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E-WASTE: AN INTEGRATED PROCESS FOR RECYCLING AND RESOURCE RECOVERY

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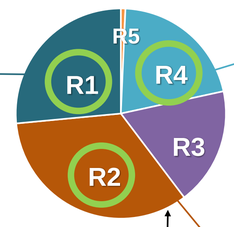
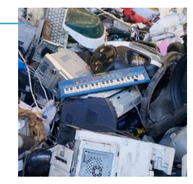
The Project and The Partnership

The PINECOR project aims at developing innovative solutions for optimizing the recovery of **glass** and of **siliceous** and (precious and not precious) **metal fractions** deriving from the recycling of WEEE. The partnership, among the University of Modena and Reggio Emilia, Modena, Italy (project leader), Treee Srl, Milan, Italy (leading Italian group in the WEEE sector) and Tre Effe Industrial Hydraulic Supplies Srl, Bergamo, Italy, aims at bridging the research and industry worlds.

PINECOR aims to improve the **recovery of secondary raw materials** intercepted in groups **R1**, **R2**, **R4**.

Examples of refrigerators (R1)





Examples of small household appliances (R4)

WEEE Groups	2018 (%)	2019 (%)	2020 (%)	2021 (%)	2022 (%)	Average value
R1 COOLING AND FREEZING APPLIANCES. REFRIGERATORS, FREEZERS, AIR CONDITIONING	27.1%	27.2%	26.5%	25.9%	27.8%	**26.5%**
R2 LARGE HOUSEHOLD APPLIANCES. WASHING MACHINES, DISHWASHERS, HOODS, OVENS, ETC.	32.8%	33.6%	34.3%	33.6%	32.5%	**33,8%**
R3 SCREEN AND MONITORS. TV AND CRT, PERSONAL COMPUTERS, TABLETS, SMARTPHONES, LCD SCREENS, ETC	19.2%	17.4%	17.0%	19.8%	20.0%	18.1%
R4 CONSUMER EQUIPMENT. SMALL APPLIANCES, PHOTOVOLTAIC PANELS, ETC.	20.3%	21.2%	21.4%	20.1%	20.1%	**20.9%**
R5 LIGHTING EQUIPMENT. DISCHARGE LAMPS, FLUORESCENT LAMPS, OTHER LIGHTING , ETC.	0.6%	0.6%	0.7%	0.7%	0.7%	0.7%

Percentages of types of WEEE disposed of in Italy in different years. Source: Italian WEEE Coordination Center

Examples of washing machines (R2)

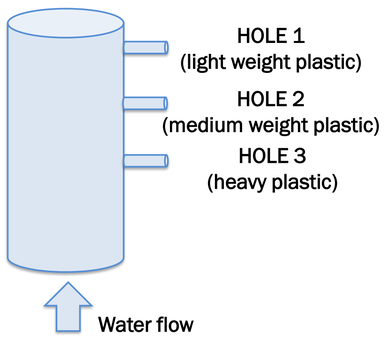
Waste Group R4 (Small Household Appliances)

For wastes from Group R4, in particular, **small household appliances**, two processes have been tested to separate product fractions (mainly metals and plastics): **separation using dense homogenous liquids** and the **elutriation process**. From the latter we obtained the separation of plastics into three fractions (corresponding to three holes located at the back of the elutriator tube which, from top to bottom, enable the progressive outflow of increasing specific weight plastics).

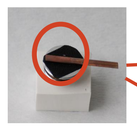
Principal types of plastic identified in stages by FTIR and DSC analysis

HOLE 1 – LIGHTWEIGHT PLASTIC	HOLE 2 – MEDIUM WEIGHT PLASTIC	HOLE 3 – HEAVY PLASTIC
POLYSTYRENE (density approx. 1,050 g/cm^3)	POLYPROPYLENE (PP) (density approx. 0.855 g/cm^3, amorphous or 0.946 g/cm^3, crystalline)	POLYCARBONATE (PC) (density approx. 1.20–1.22 g/cm^3)
POLYPROPYLENE (PP) (density approx. 0.855 g/cm^3, amorphous or 0.946 g/cm^3, crystalline)	ACRYLONITRILE BUTADIENE STYRENE (ABS) (density approx. 1.060–1.080 g/cm^3)	POLYOXYMETHYLENE (ACETAL) (POM) (density approx. 1.41–1.42 g/cm^3)
STYRENE ACRYLONITRILE (SAN) (density approx. 1.08 g/cm^3)		POLYAMIDE (PA 6) (density approx. 1.084 g/cm^3)
BLEND OF POLYPROPYLEN AND ETHYLEN / PROPYLEN (PP+EPDM).		POLYCARBONATE / ACRYLONITRILE BUTADIENE STYRENE BLEND (PC + ABS)

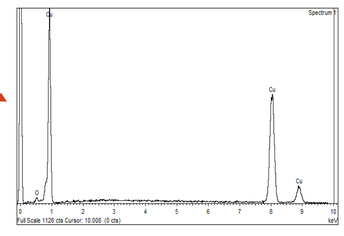
Schematic representation of an elutriator



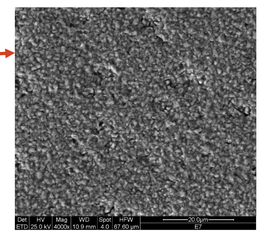
The focus was the **recovery of Cu** through a first phase of **chemical leaching** followed by **galvanic electrodeposition**, maintaining the same chemical solution. The process starts either from the ground waste as it is or from the same after the separation of the different product fractions with an elutriator. This stage enabled us to work with small amounts of solution, due to the reduction in the volume of the sample. The metallic copper obtained is extremely pure, as confirmed by the semi-quantitative analysis carried out by SEM-EDS shown below.



Copper electrode. The copper deposit is circled in red.



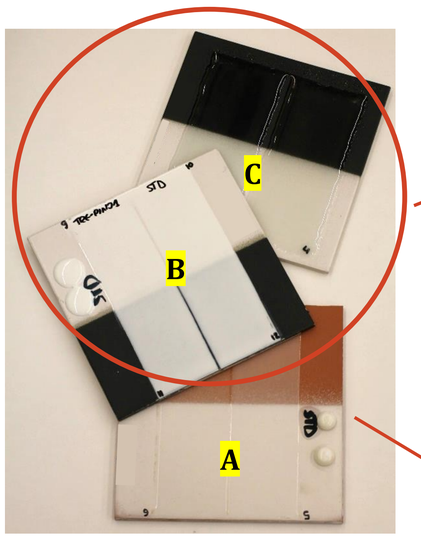
EDS spectrum of the copper deposit



SEM micrograph of the copper deposit

Waste Groups R1, R2 (Refrigerators and Washing Machines)

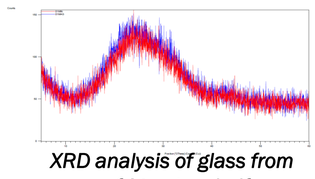
The **glasses** from the **refrigerator shelf** and **washing machine porthole** were used to modify the frit formulation for ceramic glazes in a weight percentage up to 30%.



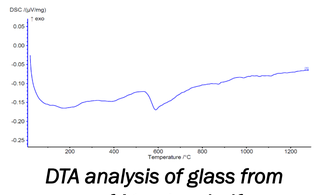
Chemical analysis (XRF and ICP wt% oxide) of glass from refrigerator shelf

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	SO_3	B_2O_3
Refrigerator shelf	73.11	0.02	1.13	0.05	3.37	8.86	13.20	0.37	0.20	-

Glass from refrigerator shelf



XRD analysis of glass from refrigerator shelf



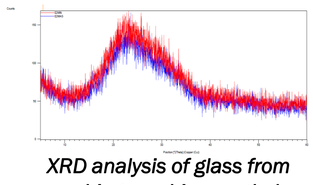
DTA analysis of glass from refrigerator shelf

By XRD and DTA analyses the totally amorphous nature of the two glasses was confirmed due to the absence of crystalline peaks in XRD patterns and exothermic events in DTA graphics.

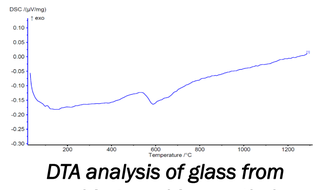
Chemical analysis (XRF and ICP wt% oxide) of glass from washing machine porthole

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	SO_3	B_2O_3
Washing machine porthole	72.52	0.02	2.06	0.04	0.79	8.34	12.11	1.05	0.15	2.81

Glass from washing machine porthole



XRD analysis of glass from washing machine porthole



DTA analysis of glass from washing machine porthole

Expansion coefficient (COE) and characteristic temperatures of standard formulations and the same WEEE glass-containing. The values of the Solar Reflectance suggest further study of glazes in the field of solar reflective building materials. The numeric difference between the three series is related to the different ceramic tile supports used.

	TILE A		TILE B		TILE C	
	Standard glaze	Glaze with glass from porthole	Standard glaze	Glaze with glass from fridge shelf	Standard glaze	Glaze with glass from fridge shelf
COE (x10^7 1/K)	66.0	65.0	84.0	82.0	85.4	85.9
Softening temperatures (°C)	830	828	948	951	1095	1096
Sphere temperatures (°C)	1030	1031	1000	999	1109	1107
Half sphere temperatures (°C)	1130	1127	1086	1084	1161	1164
Solar Reflectance (AM1GH)	0.754	0.740	0.853	0.856	0.534	0.558

The similarity between the characteristic values of standard glazes and WEEE glass-containing glazes shows that it is possible a partial replacement of traditional ceramic raw materials by glasses from E-waste.

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