



Italian National Agency for New Technologies,
Energy and Sustainable Economic Development



**MISSION
INNOVATION**
accelerating the clean energy revolution

Realization of a prototype of an experimental apparatus for photovoltaic waste recycling finalized to recovery of materials

Nano Innovation 2023

Roma, 21 Settembre 2023

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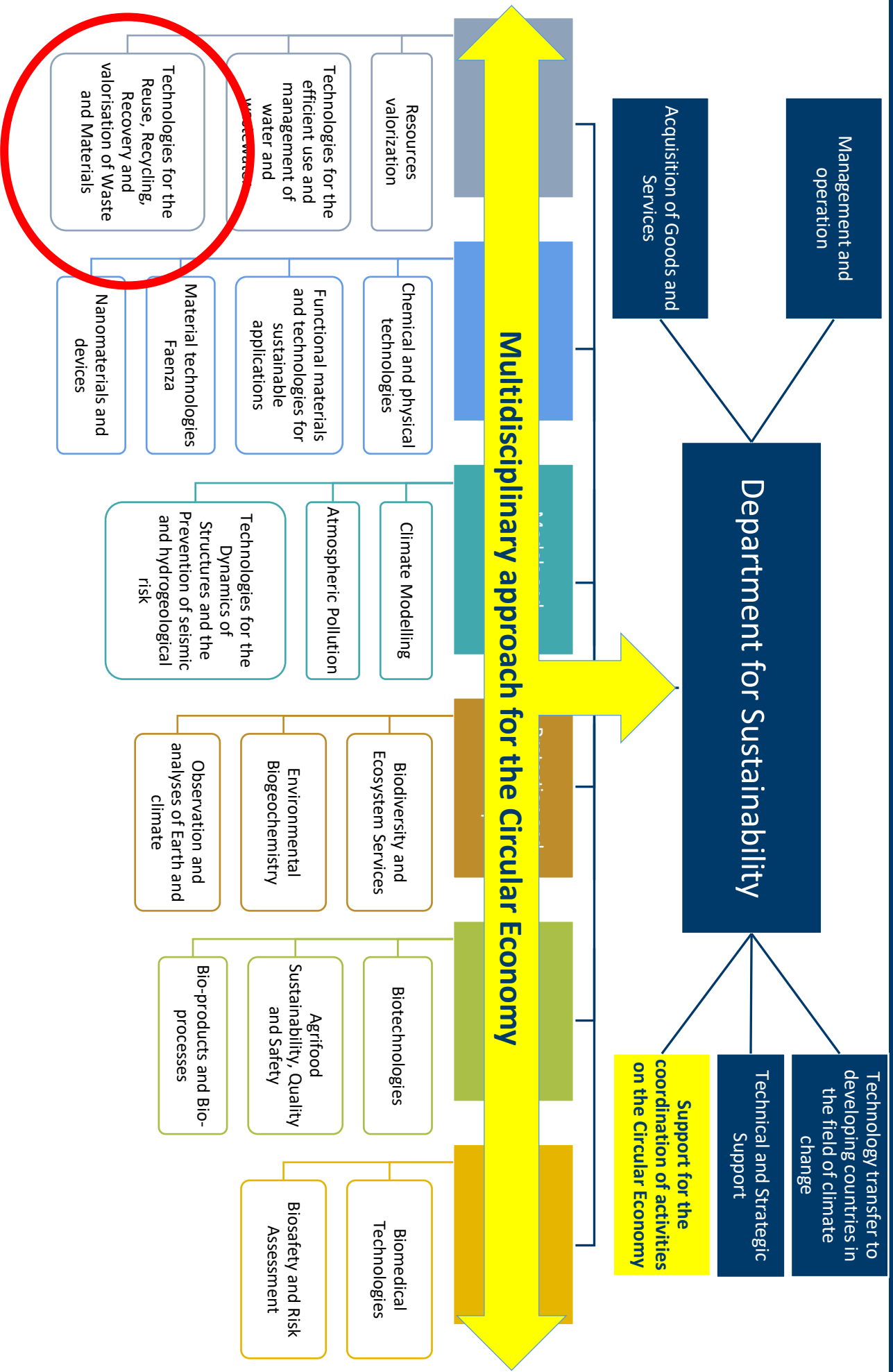
Head of Laboratory Technologies for the Reuse, Recycling, Recovery and valorization of Waste and Materials (T4RM) of ENEA

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Department for Sustainability (SSPT)



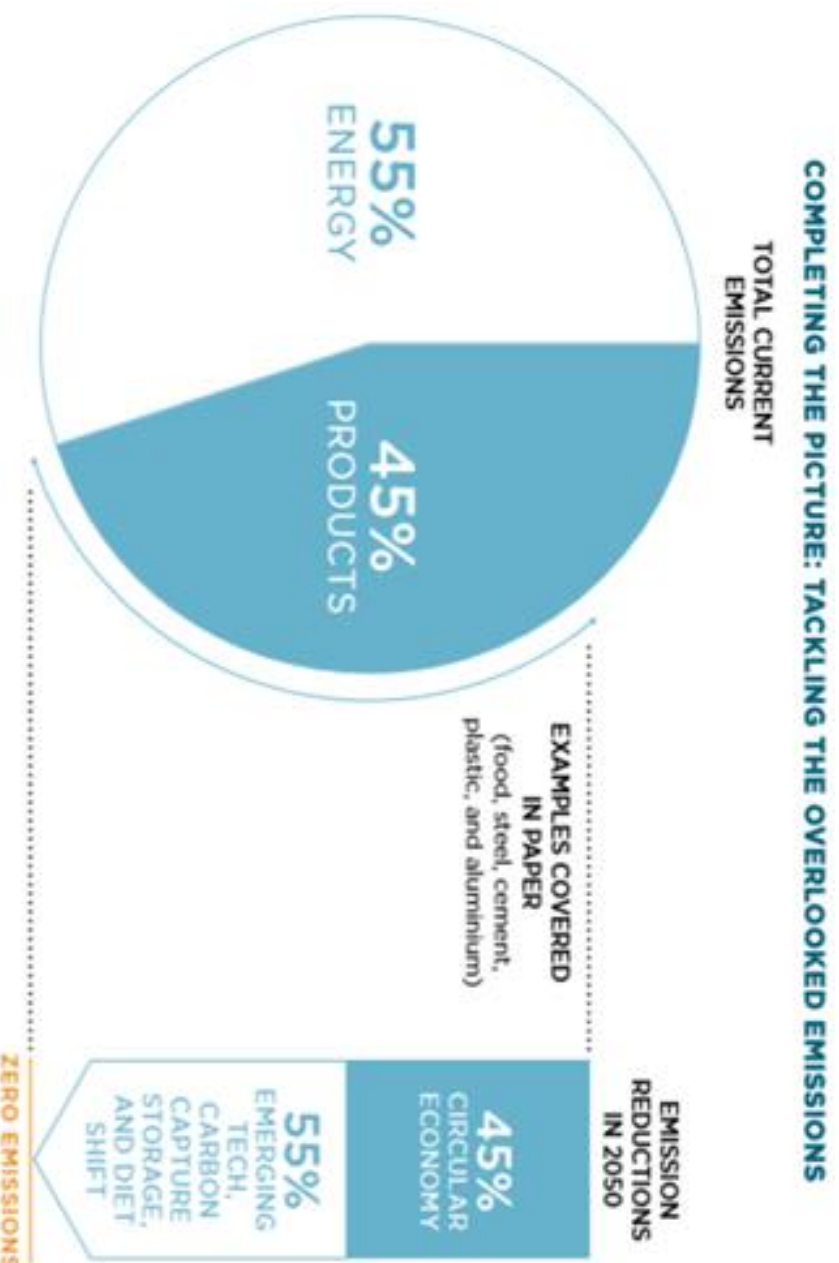
Department for Sustainability - SSPT



- **Activities in many sectors of research**
- **Environmental impacts**
- **Promotes the Circular Economy**

Waste management: treatment, recycling, materials recovery, reuse.

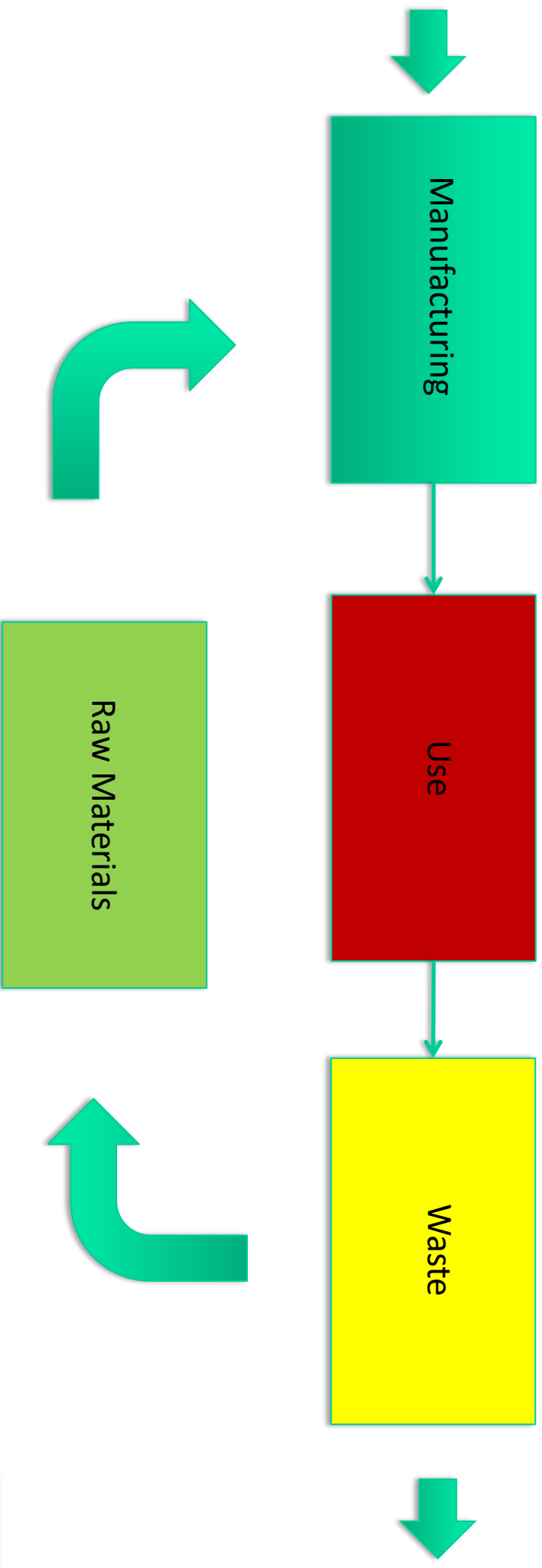
European Green Deal: the role of the circular economy in the climate challenge



The fight against climate change is the most important challenge of our future. And the Circular Economy can play a fundamental role, both in the production of renewable energy and in the production of products.

This is important for the green transition

Circular vs Linear



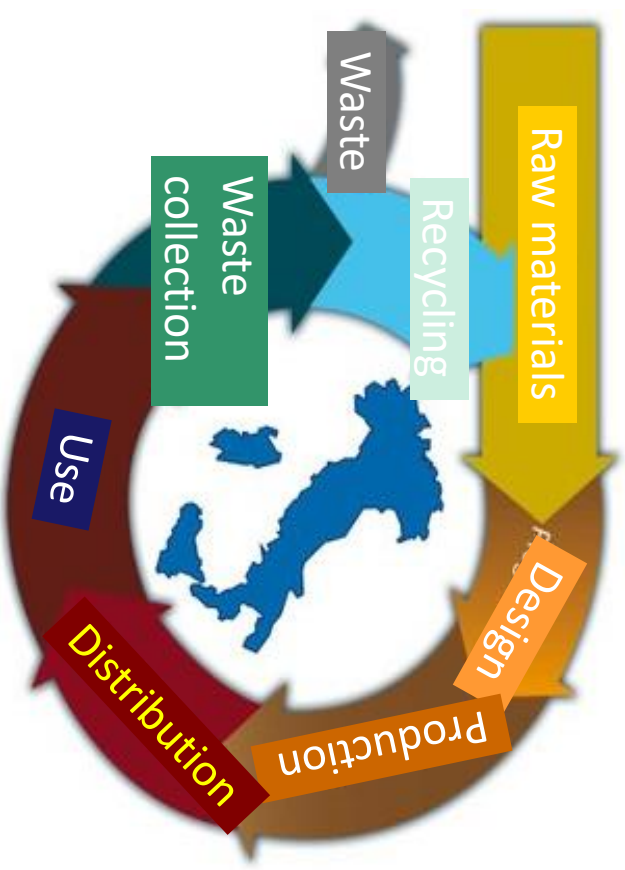
The best way to define what is the Circular Economy, is to say that it is not linear!

CIRCULAR ECONOMY

In the “circular economy” model products maintain their added value for as long as possible with a “zero waste” objective.

For the transition we need:

- Increasing efficiency in the use of resources and a minimization of waste production.
- Eco-innovation in production cycles (more sustainable technologies, new materials, recycling chains).
- Development of new sustainable treatments of wastes in order to recovery all materials as possible.
- Formation and information for citizens.



It's a simple concept but in real-world application there are many technical and regulatory constraints!

Critical Raw Materials

“Without critical raw materials, there is no green transition and digital transition”. Ursula von der Leyen

Access to resources is a security issue. The risk is that, with the ecological transition, the current dependence on fossil fuels could be replaced by a dependence on (critical) raw materials, many of which come from Countries extra Europe and for which global competition becomes more intense

Why are CRMs so important?

It is important to note that these materials are not classified as 'critical' because they are considered scarce, rather they are classified as 'critical' because:

- ✓ They have a **significant economic importance for key sectors in the European economy.**
- ✓ They have a **high-supply risk** due to the very-high import dependence and high level of concentration of set critical raw materials in particular countries

Lastly, there is a **lack of (viable) substitutes**, due to the very unique and reliable properties of these materials for existing, as well as future applications

CRM list 2023

2023 CRMs vs. 2020 CRMs

aluminium/bauxite	gallium	phosphate rock	vanadium
antimony	germanium	phosphorus	arsenic
baryte	hafnium	PGM	feldspar
beryllium	HREE	scandium	helium
bismuth	lithium	silicon metal	manganese
borate	LREE	strontium	copper
cobalt	magnesium	tantalum	nickel
coking coal	natural graphite	titanium metal	indium
fluorspar	niobium	tungsten	natural rubber

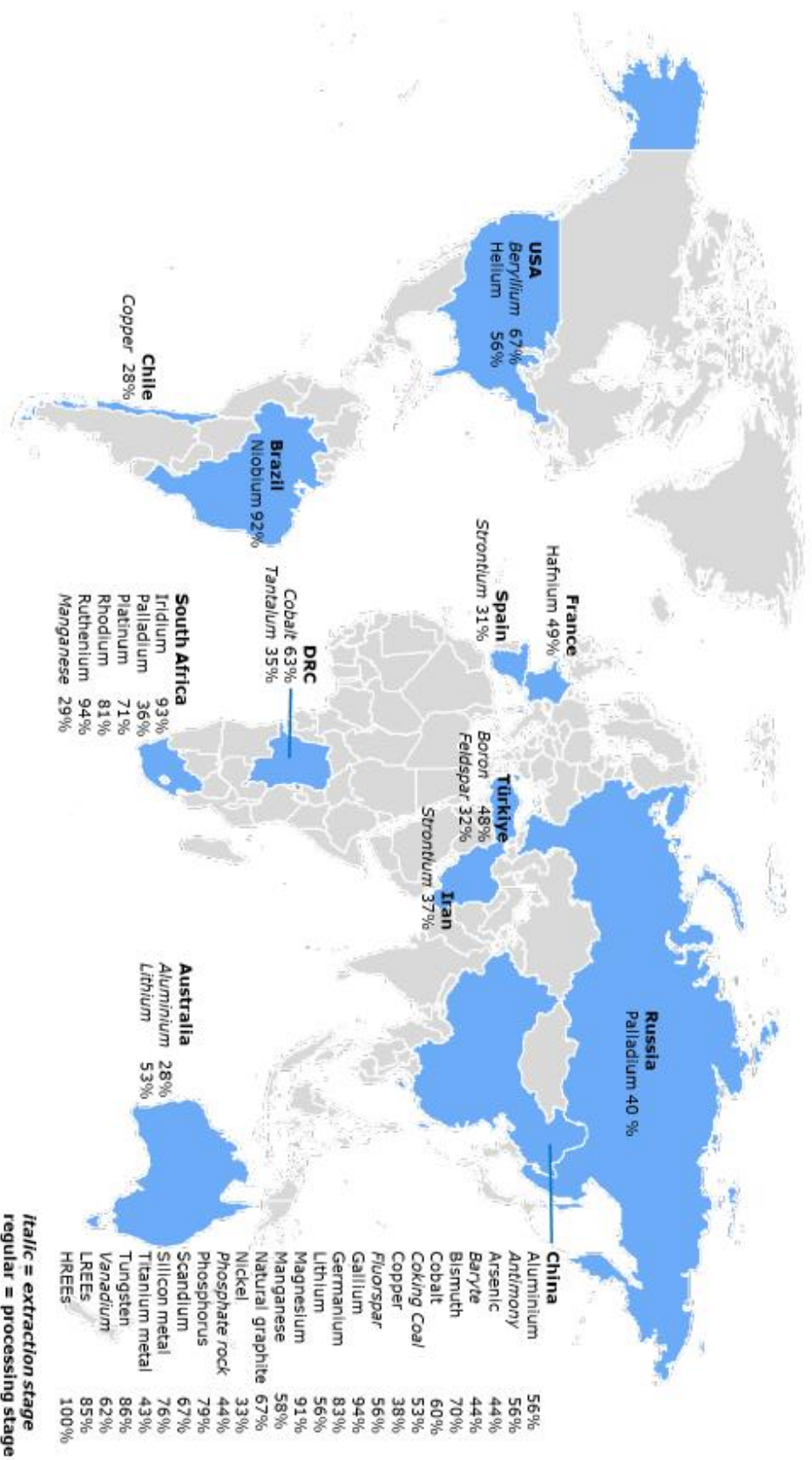
Legend:
 Black: CRMs in 2023 and 2020
 Red: CRMs in 2023, non-CRMs in 2020
~~Strike~~: Non-CRMs in 2023 that were critical in 2020

Every three years, the EU publishes a list
 In last list, 34 CRMs were identified.
 And 16 are defined as strategic.

* copper and nickel do not meet the limits for CRM, but are included as strategic raw materials

CRM mines in the world (2023)

Figure B: Countries accounting for largest share of global supply of CRMs



In this slide, the map of CRM mines in the world is reported. As can be seen, in Europe we have very few mines

Municipal Waste: Urban mines

We have no CRM mines. Our mines are the wastes!



B&D

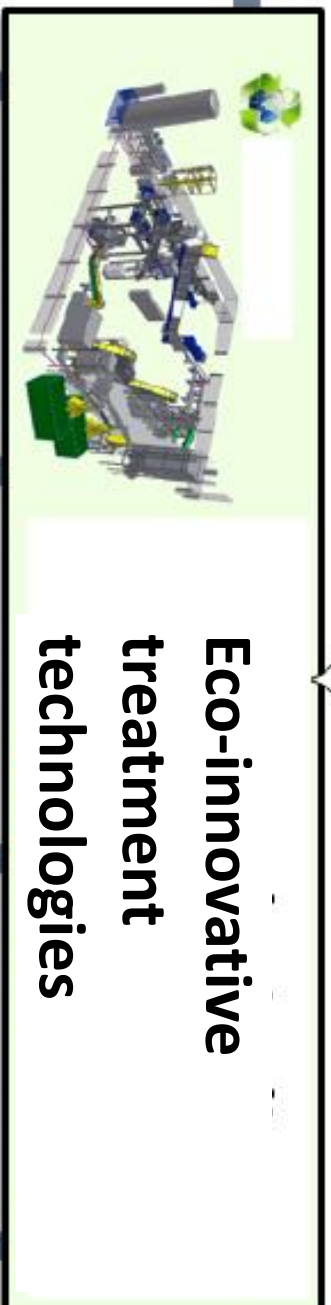
Building and demolition materials

USW

Urban Solid Waste

WEEE

TYRE



Energy
Wood, paper, etc

Metals

Glass

Plastic

Rubber

The towns, in the next future, will become a megalopolis, with several millions of inhabitants, which will produce a million tons of waste

WEEE: Waste from Electrical and Electronic Equipment

Recycling and recovery percentages established by Directive 2012/19/EU (Source: Directive 2012/19/EU)

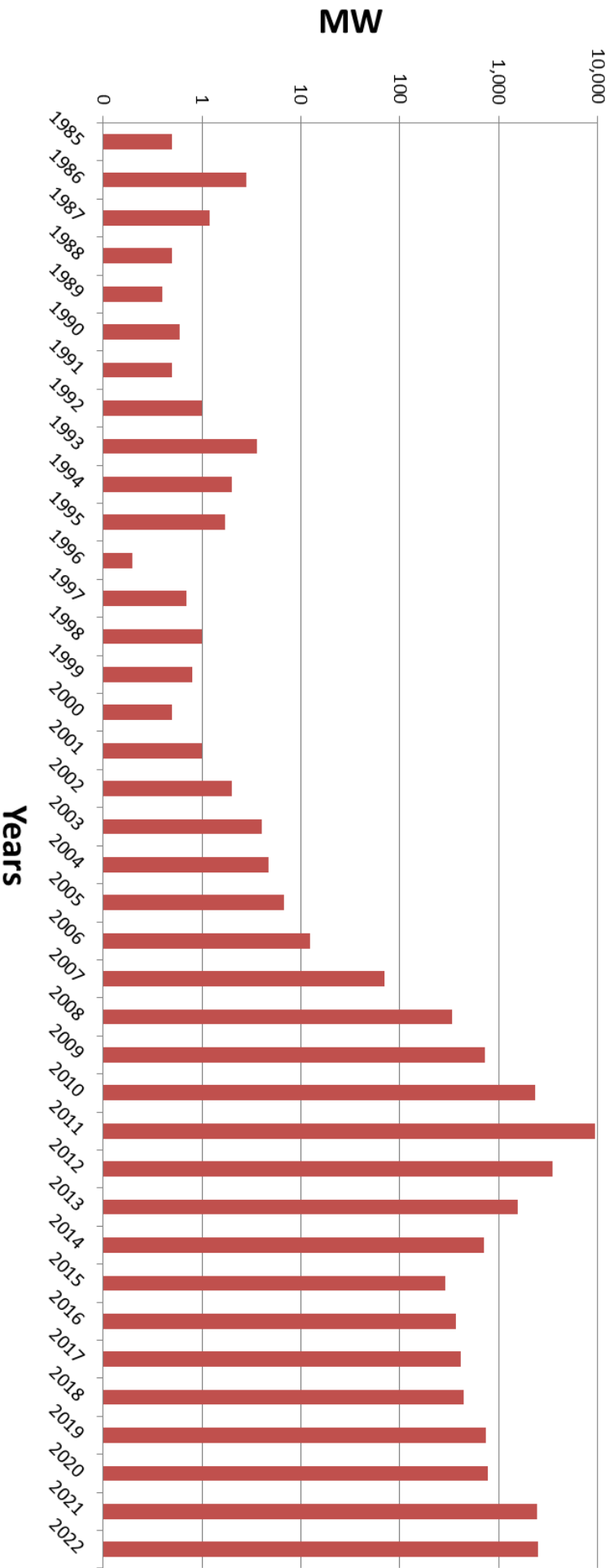
Period	Recovery (%)
From 13/08/2012 to 14/08/2015	75
From 15/08/2015 to 14/08/2018	80
From 15/08/2018	85

Aluminium frame + glass ~ 85%

Directive 2012/19/EU was implemented in Italy by Legislative Decree no. 49 in force on 12 April 2014.

PV installations in Italy

PV installation in Italy



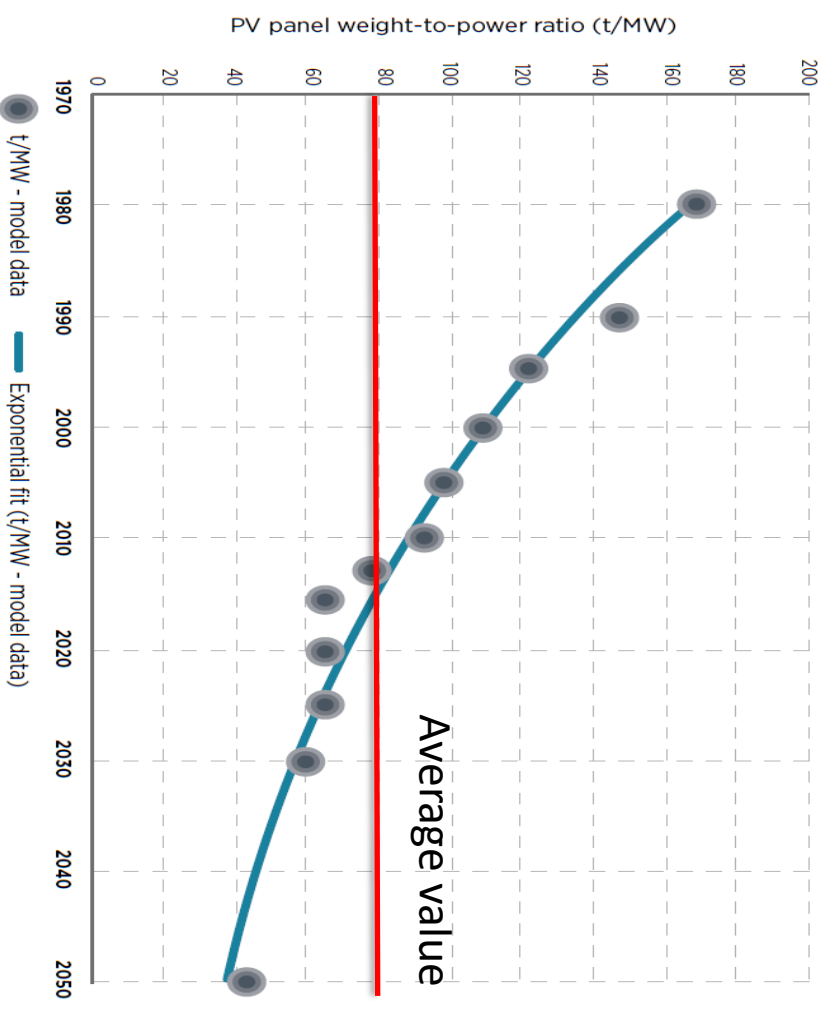
The trend is increasing until 2011. Then decreasing for few years. In the last few years, it is increasing again.

Example of calculating of the amount of materials recoverable from PV waste

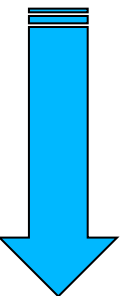
Potential curve fit of projection of PV panel weight-to-power ratio (t/MW)

This ratio is decreasing in time. This means that, at equal power, the layer of material photo active (the wafer), is decreasing. This because the efficiency of photoactive material is increasing. So, less material is requested to produce the same energy.

This graphic contains some data and a prevision for next years.



1 MW



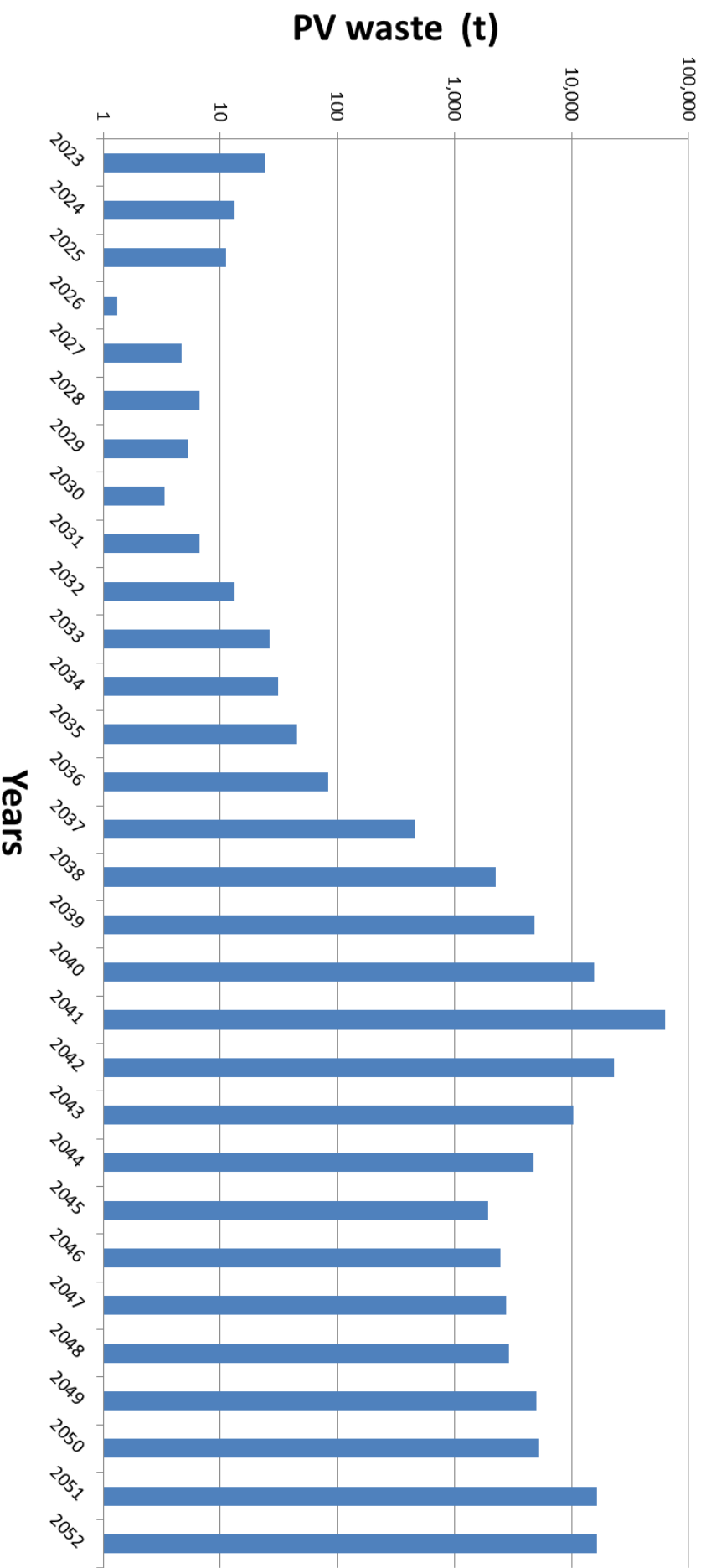
80 t waste

Life time = 30/25 years

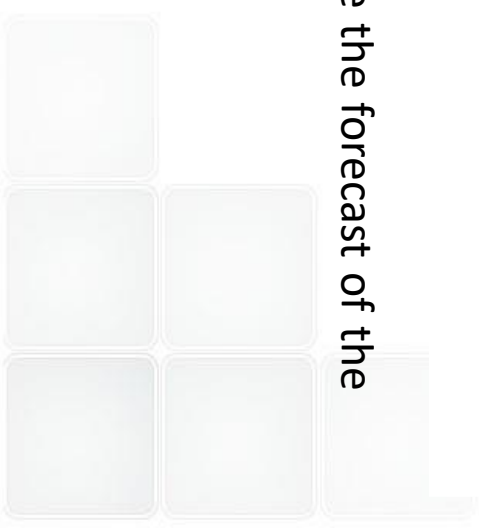
If we take the average value, we have the amount of waste produced for each MW installed. Of course, at end of life (after 20-25-30 years)

(source: IRENA)

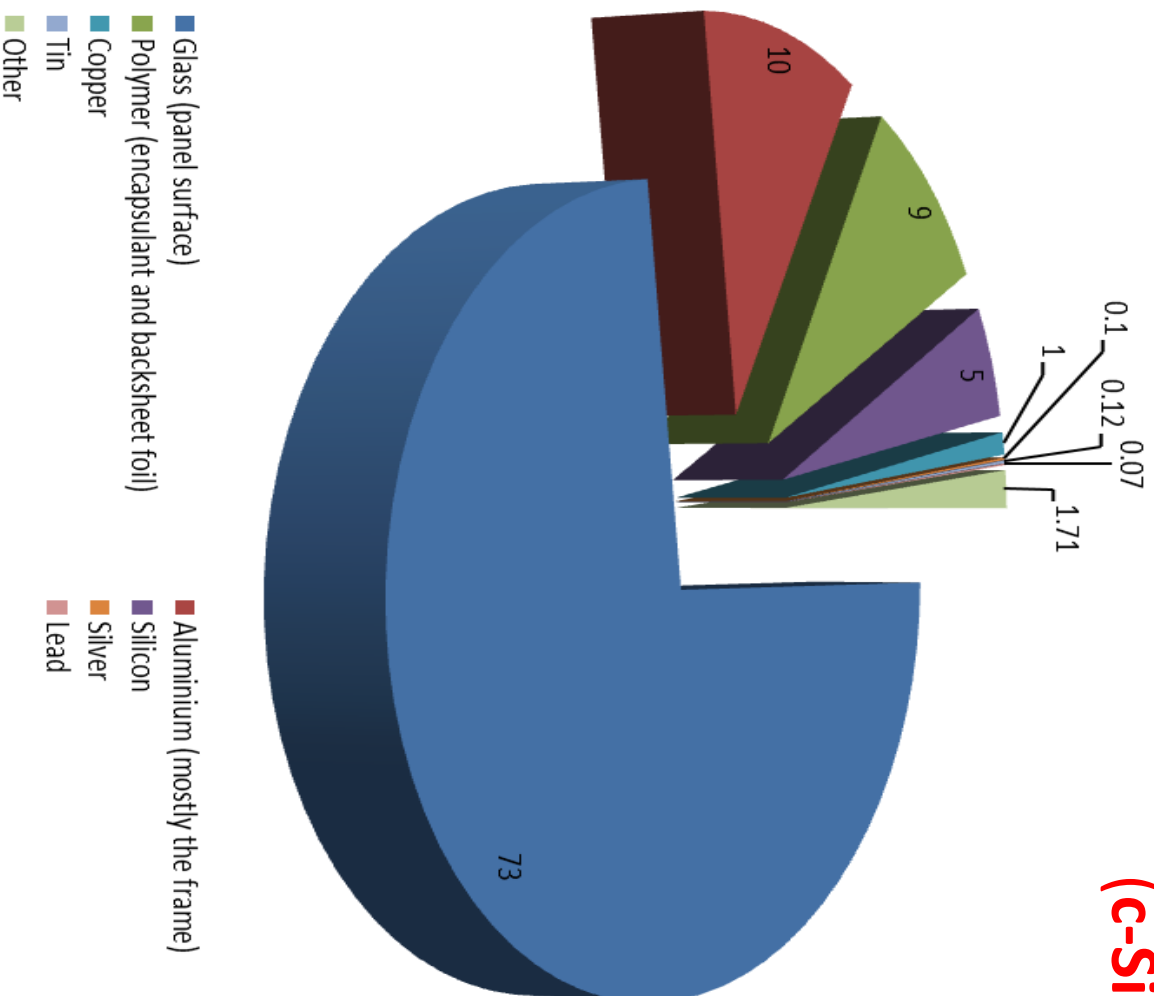
Forecast of PV waste production in Italy (no cumulative) (30 year)



Based on the hypotheses contained in the previous slides, we can extrapolate the forecast of the production of photovoltaic waste in Italy in the coming years



Panel composition crystalline silicon (c-Si)



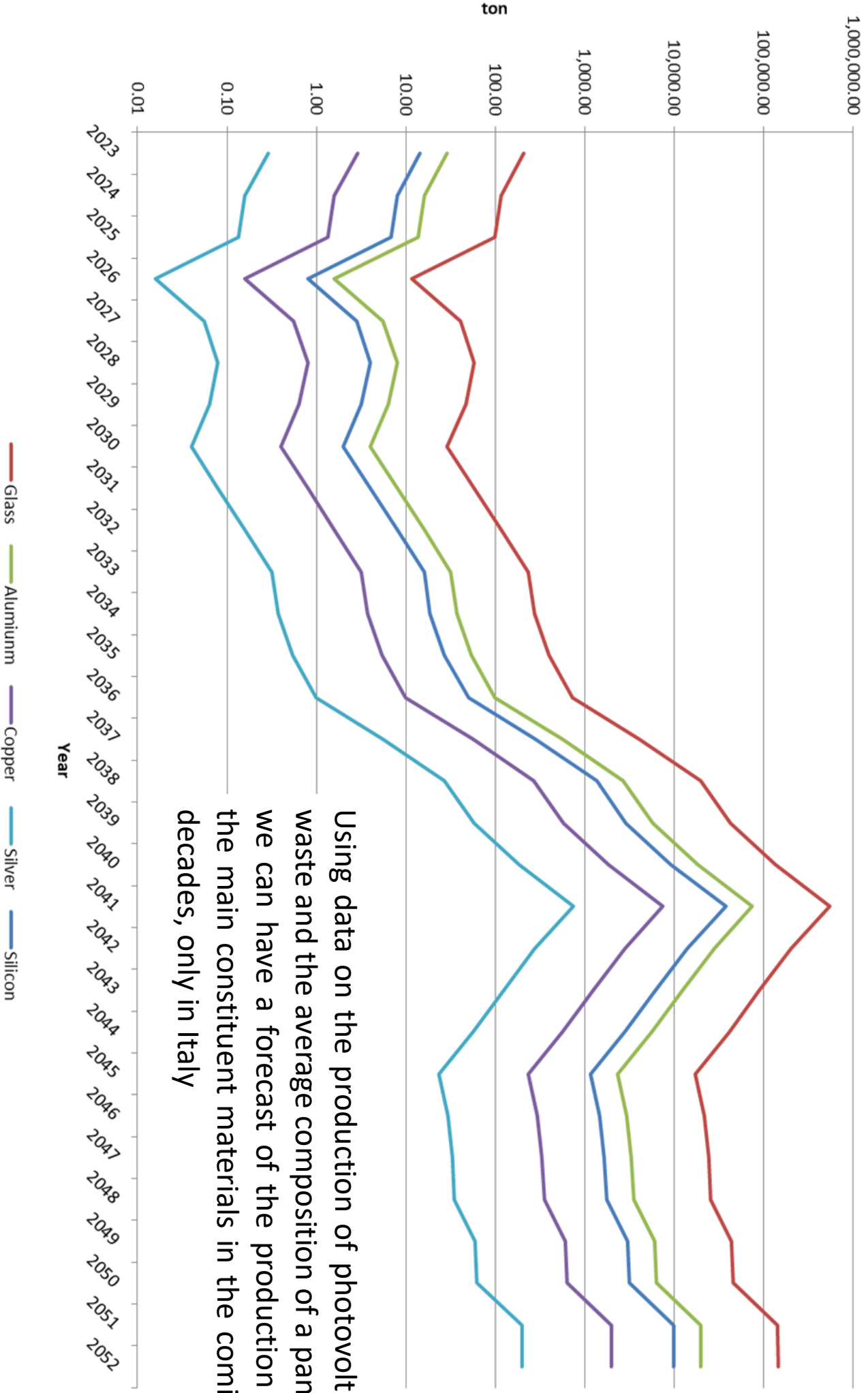
	%	kg
Glass (panel surface)	73	13.14
Aluminium (mostly the frame)	10	1.8
Polymer (encapsulant and backsheet foil)	9	1.62
Silicon	5	0.9
Copper	1	0.18
Silver	0.1	0.018
Tin	0.12	0.0216
Lead	0.07	0.0126
Other	1.71	0.3078

Panel composition (c-Si)

Average Weight: 18 kg

(Sander et al., 2007)

Forecast of material based on PV waste in Italy (no cumulative data)

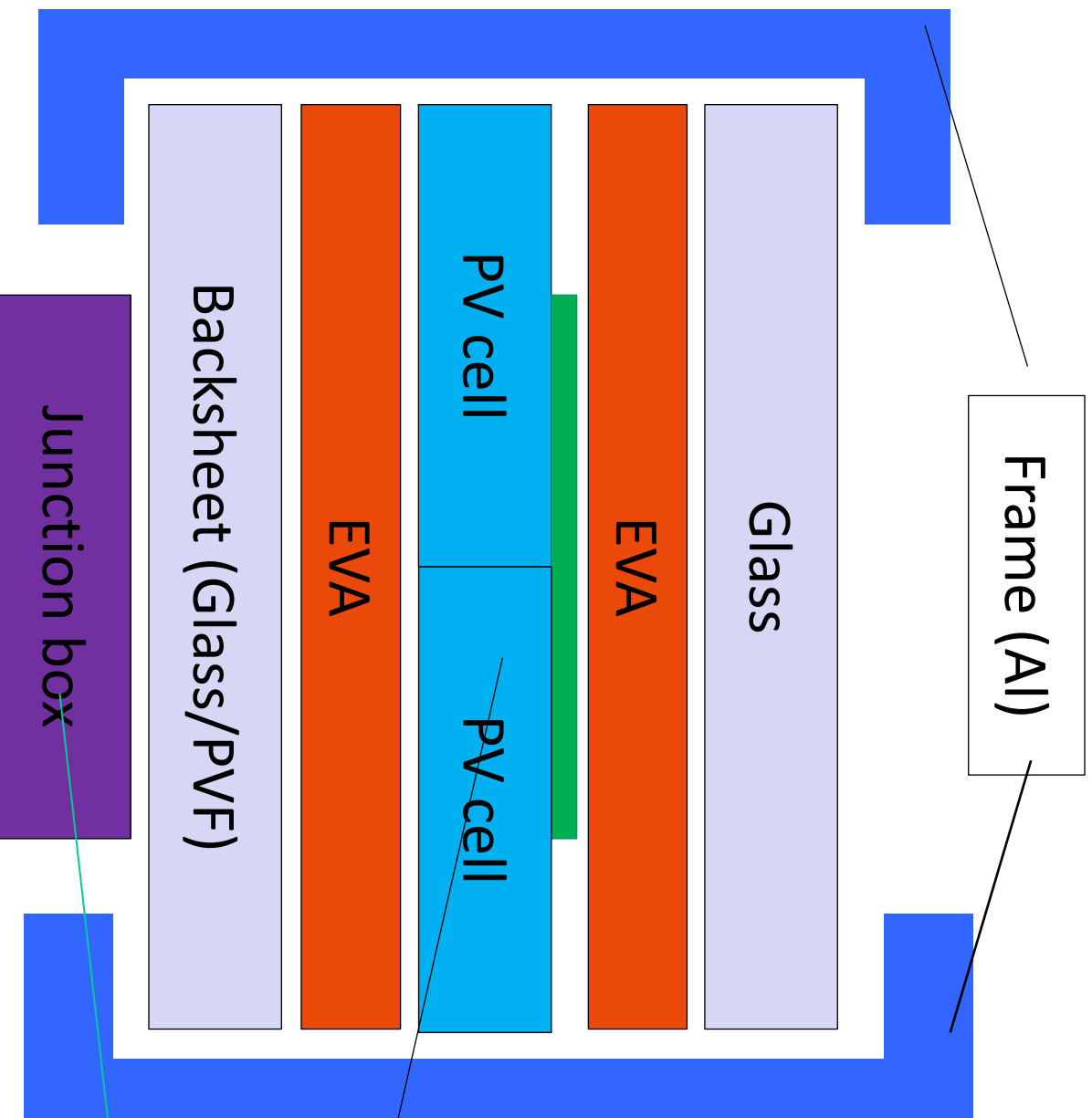


Using data on the production of photovoltaic waste and the average composition of a panel, we can have a forecast of the production of the main constituent materials in the coming decades, only in Italy

— Glass — Aluminum — Copper — Silver — Silicon



c-Si. Cross section

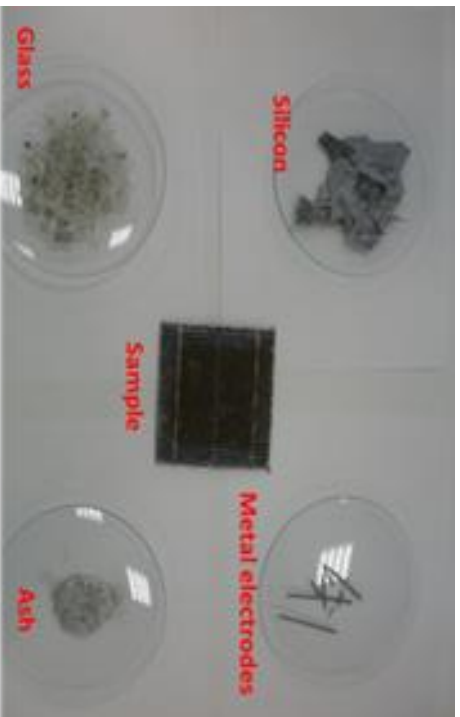
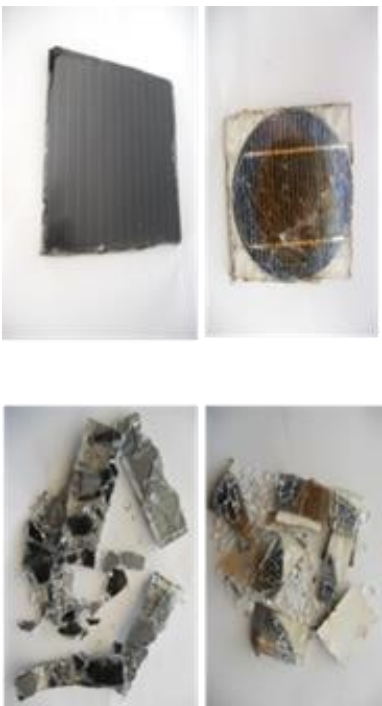


The scope of the methods of treatments is the recovery of the materials. This can be made through the separation of each layer of the panel. The first step is the removal of the junction box. The frame is removed mechanically. Then the removal of EVA is requested. This can be performed through a thermal or mechanical method.

Metal electrodes

For the electrical connections

Recovery of materials from PV panels at end of life. ENEA activities



- Scientific paper
- International Research Projects
- Patent



The aim of these activities in ENEA are to find a sustainable way to recovery materials from photovoltaic waste

ENEA patent

Thanks to all these experiences, ENEA , together with a start-up Beta-Tech, has realized a patent on a process for the treatment of PV waste finalized to recovery of all main components

“Low energy consumption and low environmental impact method for the recovery of the main components of photovoltaic panels in crystalline silicon at the end of its life” ENEA. Italian patent (N. 1020170000033488)

Inventors:

Marco Tammaro (ENEA)

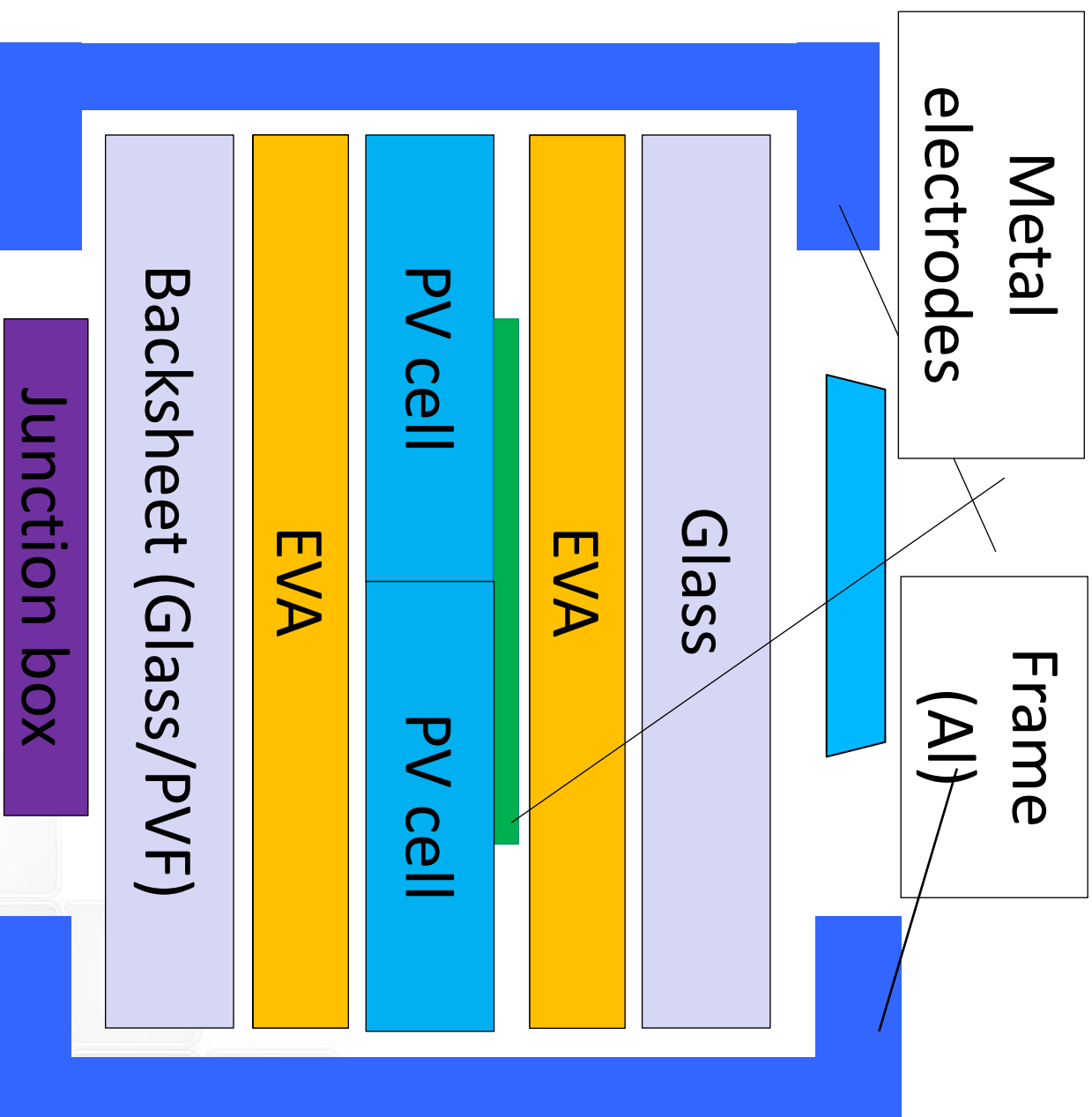
Patrizia Migliaccio (Beta-Tech Srl)

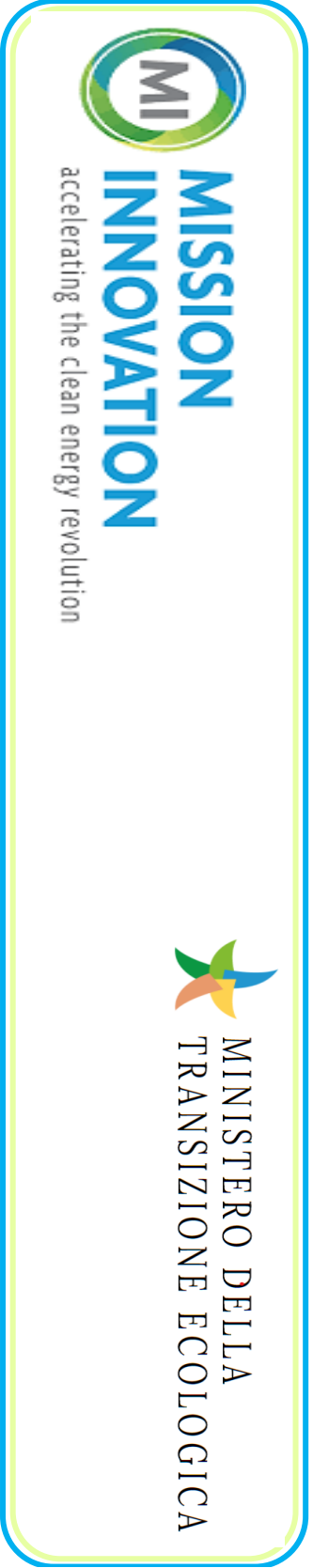
The target was to set a recovery process at low environmental impact.

ENEA. Italian patent

The method consists of controlled heating to soften the polymeric layers and the subsequent detachment of all remaining layers.

The process is roughly based on a thermal treatment that can be defined as "light". This is because the EVA layer is warmed with infrared lamps only until the softening (around 100 Celsius degree). This warming is focused and for a time strictly requested for the detachment through the rip





Progetto IEMAP

Italian Energy Materials Accelerated Platform

Project funded by MASE (Ministry of Environment and Energy Security)

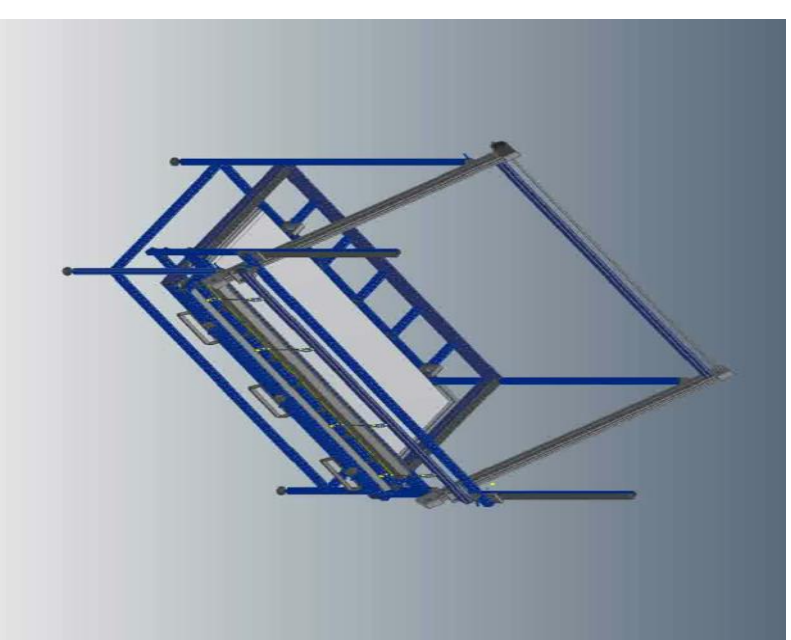
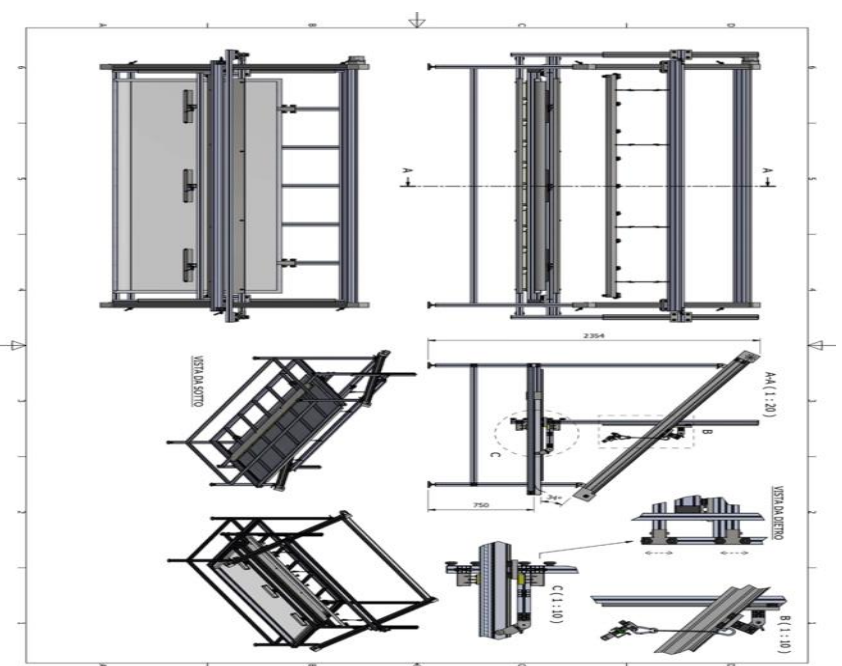
Thanks to the project IEMAP, a plant prototype based on this patent, is realized. It is a TRL 5, then semi-automatic. The experimental activities that will be performed on this prototype, will allow us to obtain important information about the future development of this technology.

WP4- LA 4.4-5-6

Realization of a prototype, whose process is based on an ENEA patent, for the treatment of waste photovoltaic and experimentation for the development of the process

Other outputs:

- Description of the low environmental impact method for the treatment of photovoltaic panels aimed at recovering of materials
- Definition of a fast method of panel characterization

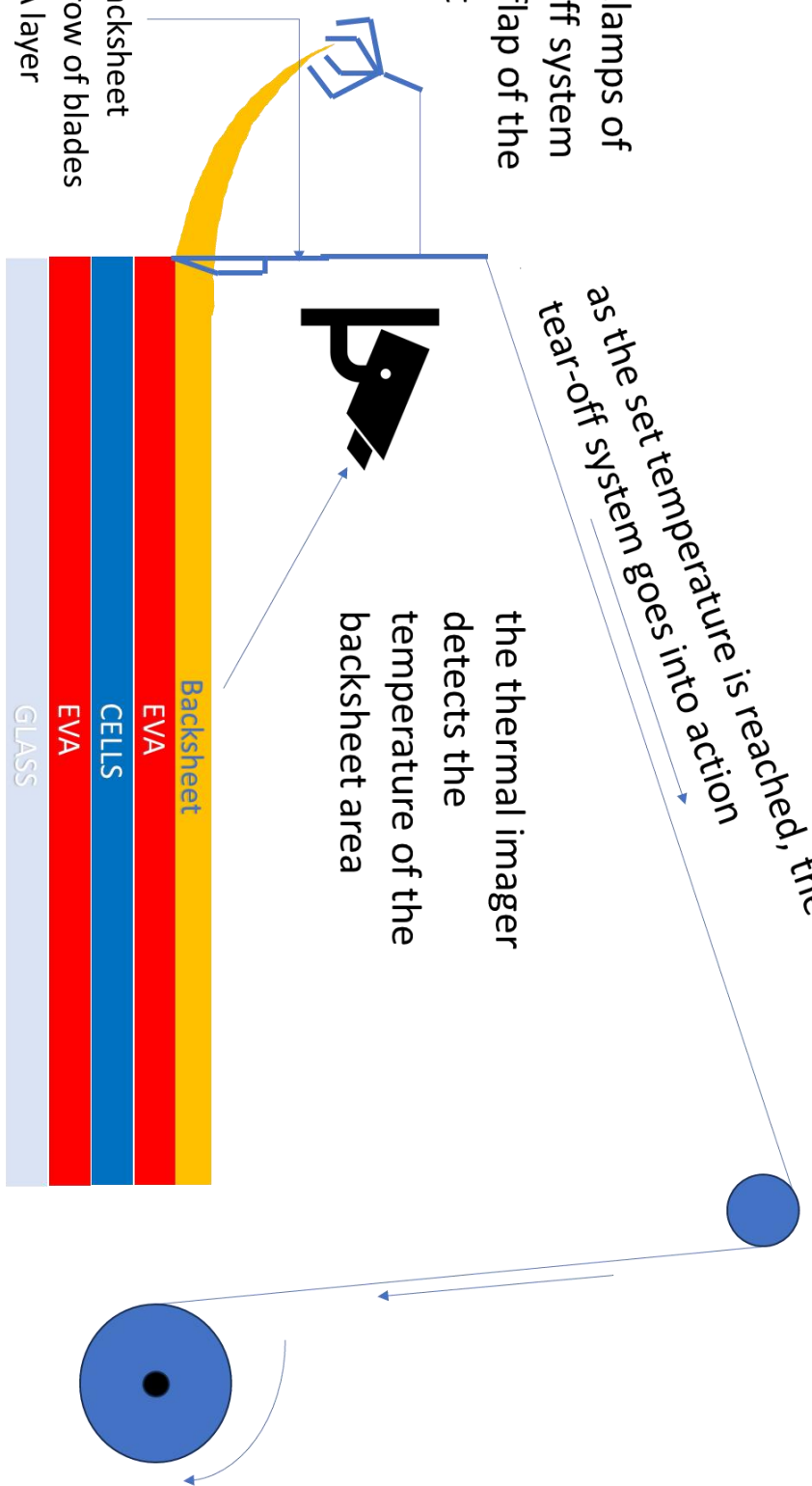


A row of clamps of the tear-off system fastens a flap of the backsheet

as the set temperature is reached, the tear-off system goes into action

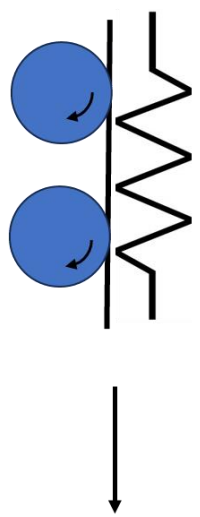
the thermal imager detects the temperature of the backsheet area

After the backsheet removal, a row of blades rips the EVA layer



Electric motor of the tear off system

A mobile heating system has the aim to promote the detachment of the backsheet at a temperature ranging between 100 and 150°C



Prototype ENEA for the treatment of PV panel: PROTEO

PORTUPOLETTI - TECNOLOGIE CENTRALE
E LO SVILUPPO ECONOMICO SOSTENIBILE



The prototype equipped with a flexible cover connected to a hood for the aspiration of diffusive emissions generated by the heating of the plastic layers

Details

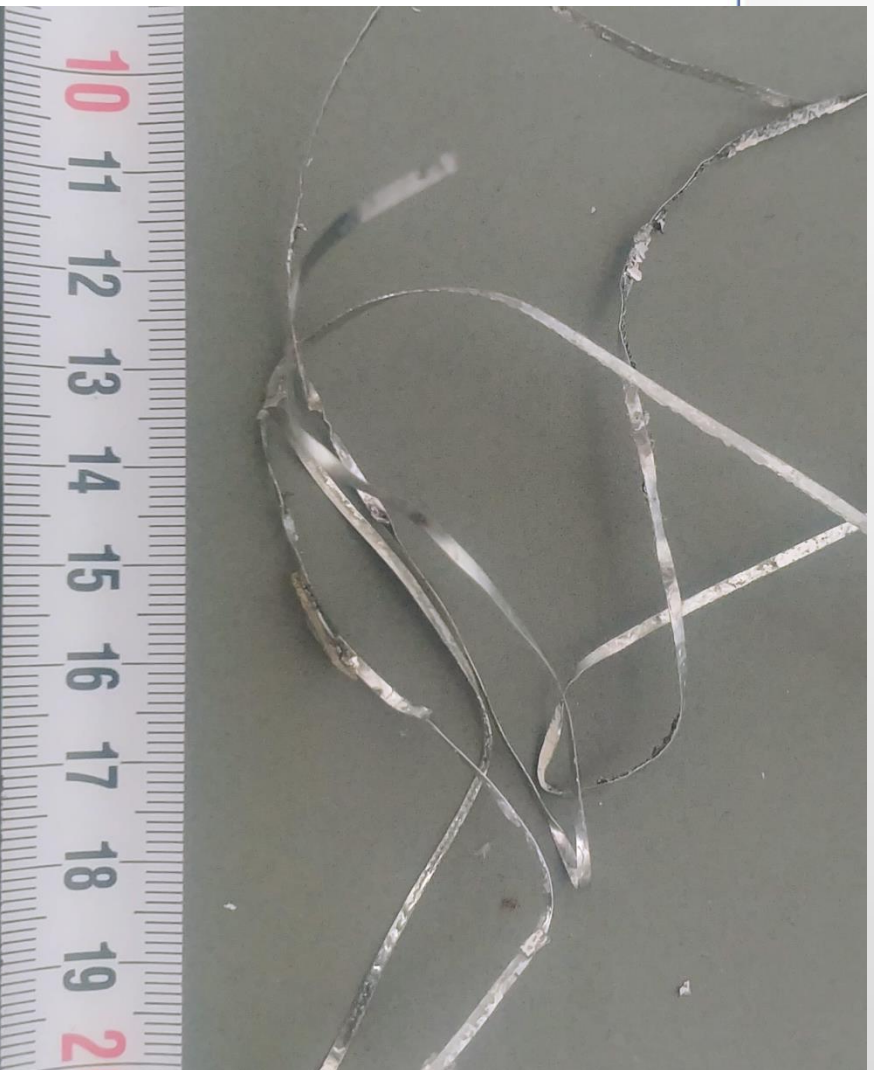


As you can see, the backsheet is intact

Details

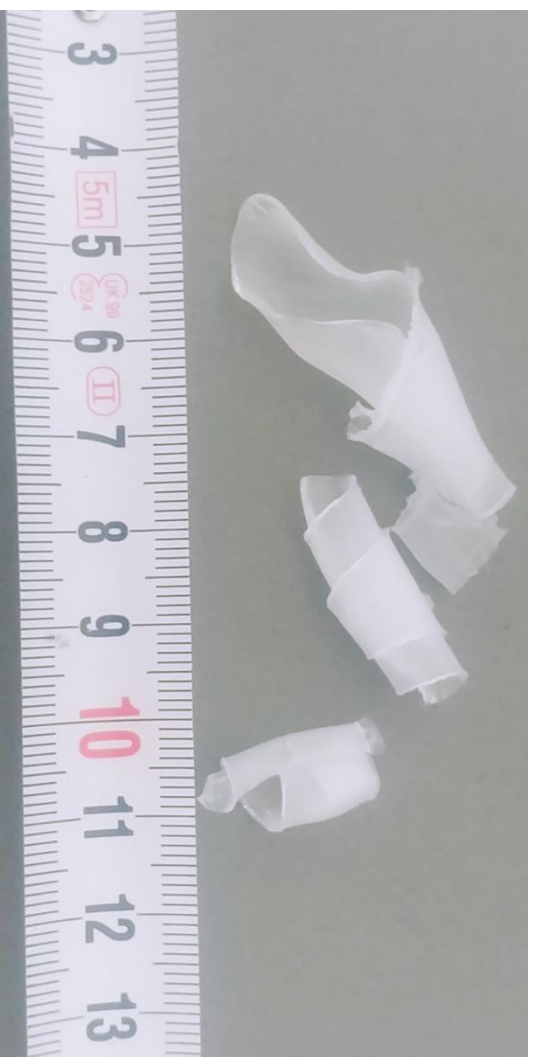
Row of clamps of tear-off system





Metals

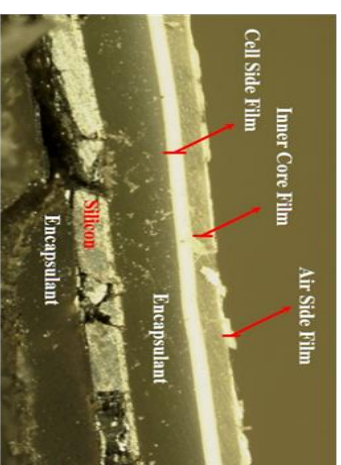
EVA



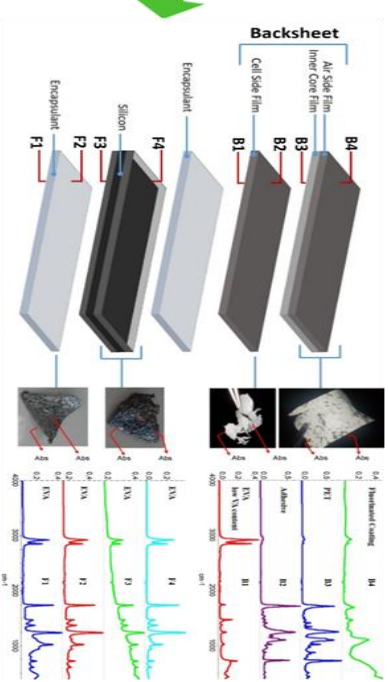
Recycling of waste photovoltaic

The project includes also experimental activities finalized to find a fast way to analyze the structure of the panel. Because is important to have information about the composition and structure of the panel in order to optimize the process's parameters.

Finally, the cells obtained from the process, are treated with a hydrometallurgical method in order to recover metals as copper, silicon, and silver



Cross sectional optical microscopy



Delamination and recognition of materials

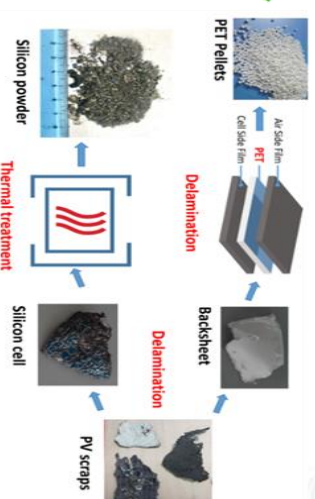


PV scraps

End of life PV panels



Possibility to apply specific recycling processes



CONCLUSIONS

- The real challenge is to recycle in a sustainable way
- There is probably no single treatment solution
- The treatment of WEEE for recovery must play an important role in ecological transition
- Challenge still open for other types of panels: perovskite, thin films, organic

Thanks

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0001 0110 1110
1101 0010 1101
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