From fridge to fridge: chemical recycling of PU Foam as enabler of circular economy

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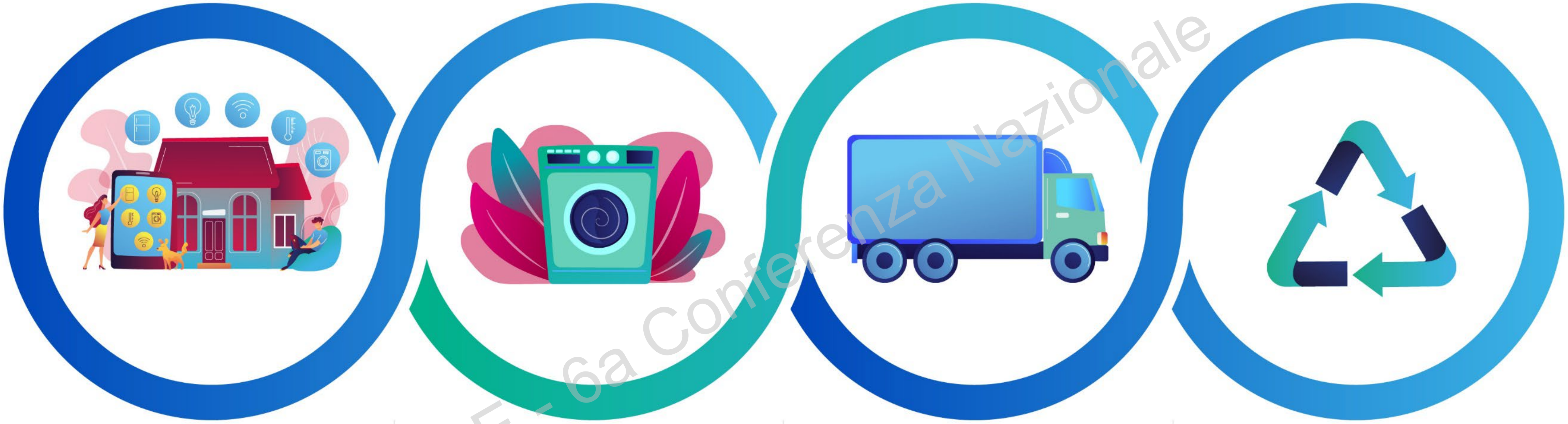
The circularity of the materials flow of the home appliance industry



6,3 million
tonnes of material placed on the market

7,9 billion
appliances installed in the EU households; 69 million tonnes of material

3,8 million
tonnes of appliances collected annually

3,7 million
tonnes of material recovered

Source: APPLIA

Quantity of single material used by home appliance sector

Aluminium 0,17 Mt

Concrete 0,39 Mt

Copper 0,15 Mt

Electronics 0,16 Mt

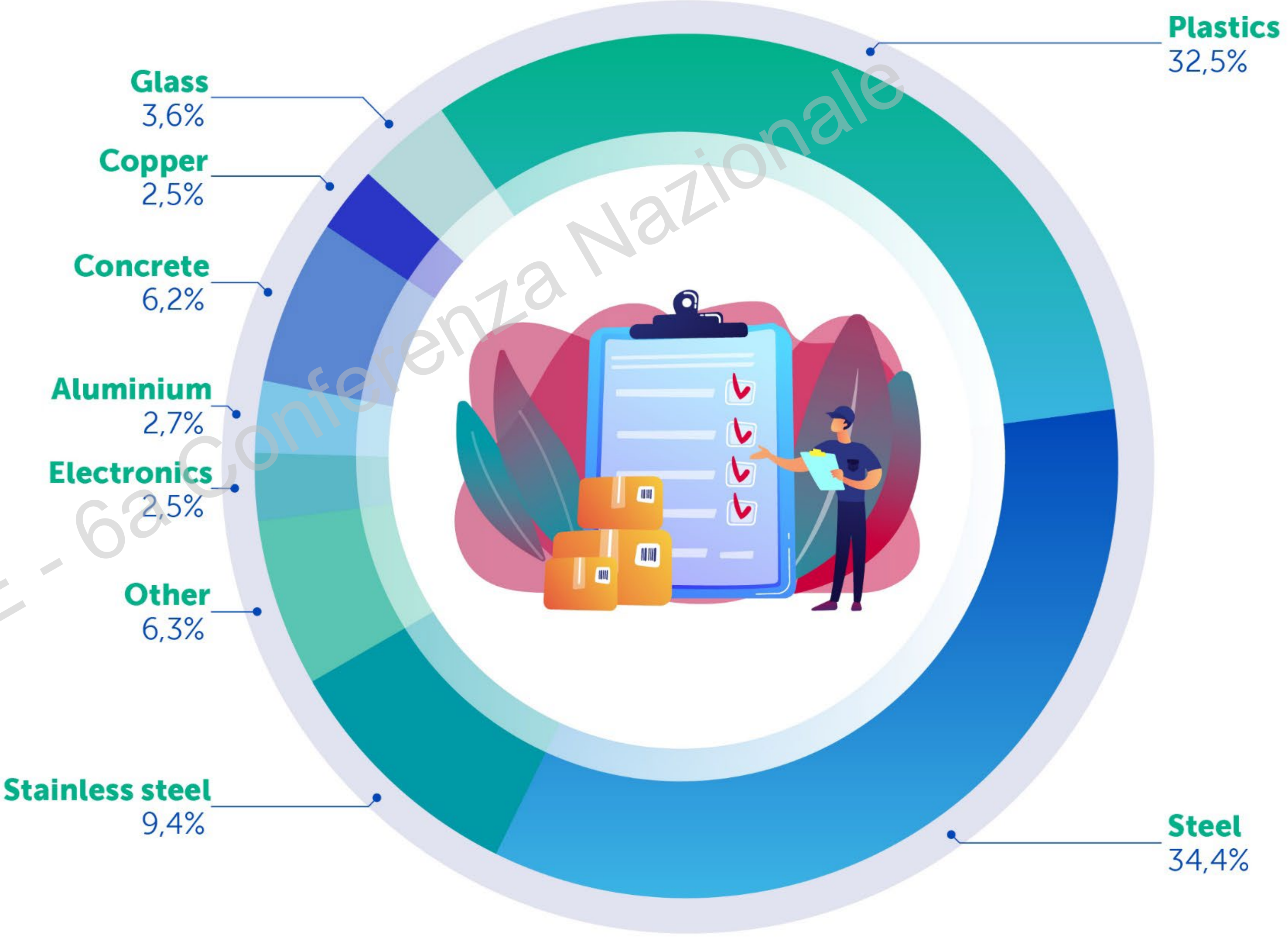
Glass 0,23 Mt

Plastics 2,04 Mt

Stainless steel 0,59 Mt

Steel 2,16 Mt

Other 0,40 Mt



Source: APPLIA

Six fractions from refrigerator shredding to further treatments

PLASTICS

Automathed treatment
15% of total volumes

Composition
- 92% of Plastic mix
- 8% impurities

FERROUS METALS

Automathed treatment
38% of total volumes

Composition
- 99% of Ferrous
- 1% impurities

NON-FERROUS METALS

Automathed treatment
2% of total volumes

Composition
- 87% of Aluminium
- 4% Copper
- 9% impurities

GLASS

Manual treatment
3% of total volumes

Composition
- 93% Glass
- 7% Plastic (energy)

COMPRESSOR

Manual treatment
19% of total volumes

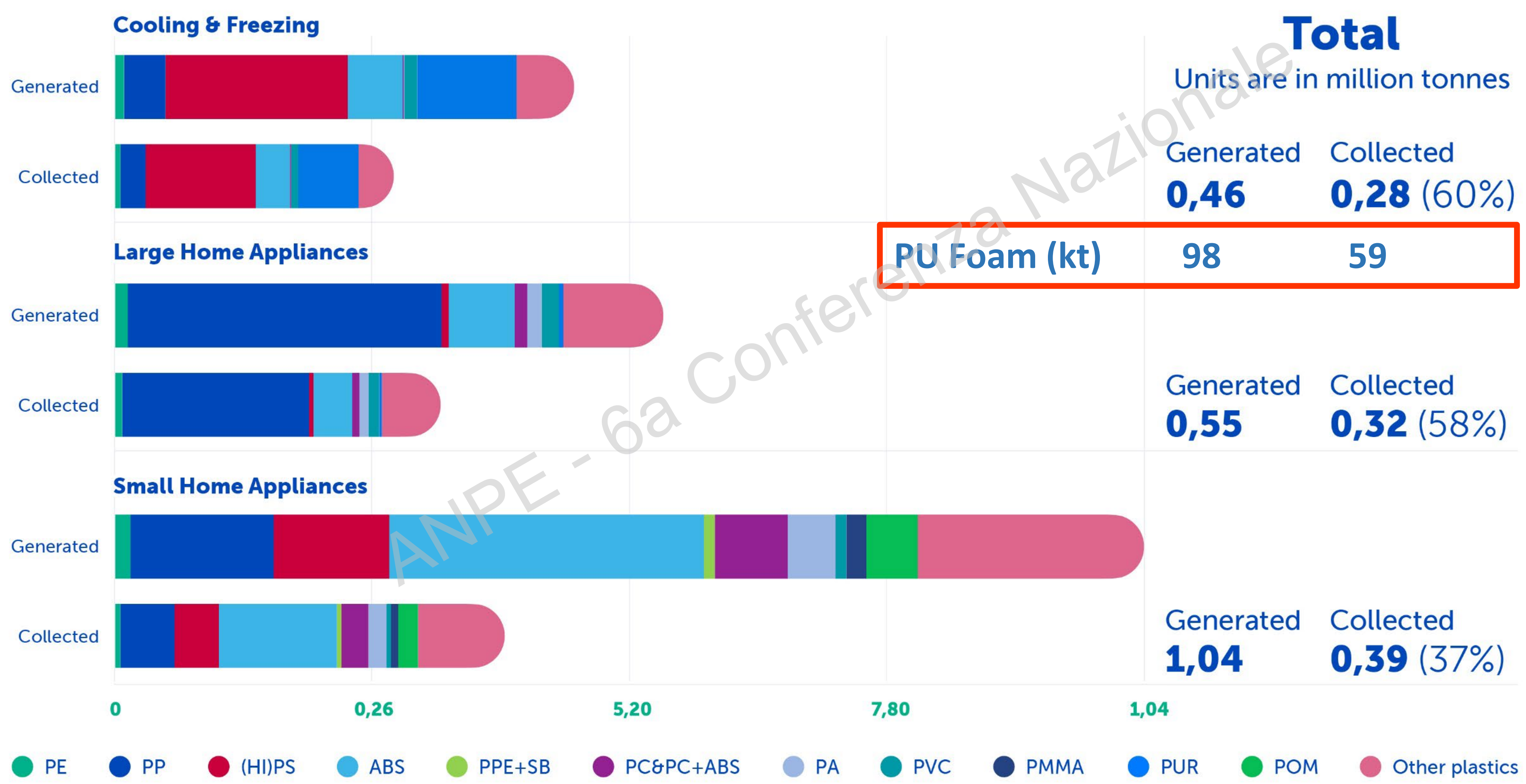
Composition
- 92% of Ferrous
- 8% Copper

PU FOAM

Automathed treatment
14% of total volumes

Composition
- 85-90% PU Foam
- 15-10% impurities

Type of plastic polymers generated vs collected in WEEE



Source: APPLIA

Electrolux’s commitment to sustainability

PLASTICS RECYCLING AWARDS EUROPE 2023 WINNER

HIPS – 15% of total appliance weight

First refrigerator with 70% recycled HIPS into inner liner launched in the market in 2022

Steel – 38% of total appliance weight

Project to use 70% recycled steel from 2025

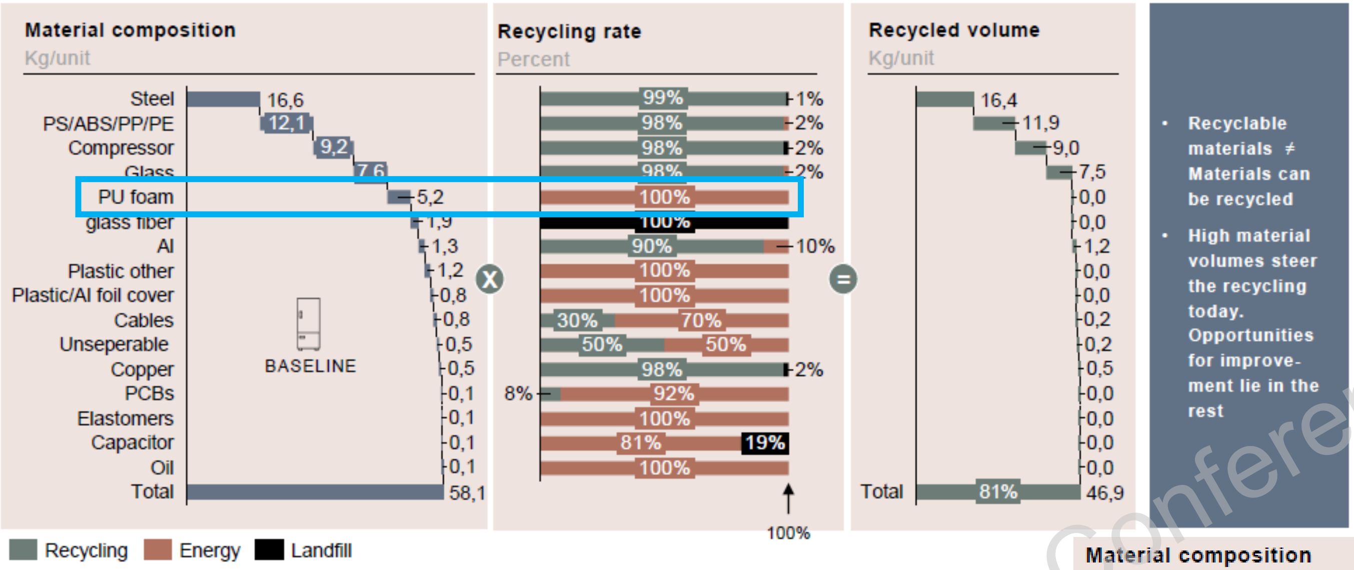
PU – 14% of total appliance weight

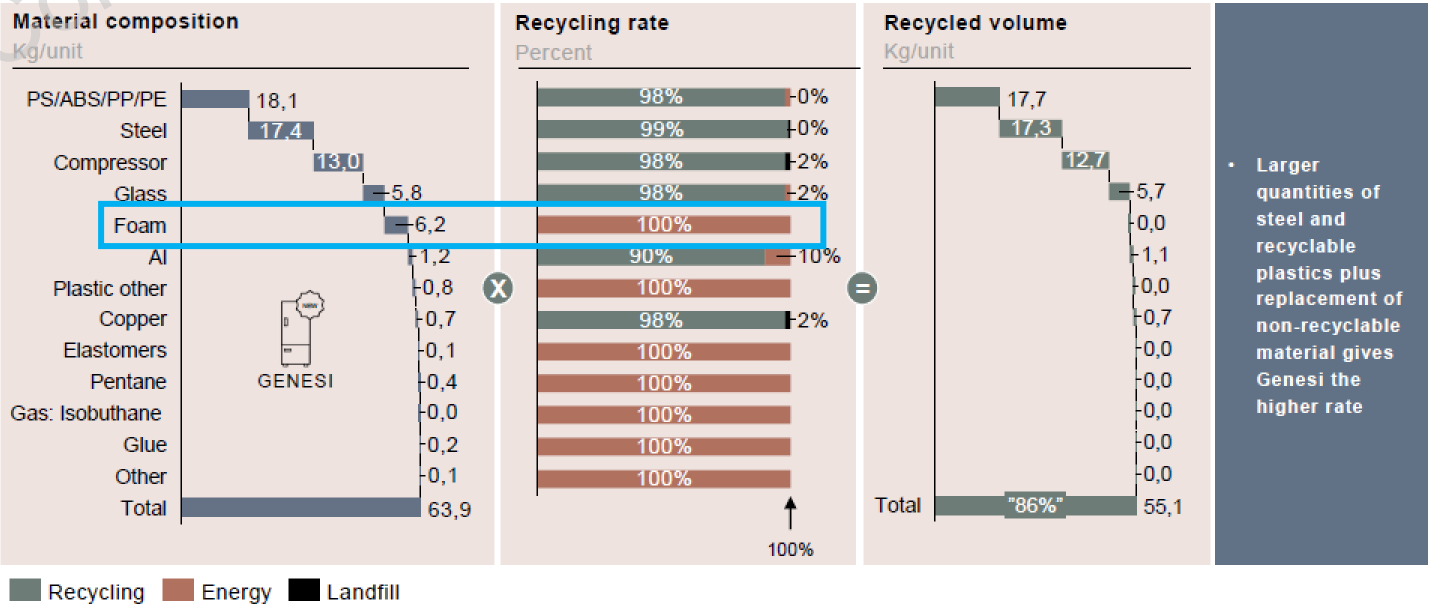
Chemical recycling to get back polyols and PMDI

Preliminary step: design for recycling

A	COMPRESSOR COMPARTMENT	New modular compartment for standardization and automated assembly
B	BACK METAL PANEL	Back cover from composite to steel plate for automated assembly
C	SIDE METAL PANELS	Side cover from only steel plate to steel+plastic detail for automated assembly
D	TOP PANEL ELECTRONICS	Updated module accessible top cover for upgradability and maintenance
E	DOORS	Doors from only steel plate to steel+plastic detail for automated assembly and maintenance.
F	CABLES	Cable mounting from taping to plastic clips for automated assembly.
G	PU FOAM	New foam recipe for improved insulation and shorter curing time.

Design for recycling: new vs old BI range – Index improved from 81% up to 86%, but PU Foam still incinereted for enery recovery



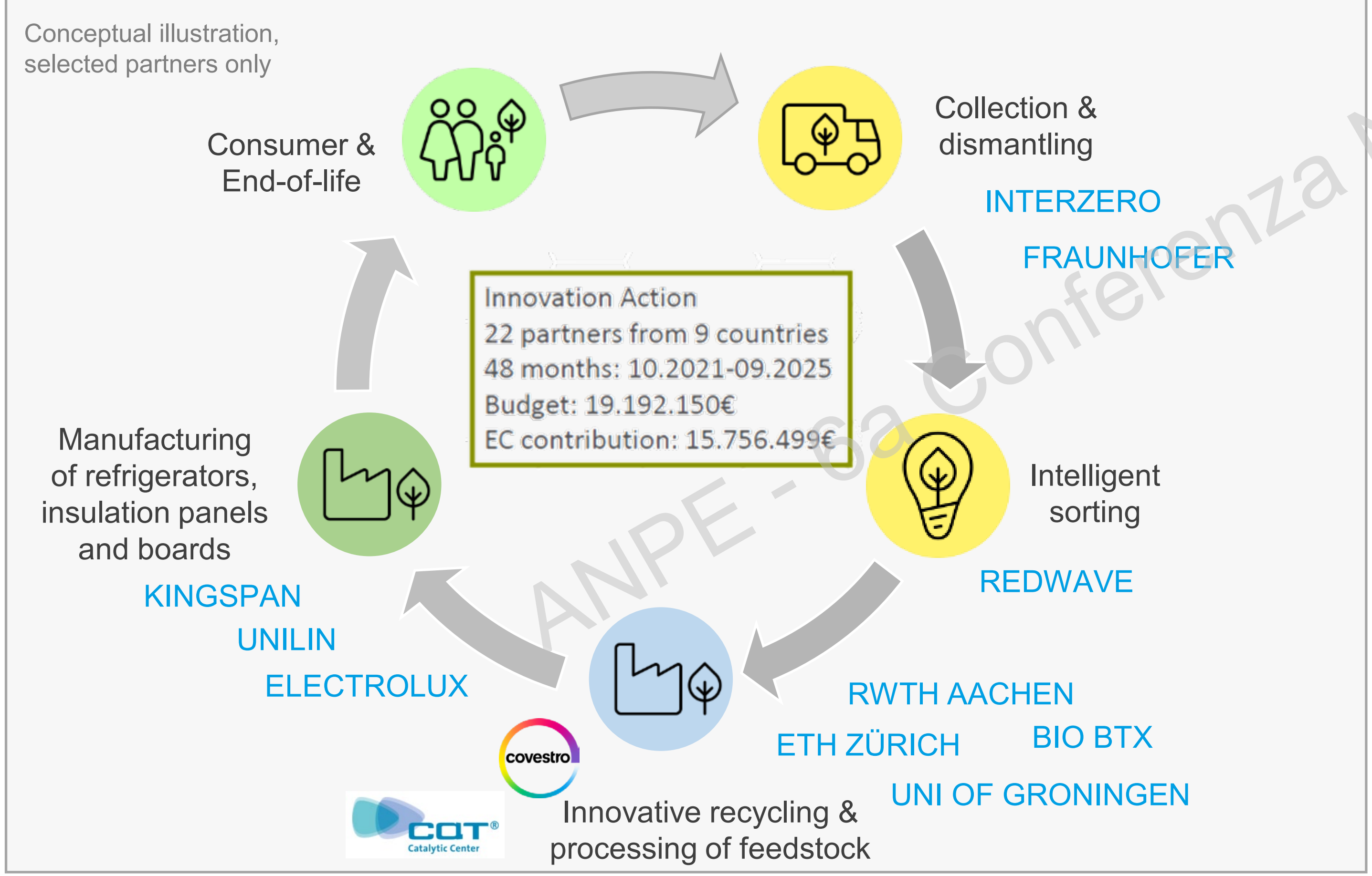


“Systemic expansion of territorial CIRCULAR ecosystems for end-of-life FOAM” or “CIRCULAR FOAM”

The project has received funding from the European Union‘s Horizon 2020 research and innovation program under grant agreement No **101036854**

CIRCULAR FOAM

CONCEPT



HIGHLIGHTS

GOAL AND BENEFIT

- Establish coordinated waste management and suitable dismantling / sorting processes for a sustainable circular economy for rigid PU foam.
- Develop innovative chemical recycling processes for rigid PU foams (applications appliance, metal panel and insulation board).

INNOVATIVE RECYCLING

- Target: obtaining high quality recycled feedstock (polyols and/or amines as precursors for MDI) for use in the original applications.

DEMONSTRATION in year 4

- Of collection, dismantling and sorting as well as chemical recycling technology (TRL7).
- New refrigerator produced with re-raw materials.

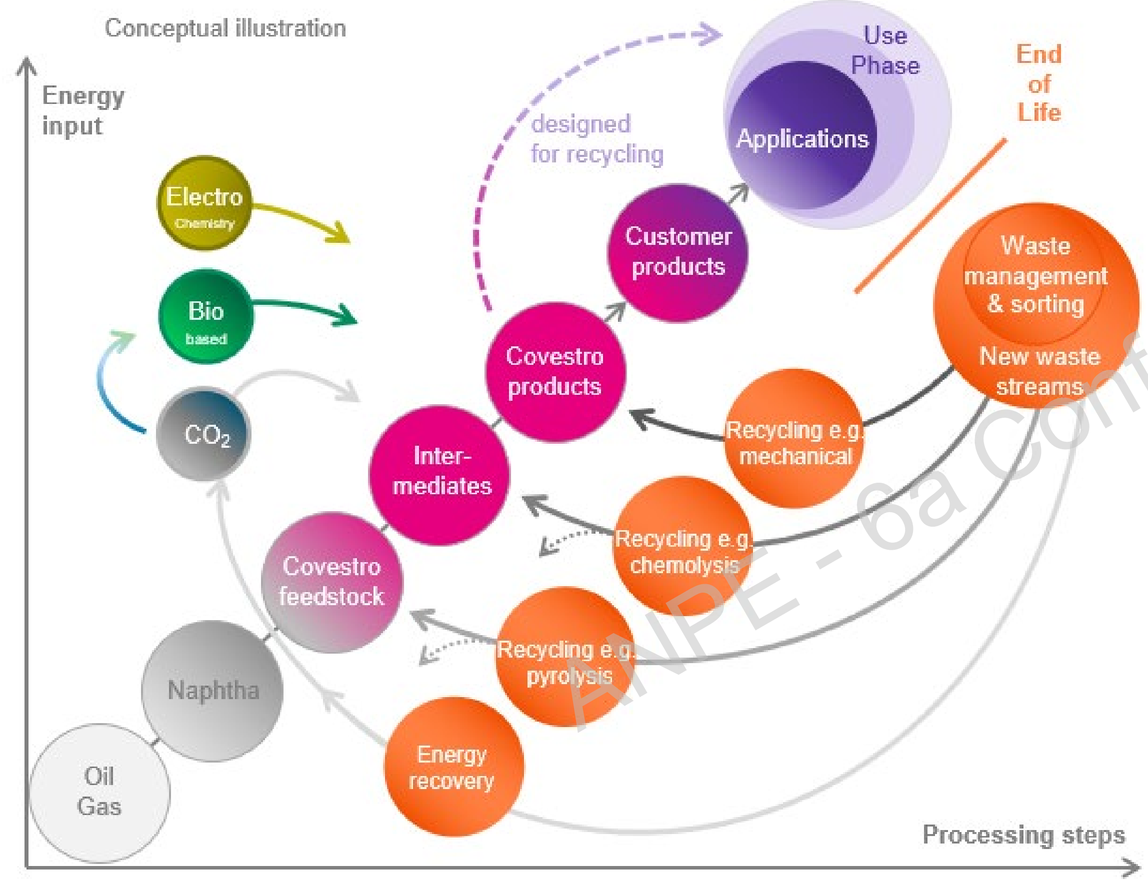
Traceability is a key tool to support design for recycling on future products

- Ensure regulatory compliance
- Exchange data with confidentiality
- Mitigate risks across the supply chain
- Enables new revenue streams
- Meet safety and quality requirements
- Track sustainability metrics
- Visibility beyond tier 1 suppliers
- Substantiated claims

Chemical recycling technologies

After replication in the EU, the following reductions could be attained by 2040:

- 1 mt per year less waste
- 2.9 mt per year less CO_2 emissions
- 150 m€ less cost for incineration



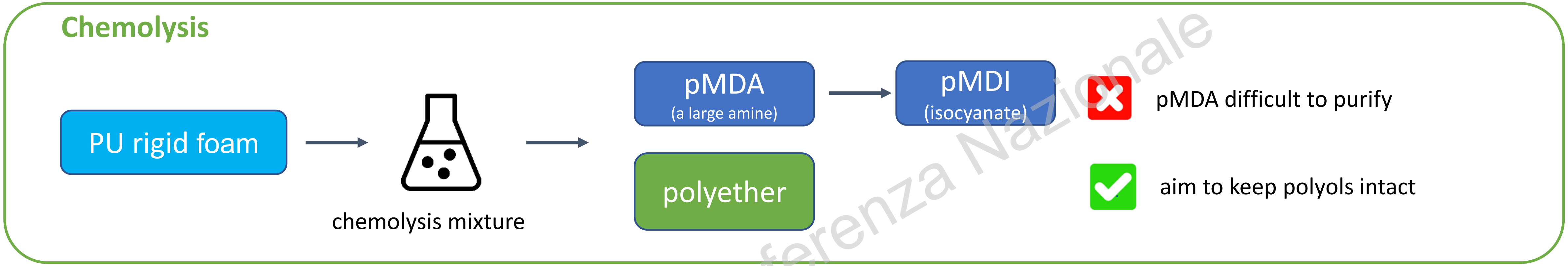
Chemolysis

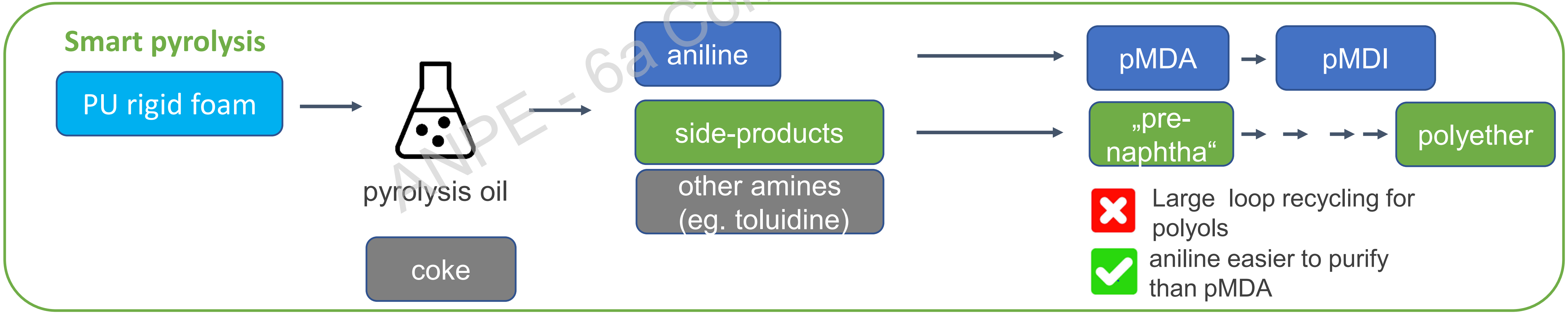
Breaking polymeric materials down into individual components (monomers or other useful intermediates) via chemical reactions. Using solvents, catalysts, heat (150 to 200°C) and sometimes pressure.

Catalytic pyrolysis

Thermal degradation of polymeric materials into individual components (monomers or other useful intermediates) at temperatures of ca. 400 – 500°C.

Overview of route concepts





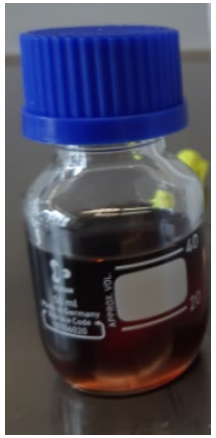
Chemolysis and downstream

Re-MDI

- Re-pMDA can be recovered but some contaminants present.
- A sample was phosgenated to re-pMDI at COV as a proof-of principle.
    - Phosgenation mixture turbid → small differences compared to standard MDI.
    - Re-pMDI somewhat darker than standard.
    - NCO value (concentration of reactive groups) similar to that of standard fossil-based product.
- Further improving the re-pMDA quality is the main target for the chemolysis process at the moment.

Re-Polyol

- Chemolysis on a model Appliance PU foam led to ca. 1 kg of re-polyol formulation.
- Polyol chains remain intact (high quality material).
- The re-polyol-formulation is darker than a standard polyol but the OH-no (concentration of reactive groups) is in the standard range
- This re-polyol-formulation could be used for foaming trials in the appliance application lab at COV.

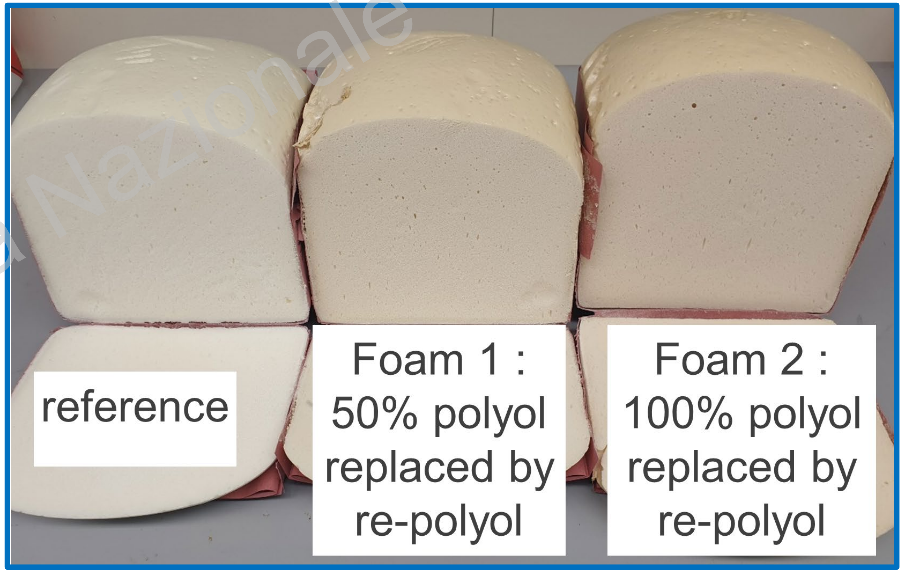


Proof of principle: use of Re-Polyol in new appliance foams

- The standard formulation could be replaced completely with re-polyol:

	unit	Reference	Foam 1 based on re-polyol	Foam 2 based on re-polyol
Polyol formulation	pbw	100	50	
Re-polyol	pbw		50	100
Additives and catalysts	pbw	7.0	7.0	8.2
c-Pentane	pbw	13	13.5	13
Isocyanate Desmodur®44V 20 L	pbw	147	144	148
Foam index		115	115	122
Cream time of lab-foam	s	8	12	10
String time of lab-foam	s	67	90	73

- Recycled content of 37% in new foam (made with standard isocyanate in this case).
- Comparable re-polyol purities are obtained after depolymerisation of EoL foam at small scale.



- Currently: production of larger samples of re-polyol from EoL foam for testing in new appliance foams.

Evaluation through foaming simulation: generation of input data

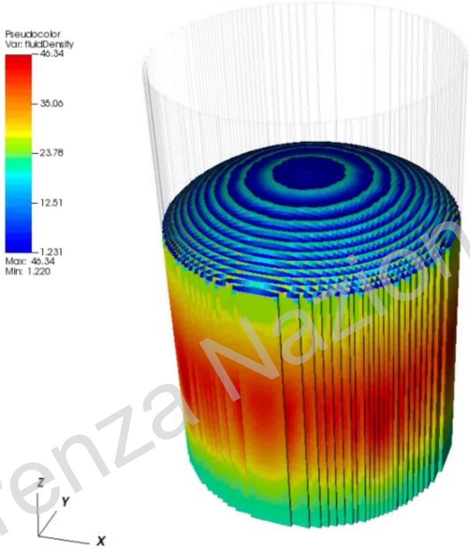
25 cm diameter: 300 [g]

$$V(t) = A_0 e^{(-A_1/((t+t_0)^{A_2}))} + A_3$$

Expansion term in equations: $S_p = \frac{1}{V(t)}\frac{dV(t)}{dt}$

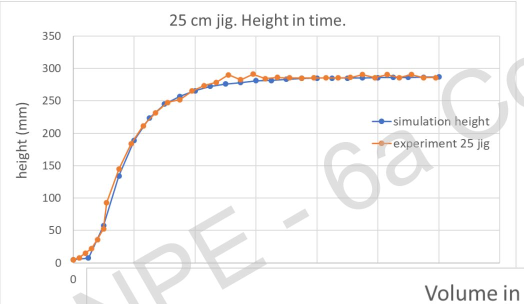
$$\nabla \cdot v = S_p$$

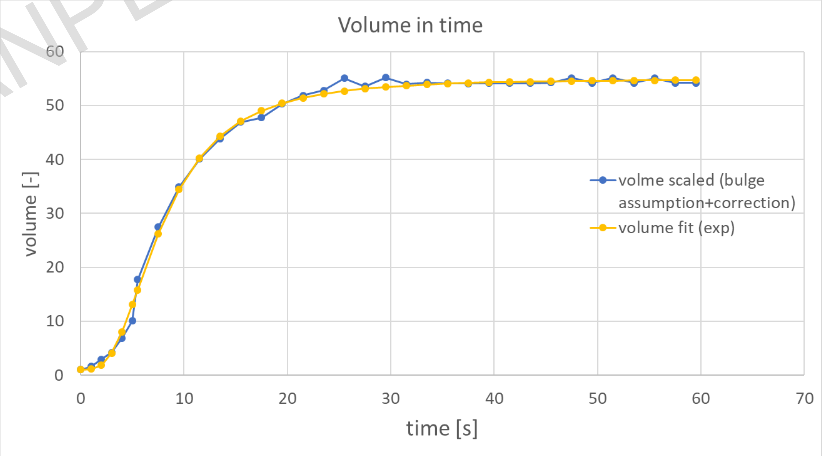
- A_0 = 53.8872
- A_1 = 13834.4
- A_2 = 3.64589
- A_3 = 1
- t_0 = 7.24366

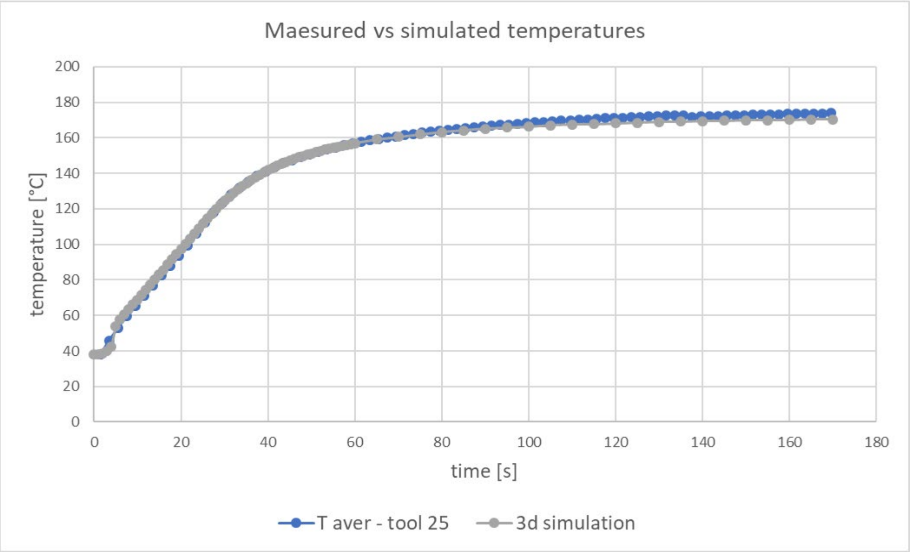


Adapted parameters (python regression)	
H_R	150.6994
A	0.187692
k_0	6.081347
E_ξ/R	553.7144
b	0.026249
m	3
n	3.600543
t_s^ξ	1.79E-06
B	0.2

Fixed parameters (insensitive)	
ω	0.2
β	0.2
C_1	25
C_2	30
T_{g0}	250
$T_{g\infty}$	405

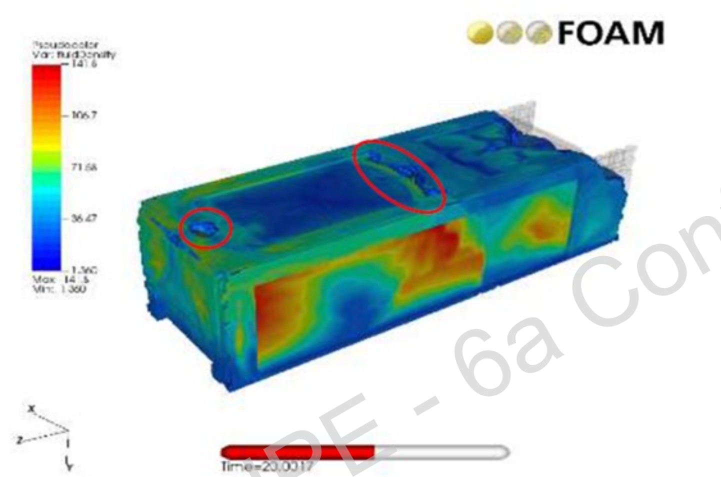




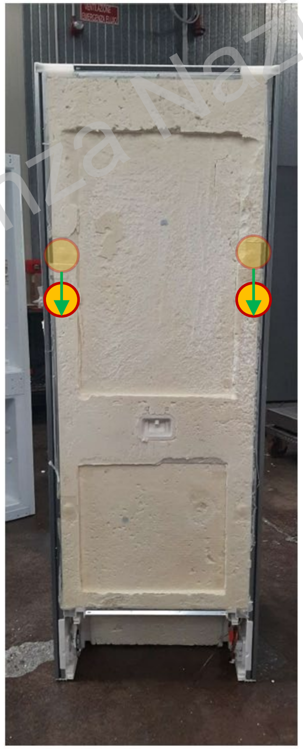


Foaming simulation: example of reliability

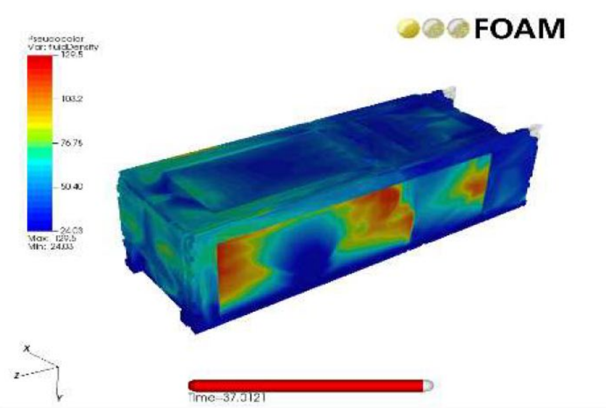
Foaming simulation first trial



First foaming trial (FFP): Foam voids under the VIP om the back of the refrigerator compartment.



Foaming simulation second trial



Second trial: modified injection holes position in the refrigerator compartment (90 mm approx. backwards). Added a row of venting holes on the top of the back panel.

Conclusion

- The implementation of the WEEE directive has supported the growth of recycling business across Europe, making available important streams of secondary raw materials.
- The end-of-life treatment of domestic refrigerators and freezers produces every year in Europe approximately 60 kt PU Foam, currently incinereted under controlled conditions for energy recovery.
- Covestro has identified chemical recycling as preferred route to get back PU chemicals to be reused in the production of domestic refrigerators and freezers, in the frame of the Circular Foam project.
- Electrolux has been working to optimize the design of new appliances to facilitate dismantling and recycling with aim at achieveing higher yield and purity of PU foam fraction.
- First lab-scale samples look pretty promising; thanks to the tool to simulate PU foaming process, a first comparison with the reference PU systems can be performed, waiting to foam real scale refrigerators when larger size samples will be available.

Electrolux

Shape living for the better!

covestro

Thanks for your attention