



**PROGETTARE l'efficienza  
COSTRUIRE il cambiamento**

7 maggio 2026

Centro Congressi Precise House Mantegna  
Roma

[www.conferenzapoliuretano.it](http://www.conferenzapoliuretano.it)



organizzata da

**DESIGN efficiency, BUILD change**

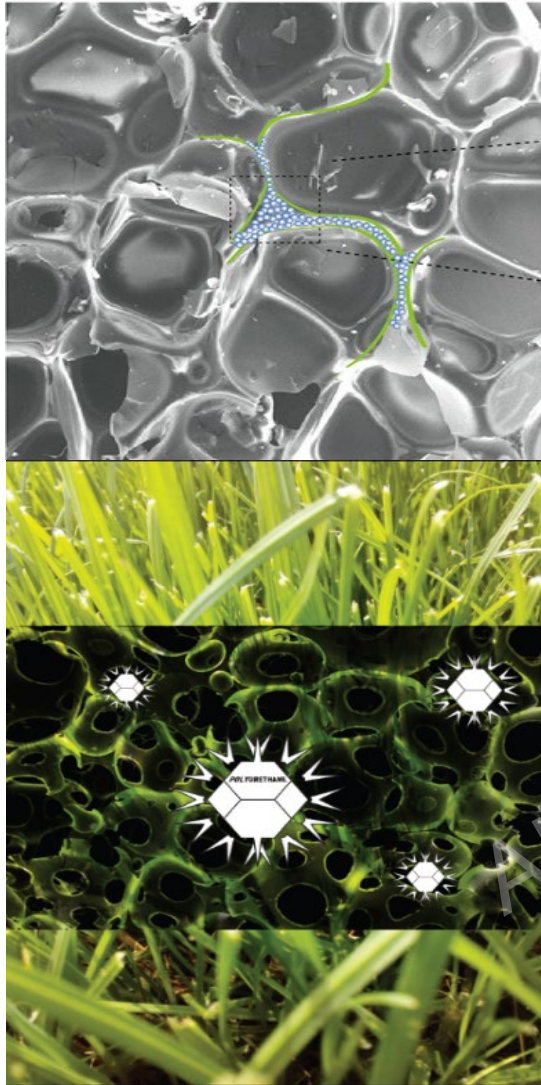


*Reinventing Polyurethane Foams: Enabling Reprocessability through Covalent Adaptable Networks and Isocyanate-Free Innovation from Lab to Pilot-Scale*



Dr. Letizia VERDOLOTTI, email: [letizia.verdolotti@cnr.it](mailto:letizia.verdolotti@cnr.it)

# Outline, *Sustainability pathways for PU foams*



## ☛ Sustainable Polyurethane composite foams, *Up-scaling*

Up-scaled production and application in real scenario of Sustainable composite Polyurethane foams

## ☛ Customized PUPackaging for Artwork

Green packaging foam materials in real case scenarios

## ☛ *Reprocessing routes*

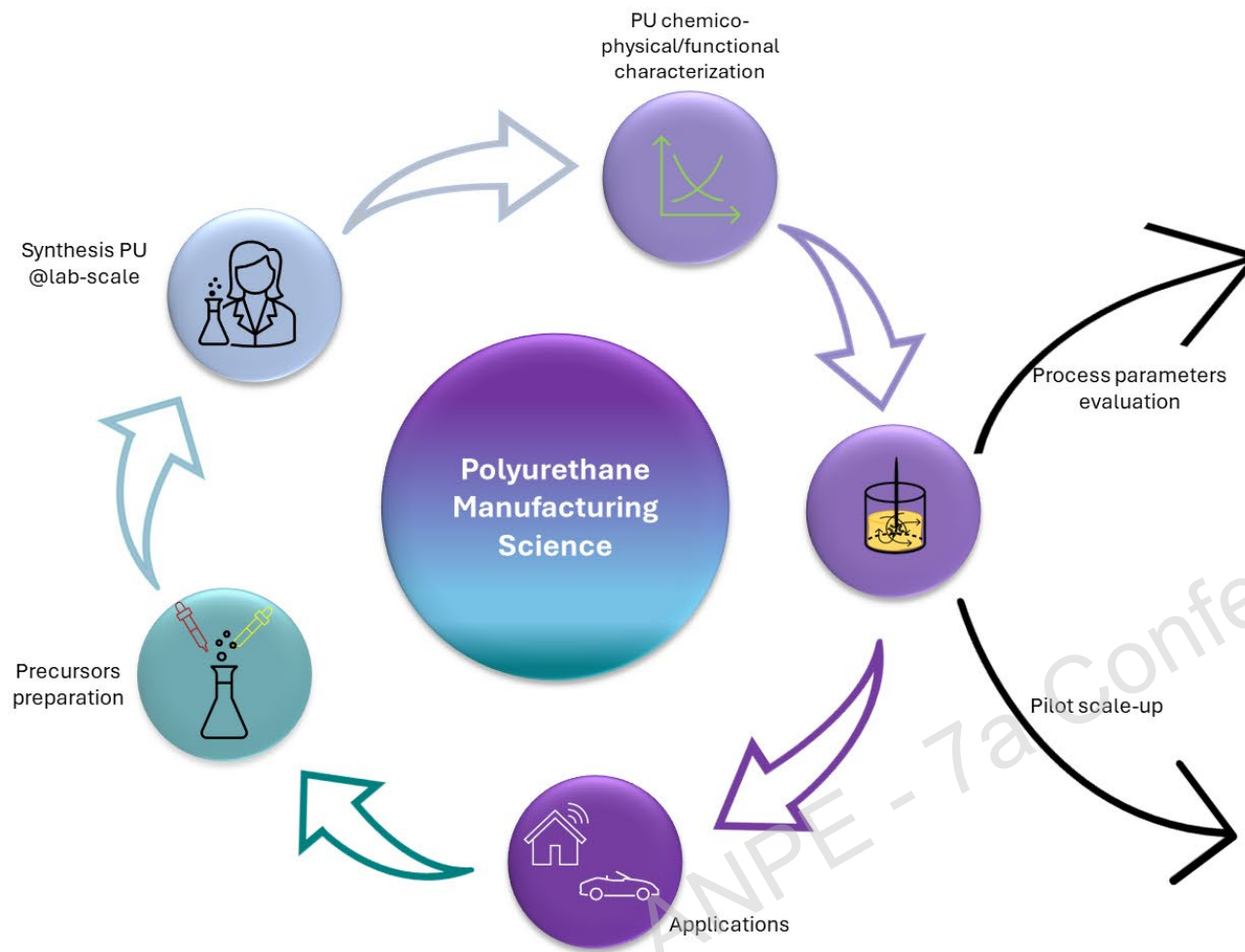
ReProcessable Sustainable Polyurethane foams induced by **C**ovalent **A**daptable **N**etworks

## ☛ Non Isocyanate routes

composite Non Isocyanate Polyurethane-**cNIPUs** foams, from lab to pilot scale

## ☛ Polyurethane foams include in IAM-I

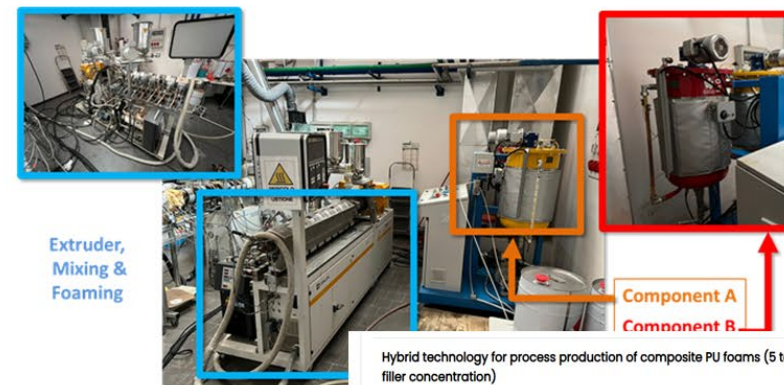
# Up-scaled production of Sustainable composite Polyurethane foams



**FOAMAT® 285**



**Semi-continuous pilot plant**



Hybrid technology for process production of composite PU foams (5 to 50 wt.% of filler concentration)

Market maturity: Exploring  
Market creation potential: No MCP category  
Project: BIOMAT  
Innovation Topic: Other

CONSIGLIO NAZIONALE DELLE RICERCHE 9 - Italy

9 INDUSTRIAL INNOVATION AND INFRASTRUCTURE 11 SUSTAINABLE LIFESTYLES AND CONSUMPTIONS 13 CLIMATE ACTION

## Lab scale (TRL 5)

Formulations

- **Component A:** bio-polyols blend cardanol-based
- **Fillers:** powder mixture Diatomite/functionalized SiO<sub>2</sub>
- **MDI:** petrol-based isocyanate
- **NCO/OH:** 1.5

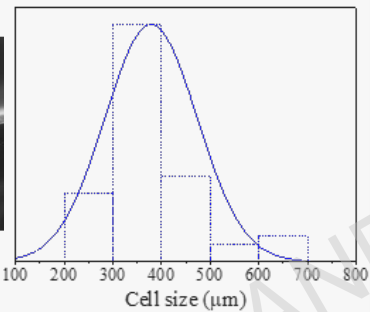
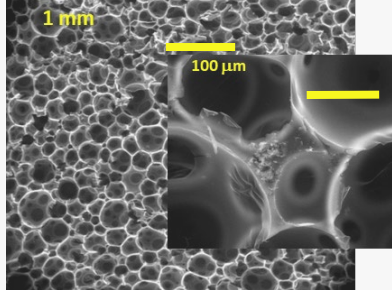
## Pilot scale (TRL 7)

- Highly filled composite PUR-based (up to 60 wt.%).
- Fillers with different granulometric characteristics and aspect ratio can be employed.
- 6 m<sup>2</sup>/day, 16 panels x 0.35 m<sup>2</sup>, 10 cm thickness
- Cell morphology induced by the flow rate
- Thermal conductivity ≤35 mW/mK

# Up-scaled production of Sustainable composite Polyurethane foams



Demo cases, under monitoring



Closed like structure

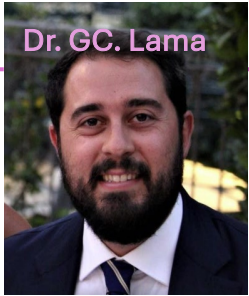
- Panels:  $65 \times 65 \times 5 \text{ cm}^3$
- $\sigma$  (10%) =  $0.69 \pm 0.03 \text{ Mpa}$ ;  $\rho = 102.5 \pm 1.26 \text{ kg/m}^3$
- $\lambda = 35 \pm 0.2 \text{ mW/m} \cdot \text{K}$
- sustainability index  $\geq 50 \%$



Madrid (Spain) applied @2024



Dr. GC. Lama



UNISANNIO



Benevento (Italy) applied @2025

PRIN2022-HERITAGE



Riga (Lettonia) applied @2024



# Customized PU Packaging for Artwork



BOX IN A VALISE



EUROPASAURUS SKULL



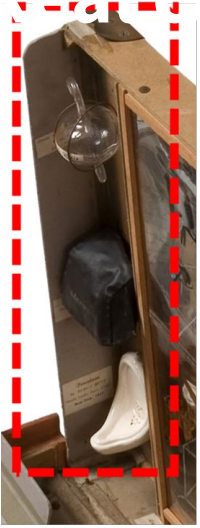
# CASE STUDY 1



**ARTWORK:** BOX IN A VALISE (1941) BY MARCEL DUCHAMP



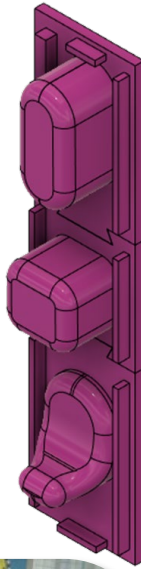
Scan of this complex section from Peggy Guggenheim to realize *via* 3D printing customized inserts in **tailored PU foam**.



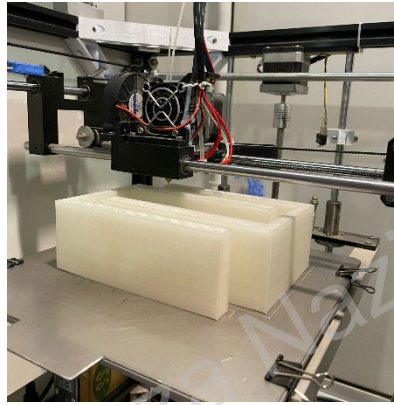
3D  
Scan



Digital  
adaptation



3D  
Print



PU casting in 3D  
printed mould

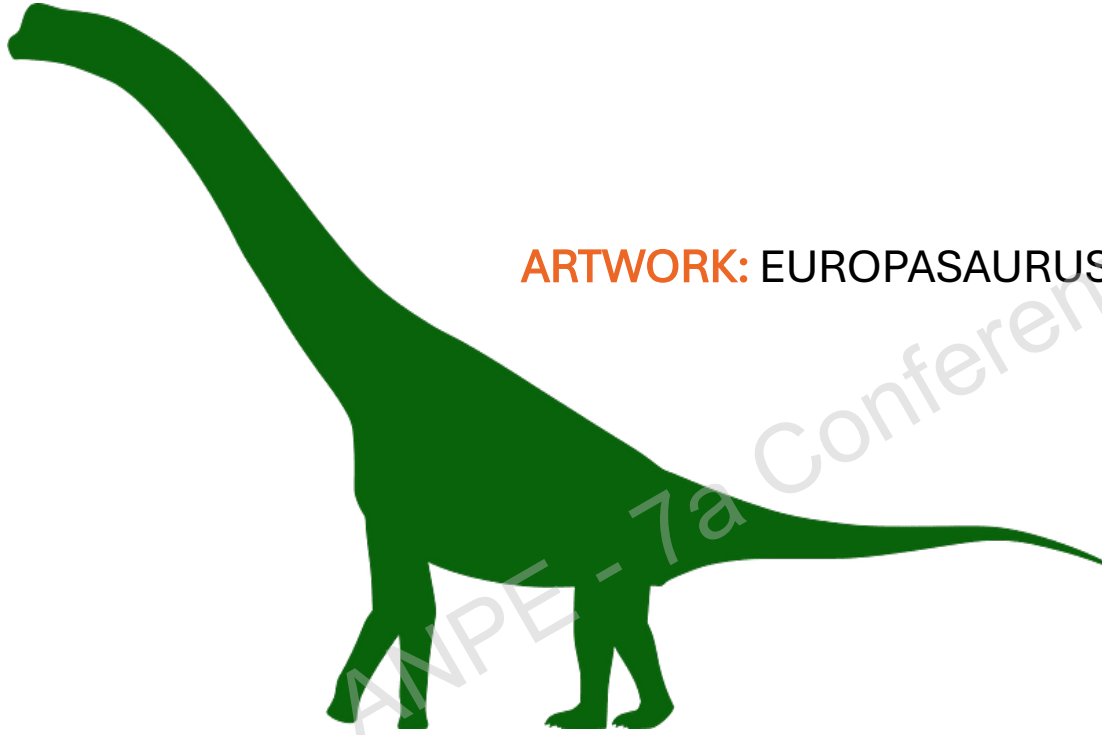


Demould.



Customized  
packaging, tested  
from Venice to NY





ARTWORK: EUROPASAURUS SKULL



Scan of skull from MNM to realize *via* 3D printing customized mould to be used for producing **tailored PU foam packaging**.

# CASE STUDY 2



# Re-processing routes

ReProcessable Sustainable Polyurethane foams induced by Covalent Adaptable Networks



THERMOSETS



STIMULUS



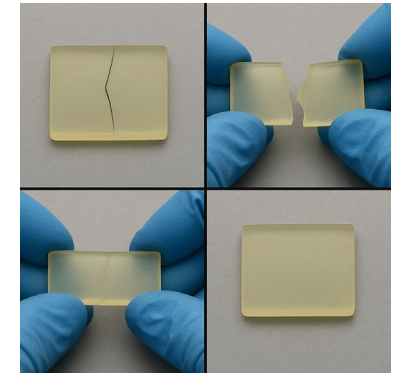
THERMOPLASTIC

Thermal/mechanical treatment, pH variation

Reprocessable  
New useful products

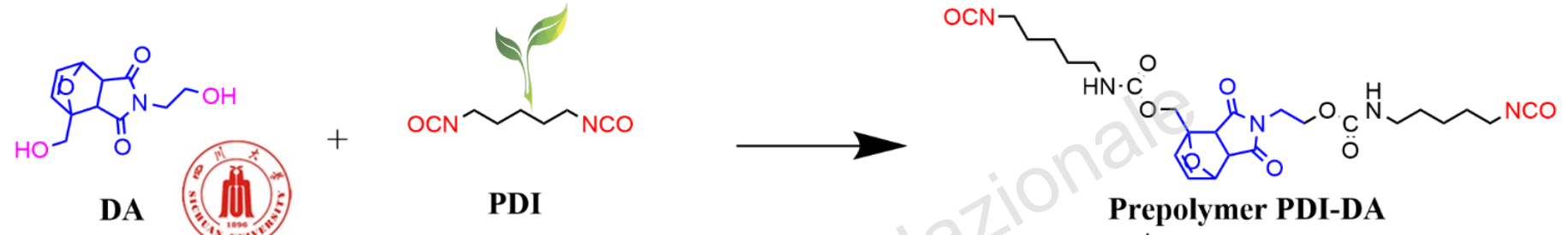
## Main properties

- Reprocessability
- Recyclability
- Self-healing
- Shape memory

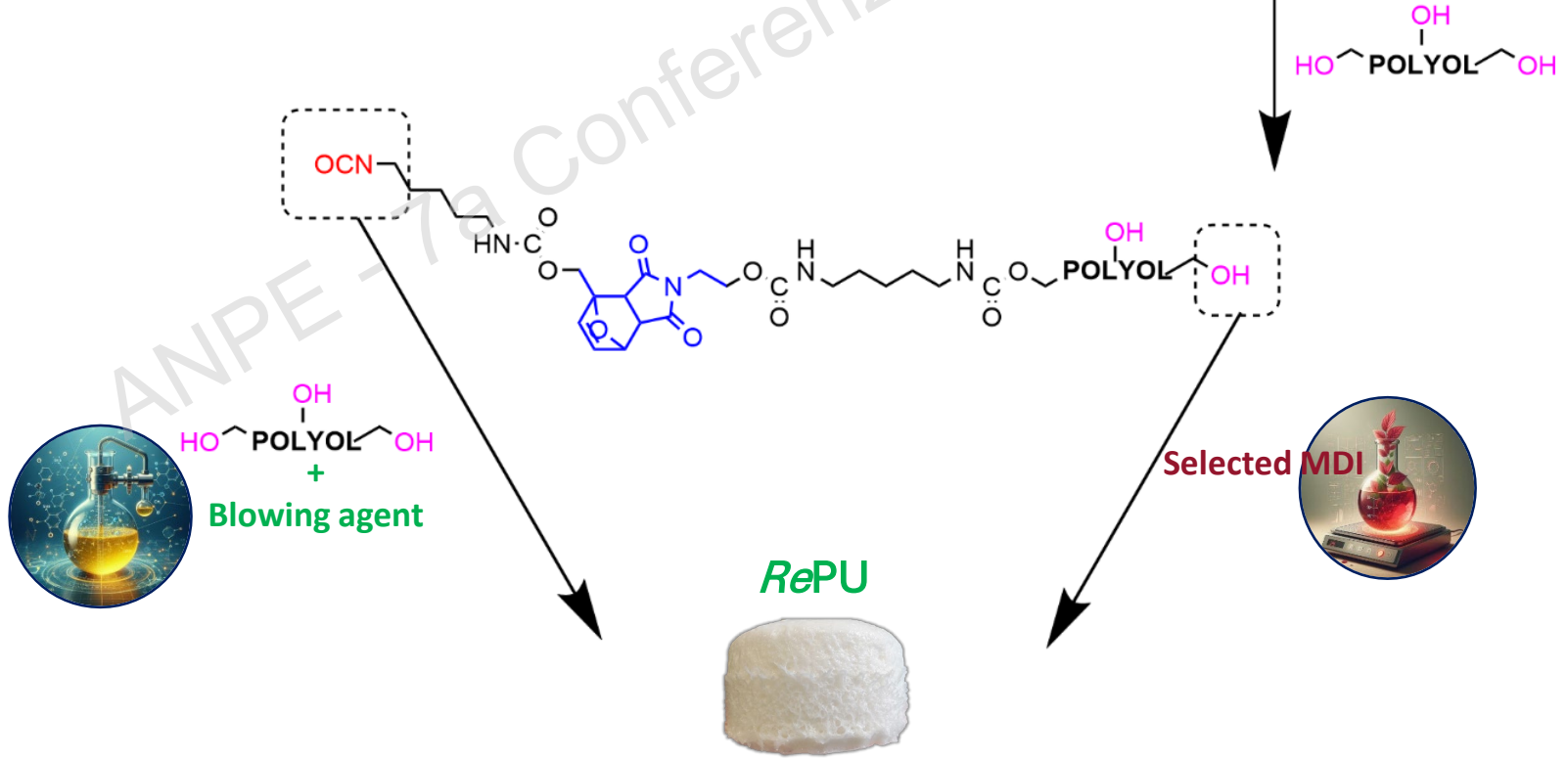


# The strategy

## Step 1-Synthesis of Isocyanate-terminated prepolymers



## Step 2-Synthesis of *Re*PUR



# Re-processability of PU foams (*Re-PUR*)



THERMOSETS

PU foams with and without DA-based propolymer



MILLING

Milled PU foam



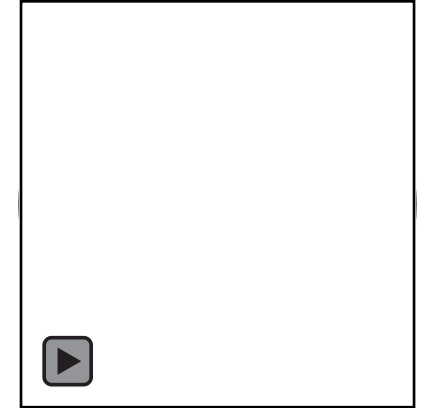
STIMULUS

Thermal Treatment  
T=125°C  
P=10ton

Conventional  
PU foam



*RePUR*



# RePUR film, Mechanical properties

## 1° Re-processing (from foams to bulk films)



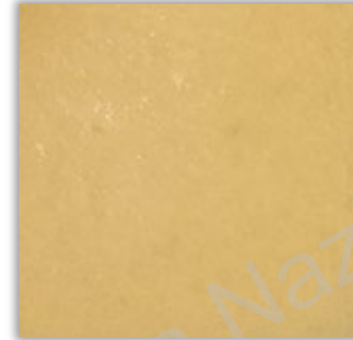
PDI\_DA\_2:1



PDI\_DA\_3:1



PDI\_DA\_4:1



PDI\_DA\_5:1

Sample	Tensile strength (MPa)	Elongation at break (%)	Gel content (%)
PU_DA_2:1	4.0 ± 0.1	53.8 ± 3.0	94.1 ± 0.1
PU_DA_3:1	2.8 ± 0.09	56.2 ± 3	94.7 ± 0.6
PU_DA_4:1	2.6 ± 0.2	44.9 ± 1.0	95.4 ± 0.6
PU_DA_5:1	2.4 ± 0.2	44.5 ± 0.7	94.5 ± 0.1

## 2° Re-processing (from bulk films to bulk films)



PDI\_DA\_2:1



PDI\_DA\_3:1



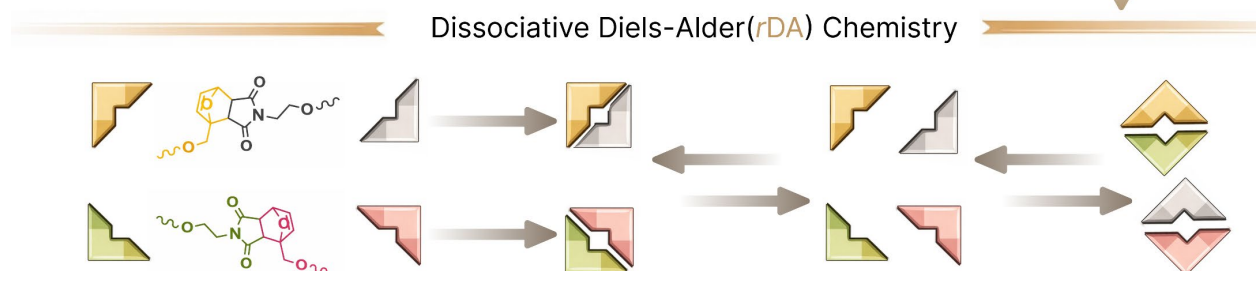
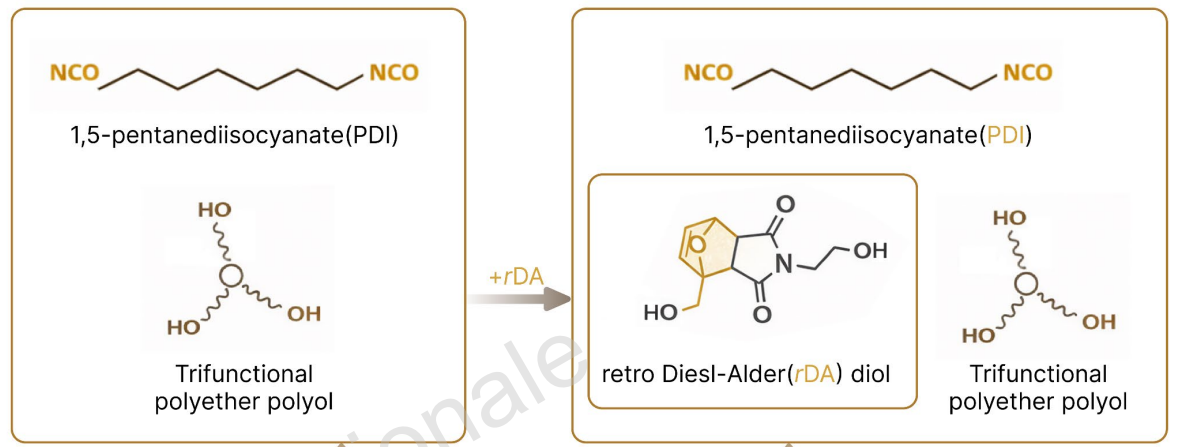
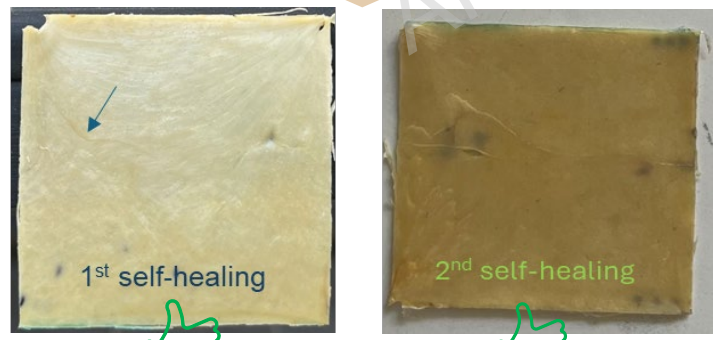
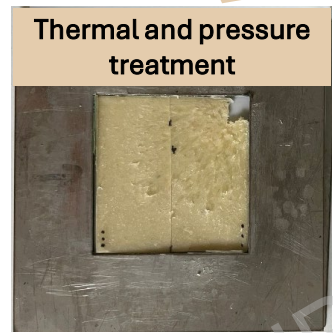
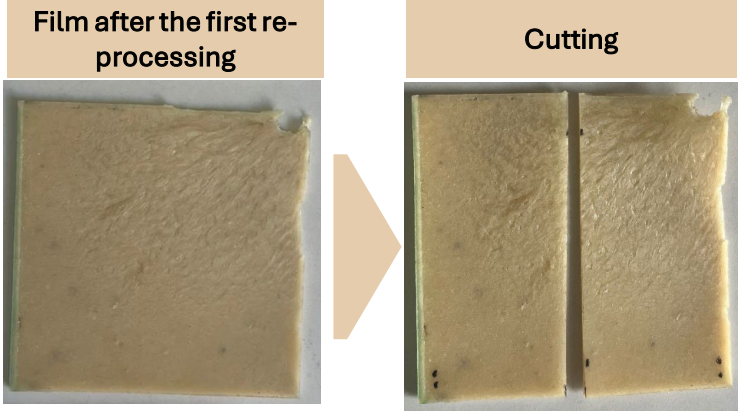
PDI\_DA\_4:1



PDI\_DA\_5:1

Sample	Tensile strength (MPa)	Elongation at break (%)	Gel content (%)
PU_DA_2:1	3.1 ± 0.2	37.4 ± 2.7	91.6 ± 1.0
PU_DA_3:1	2.0 ± 0.1	38.7 ± 1.9	91.9 ± 0.9
PU_DA_4:1	1.8 ± 0.1	37.6 ± 0.8	92.9 ± 0.9
PU_DA_5:1	1.2 ± 0.08	32.2 ± 2.6	91.6 ± 2.3

# RePUR film, Self-healing properties



# Non Isocyanate routes

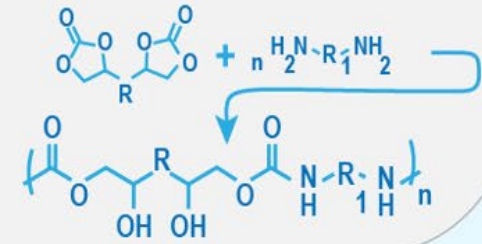
## BIO-BASED RAW MATERIALS



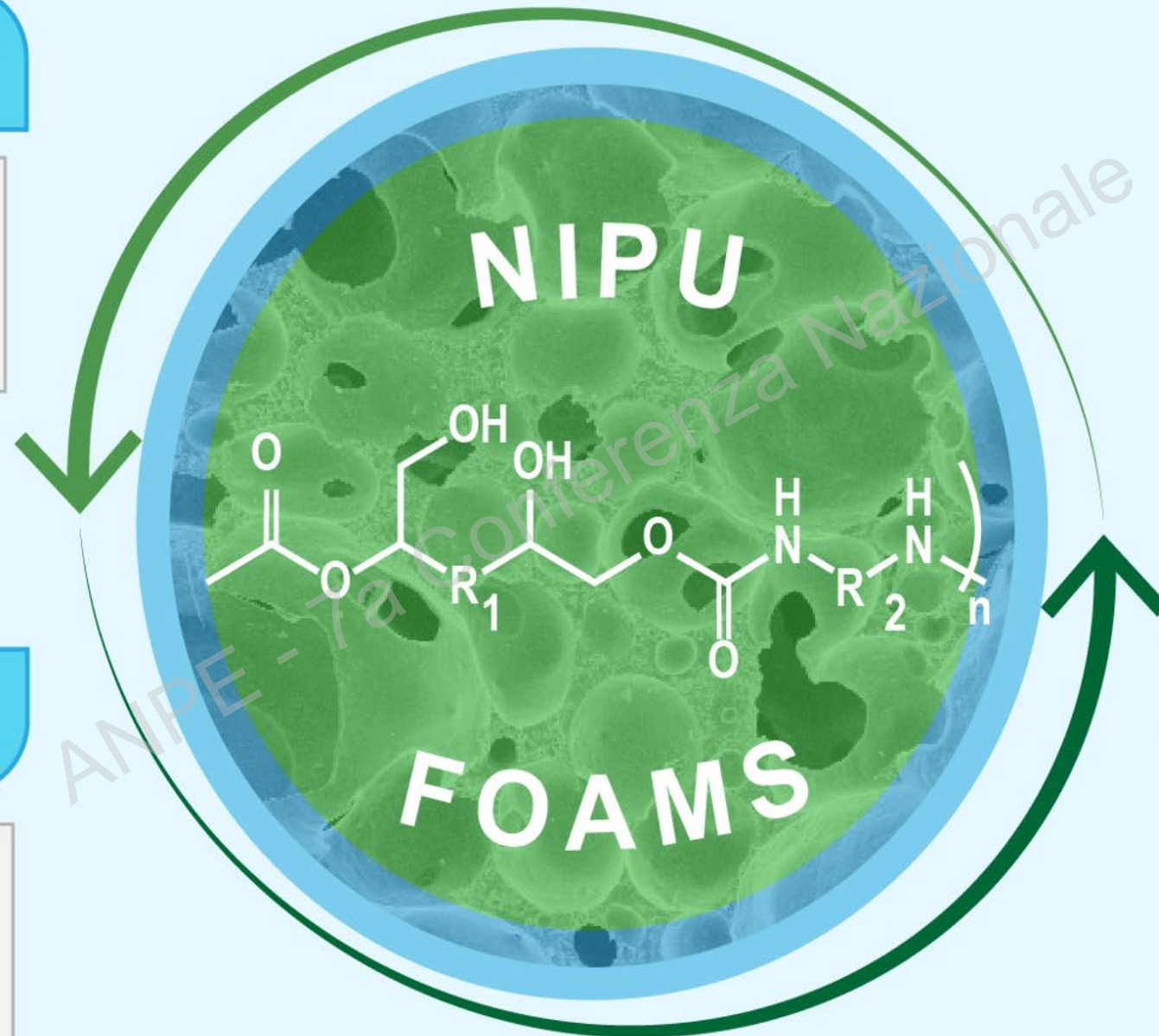
## RECYCLING AND REPROCESSABILITY



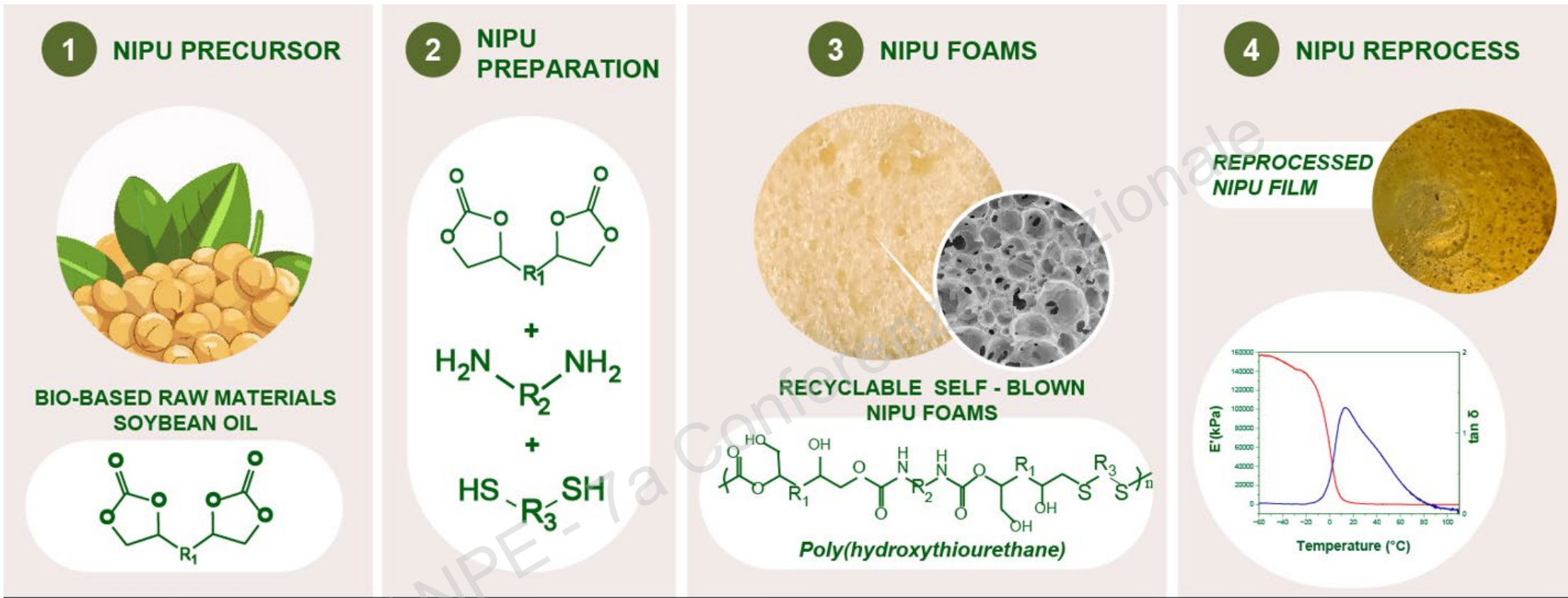
## GREEN SYNTHESIS



## APPLICATIONS



# Step strategy process



F. Orabona, Chem. Eng. J. 2024, 493, 152677  
 F. Orabona, Chem. Eng. J. 2025, 168292

L Verdolotti et al, RSC Sustainability 2026  
 L Verdolotti et al ACS, Sustainable Chemi Eng 2026  
 L. Verdolotti et al., Green Chemistry., 2025

PhD program of F. Orabona



# RePUR film, morphological, mechanical and thermal degradation characteristics

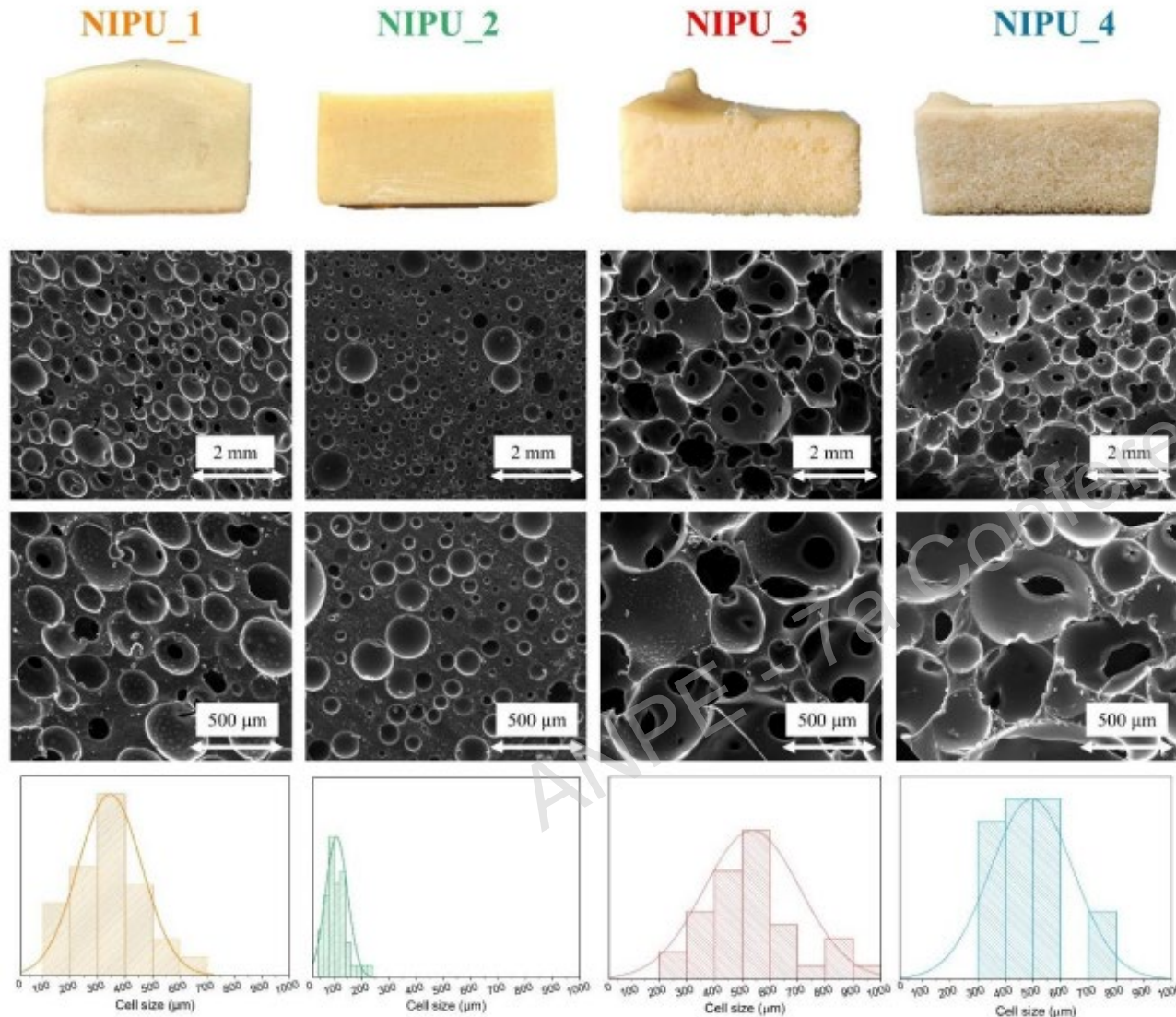
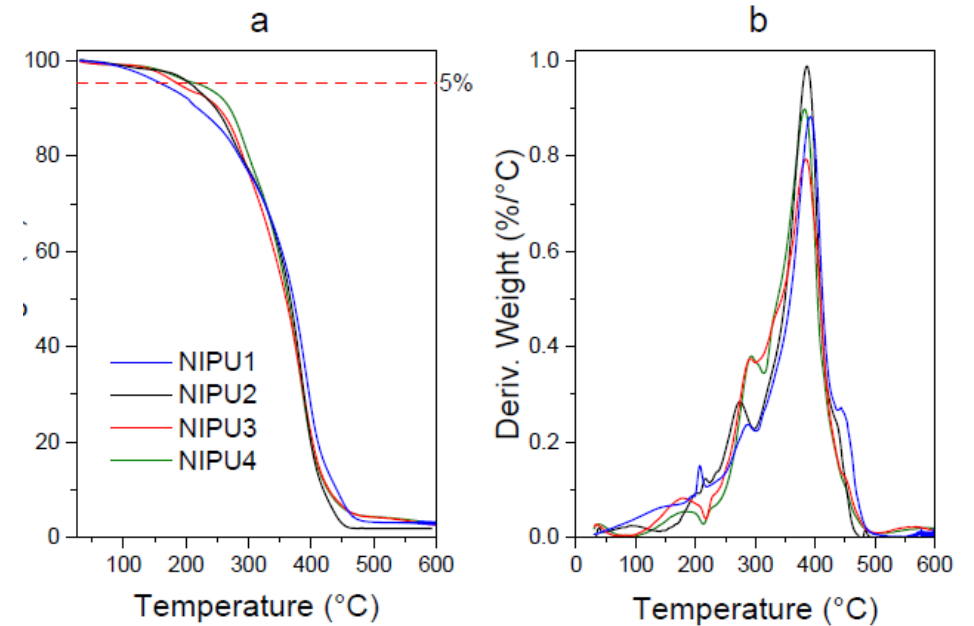


Table 2. Gel content, physical, morphological, and mechanical properties of the NIPU foams. Results are expressed as the average and standard deviation of three independent measurements.

Sample name	GC (%)	$\rho$ (kg/m <sup>3</sup> )	$D_h$ ( $\mu$ m)	$N \cdot 10^{-3}$ (cm <sup>-3</sup> )	Anisotropy coefficient (-)
NIPU_1	78.6 $\pm$ 5.2	600 $\pm$ 50	366 $\pm$ 13.3	4.4 $\pm$ 0.1	0.9 $\pm$ 0.1
NIPU_2	83.2 $\pm$ 4.3	700 $\pm$ 55	100 $\pm$ 80	0.02 $\pm$ 0.0005	1.1 $\pm$ 0.3
NIPU_3	77.2 $\pm$ 8.2	200 $\pm$ 70	535 $\pm$ 173	0.6 $\pm$ 0.03	0.9 $\pm$ 0.2
NIPU_4	78.0 $\pm$ 2.0	250 $\pm$ 10	495 $\pm$ 150	1.2 $\pm$ 0.06	0.94 $\pm$ 0.1



# Re-processability of cNIPU foams

cNIPU foams were successfully reprocessed via compression molding at 140 °C for 2 h.



NIPU	$T_g$ (°C)	E, (kPa)	$\sigma_{max}$ (MPa)	$\epsilon$ (%)
Bulk material	0.8	$0.4 \pm 0.05$	$0.43 \pm 0.02$	$137.9 \pm 3.0$

$T_g$ : Glass transition temperature. E: Elastic modulus,  $\sigma_{max}$ : Stress at break,  $\epsilon$ : elongation at break

# Ongoing research about NIPU foams

## Chemicals

**Cyclocarbonate** synthesis from other renewable sources

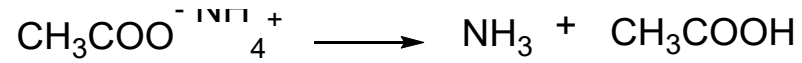
↳ Limonene



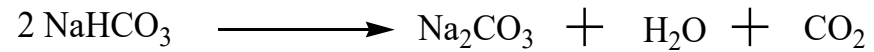
## Different Blowing routes

↳ H<sub>2</sub>O

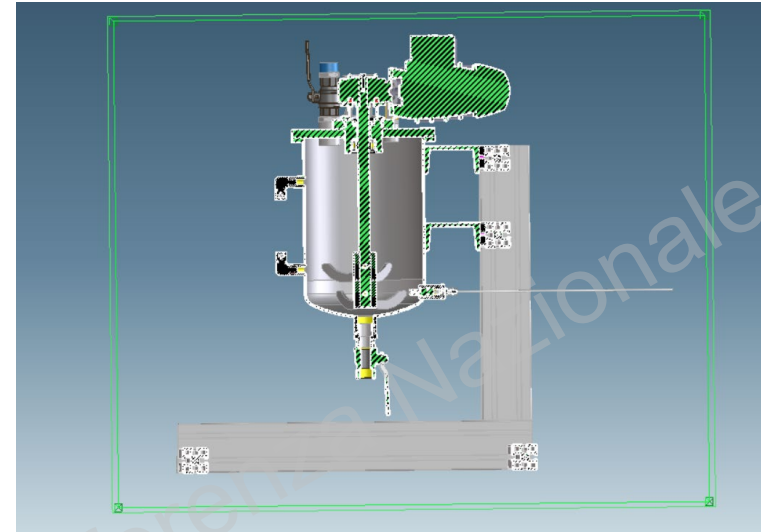
↳ Acetate chemical:



↳ Sodium bicarbonate



## Process upscaling



## Partnership for upscaling



WP 2026-2027



HORIZON EUROPE - WORK PROGRAMME 2026 - 2027  
Cluster 4  
Digital, Industry and Space



IAM4EU ▾ About IAM-I ▾ Our Work ▾ Events News Membership ▾ Members Area  
Contact

WORKING GROUPS



WG #1  
Materials Digitalisation Across the Value Chain



WG #2  
Resilient and Circular Value Chains



WG #3  
Working Group on Construction



WG #4  
Working Group on Electronics



WG #5  
Working Group on Energy



WG #6  
Working Group on Mobility



WG #7  
Working Group on Health

**IAM-I (Innovative Advanced Materials Initiative):** associazione internazionale no-profit che guida la partnership europea IAM4EU, coordinando ricerca, industria e istituzioni per accelerare lo sviluppo e l'adozione di materiali avanzati in Europa.

**SRIA (Strategic Research & Innovation Agenda)** definisce le **priorità strategiche-ST/STF** su materiali avanzati

- Le **priorità strategiche-ST/STF** contribuiscono a definire i **Work Programme** di Horizon Europe
- I **Work Programme** si traducono in **call for proposals** (bandi)

**Ruolo WG3 – Construction**

- **Identifica i Materiali avanzati** (challenges & needs) del settore costruzioni per la stesura dello SRIA
- Contribuisce a orientare le call principalmente verso:
  - ↔ *sostenibilità e circolarità*
  - ↔ *efficienza energetica*
  - ↔ *resilienza e durabilità delle infrastrutture*

**Lead (INDUSTRY member)**  
Maddalena Rostagno  
GAE Engineering

**Co-Lead (RESEARCH member)**  
Javier García Jaca  
TECNALIA

**Technical Advisor (either)**  
Gaute Gruben  
SINTEF

**WG#3 – Working Group on Construction**

This WG addresses the specific challenges and opportunities in the construction sector through the use of advanced materials. It brings together stakeholders from industry, research and academia to support the development of materials that contribute to more sustainable, energy-efficient, durable, and climate-resilient buildings and infrastructure.

Focus areas include the integration of smart materials, low-carbon alternatives (e.g. sustainable concrete or insulation), and digital tools that enhance performance monitoring and lifecycle analysis. The WG also considers regulatory frameworks and the broader ecosystem needed to accelerate the uptake of advanced materials in construction, helping to meet environmental goals and support the

**Chapter 3 of SRIA**

**Overarching Needs,**

**Energy efficiency**  
IAMs for temperature control. To reduce embodied and operating energy for built environment such as thermal insulation systems, efficient heat radiation or cooling solutions (e.g. wall-integrated (light-weight) IAMs with reduced embodied energy, IAMs for thermal energy management (heating/cooling), energy storage, capture and harvesting solutions (e.g. thermoelectricity) integrable into construction materials and components, as well as smart low-energy features (e.g. dynamic glazing, lighting).

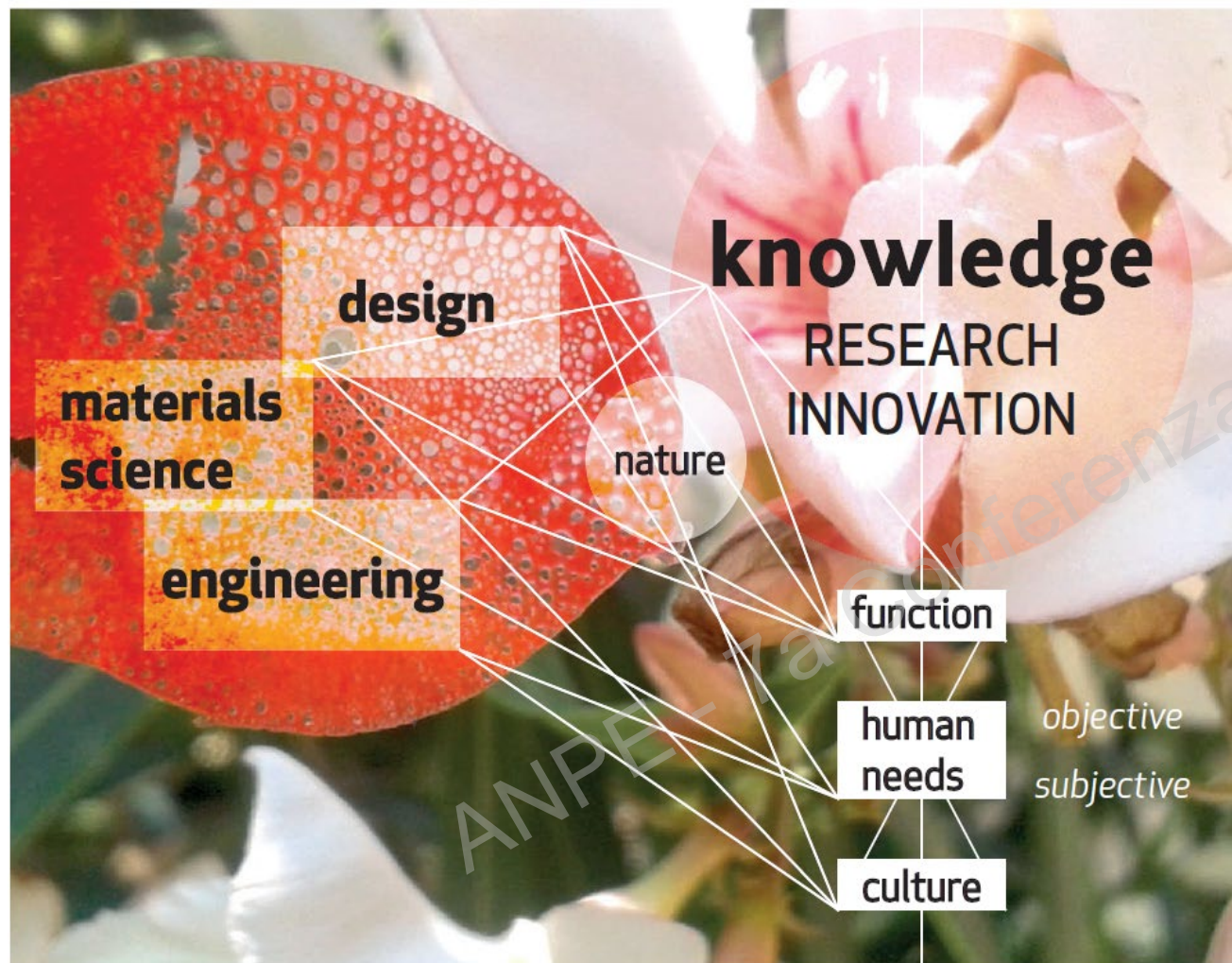
**Materials efficiency**  
IAMs to support the design for re-use of renewable materials and components. IAMs for easy deconstruction and separation at end of life (e.g. reversible adhesives) for prefabricated products, such as e.g. multi-layer components. Self-monitoring, self-repairing, recyclable/repurpose IAMs and on-site recycling processes (e.g. tracer particles), increasing use of bio-based or bio-inspired IAMs (e.g. wood composites, enhanced natural fibers); IAMs for CRM substitution or reduction; IAMs to decrease land impermeabilization, such as permeable surfaces and lightweight materials for flexibility of spaces and uses.

**Safety & protection, comfort, preservation of heritage**  
IAMs for easy/self-repair or renovation solutions and increased comfort (e.g. odour/ noise reduction). Sensing functions for resilience or safety (e.g. early warning) and cultural heritage preservation needs (e.g. transparent insulation). IAMs for more efficient 3d printing, prefabrication, and for safer construction processes. IAM for multi-functional characteristics, improved fire resistance, load bearing

**PU foams included**

ST3 - STF 3.2 Energy Efficient Buildings	
Challenges	Examples
<ul style="list-style-type: none"> <li>• High thermal and acoustic performance while ensuring full</li> </ul>	<ul style="list-style-type: none"> <li>• PU foams with diatomite/silica fillers for fire-safe lightweight insulation</li> </ul>
ST2 - STF 2.1 Advanced Building Envelopes	
Challenges	Examples
<ul style="list-style-type: none"> <li>Ultra-low thermal conductivity combined with fire resistance in lightweight materials</li> </ul>	<ul style="list-style-type: none"> <li>• Ultra-lightweight PU foam panels with bio-based feedstocks and integrated sensing</li> </ul>





# Thank you



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