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

CNR iPCB
Istituto per i Polimeri, Compositi e Biomateriali

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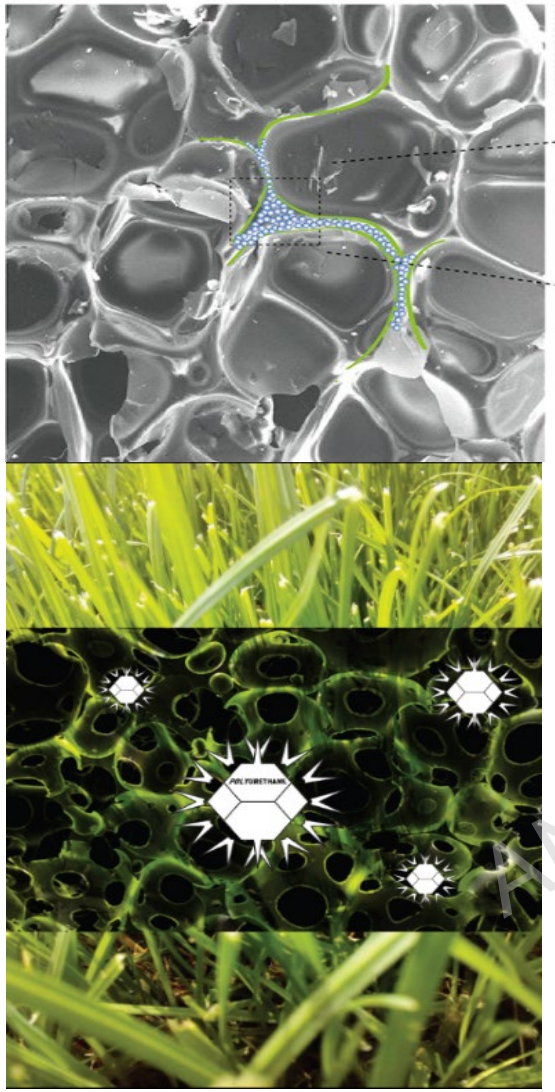
Outline, *Sustainability pathways for PU foams*



- 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

- *Re*processing routes

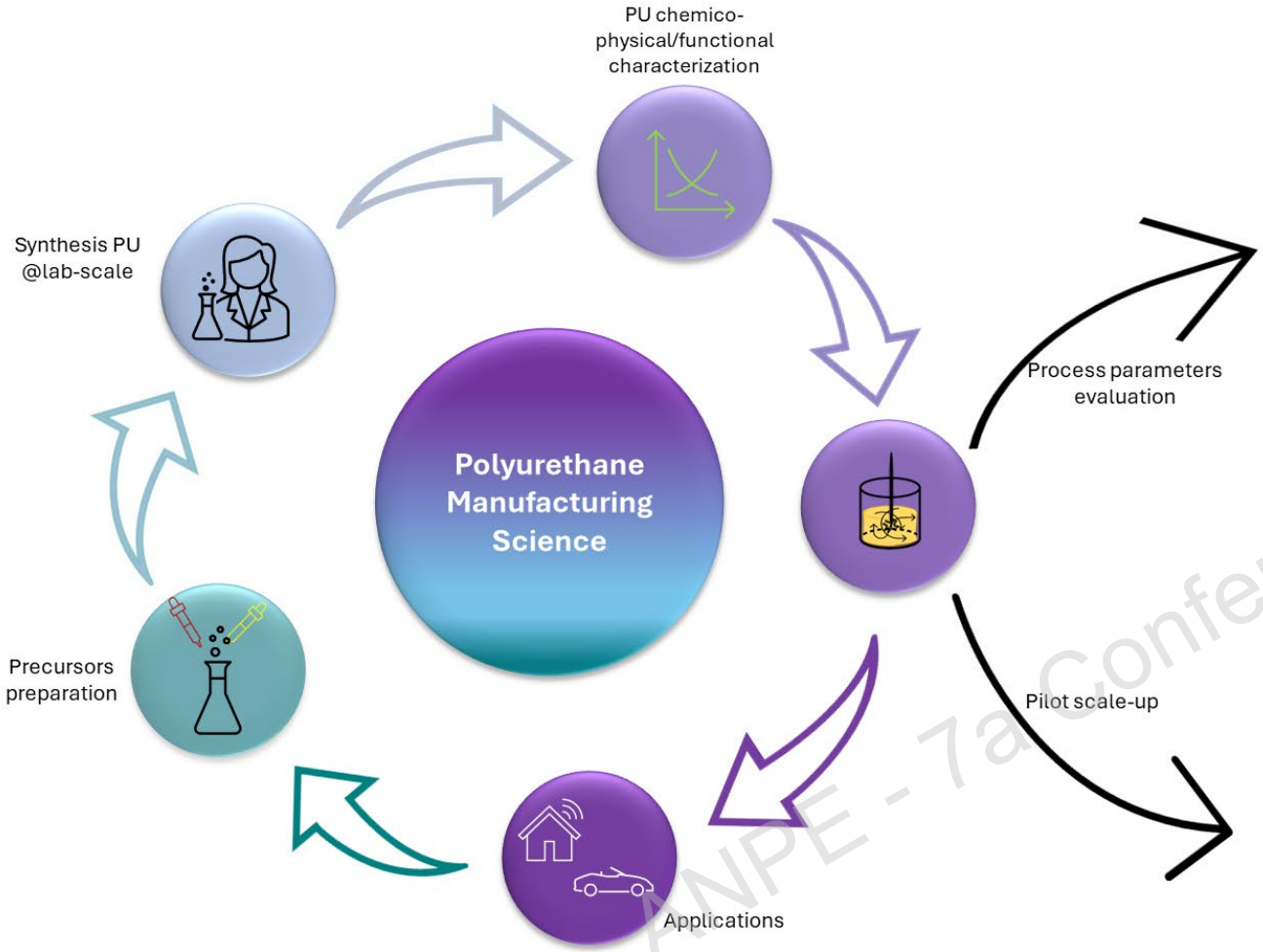
*Re*Processable Sustainable Polyurethane foams induced by *C*ovalent *A*daptable *N*etworks

- 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



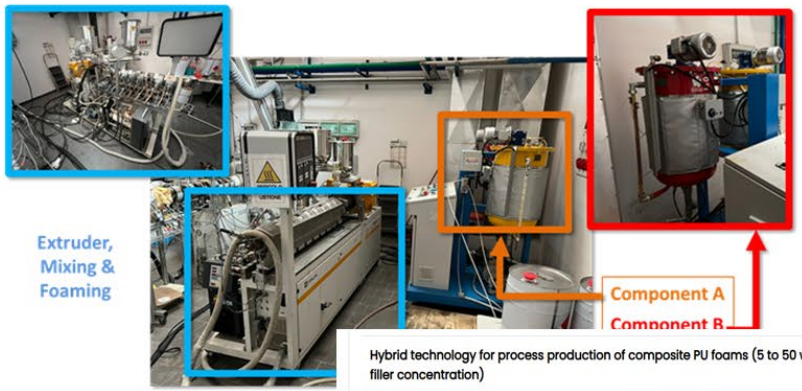
FOAMAT® 285

Lab scale (TRL 5)

Formulations

- Component A: bio-polyols blend cardanol-based
- Fillers: powder mixture Diatomite/functionalized SiO_2 MDI: petrol-based isocyanate
- NCO/OH: 1.5

Semi-continuous pilot plant



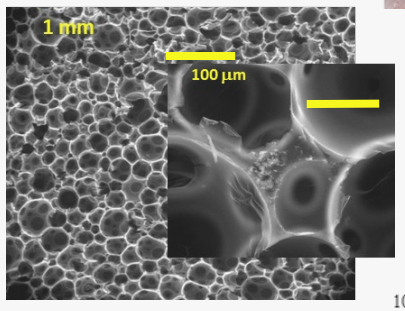
https://innovation-radar.ec.europa.eu/resultbykeyword

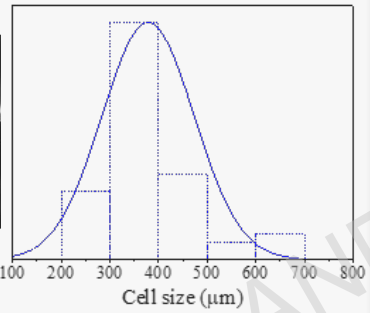
Pilot scale (TRL 7)

- Highly **filled composite PUR-based** (up to 60 wt.%).
- Fillers with different granulometric characteristics and aspect ratio can be employed.
- 6 m^2/day, 16 panels x 0.35 m^2, 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

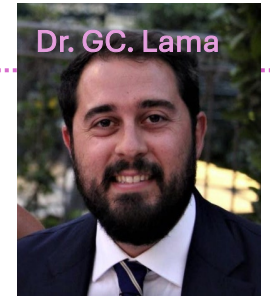
- Panels:65x65x5cm^3
- σ (10 %)=0.69 ±0.03 Mpa; ρ=102.5±1.26 kg/m^3
- λ=35 ±0.2 mW/m·K
- sustainability index>=50 %

acciona

Madrid (Spain) applied @2024

BIOMAT

UNISANNIO



Benevento (Italy) applied @2025

PRIN2022-HERITAGE

RITOLS

Riga (Lettonia) applied @2024

BIOMAT

Customized PU Packaging for Artwork

BOX IN A VALISE

EUROPASAURUS SKULL

HUNGARIAN NATIONAL MUSEUM

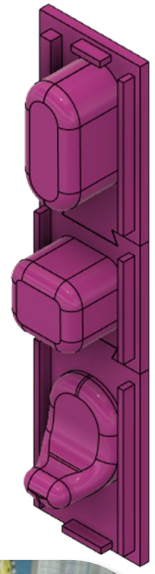
CASE STUDY 1

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

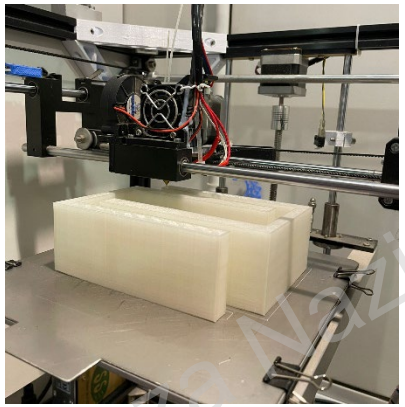
Scan of this complex section from Peggy Guggenheim to realize *via* 3D printing customized inserts in tailored PU foam.

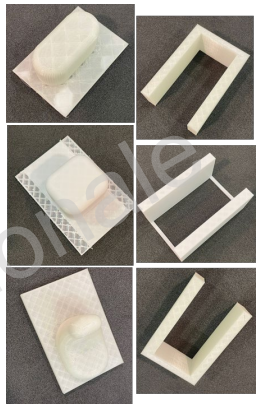
3D
Scan

Digital
adaptation



3D
Print





PU casting in 3D
printed mould

Demould.

Customized
packaging, tested
from Venice to NY

CASE STUDY 2

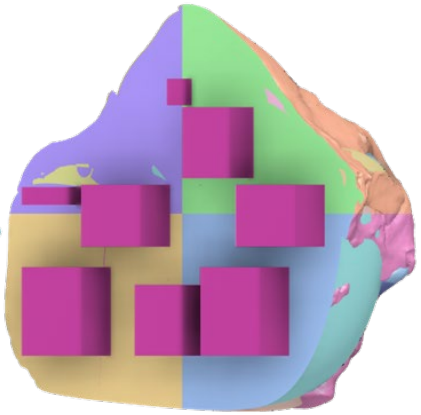
ARTWORK: EUROPASAURUS SKULL

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

CASE STUDY 2

3D Scan

Digital adaptatation



PUF Mold

Customized PU packaging

Re-processing routes

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

THERMOSETS

STIMULUS

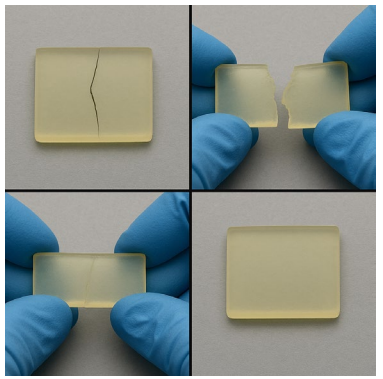
Thermal/mechanical treatment, pH variation

THERMOPLASTIC

Reprocessable
New useful products

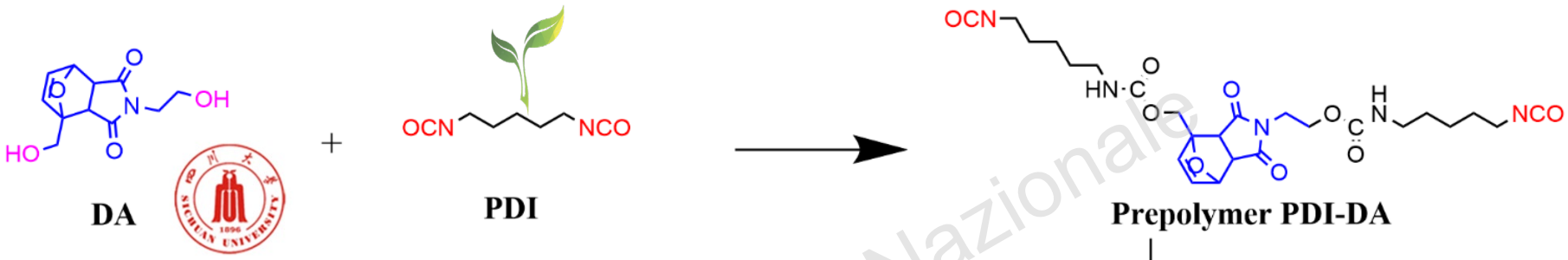
Main properties

→ *R*eprocessability
→ *R*ecyclability
→ Self-healing
→ Shape memory

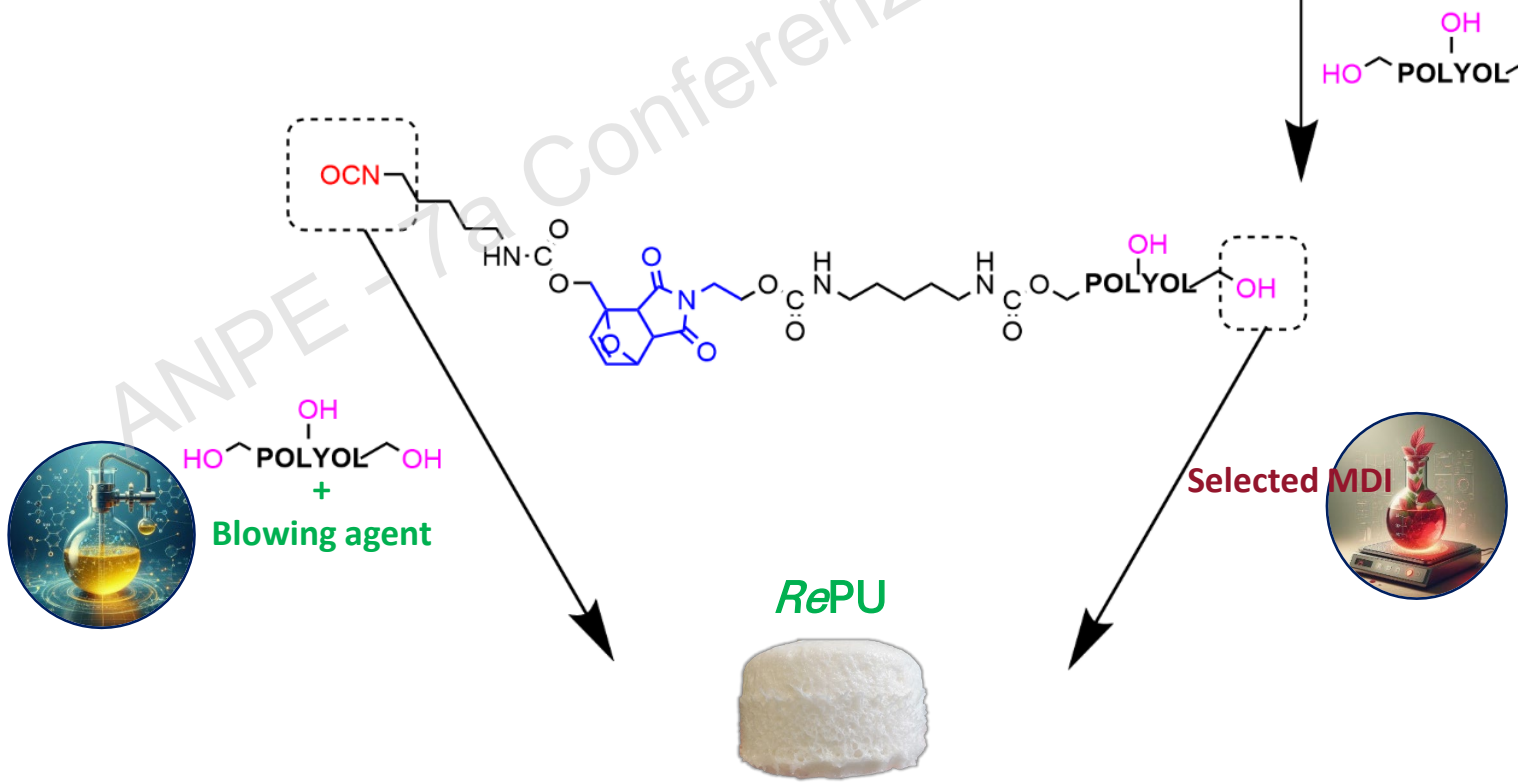


The strategy

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

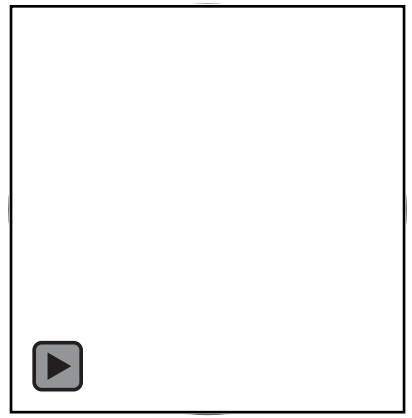
Milled PU foam

STIMULUS

Thermal Treatment
T=125°C
P=10ton

Conventional PU foam

RePUR



*Re*PUR 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

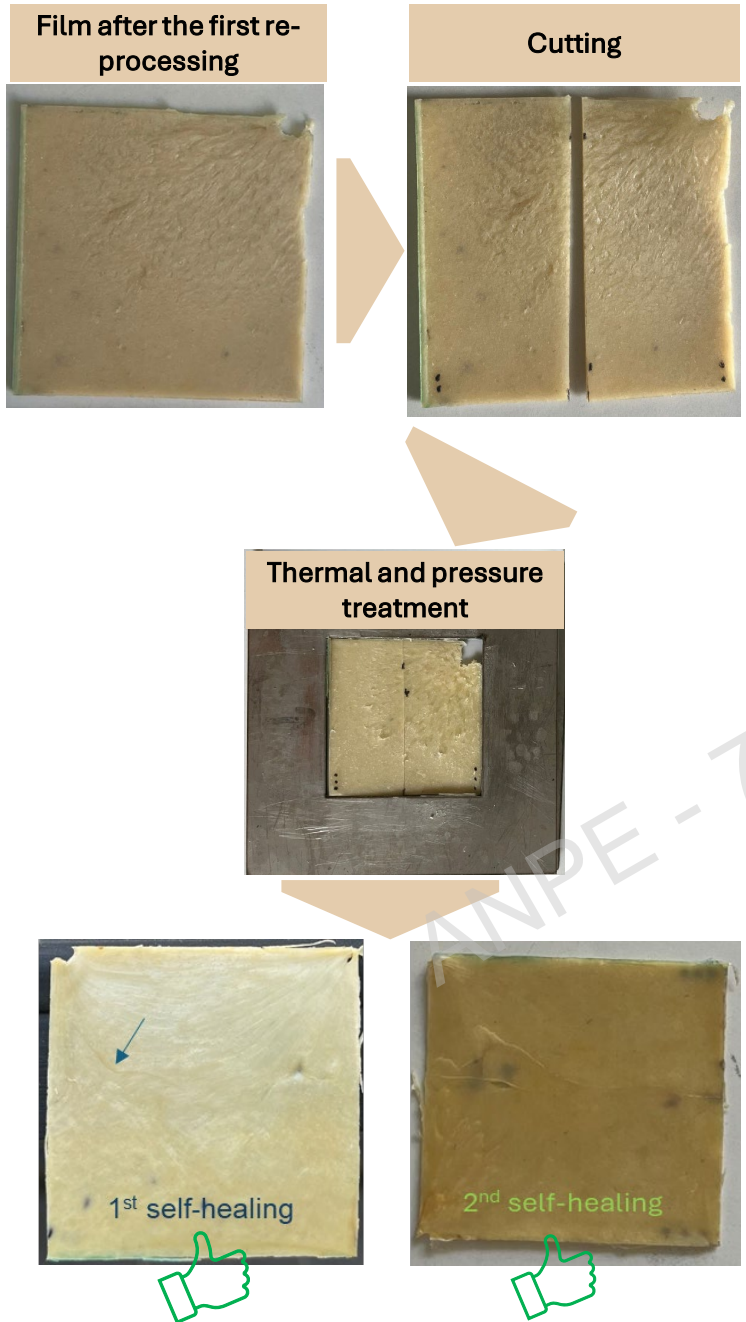
PDI_DA_3:1

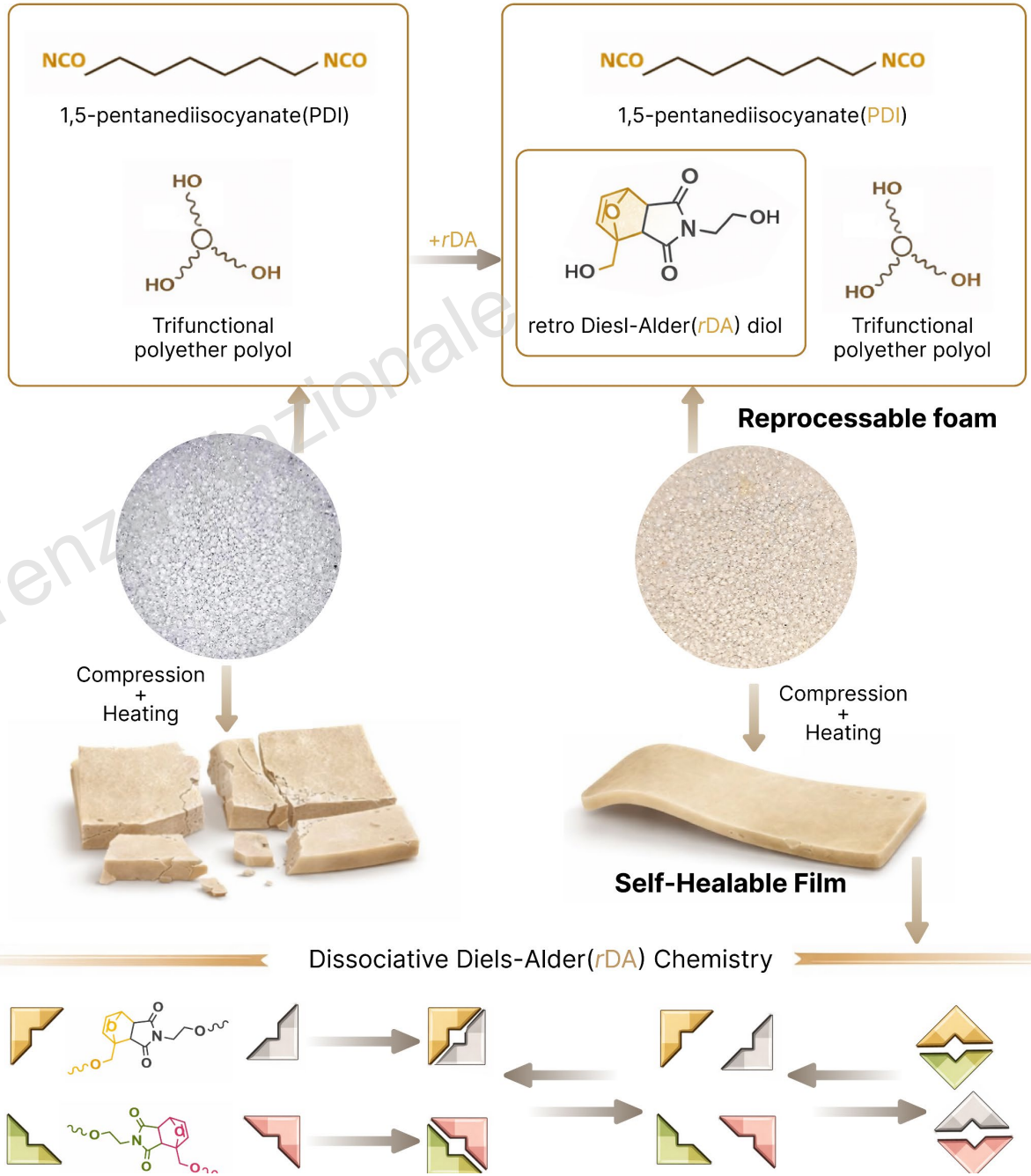
PDI_DA_4:1

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

*Re*PUR film, *Self-healing properties*



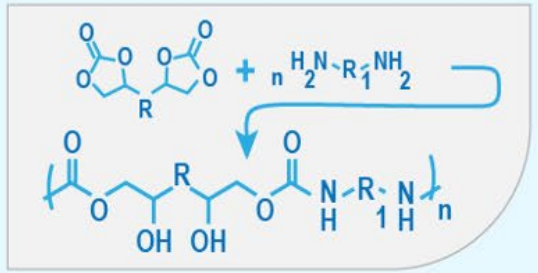


Verdolotti et al., Chemical Eng J., 2026-10.1016/j.cej.2026.176175

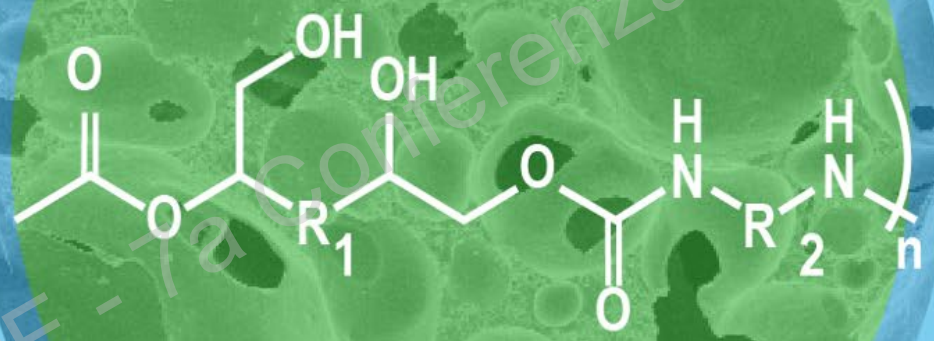
Non Isocyanate routes

BIO-BASED RAW MATERIALS

GREEN SYNTHESIS

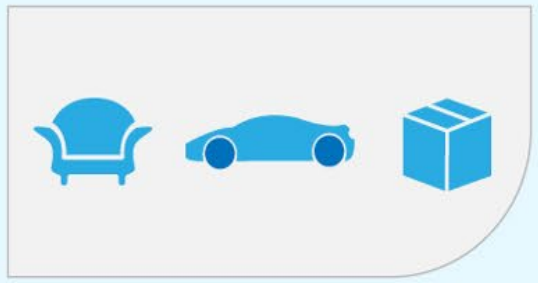


NIPU FOAMS

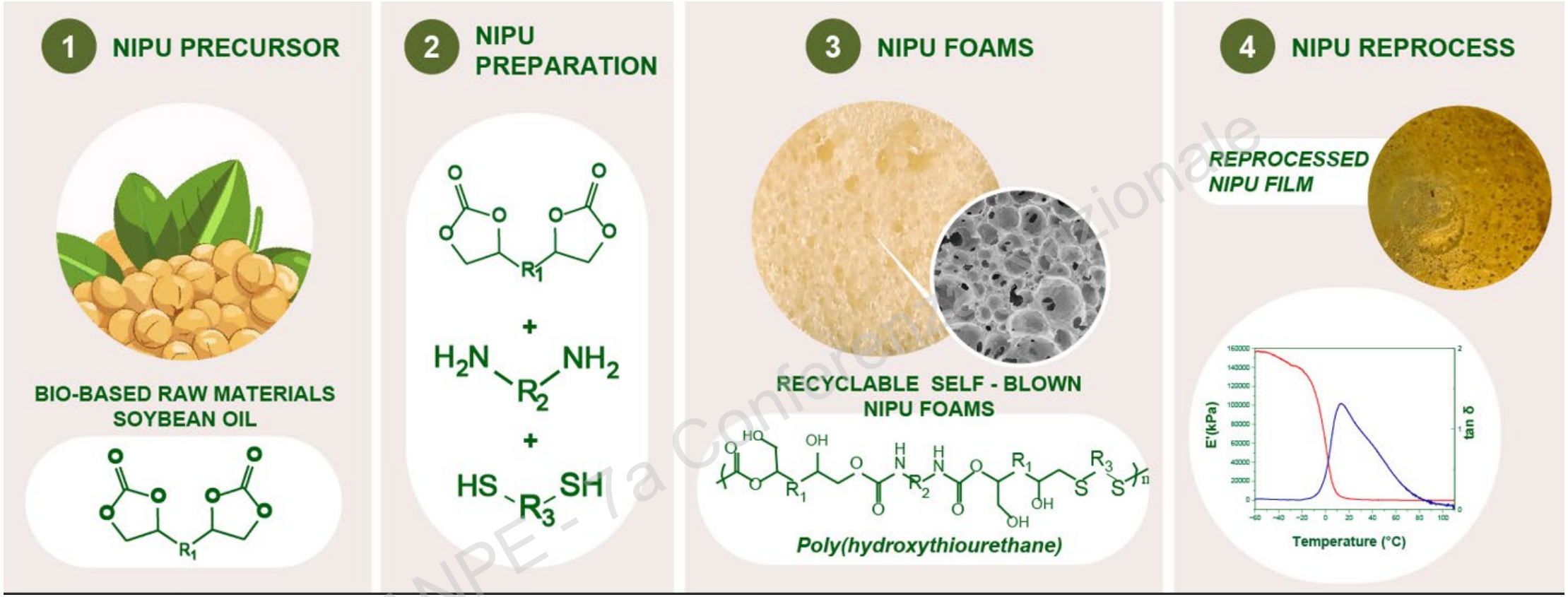


RECYCLING AND REPROCESSABILITY

APPLICATIONS



Step strategy process



Åbo Akademi

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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

*Re*PUR film, *morphological, mechanical and thermal degradation characteristis*

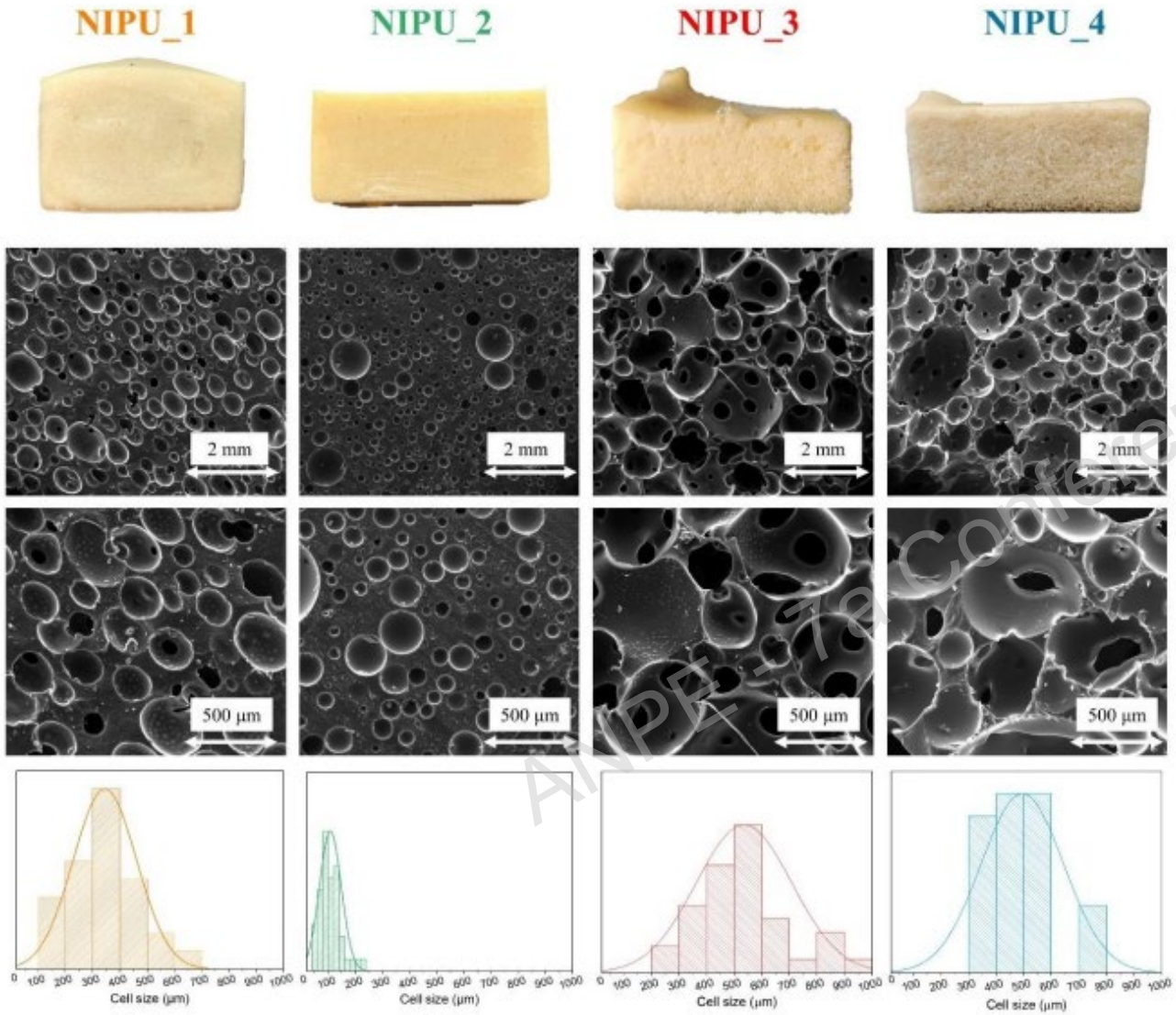
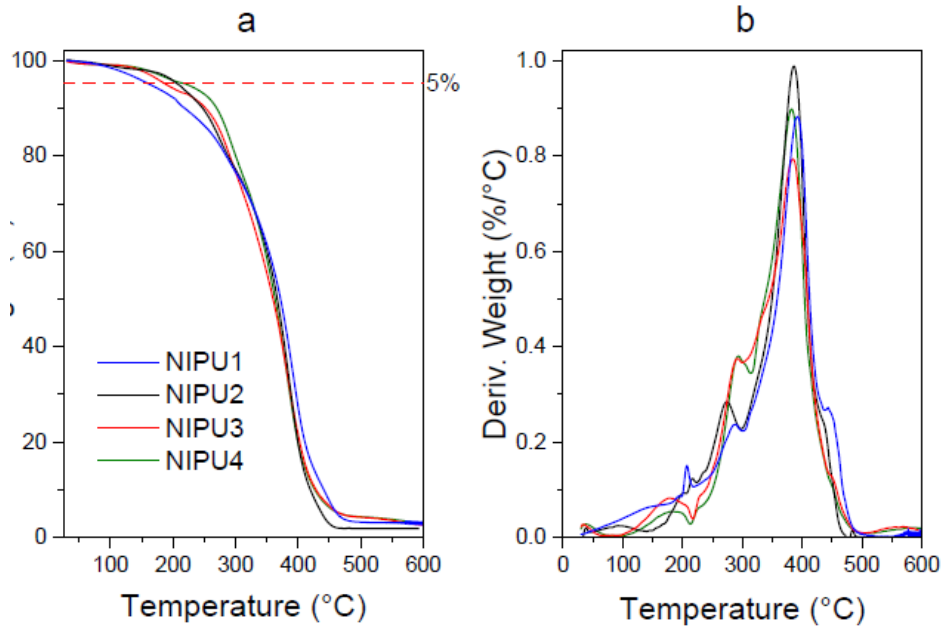


Table 2. Gel content, physical, morphological, and mechanical properties of the NIPU foams. Results are expressed as the average and standard deviation of three independent measurements.

Sample name	GC (%)	ρ (kg/m^3)	D_h (µm)	N·10^{-3} (cm^{-3})	Anisotropy coefficient (-)
NIPU_1	78.6±5.2	600±50	366±13.3	4.4±0.1	0.9±0.1
NIPU_2	83.2±4.3	700±55	100 ±80	0.02±0.0005	1.1 ±0.3
NIPU_3	77.2±8.2	200±70	535±173	0.6 ±0.03	0.9±0.2
NIPU_4	78.0±2.0	250±10	495 ±150	1.2 ±0.06	0.94±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)	σ_{max} (MPa)	ε (%)
Bulk material	0.8	0.4 ± 0.05	0.43 ± 0.02	137.9 ± 3.0

T_g : Glass transition temperature. E: Elastic modulus, σ_{max} : Stress at break,ε; elongation at break

L Verdolotti et al, RSC Sustainability 2026
L Verdolotti et al ACS, Sustainable Chemi Eng 2026

Ongoing research about NIPU foams

Chemicals

Cyclocarbonate synthesis **from other renewable sources**

- Limonene 

Different Blowing routes

- H_2O
- Acetate chemical:

$$CH_3COO^- NH_4^+ \longrightarrow NH_3 + CH_3COOH$$

- Sodium bicarbonate

$$2\ NaHCO_3 \longrightarrow Na_2CO_3 + H_2O + CO_2$$

Partnership for upscaling

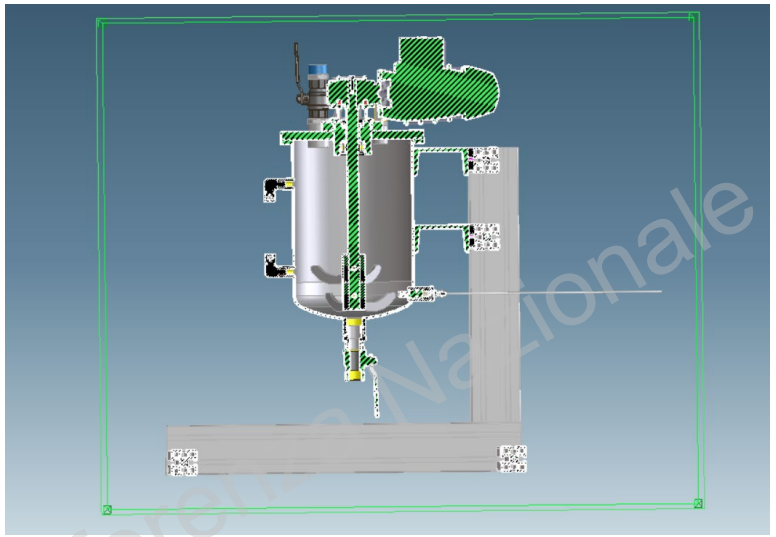
CNR iPCB Istituto per i Polimeri, Compositi e Biomateriali

Università degli Studi di Napoli Federico II

Åbo Akademi University

POZZI-AROSIO ADVANCED POLYURETHANE SYSTEMS

Process upscaling



SAIP ADVANCED POLYURETHANE EQUIPMENT

POZZI-AROSIO ADVANCED POLYURETHANE SYSTEMS

https://www.iam-i.eu/iam4eu-partnership/

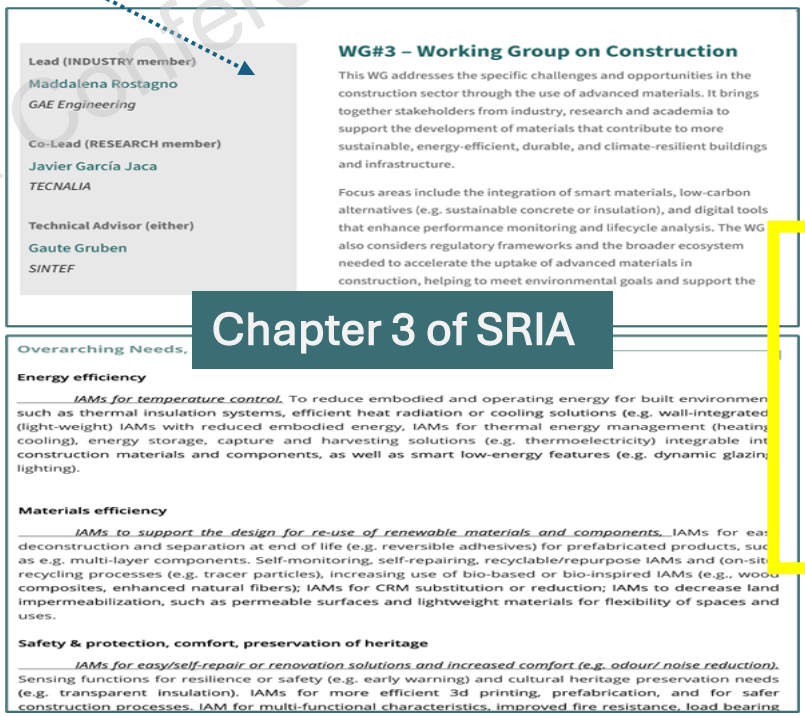
IAM-I (Innovative Advanced Materials Initiative): associazione internazionale no-profit che guida la partnership europea IAM4EU, coordinando ricerca, industria e istituzioni per accelerare lo sviluppo e l'adozione di materiali avanzati in Europa.

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)

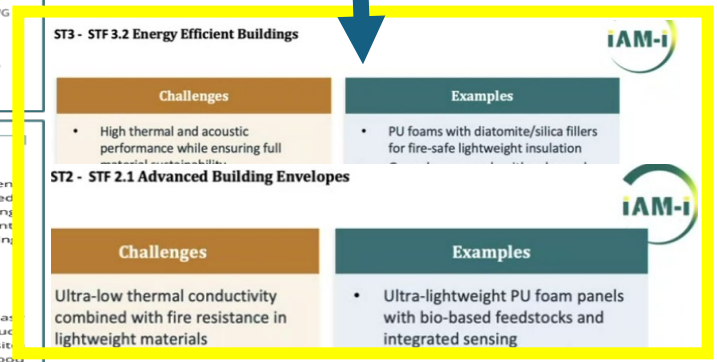
Ruolo WG3 – Construction

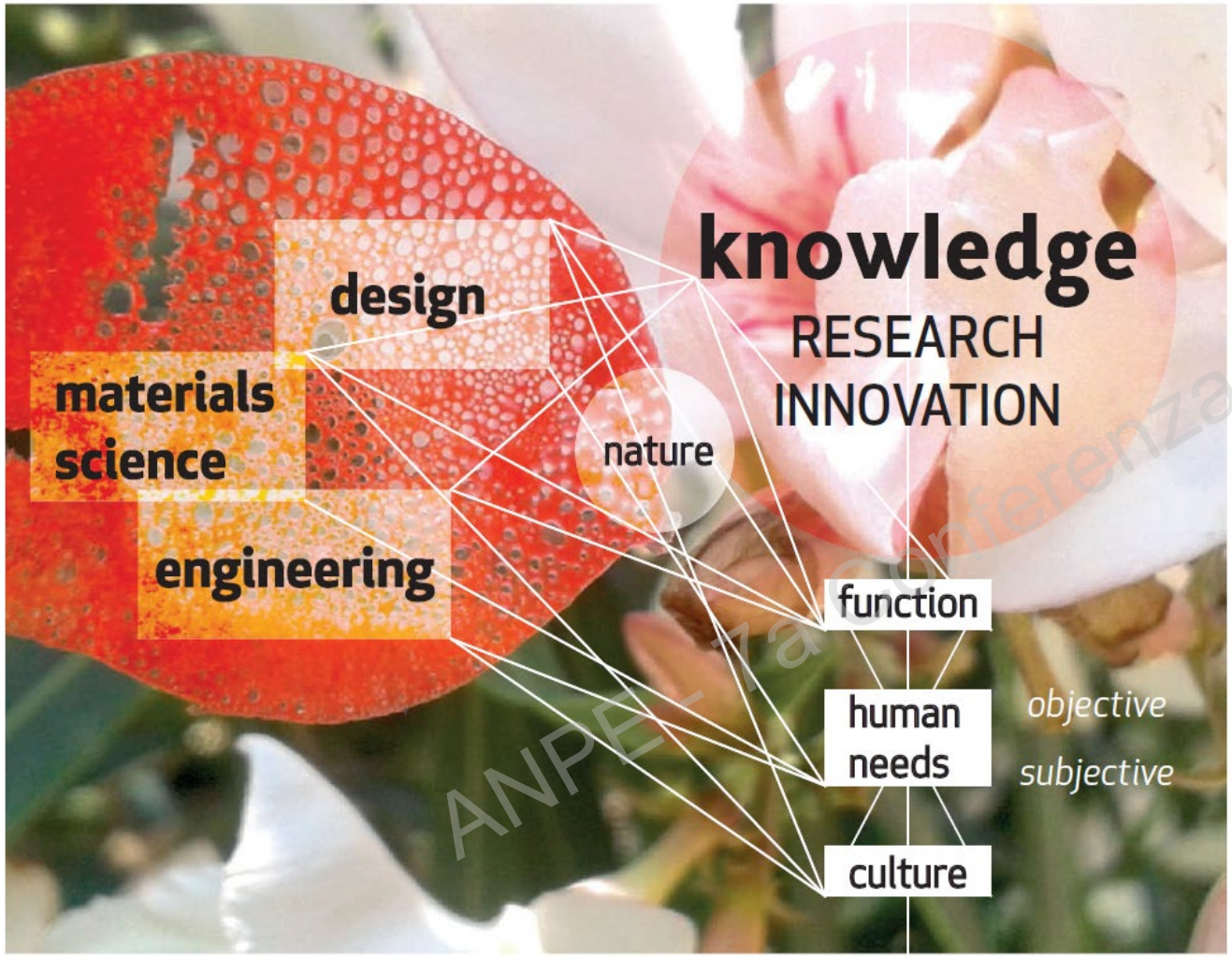
- **Identifica i Materiali avanzati** (challenges & needs) del settore costruzioni per la stesura dello SRIA
- Contribuisce a orientare le call principalmente verso:
  - ↔ *sostenibilità e circolarità*
  - ↔ *efficienza energetica*
  - ↔ *resilienza e durabilità delle infrastrutture*



Chapter 3 of SRIA

PU foams included





Thank you

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