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FRELP: FULL RECOVERY END-OF-LIFE PHOTOVOLTAIC

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INTRODUCTION TO THE PROJECT

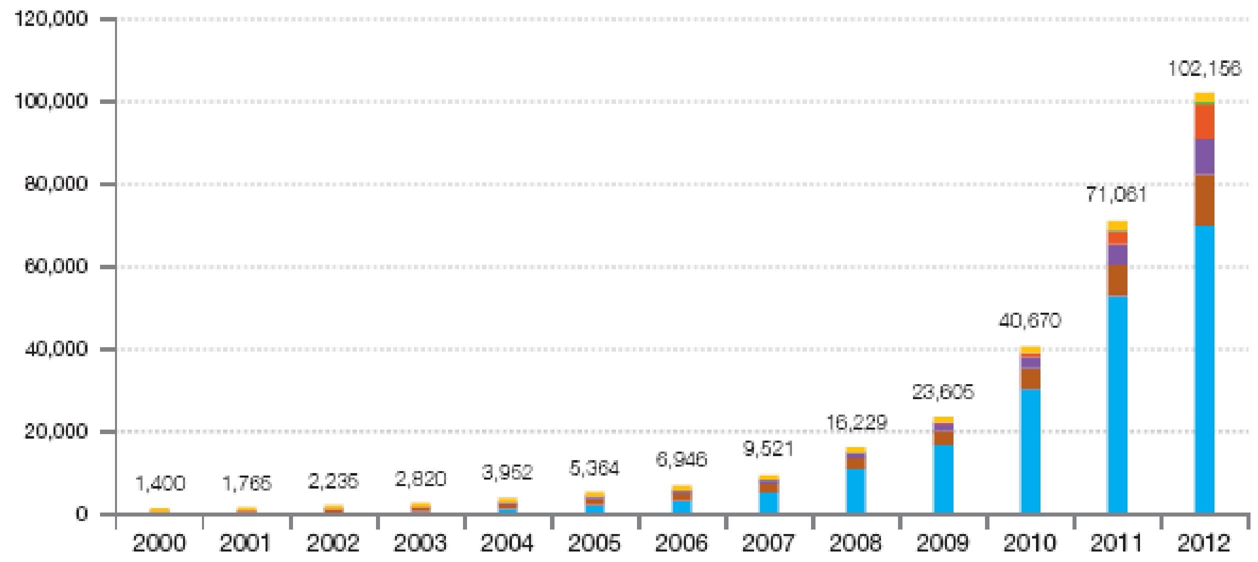
- TIMETABLE PROJECT: III 2013 – end II 2017
- CO-FINANCED BY EUROPEAN COMMUNITY:
  LIFE PROGRAMM (http://ec.europa.eu/environment/life/index.htm)
- BUDGET: 4,887,035 Euro (EC contribution 50%)
- PARTNERS: SASIL SPA (http://www.sasil-life.com)
  SSV (http://www.spevetro.it)
  PV CYCLE (http://www.pccycle.org)

PV MARKET WORLWIDE

Europe remains the world's leading region in terms of cumulative installed capacity, with more than 70 GW as of 2012.

This represents about 70% of the world's cumulative PV capacity (compared to about 75% of the world's capacity in 2011). Next in the ranking are China (8.3 GW) and the USA (7.8 GW), followed by Japan (6.9 GW)

Figure 1 - Evolution of global PV cumulative installed capacity 2000-2012 (MW)

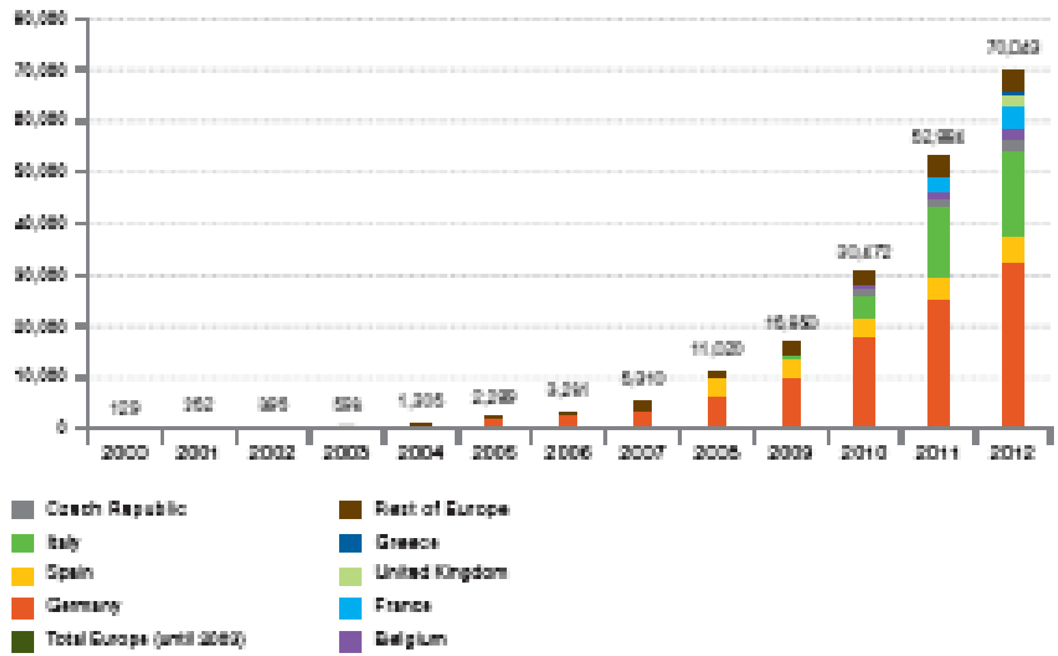


GLOBAL MARKET OUTLOOK FOR PHOTOVOLTAICS 2013-2017- EPIA 2013 - http://www.epia.org/fileadmin/user_upload/Publications/GMO_2013_-_Final_PDF.pdf

PV PANNEL MARKET IN EUROPE

The amount of PV (Photo Voltaic) panels placed on the EU territory has been rising sharply in recent years, reaching 3 million tons today, while sustainable solutions for recovery of photovoltaic waste have not yet been sufficiently identified.

Figure 5 - Evolution of European PV cumulative installed capacity 2000-2012 (MW)



GLOBAL MARKET OUTLOOK FOR PHOTOVOLTAICS 2013-2017- EPIA 2013 - http://www.epia.org/fileadmin/user_upload/Publications/GMO_2013_-_Final_PDF.pdf

WASTE FORECAST

- Photovoltaic (PV) modules have a technical lifetime of +30 years
- The development of important PV capacity only started in the 1990s
- PV CYCLE expects a significant number of discarded PV modules in the next 10-15 years.

It is forecast, for example, that from 2015 onwards, 30.000 t/year will be disposed in Europe, and over the next 20 years this amount could reach 500.000 t/year

PV CYCLE WASTE FORECAST

The most important factors, which influence the quantity of waste generated, are:

- Transportation damage
- Installation damage
- Guarantee/Warranty cases
- Lifetime of PV modules

Currently, only 1% of all collected photovoltaic (PV) modules have reached the end of their lifetime. The largest amounts of collected PV modules come from transportation or installation damages. Therefore the amount and timing of future waste streams will also depend on the PV market and its executing parties.

AIMS OF THE FRELP PROJECT

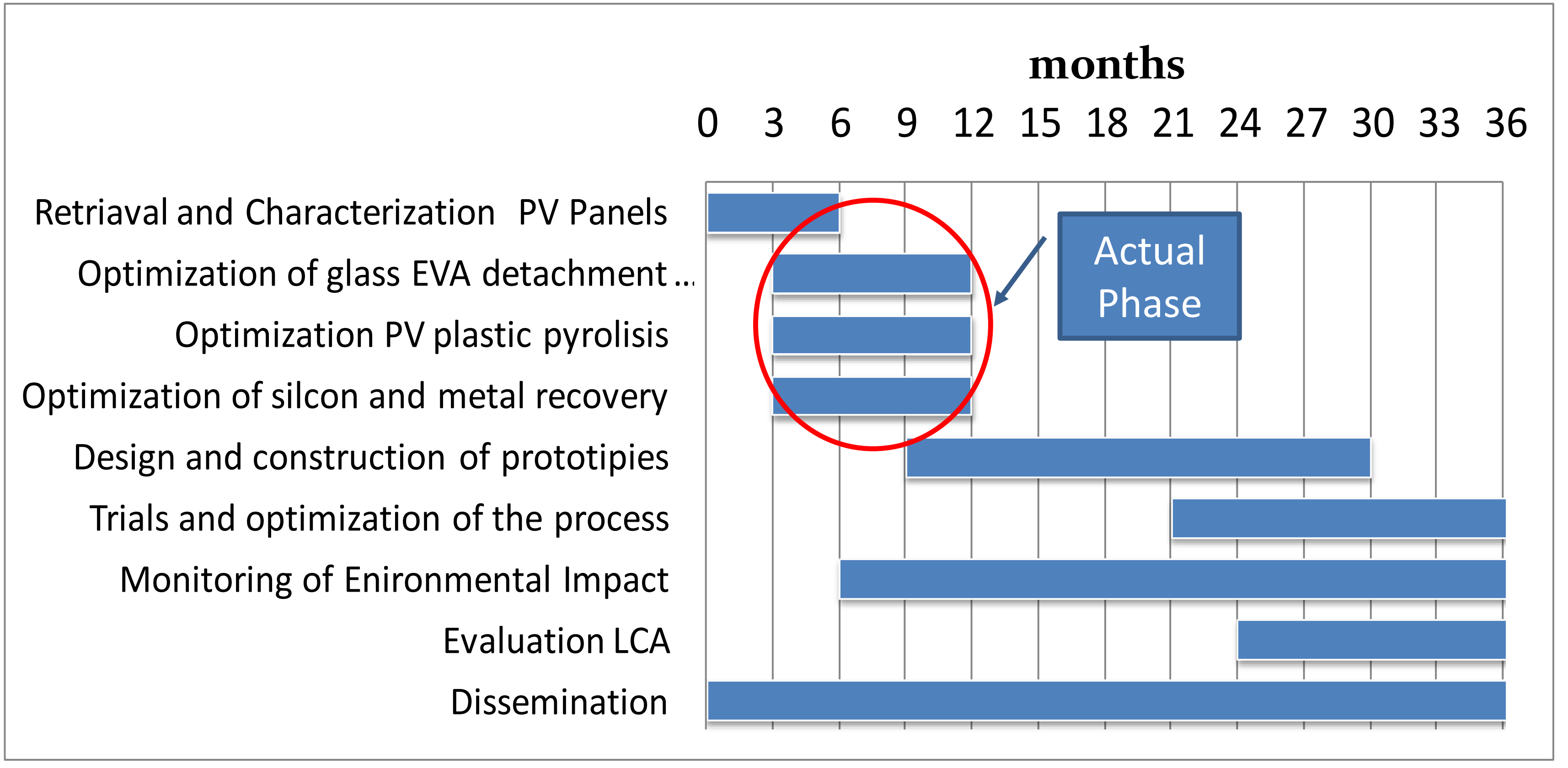
The main aim of the project is to test and demonstrate the application of existing technologies for 100 % recycling of end-of-life PV panels, mono and poly-crystalline in an economically and viable way. Two key environmental solutions are thereto proposed:

- Recovery of high quality extra clear glass, to be employed in hollow and flat glass industry, implying very significant energy and CO_2 emission saving in the glass melting process.
- Recovery of (metallic) silicon, to be employed as ferrosilicon in iron silicon alloys or, if enough purity is obtained, transformed in amorphous silicon to be employed in the production of thin films, thus saving important energy cost and CO_2 emission for the production of primary silicon.

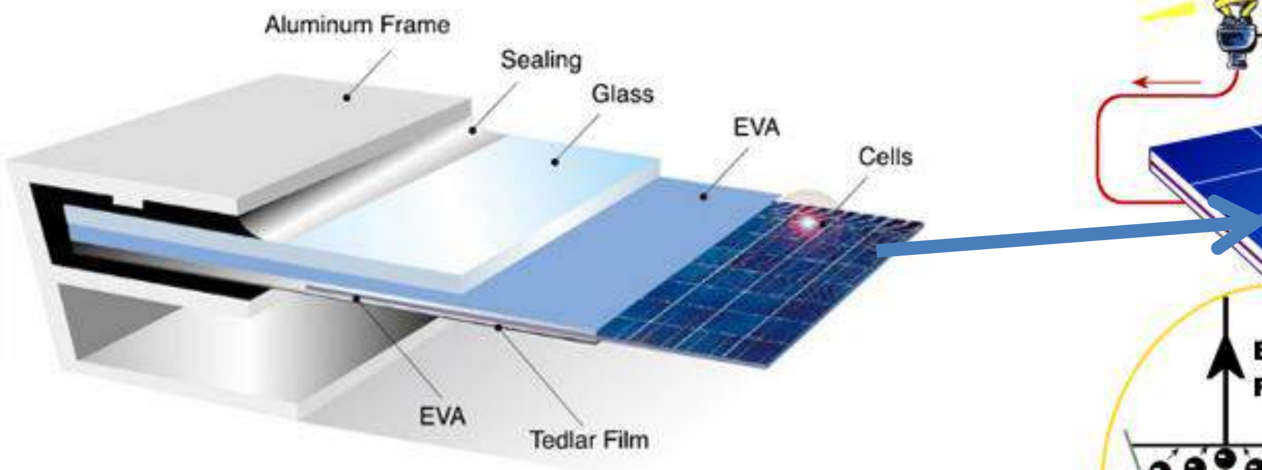
TIMETABLE OF THE PROJECT

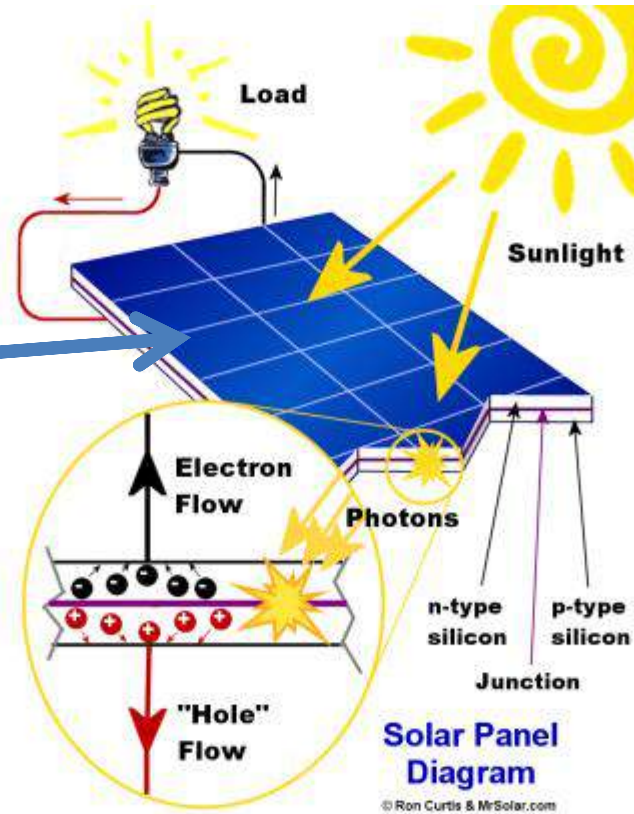
Start time: August 2013

End time: June 2017



STRUCTURE OF A SILICON PV PANEL





The PV Cells are protected by encapsulation with EVA.

CHARACTERIZATION OF END-OF-LIFE PANELS

PVCycle and SASIL have provided the Stazione Sperimentale del Vetro with a total of 21 disused photovoltaic panels, produced by 9 multinationals, leaders in the sector.

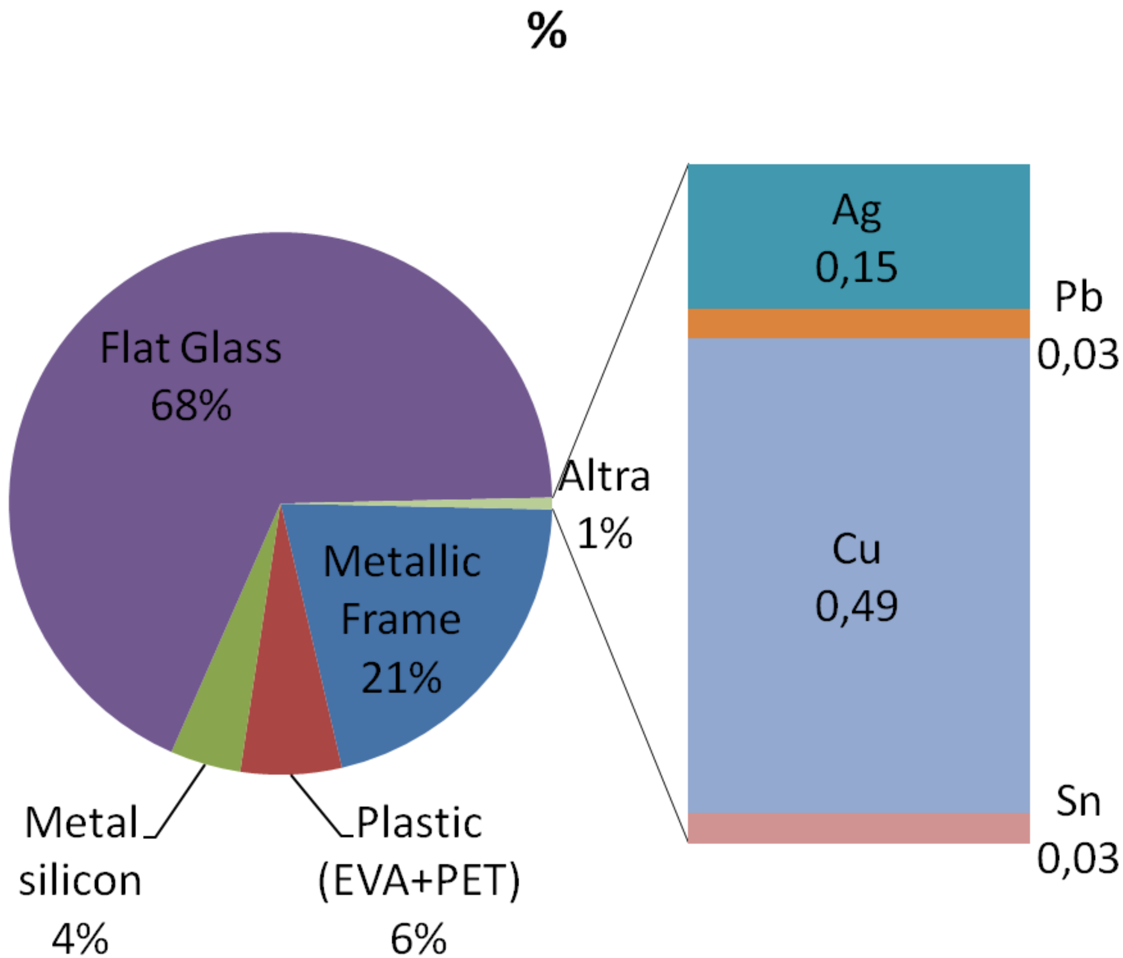
Average Weight ≈ 19 kg

More common Size: 164 x 99

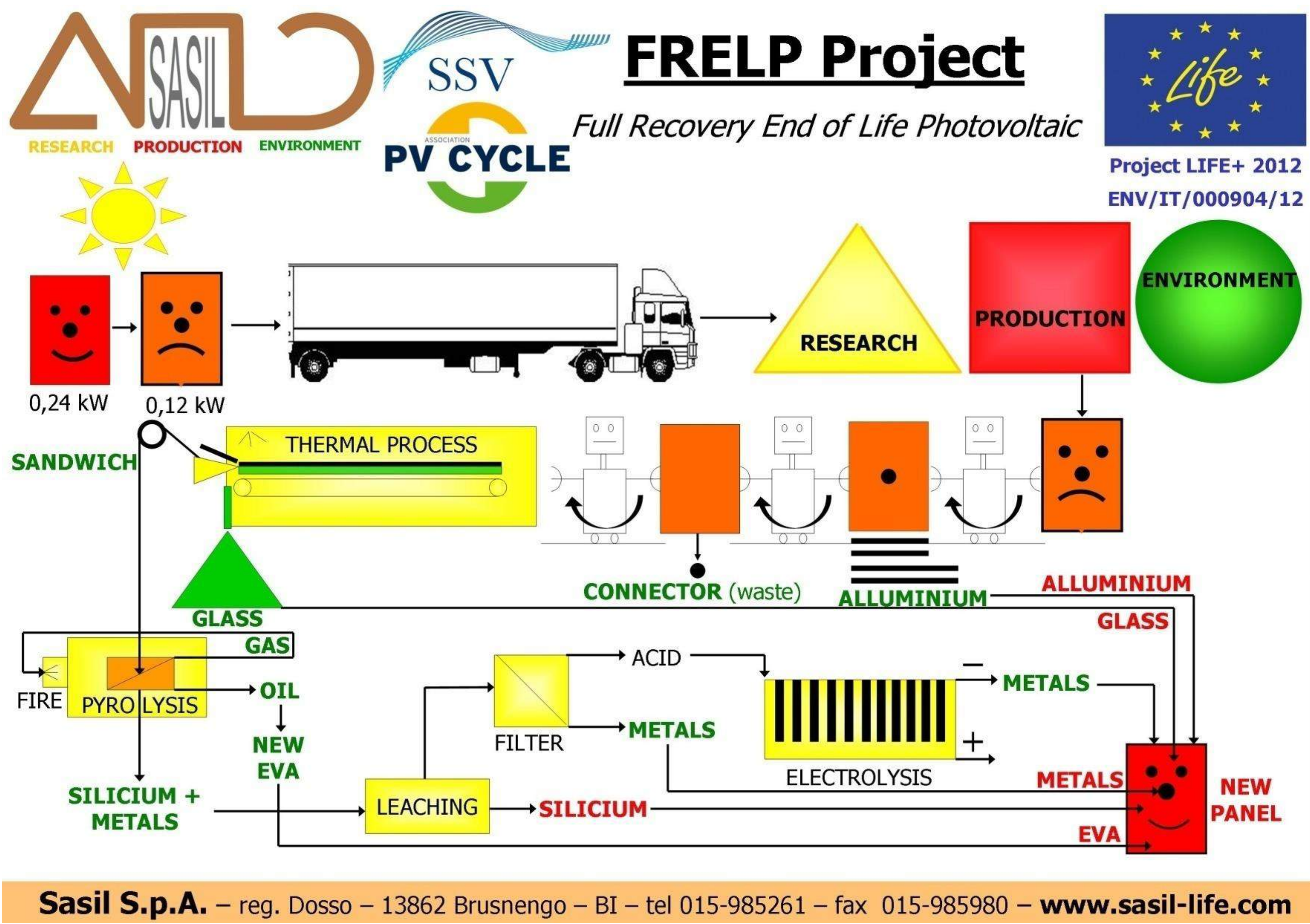
COMPANY	WEIGHT kg	SIZE cm
Sunpower* USA	14.58	156x80
Chaori* Cina	11.93	158x81
Mitsubishi* Japan	16.96	166x83
Mitsubishi* Japan	16.98	166x83
Mitsubishi* Japan	16.80	166x83
Risun* Cina	22.54	165x99
Risun* Cina	22.43	165x99
Siliken* Spain	18.72	164x99
Siliken* Spain	18.61	164x99
Siliken* Spain	18.63	164x99
Siiken* Spain	18.44	164x99
Csi* Canada	19.52	164x98
Jinko* Cina	19.17	164x99
Jinko* Cina	19.10	164x99
Jinko* Cina	19.17	164x99
Jinko* Cina	19.13	164x99
Jinko* Cina	19.13	164x99
Jinko* Cina	19.05	164x99
Jinko* Cina	19.18	164x99
Hyundai** Korea	16.77	149x98
Yaxtec** Cina	21.87	167x100

CHARACTERIZATION OF END-OF-LIFE PANELS

Merging the information obtained from the investigation with SEM and the chemical characterization of the Silicon PV cell, it is possible to estimate the composition of the material in a PV panel.

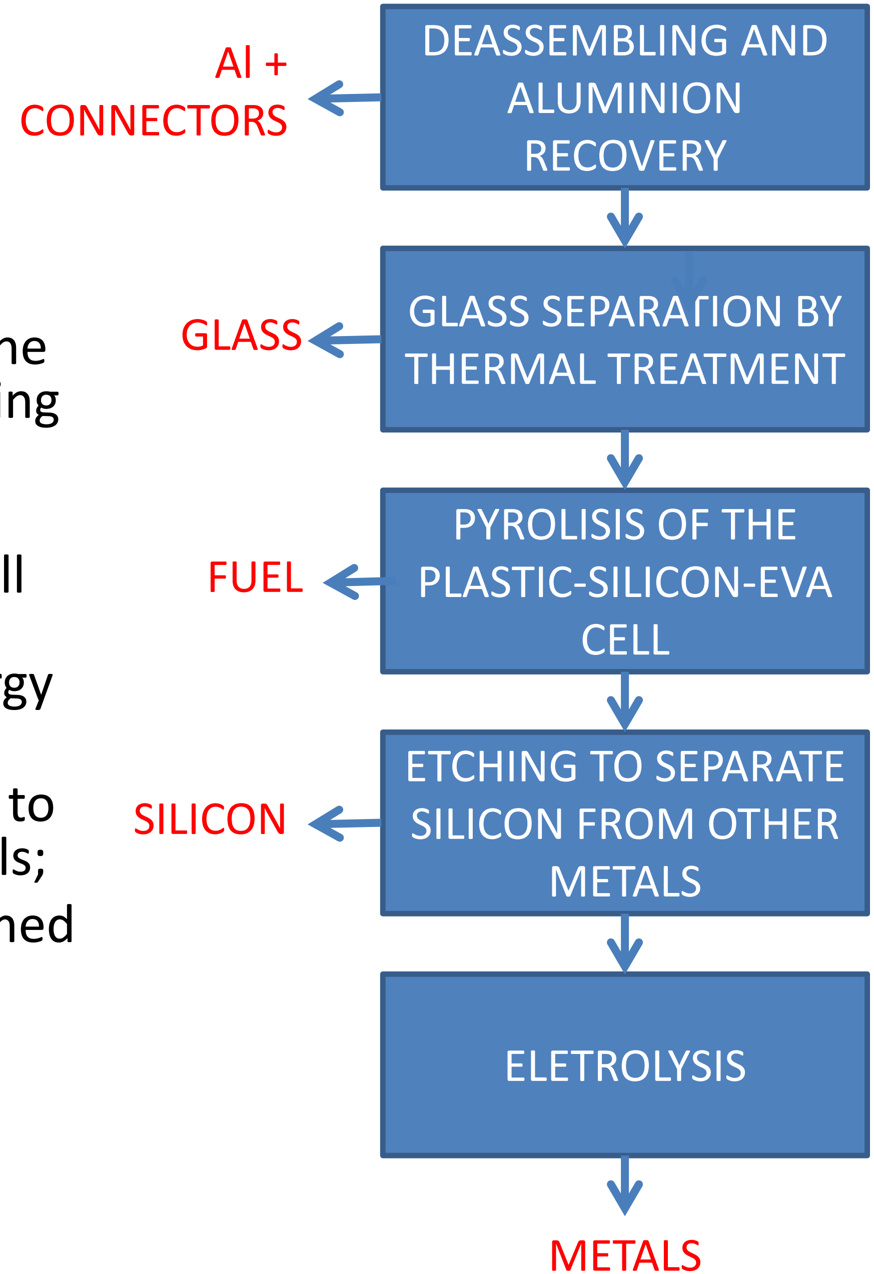


FLOW CHART OF THE PROCESS



FRELP PROCESS

- recovery of aluminum profiles and connectors;
- separation of glass from the rest of the panel through thermal effect, softening and cutting the EVA (ethylene vinyl acetate) adhesive;
- pyrolysis of the plastic silicon-EVA-cell structure conductor-back-sheet sandwich, recovering ashes and energy by obtaining fuel oil;
- treatment of ashes with acid etching to separate silicon from the other metals;
- Selective recovery of the eluate, formed by the silicon and the other metals, through micro and nano filtering and selective electrolysis of the acid solution.



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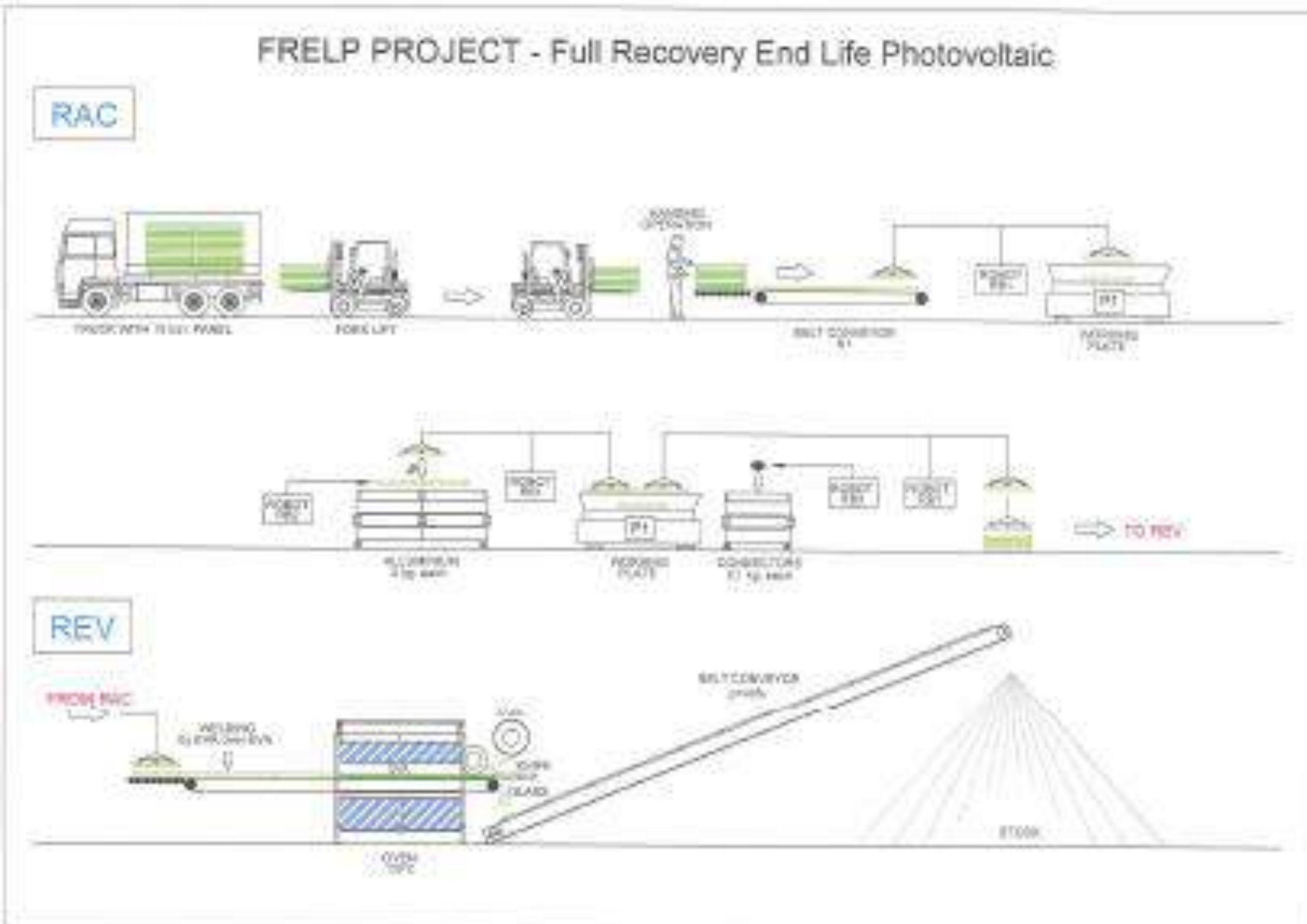
RAC AND REV PHASES



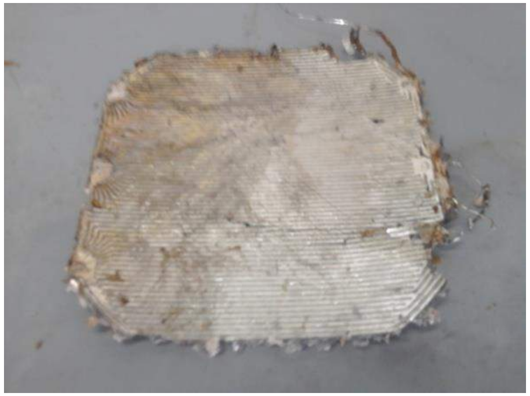
GLASS DETACHMENT TEST

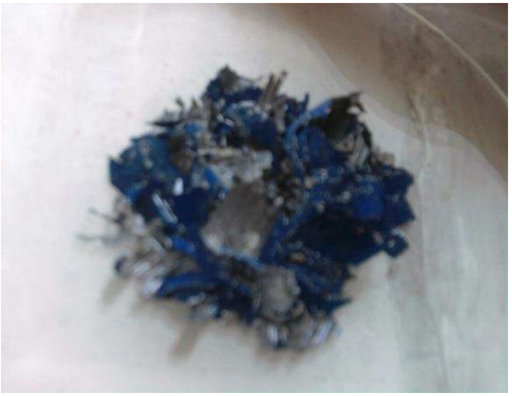
Before designing the pilot plant to detach the glass from the rest of the photovoltaic panel, various EVA softening systems through heating were considered to ease the detachment of the flat surface glass:

- microwaves
- powerful laser
- IR lamp heating

Test Carried Out at Lab Scale with 500 W IR lamps

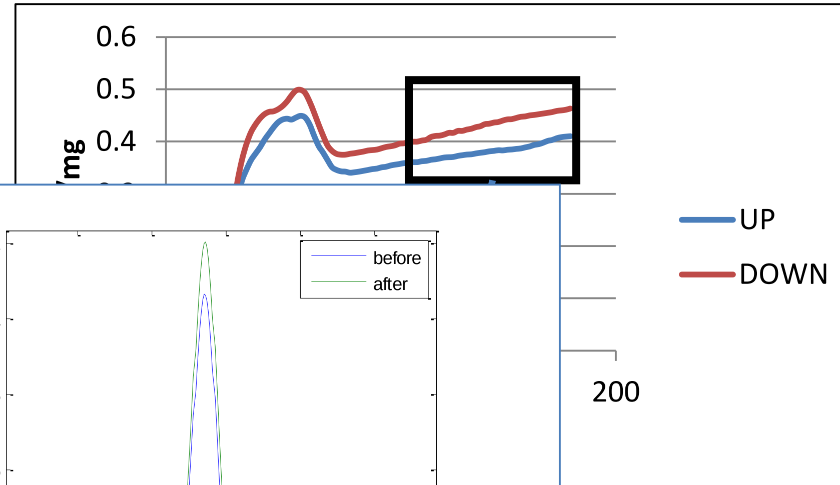
The use of IR radiation released by lamps has proved to be the simplest and cheapest system from an energy point of view, to soften the EVA and ease glass detachment.

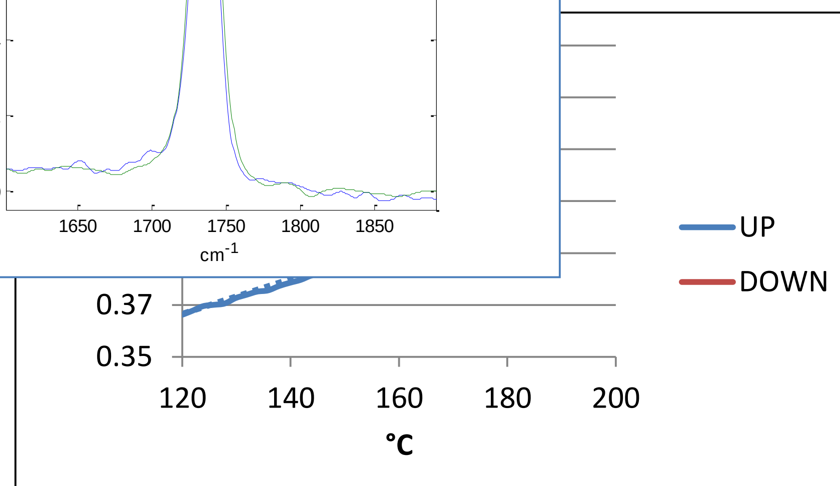


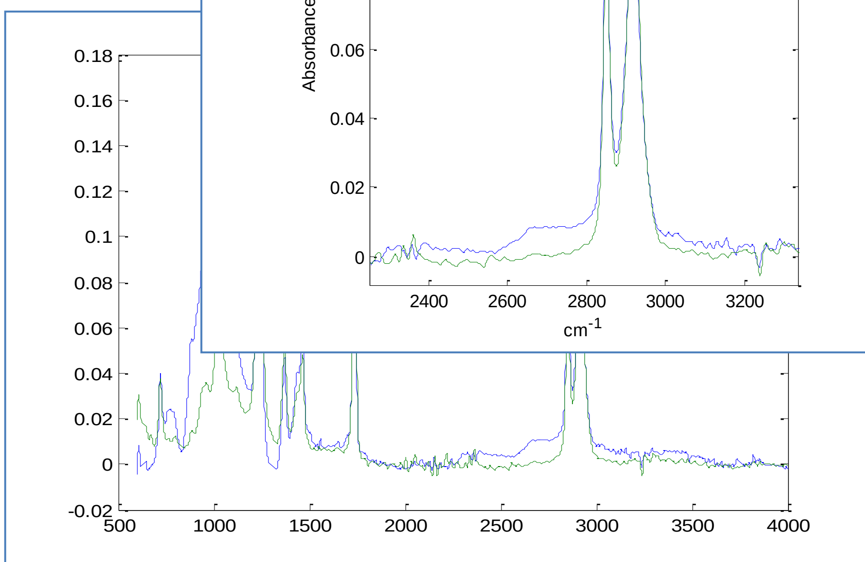


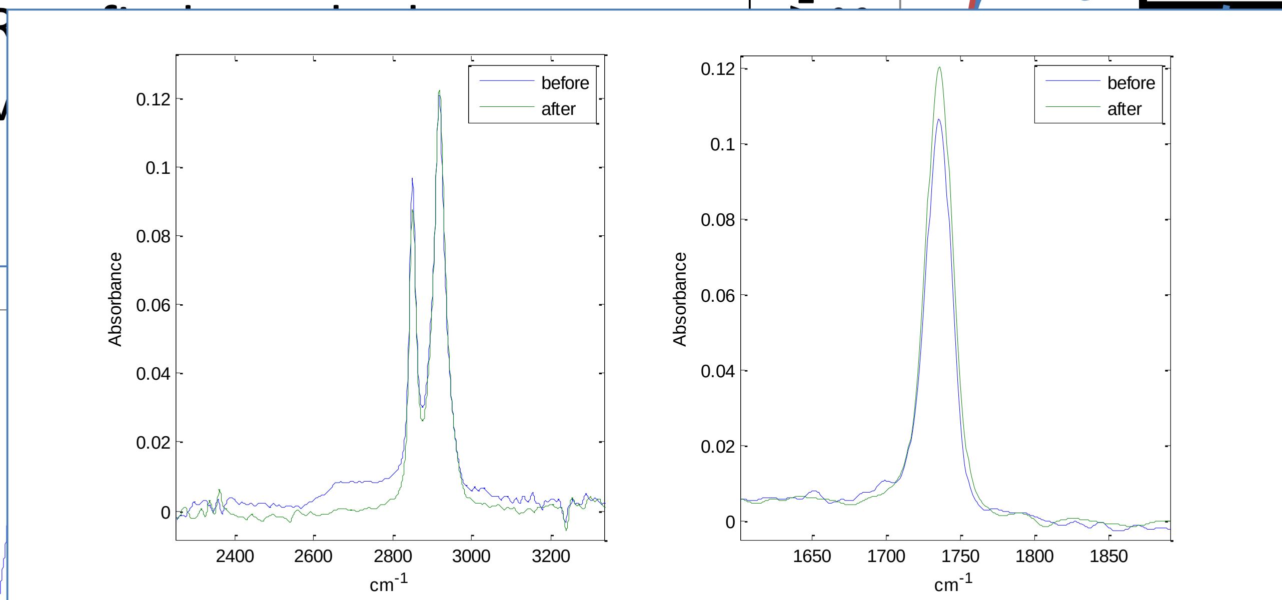
STUDIES ON EVA SOFTNING

The cross-linking behavior of EVA has been studied by DSC and micro-IR
operativ
heater









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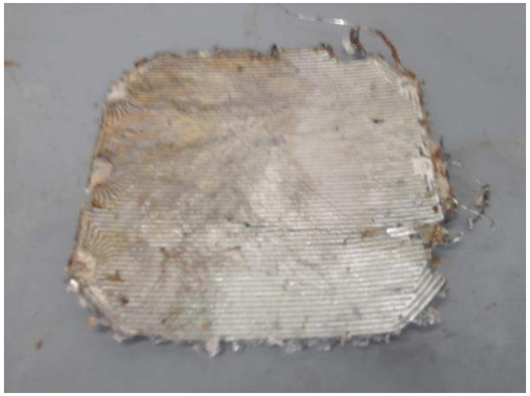

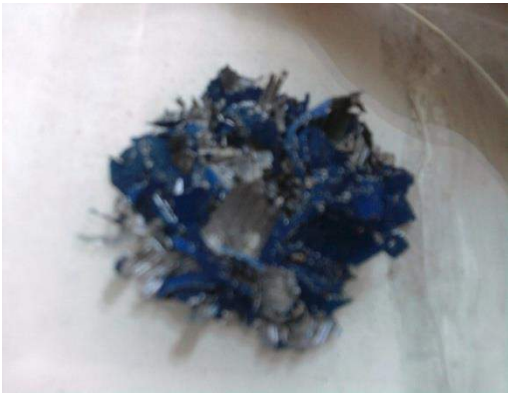

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PILOT SCALE DETACHMENT MACHINE

- Heating differentiated on the two sides of the sandwich (glass side and side wafer) with three different heating devices which ensure a delta of 20-30 degrees in temperature between the glass side and the side of the wafer.
- Mechanical Detachment of the glass by means of a pulsating knife, leveled at a fixed distance from the intrados side of the glass.
- Complete automation of the progress of the panel as a function of 5 parameters: frequency of the pulsations of the knife; temperature in the transport section; temperature in the cutting section; thickness of the glass; typology of the backsheet.

schema

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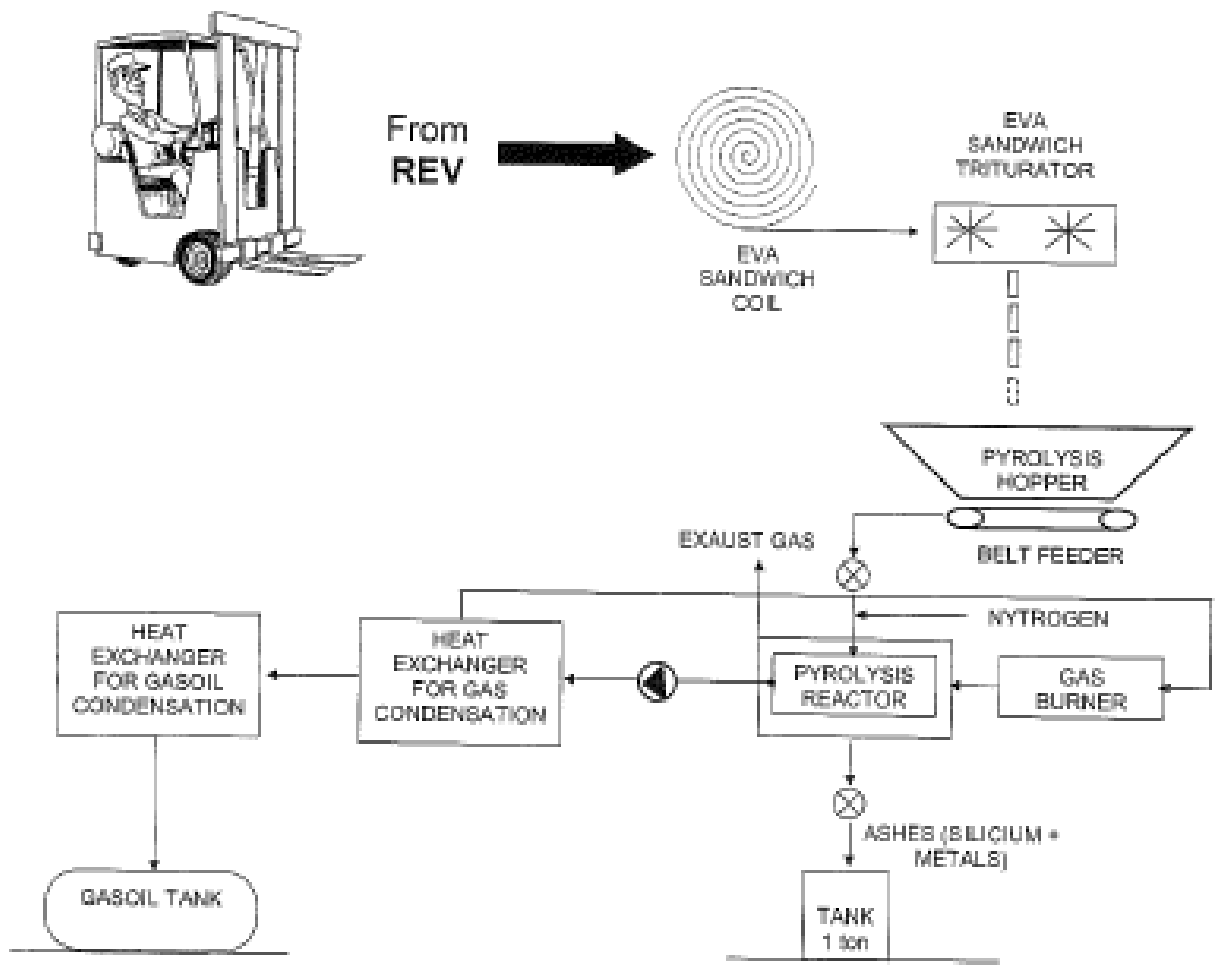
FRELP PROJECT – Full Recovery End Life Photovoltaic

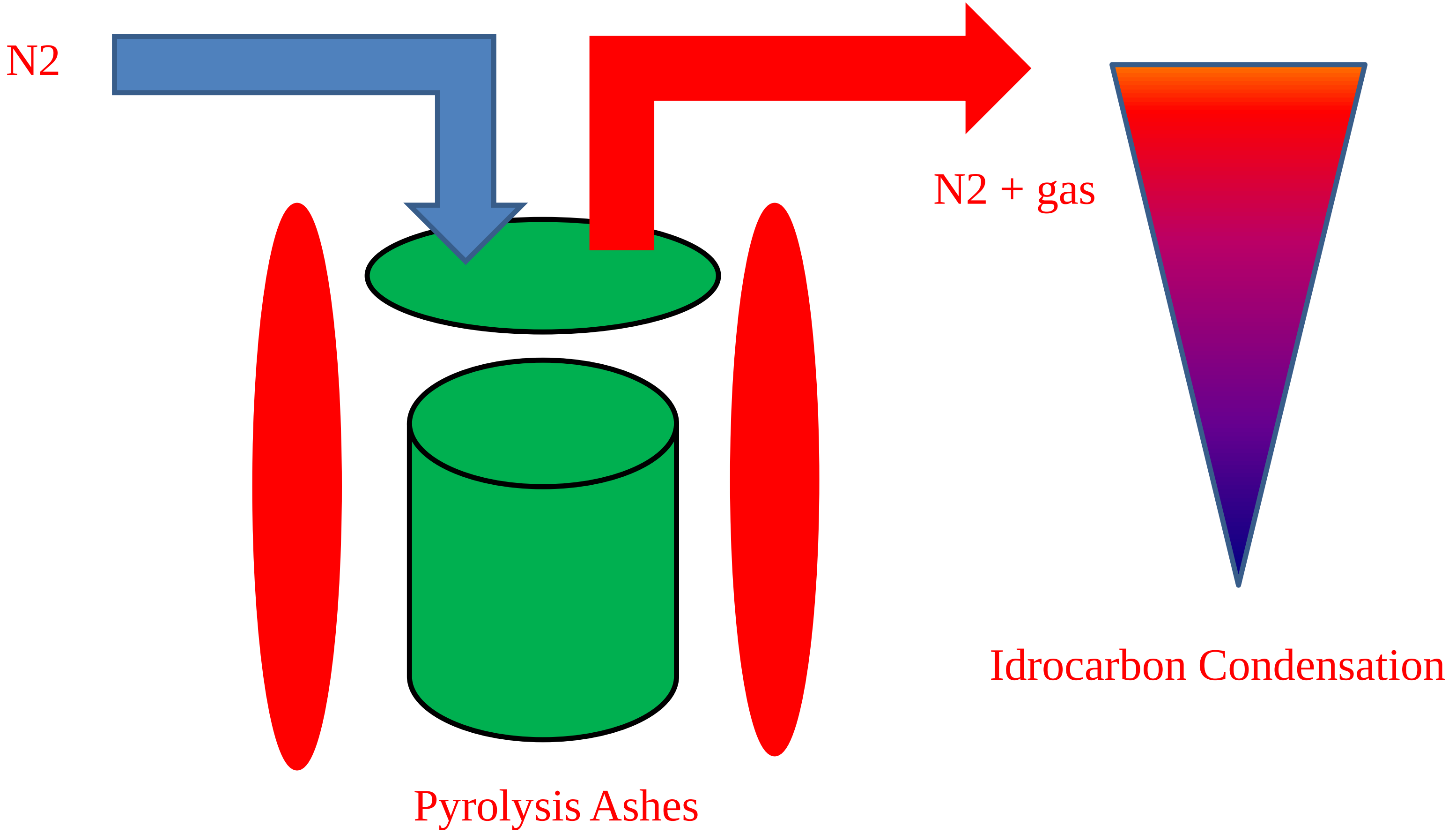
PES = PYROLYSIS EVA SANDWICH

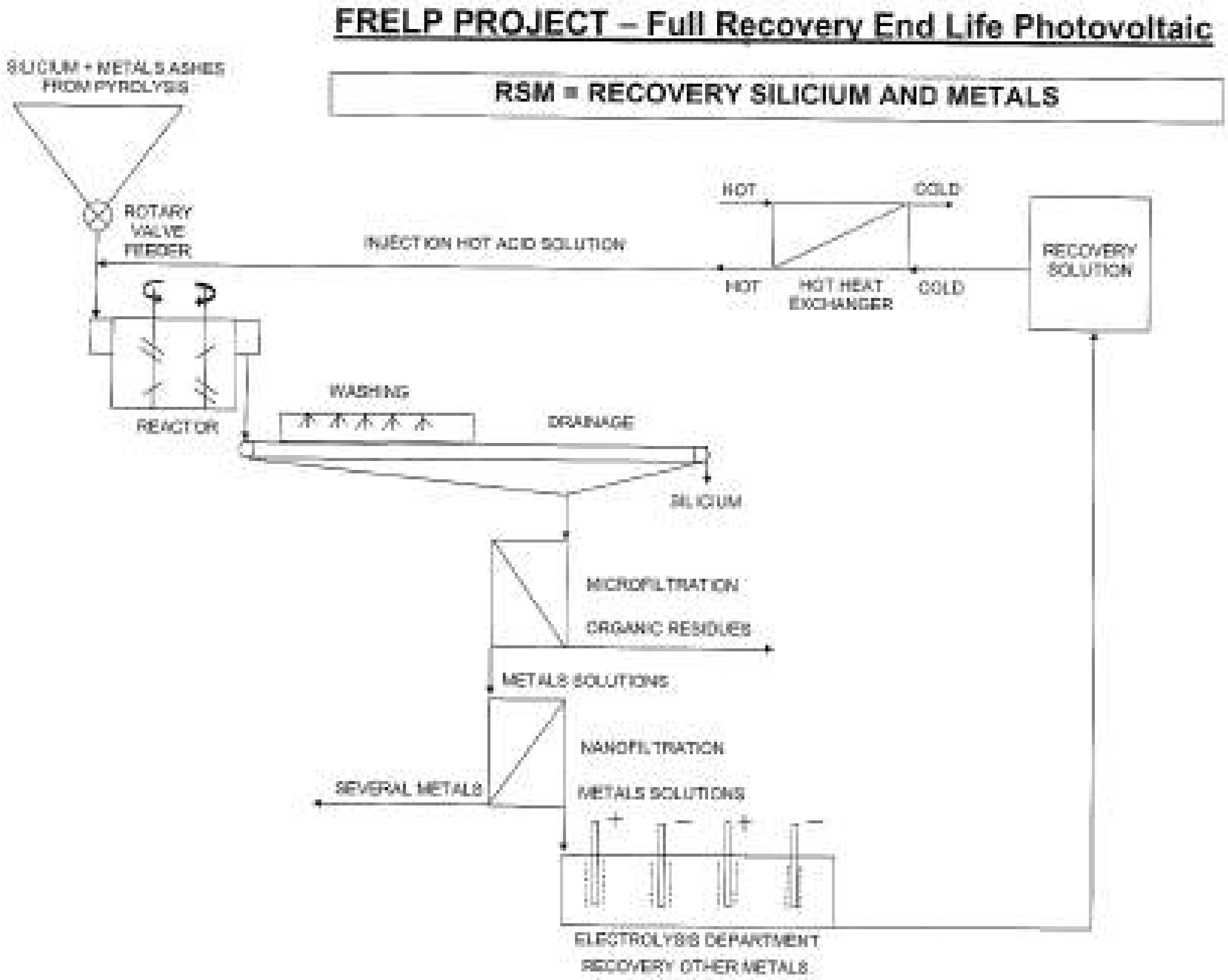
PES PHASE



PYROLYSIS EVA SANDWICH

Some lab test have been carried out at lab scale showing Silver recovery around 1 % of the input. A lab scale pilot plant is in preparation in SSV





FRELP PROJECT – Full Recovery End Life Photovoltaic
RSM = RECOVERY SILICIUM AND METALS
SILICIUM + METALS ASHES FROM PYROLYSIS
ROTARY VALVE FEEDER
INJECTION HOT ACID SOLUTION
HOT
COLD
HOT
HOT HEAT EXCHANGER
COLD
RECOVERY SOLUTION
REACTOR
WASHING
DRAINAGE
SILICIUM
MICROFILTRATION
ORGANIC RESIDUES
METALS SOLUTIONS
NANOFILTRATION
SEVERAL METALS
METALS SOLUTIONS
ELECTROLYSIS DEPARTMENT
RECOVERY OTHER METALS

RSM PHASE

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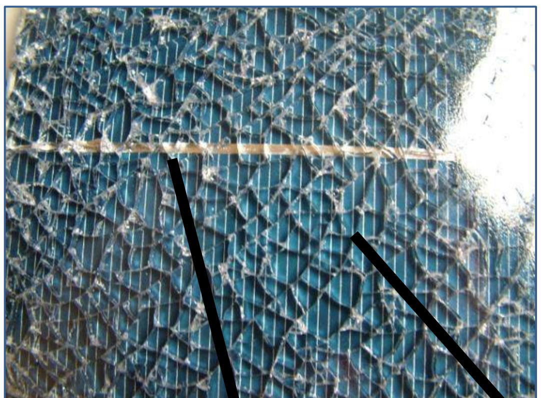
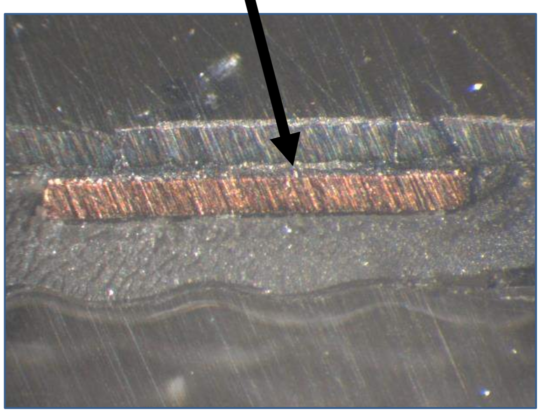
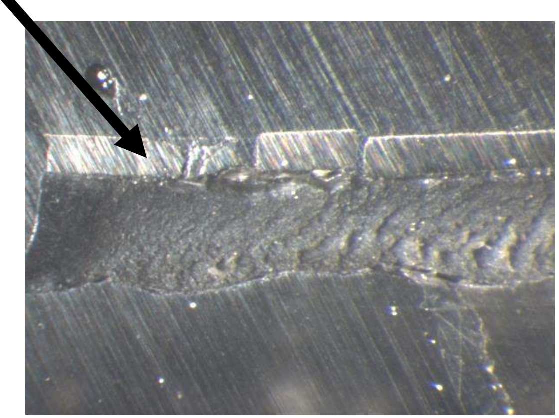
PHYSICAL CHARACTERIZATION

Silicon cell cut from a PV panel



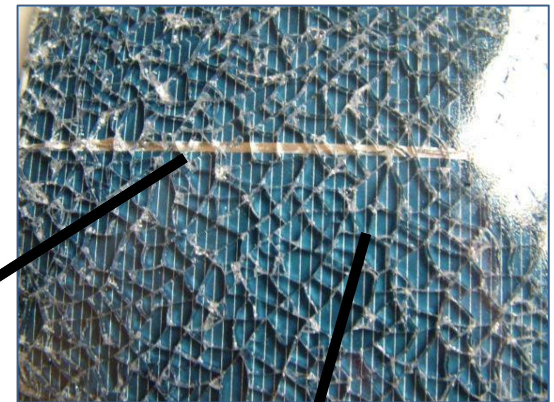
The cell shows a pattern of thick metallic grid, connected by a thin pattern of another metallic, immediately under the glass. For the analysis two sample were prepared (1 x 1 cm), each cut along and orthogonal to the direction of the thick grid and cleared from the white plastic

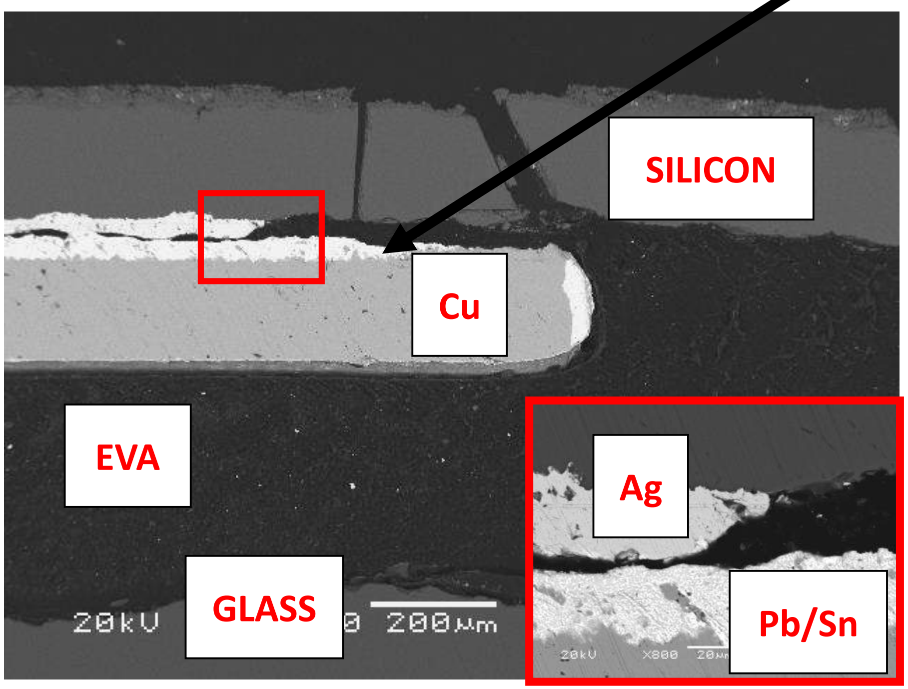


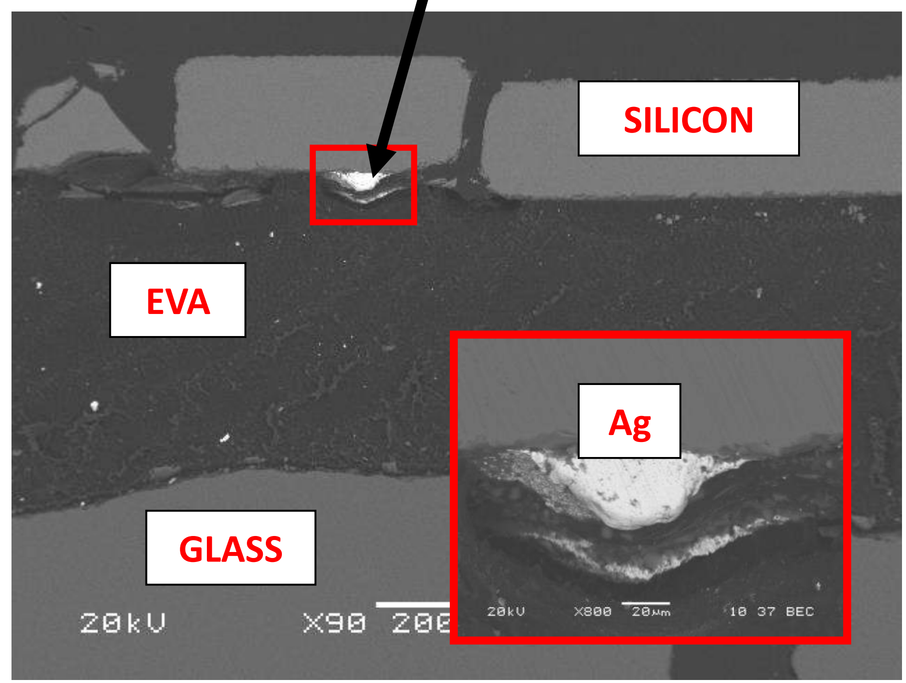


SEM CHARACTERIZATION

Samples observed by SEM in BS mode. Images are respectively for the sample cut orthogonal to the thin grid and the sample cut orthogonal to the thick grid







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CHEMICAL ANALYSIS

Some samples of glasses where melted and analyzed by XRF

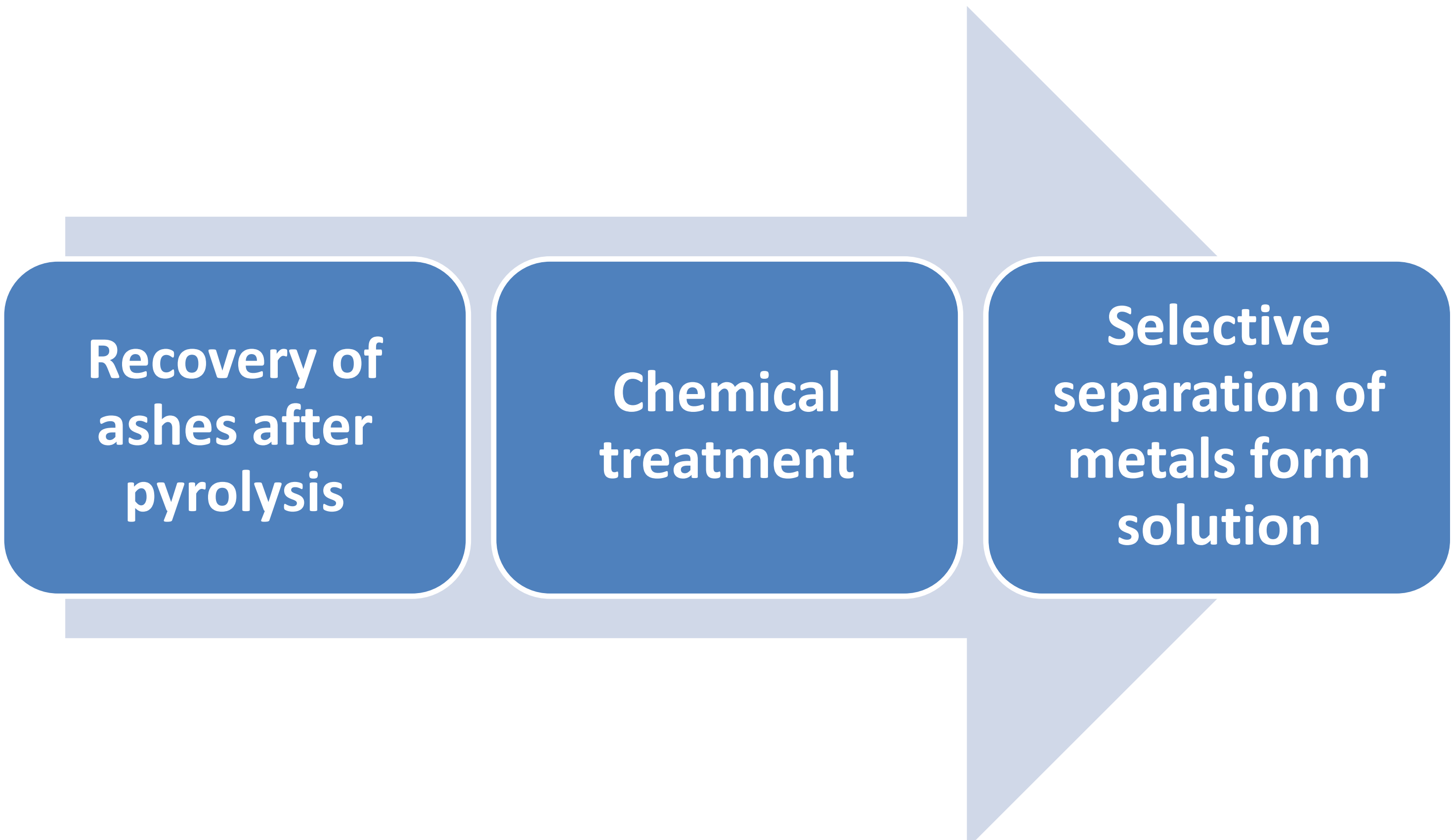
Oxides	Weight %
SiO_2	71.5
Na_2O	14.73
Al_2O_3	0.89
CaO	8.11
MgO	4.17
Fe_2O_3	0.011
Sb_2O_3	0.22
SO_3	0.28

A sample from one PV panel (without glass) was cut and submitted to chemical treatment, in order to extract the metals for chemical analysis. The solution was analyzed by ICP-MS and ICP-OES

Element	ppm	Element	ppm
Si	89.0	Cr	0.0025
Sn	0.95	Li	0.002
Al	9.5	Mn	0.001
Ti	0.55	Ba	0.0007
Pb	0.21	V	0.0005
Bi	0.11	Se	0.002
Sb	0.025	Fe	0.025
Sr	0.015	P	0.01
Ag	0.75	Co	0.0003
B	0.31	Zn	0.01
Mo	0.007	Ni	0.005
Cu	0.16		

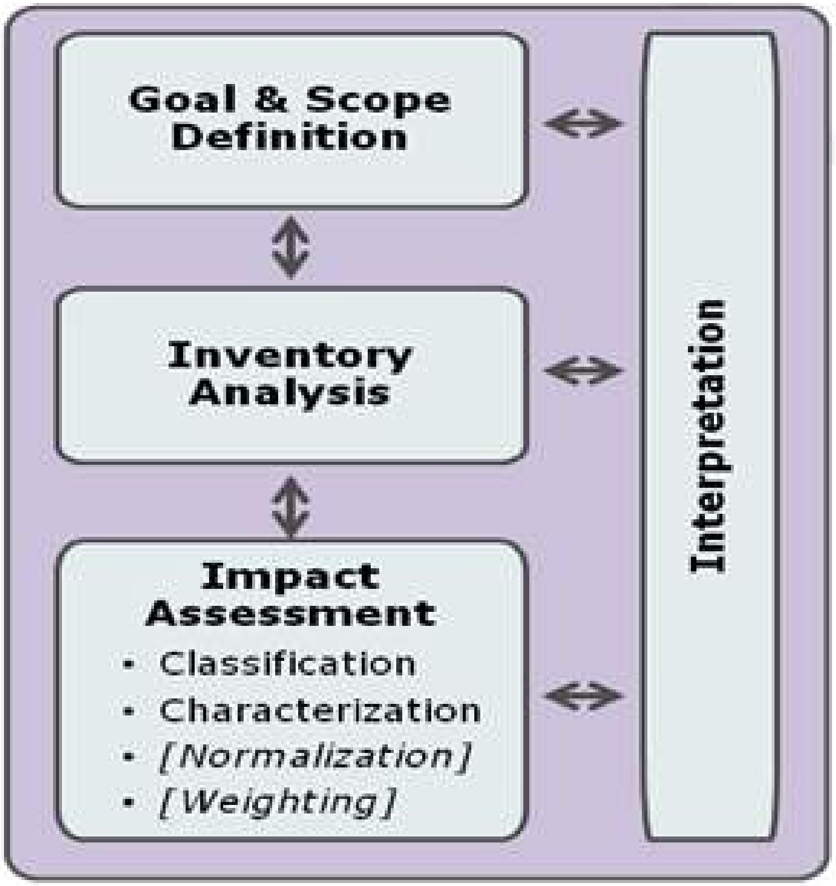
ASHES RECOVERY

Based on the literature available and considering the need of a industrial process the following strategy will be applied:



LCA – LIFE CYCLE ASSESSMENT

- The project foresees the development of a LCA to assess the environmental impact of the process and compare the results with alternative solution
- The LCA is done in collaboration with JRC in the contest of a possible End of Waste guideline



LCA – LIFE CYCLE ASSESSMENT

The following assumptions are applied based on the information up to now available.

Glass with Antimony: Glass constitutes the biggest part of crystalline-based PV panel in terms of weight. The recovery process of 1000 kg of PV panel is expected to generate 700 kg of low iron solar glass which contains at maximum 1% of weight Antimony. The glass scrap is assumed to be recycled as new high quality flat clear glass (“medium level” downcycling).

Aluminum: At least 170 kg of Aluminum is expected to be obtained from the PV panel frame and 0.8 kg from the solar cell internal connector. The scrap is transported from SASIL site to further recycler. The recovered Aluminum is assumed to be Aluminum scrap that is used to produce secondary aluminum with 100% efficiency. The positive contribution of this process is assigned to the production of primary aluminum from bauxite..

LCA – LIFE CYCLE ASSESSMENT

Copper: Copper is contained in PV panel as connector and in a small quantity in the solar cell metal mixture. The expected quantity of copper recovered from the plant is 20-30 kg every 1000 kg of panel. Copper is assumed to be collected as copper scrap that will be transported to copper recycler. It is assumed that the copper scrap will be used to produce secondary copper with 1% of mass loss. The credit of the copper recycling is assigned to the production of primary copper.

Silicon Metal: Currently, the market of silicon metal scrap does not exist yet. The expected quantity of silicon metal recovered from the plant is 38 kg per 1000 kg of PV module. Silicon metal in solar cell is assumed to be recovered as Metallurgical grade silicon metal that will directly substitute the production of Metallurgical grade silicon metal without mass loss.

Silver: Silver is used in a very small quantity in metallization paste of PV panel. The maximum expected quantity recovered from the plant is 0.15 kg per 1000 kg of PV panels. The silver is recovered as Silver Sulfate.

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