75172 Pforzheim, Germany
Phone: + 49 7231 58598-0
info@TheSmarterE.de
www.TheSmarterE.de



SolarPower Europe

Rond-Point Robert Schuman 3
Brussels 1040, Belgium
info@solarpowereurope.org
www.solarpowereurope.org