Processes and methods for recycling, reuse, and recovery of advanced composite materials in the transport sector

REPOXYBLE Project: First Open Innovation Workshop

7th June 2024, Rue du Trône 62, Brussels, Belgium, 09:30-11.30 CET

REPOXYBLE - Depolymerizable bio-based multifunctional closed loop recyclable epoxy systems for energy efficient structures
Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

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BIO-BASED MULTIFUNCTIONAL RECYCLABLE COMPOSITES

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Discover more on REPOXYBLE

www.repoxyble.eu

LinkedIn: REPOXYBLE project

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Agenda

- *Introduction from the chairs*
  Elvira Villaro, **Avanzare Innovacion Tecnologica** and **REPOXYBLE coordinator**
  Andrea Porcari, **Italian Association for Industrial Research (Airi)** & **REPOXYBLE**

- *Recycling of composite and epoxy materials*
  Christoph Olscher, **University of Natural Resources and Life Sciences of Vienna (BOKU)** & **REPOXYBLE**

- *Bio-based and recyclable composite materials for transport application*
  Luigia Longo, **CETMA** & **FURHY**
- *r-LightBioCom Circularity and Recyclability Innovations*
  Fernando Cepero Mejias, **Coventry University** & **r-LightBioCom**
- *Advanced lightweight materials FOR Energy-efficient STructures*
  Rocío Ruiz Gallardo, **AIMPLAS** & **FOREST**
- *EURECOMP- European recycling and circularity in large composites components*
  Dionisis Semitekolos, **National Technical University of Athens – R-NanoLab** & **EuReComp**
- *Carbo4Power - New generation of offshore turbine blades with intelligent architectures of hybrid, nano-enabled multi-materials via advanced manufacturing*
  Tatjana Kosanovic Milickovic, **National Technical University of Athens – R-NanoLab** & **Carbo4Power**

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Elvira Villaro, Avanzare Innovacion Tecnologica & REPOXYBLE coordinator
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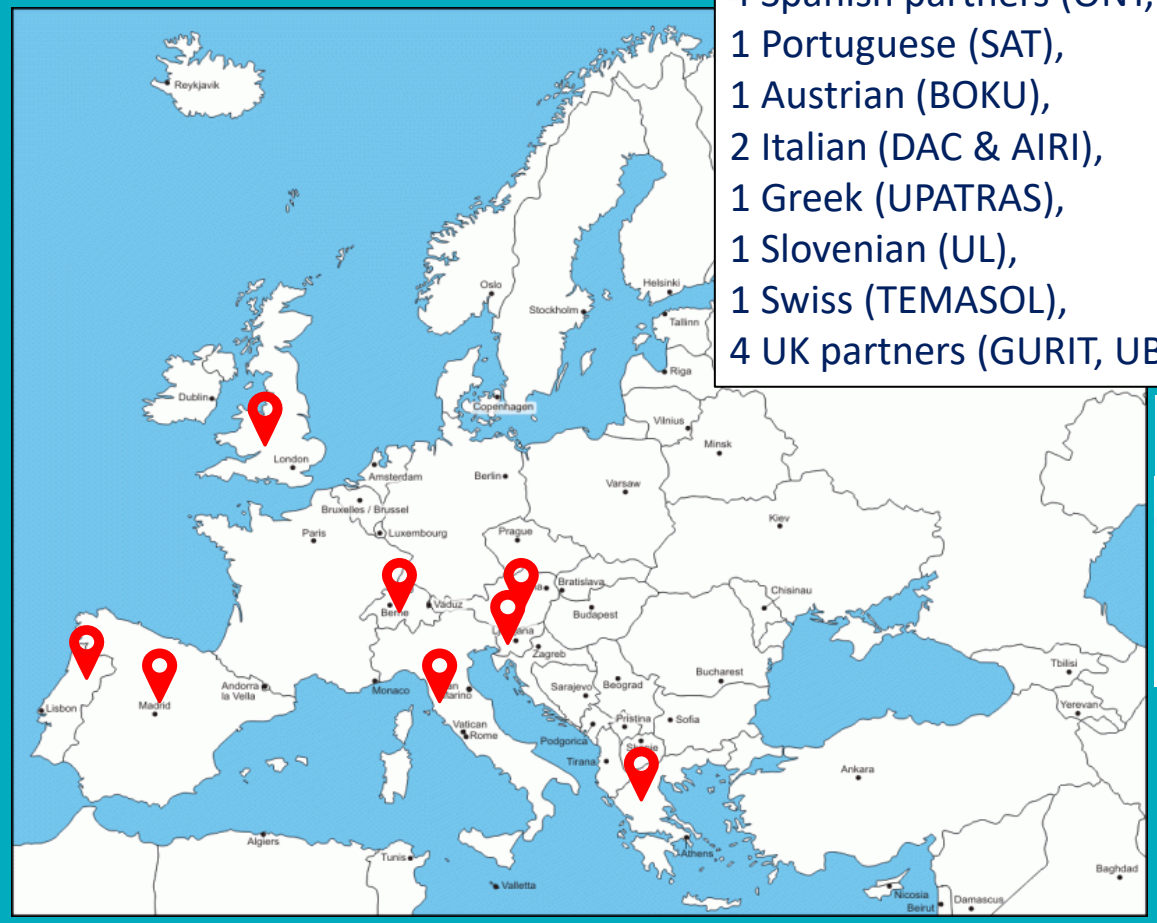
REPOXYBLE goals & objectives

REPOXYBLE aims to contribute to the developement of a new generation of multifunctional, safe and sustainable by design polymers.

- **O1** — **New chemistries** for fast curing resins, new bio-based composites and novel production techniques with advanced functionalities with potential to extended use in extreme conditions (high temperatures)
- **O2** — Integrate **multifunctional composites** with enhanced thermal and electrical conductivity for thermal management and in-situ strain sensing
- **O3** — **Closed loop energy efficient recycling system**
- **O4** — Energy efficient lightweight composites with **positive environmental impact over their entire life cycle**
- **O5** — **Economic feasibility in different market applications, business models and circular value chains** for lightweight bio-based components, improving **time to market**

Repoxyble consortium



4 Spanish partners (ONY, AVA, GAIKER, UDG),
1 Portuguese (SAT),
1 Austrian (BOKU),
2 Italian (DAC & AIRI),
1 Greek (UPATRAS),
1 Slovenian (UL),
1 Swiss (TEMASOL),
4 UK partners (GURIT, UBAH, RIVERS, AEROGEL CORE)

Project management

avanzare

Technology development

MATERIAL LIFECYCLE VALUE CHAIN

ONYRIO Gurit — Polymer synthesis building blocks
avanzare — Resin formulation, additives
Aerogel Core Ltd — Composite design and manufacturing
Universitat de Girona — Material characterization
University of Bath / University of Patras — Energy Efficient Manufacturing
BOKU — Chemical recycling
riversimple / DAC — Automotive and Aerospace end users

Horizontal aspects:
safety, sustainability, legal, dissemination, exploitation

SSbD & MATERIAL VALUE CHAIN SUPPORT

Airi (Associazione Italiana per la Ricerca Industriale) — Diss & Comm Multicriteria Decision analysis
Gaiker (Member of Basque Research & Technology Alliance) — Safety and risk assessment
TEMAS Solutions — SSbD, legal criteria
SATURN TECH — IPR management Exploitation strategies
University of Ljubljana — Data collection & management

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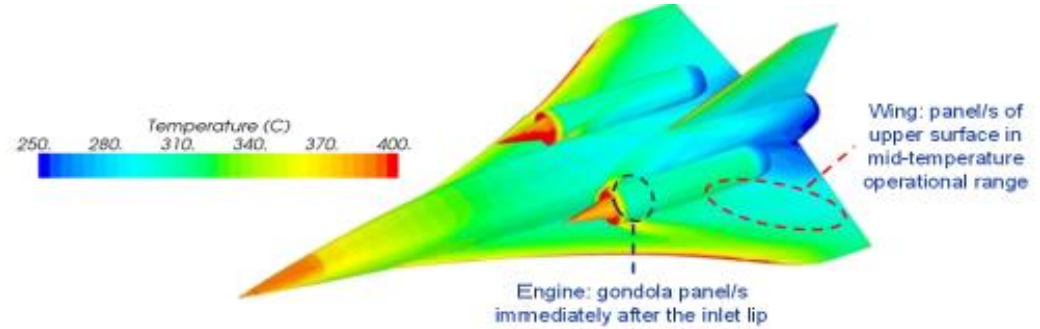
REPOXYBLE case studies



Two key case studies:

- **Aerospace:**

High technical requirements (e.g. lightweight, high temperature resistence)

- **Automobile**

High sustainability (e.g. Recyclability, high bio-based content)

REPOXYBLE (M18 on 42): achievements

- Developed:
  - **all the building blocks**
  - **resins formulations** and the recycling process
  - Working on the composite **IR-based curing process**
  - materials and techniques for **multifunctional properties**: electrical conductivity, thermal dissipation, and structural self-monitoring

- Next
  - Full characterization and testing, upscale and first prototypes.

Key challenge: successfully recycle the epoxy system into valuable primary and secondary materials with high potential for several markets

Recycling of composite and epoxy materials

Christoph Olscher, University of Natural Resources and Life Sciences of Vienna (BOKU)

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What are **epoxy resins** and **composites**?

- Epoxy resins are a **family of synthetic resins** which contain at least one reactive side of either oxirane or epoxide and hydroxyl groups. For use they **must be cross-linked** with a curing agent/hardener.

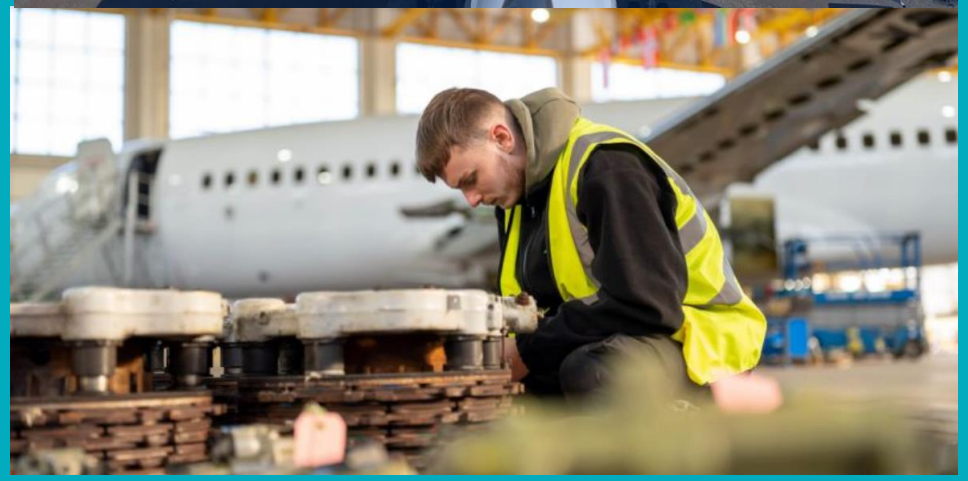
- However the simple mixture of resin and curing agent rarely provides a material with the desired properties for a specific application therefore other materials are added, forming a **composite.**

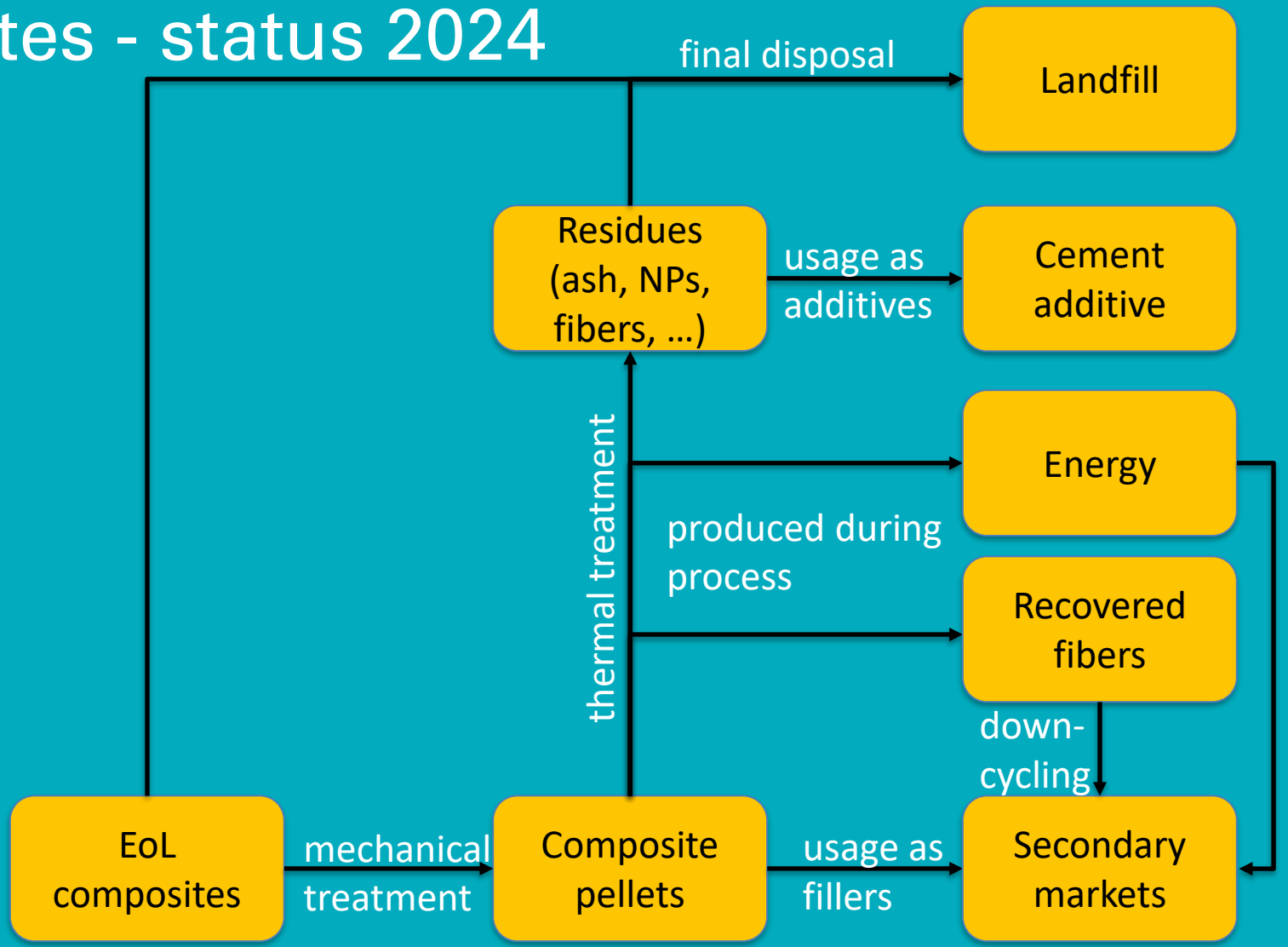
Source: *Plastics Europe; 2006; Epoxy resins and curing agents – toxicology, health, safety and environmental aspects*

State of composite (recycling)

- **323.000 tonnes** of composite material **produced** in EU in 2017, trend rising
- **Key sectors**: Energy; Food & Water; Transportation; Home, Leisure, Information & ICT; Construction
- Main methods of disposal: **Thermal treatment, landfilling**
- Main problem: **Heterogenity of composites; no industrial-scale recycling route (closed loop) available**

Recycling of composites - status 2024





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Recycling options for composites

Mechanical Recycling:
Milling, Grinding, Shredding, etc.

TRL

TRL ≥ 9

Thermal recycling:
Pyrolysis, Fluidized Bed, Joule heating, etc.

TRL < 6

Chemical Recycling:
Solvolysis (Hydrolysis, Glycolysis, Aminolysis, Supercritical)

Electrical Recycling:
Pulse discharge, electrical driven heterocatalytic decoposition, etc.

TRL < 4

Biological Recycling:
Microbial, fungal, etc.

Mechanical Recycling:

Milling, Grinding, Shredding,etc.

Pros	Cons
Already established (TRL ≥ 9)	No clear separation of base materials
High throughput	Damage to Fibers
Market for product established	Limited application of products

Thermal Recycling:

Pyrolysis, Fluidized Bed, Joule heating, etc.

Pros	Cons
Already established (TRL ≥ 9)	Energy intensive
Products for multiple uses (gas, fluids, solids)	May damage e.g. fibres
Volume reduction of waste material	Not all base materials can be recovered
Markets for products established	Problematic emissions
High throughput	

Chemical Recycling:

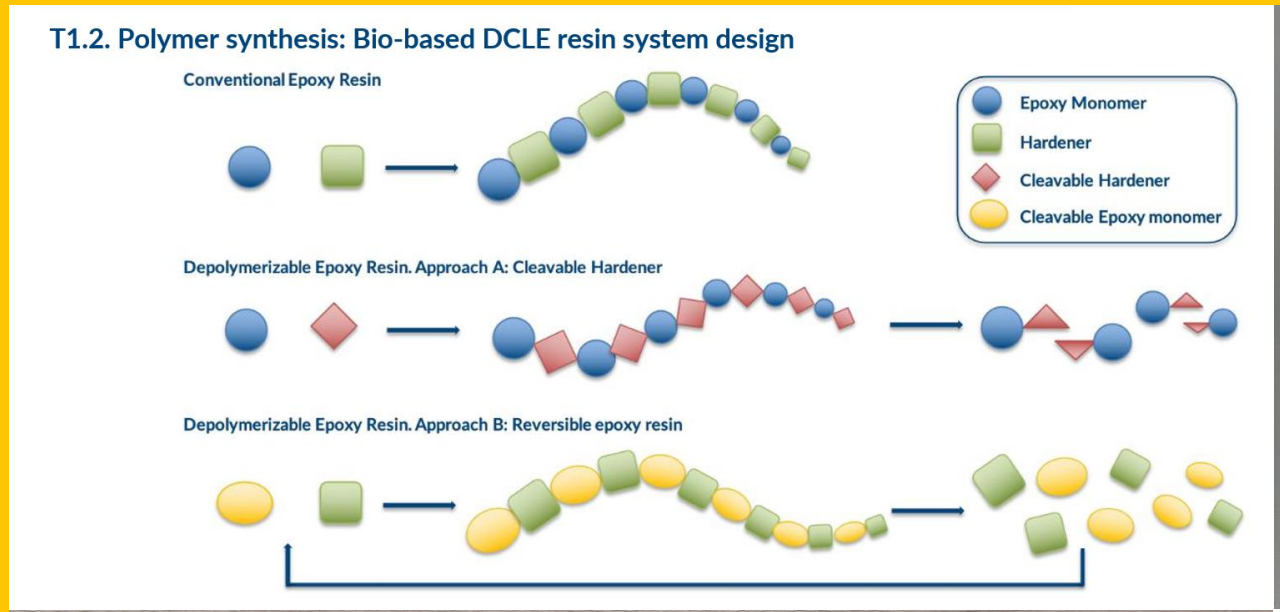
Solvolysis (Hydrolysis, Aminolysis, Supercritical)

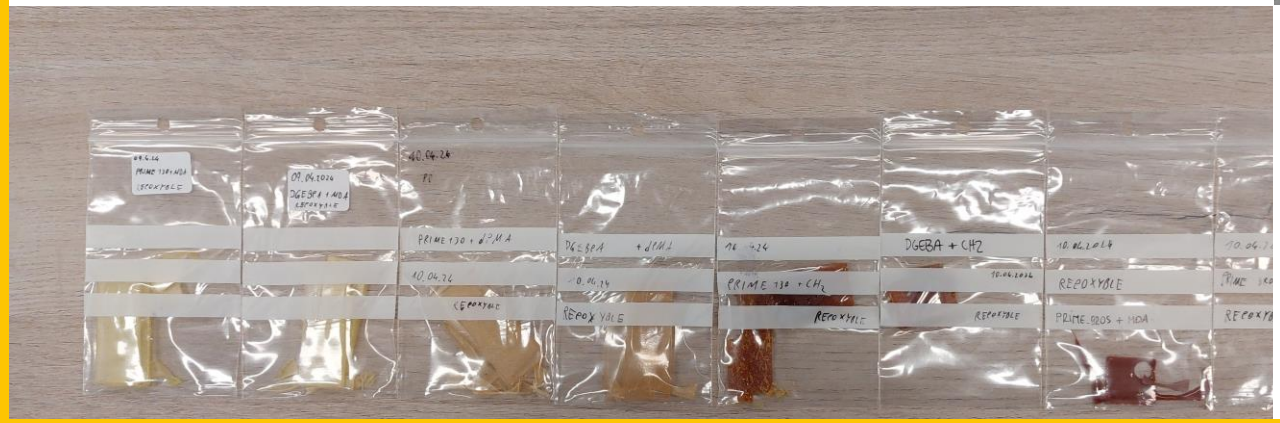
Pros	Cons
High recovery rate (lab scale)	Moderate TRL (< 6)
Enables recovery of most base materials	Usage of hazardous substances
„Good quality“ of recycled material	Market for recycled products not established on larger scale
Depending on method, not energy intensive	

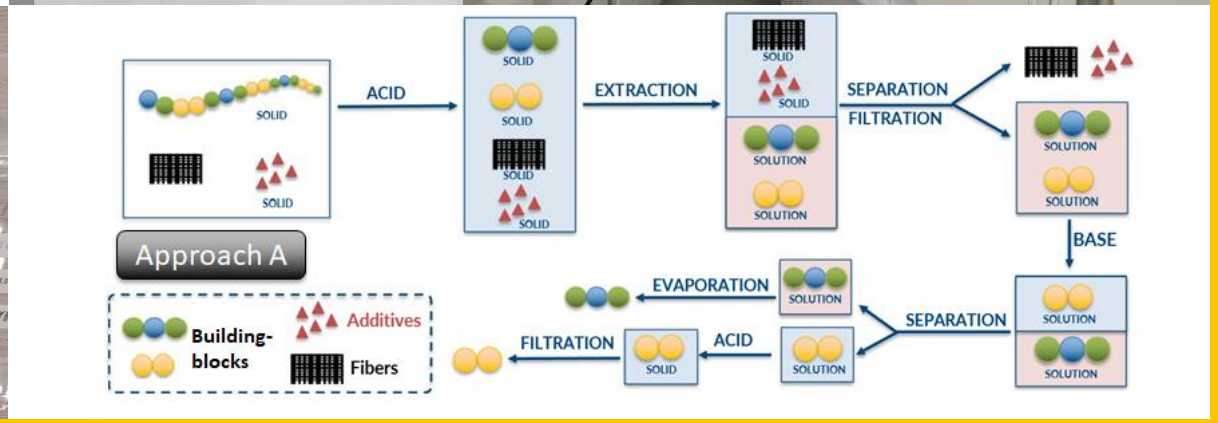
👉Conclusion from recycling comparison

- **Chemical recycling** can recover all base materials
- Pyrolysis for recovery of carbon fibers as secondary option
- Mechanical (pre)treatment as last resort as fibers are irreversibly damaged
- Cement and or use as filler as last product option

DCLE system in REPOXYBLE (developed by ONYRIQ)







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Interactions between REPOXYBLE and legal guidelines

- A new circular economy action plan (COM/2020/98)
- The european green deal (COM/2019/640)
- Waste Framework Directive
- Extended producer responsibility (Directive 2008/98/EG)
- End-of-Life Vehicles (proposal, July 2023) (Directive 2000/53/EG)
- Eco-Design Directive (Directive 2009/125/EC)
- Civil aviation & EU Aviation safety agency (Regulation (EU) 2018/1139)
- REACH (Regulation (EC) No1907/2006)

Drivers/requirements for recycling:

end of life forcing recycling (classification in vertical regulations), sector quality (for recycled plastic); safety (*e.g*, plastics in REACH)

REPOXYBLE - Outlook

- **Next Steps:**
  - Achieve complete depolymerization
  - Recyling of composite with additives (NPs + Graphene)
  - Validate and optimize the chemical recycling scheme
  - Upscale by factor 10

- **Barriers & Opportunities:**
  - Bio-based content as gatekeeper for technical application
  - Complete depolymerization mandatory
  - Legal challenges: inclusion of polymers into REACH
  - SSbD in evaluation phase → opportunity to give input

Agenda

Setting the scene

New generation of high-performance, sustainable composites, technologies for circularity and recyclability, experiences, roadblocks and solutions:

- *Bio-based and recyclable composite materials for transport application*
  Luigia Longo, **CETMA** & **FURHY**
- *r-LightBioCom Circularity and Recyclability Innovations*
  Fernando Cepero Mejias, **Coventry University** & **r-LightBioCom**
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Bio-based and recyclable composite materials for transport application

Luigia Longo, CETMA & FURHY

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Bio-based and recyclable composite materials for transport applications

Bruxelles, 07th June 2024

Luigia Longo
Materials and Structures Technology Department

Co-funded by the European Union

CETMA - Research and Technology Organization

- **Research and Technology Organization (RTO);**
- Applied research, experimental development and technology transfer in the field of **advanced materials**, **ICT** and **product development;**
- **65+ Employees: r**esearchers, engineers, designer & manager;
- **Offices and laboratories** extended for over 3.500 m^2.

Photo © Federica Bruno Stamerra

European Project

FURHY

PROJECT	
Project number	101091828
Project name	FULLY RECYCLABLE HYBRID BIO-COMPOSITE FOR TRANSPORT APPLICATIONS
Project acronym	FURHY
Call	HORIZON-CL4-2022-RESILIENCE-01
Topic	HORIZON-CL4-2022-RESILIENCE-01-11
Project starting date	1 July 2023
Project duration	42 months

- FURHY: **42-month EU project**, funded by Horizon Europe program, started on 1st of July 2023.
- Project Coordinator: **CETMA**
- Consortium: consists of **9 Partners across 5 countries**.

FURHY
Project Summary

The project aims at the development of a **new, bio-based, smart and completely recyclable composite material**, obtained by fast and low energy consumption out-of-autoclave process.

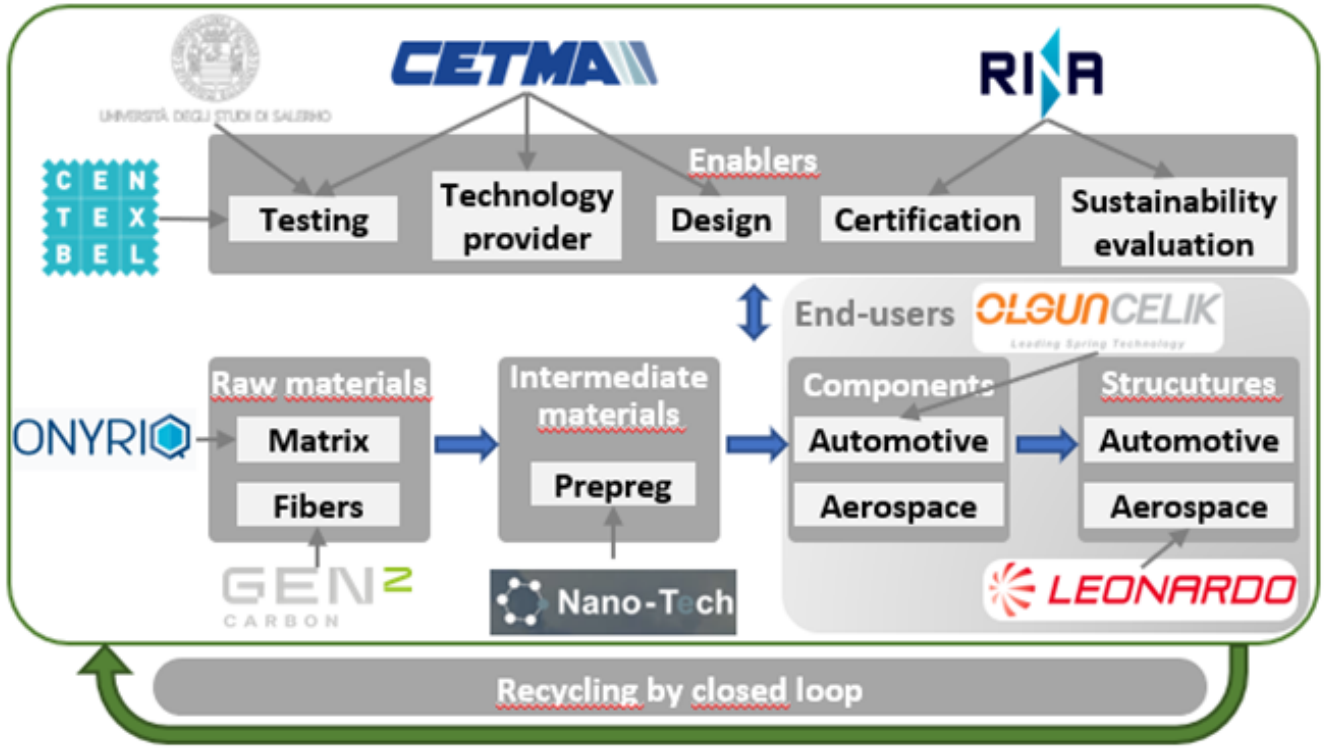
- **Matrix: new bio-based epoxy resin formulation filled by expanded graphite (EG);**
- **Hybrid composite: hemp and recycled carbon fibers (rCFs) as reinforcement;**
- **Manufacturing process: low energy version of the prepreg compression moulding (PCM);**
- **Main sectors of interest: aeronautics and automotive.**

FURHY
Consortium

- **8 partners** come from 4 different European countries;
- **1 associated partner** from UK.

N.	Role	Legal name	Short name	Type	Country
1	COO	CETMA - CENTRO DI RICERCHE EUROPEO DI TECNOLOGIE DESIGN E MATERIALI	CETMA	RTO	Italy
2	BEN	ONYRIQ LABS, SL	ONY	SME	Spain
3	BEN	LEONARDO - SOCIETA PER AZIONI	LND	LE	Italy
4	BEN	RINA CONSULTING SPA	RINA-C	LE	Italy
5	BEN	OLGUN CELIK SANAYI VE TICARET ANONIM SIRKETI	OLGUN	LE	Turkey
6	BEN	UNIVERSITA' DEGLI STUDI DI SALERNO	UNISA	HE	Italy
7	BEN	NANO-TECH SPA	NANO	SME	Italy
8	BEN	CENTRE SCIENTIFIQUE & TECHNIQUE DEL'INDUSTRIE TEXTILE BELGE ASBL	CTB	RTO	Belgium
9	AP	GEN 2 CARBON LIMITED	GEN2C	SME	UK

FURHY
Consortium



- All the **expertise** necessary to finalize the project activities in the best way;
- A strong **complementary** in the know-how and equipment of the partners involved.

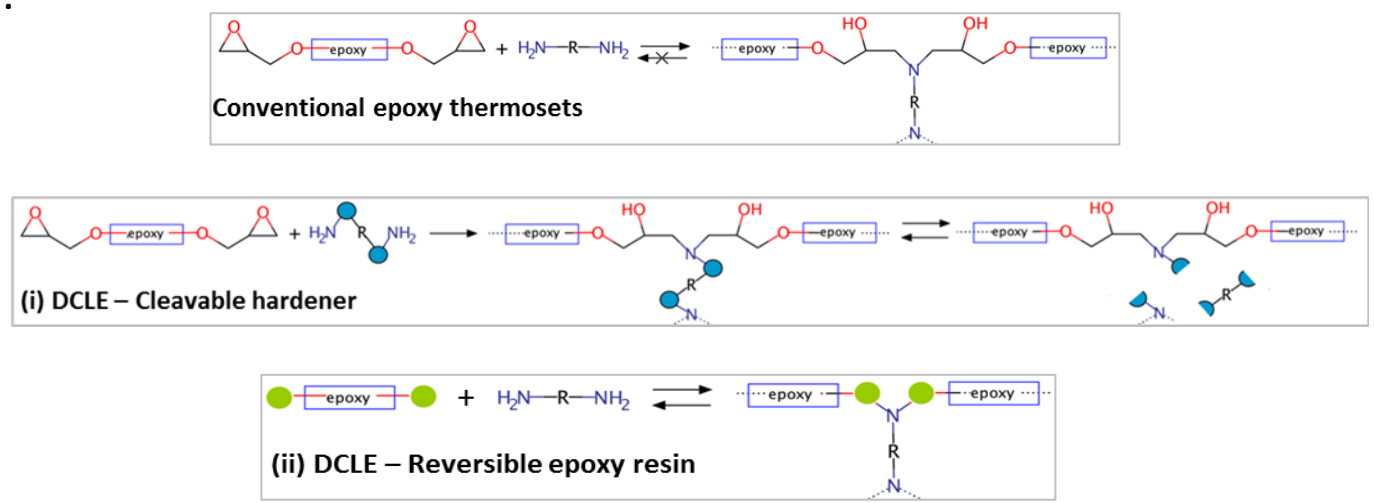
FURHY

Project objectives

OB1. To develop an optimized **bio-based, fast curing, recyclable epoxy resin**, filled with **expanded graphite (EG)** that will promote electro-curing and will provide multifunctional and self-monitoring capability and a list of enhanced properties to the final composite material.

KPIs:

- Percentage of components coming from renewable resources in the epoxy resin: up to 80% with respect to the total components of the resin formulation.
- Glass transition temperature (Tg) of the final resin: 200°C - the target Tg of unfilled epoxy resin will be 150°C, increased of more than 30% thanks to EG.



Scheme of the two approaches of the Depolymerizable Closed Loop Epoxy (DCLE) system, compared with conventional epoxy thermosets

FURHY
Project objectives

OB2. To develop hybrid reinforcing fibers textiles by combinations of **bio-based virgin fibers and recycled carbon fibres**, including **appropriate fibre coatings** to maximize the fiber properties.

KPIs:

- Composite mechanical properties increase, given by the application of the coating to the fibers, of at least the 20% (both static and dynamic properties).
- Commingled hemp/rCF non-woven: fibre areal weight variation lower than +/-8% to ensure properties repeatability and correct closed mould processing.

Fiber architectures at ply level - (a) innovative hybrid commingled hemp/ rCF non-woven, (b) commercial rCF non-woven, (c) hemp fabric

FURHY
Project objectives

OB3. To develop a new effective and **reduced energy consumption out-of-autoclave process** for the new bio-based composite component manufacturing, consisting in prepreg compression moulding (PCM).

KPIs:

- PCM cycle time: <2 min for 3 mm thick laminates.
- Void % in the final composite material: <2%.

Hot-melt prepreg line for prepreg manufacturing at Nano Tech

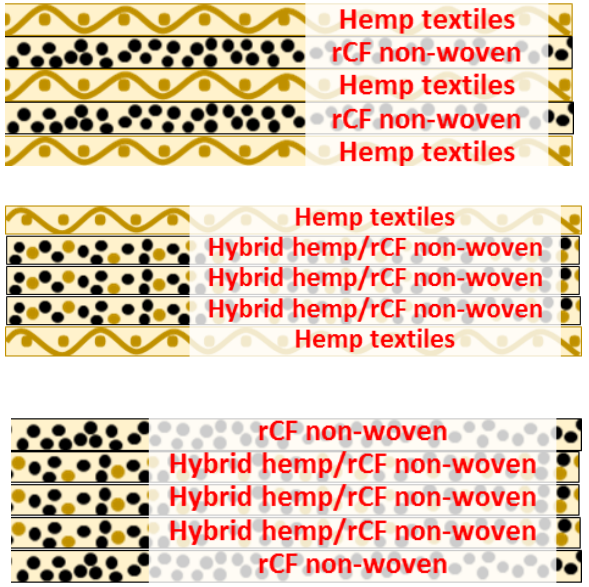
Pilot-scale (CETMA) press for PCM process development

FURHY

Project objectives

OB4. To design and develop a set of new composites, with **different lay-up**, thus providing the possibility to tailor functionality for a range of possible applications.

KPIs: New bio-based hybrid laminates with tensile modulus up to 30÷40 GPa and tensile strength up to 300÷400 MPa, with improved dumping properties.



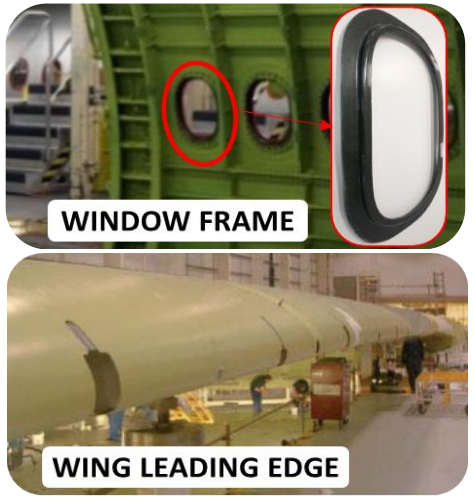
Examples of interply hybrid laminates

FURHY

Project objectives

OB5. To demonstrate the potential of the innovative composite material by the design of 2 **aeronautic** and 2 **surface transport (automotive) application**.

KPIs: Design of N° 4 demo products.



Components candidate to be selected for the aerospace (left) and the automotive (right) applications

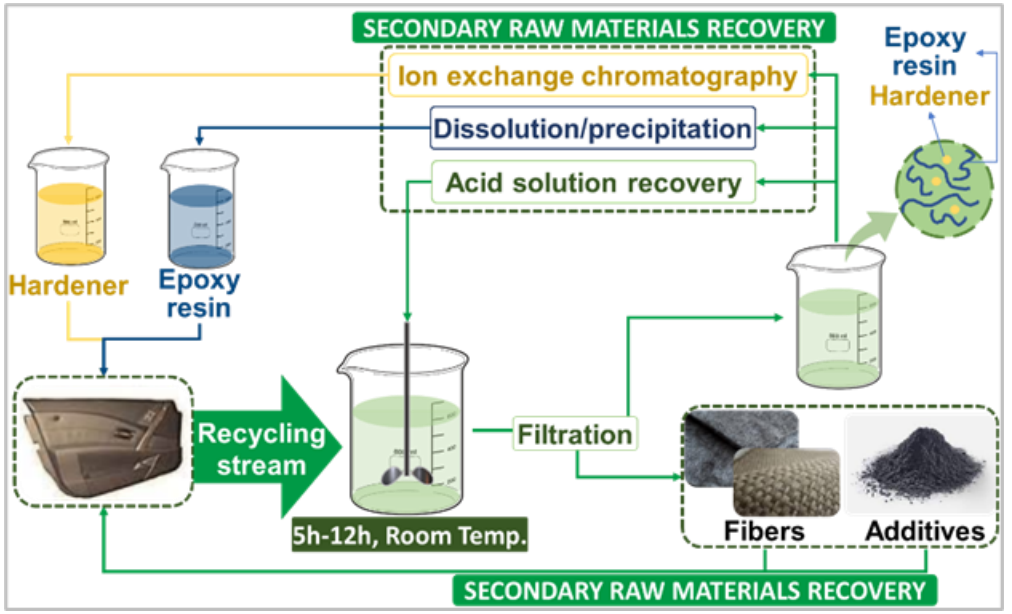
FURHY

Project objectives

OB6. To develop a **new recycling technology** suitable for the **recovery of all the constituents of the composite structure**, providing secondary raw materials having properties similar to the virgin original materials.

KPIs:

- 85% of starting monomers recovered, 90% of EG recovered, 100% of reinforcing fibers recovered.
- 75% of mechanical performances (strength and modulus) retained for hemp fibers, 95% for rCF.



Closed loop (synthesis + chemical recycling) for DCLE-based composite

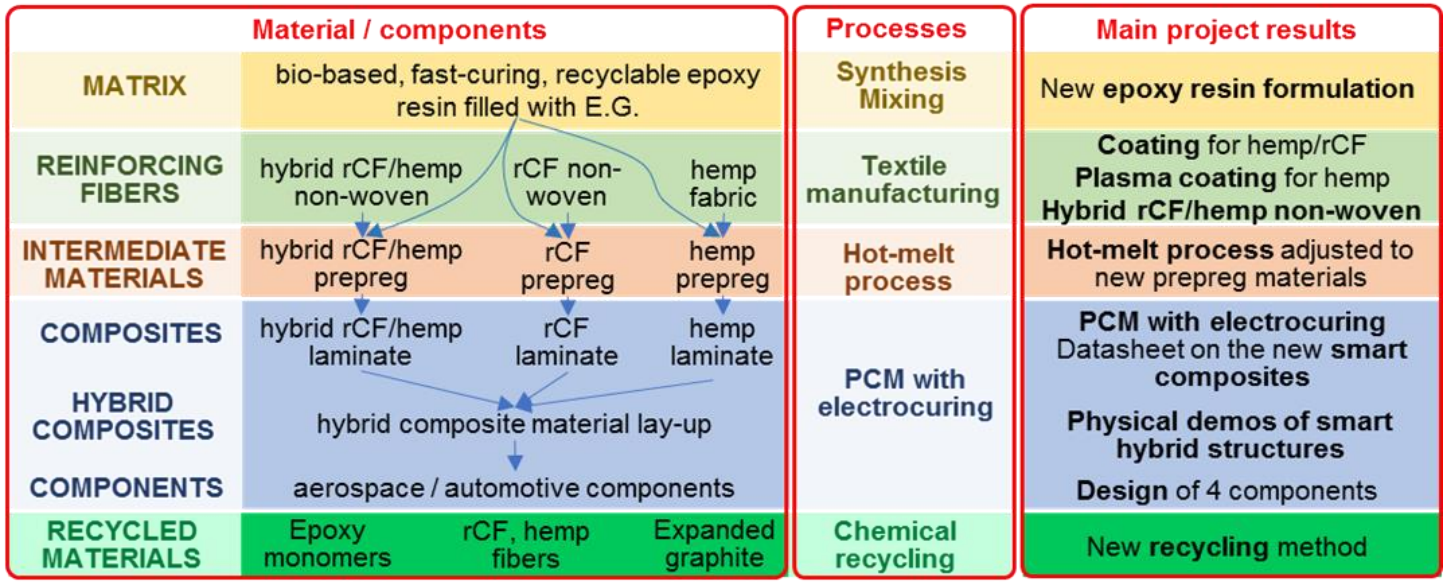
FURHY
Methodology

furhy
fully recyclable hybrid
bio-composite
for transport application

Innovative solutions in each stage of the product chain.

Real step **change** in the composite material sector.

FURHY
Methodology



- **Innovative materials and components;**
- **Innovative manufacturing processes.**

Very numerous variables involved in the new materials/processes development.

Collection of the necessary data **in all the stages of project development.**

Use of **material modelling** and **virtual testing**.

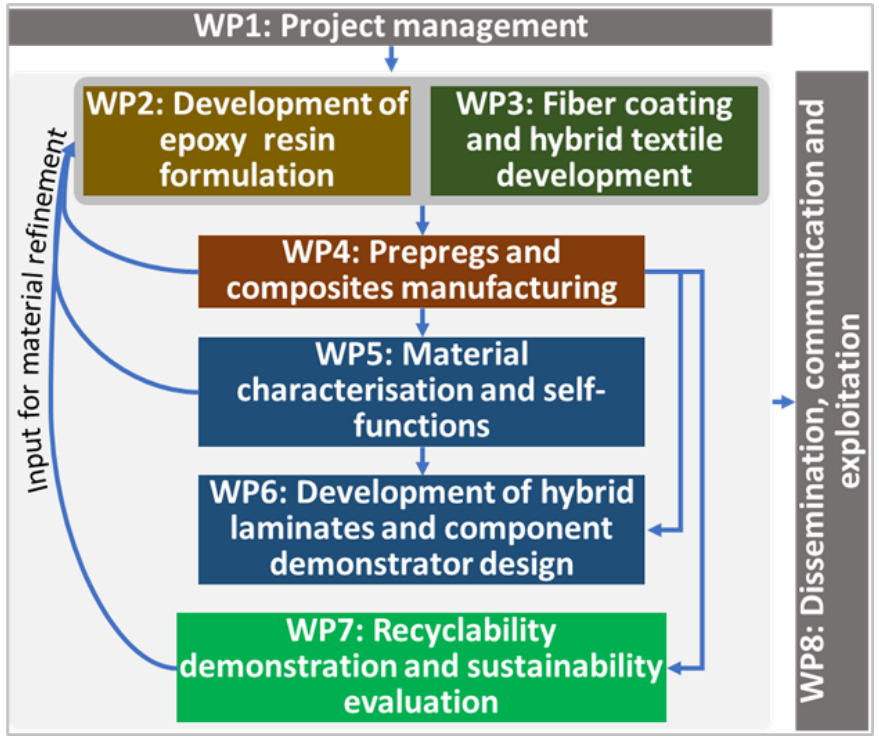
FURHY
Ambition

- High-performance bio-based epoxy resins;
- Fast-curing epoxy system;
- Fully recyclable epoxy systems;
- Hybrid hemp/rCF reinforced composites;
- Self-monitoring;
- Electro-curing (material improvement);
- Prepreg compression moulding by electro-curing (process improvement).

FURHY

WPs and Work plan

Work Package n.	Work Package name	Lead Beneficiary	Start month	End month
WP1	Project Management	CETMA	1	42
WP2	Development of epoxy resin formulation	ONY	1	39
WP3	Fiber coating and hybrid textile development	GEN2C	1	39
WP4	Prepregs and composites manufacturing processes development	CETMA	7	39
WP5	Material characterization and self-functions analysis	UNISA	22	28
WP6	Development of hybrid laminates and component demonstrator design	OLGUN	29	42
WP7	Recyclability demonstration and sustainability evaluation	UNISA	19	42
WP8	Dissemination, communication and exploitation	RINA-C	1	42



Thank you!

CETMA

S.S.7 Km.706 + 030, 72100 Brindisi – Italy

info@cetma.it +390831.449.111

Luigia Longo

luigia.longo@cetma.it

r-LightBioCom Circularity and Recyclability Innovations

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r-LightBioCom

r-LightBioCom Circularity and Recyclability Innovations

Repoxyble's 1st Open Innovation Workshop

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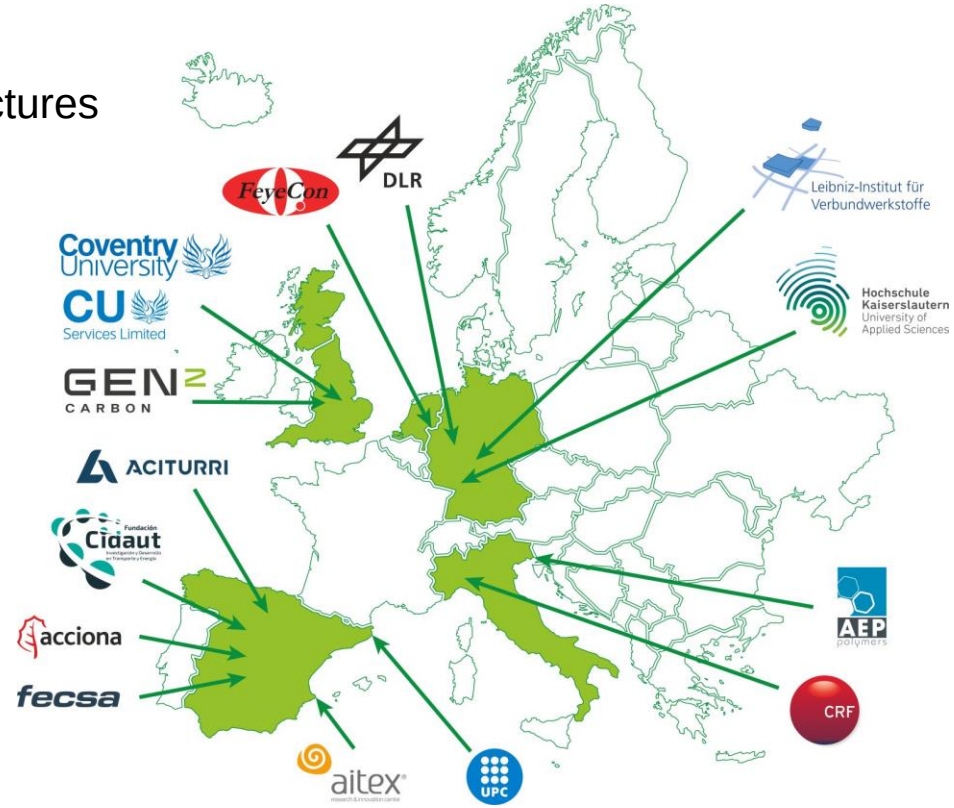
r-LightBioCom

New bio-based and sustainable **R**aw Materials enabling Circular Value Chains of High Performance **Light**weight **BioCom**posites

Topic:	HORIZON-CL4-2022-RESILIENCE-01-11 Advanced lightweight materials for energy efficient structures
Type of action:	Research and Innovation Action (RIA)
Coordinator:	AITEX
Start date:	01/01/2023
End date:	30/06/2026
Duration:	42 months
Budget:	4,201,176 €
Project no.:	101076868

https://cordis.europa.eu/project/id/101091691



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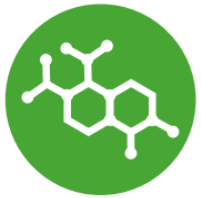
r-LightBioCom

Development Areas

Approach



MATERIALS
New advanced bio-based and recycled high-performance materials with inherent recyclability properties

PRODUCTION TECHNOLOGIES
Efficient processing techniques combined with recycling technologies

METHODS & TOOLS
for a standardised, holistic sustainable high-performance composite design, modelling and systematic optimization

Funded by the European Union

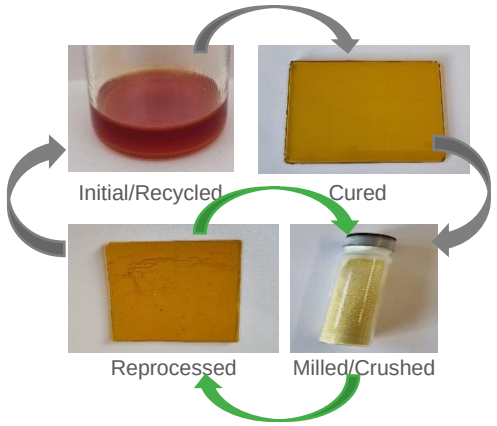
Development Areas

MATERIALS

Development of new bio-based resins, additives and formulations for HPC

New bio-based resins with improved recyclability

- Tailored reactivity
- High bio-based content
- Dynamic thermosets with inherent recyclability
- Application-oriented performance
- Multiple repair, re-processing, re-bonding, recycling, reuse



New bio-based nanomaterials as functional additives

- Low cost
- Low density and weight
- Recyclability / Degradability
- Co-reactivity with resins
- Improved polarity and dispersibility
- Enhanced thermal and mechanical properties
- With tailored functionalities

Enzymatic pre-activation of biomass

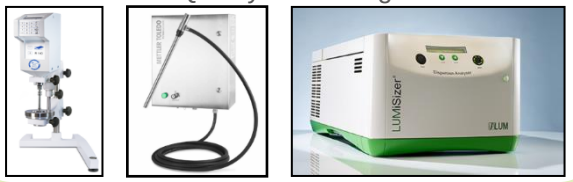
Functionalisation and nano-transformation

New bio-based resin formulations

- High flexibility of modular dispersion line
- Optimized compounding and dispersion processes
- Dispersion quality monitoring
- Adjustment to related processing technologies
- Fulfilment of application requirements

Dispersion modules

Quality monitoring



Funded by the European Union

r-LightBioCom

Development Areas

MATERIALS

New HPC components based on sustainable textile products and bio-based resins

New Sustainable Fibres

Recycled Fibres
r-CF, r-GF, r-Aramid

Natural Fibres
Basalt, Flax, Hemp

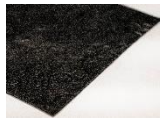
+

Adaption of processing technologies

- Carding
- Spinning

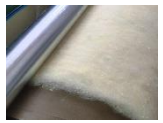
New Sustainable Textiles

Non-woven fabrics



r-CF + PA6/PP

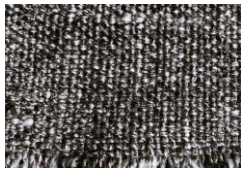
r-GF + PA6/PP



r-Aramid

Natural fibres

Hybrid fabrics with recycled fibres



r-CF + p-CF + PA6

Roving with recycled fibres and basalt

r-Aramid + PA6

r-Aramid + Basalt + PA6

Staple fibre yarn with recycled fibres

r-CF + PA6

Funded by the European Union

r-LightBioCom

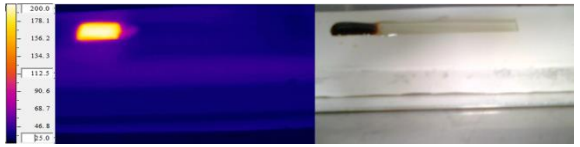
Development Areas

PRODUCTION TECHNOLOGIES

New rapid curing technologies

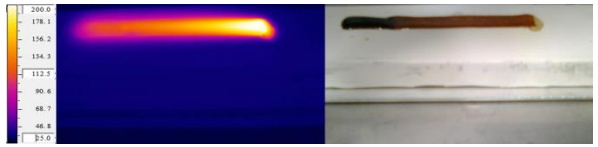
1. RTM + Frontal photopolymerization

UV activation



t=to (after UV radiation)
t= 90 s UV radiation

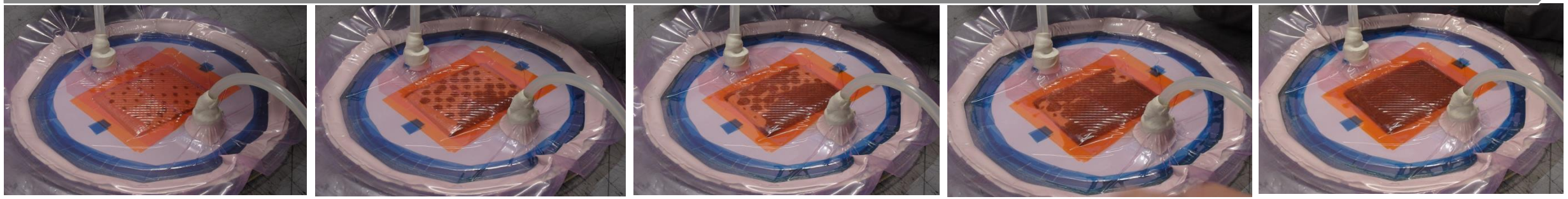
Polymerization propagation



t=120 s (without UV radiation)

2. Vacuum infusion + microwaves

Infusion process



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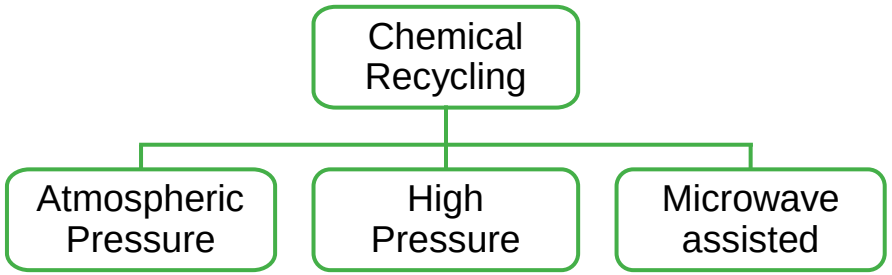
r-LightBioCom

Development Areas

PROCUDTION TECHNOLOGES

Novel recycling technologies for the high-performance composite components

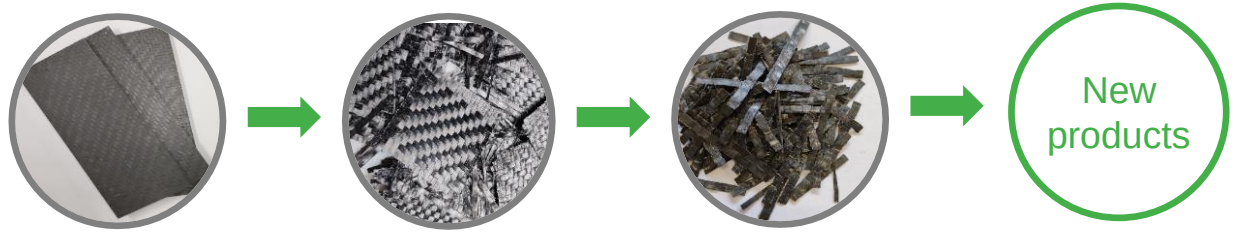
- Thermoset composites recycling into its components: resin building blocks and reinforcing fibres
- Application of newly developed recycling process to bio-resins and bio-composites



Recovered Resin Building Blocks

Aramid fibres

Carbon fibres



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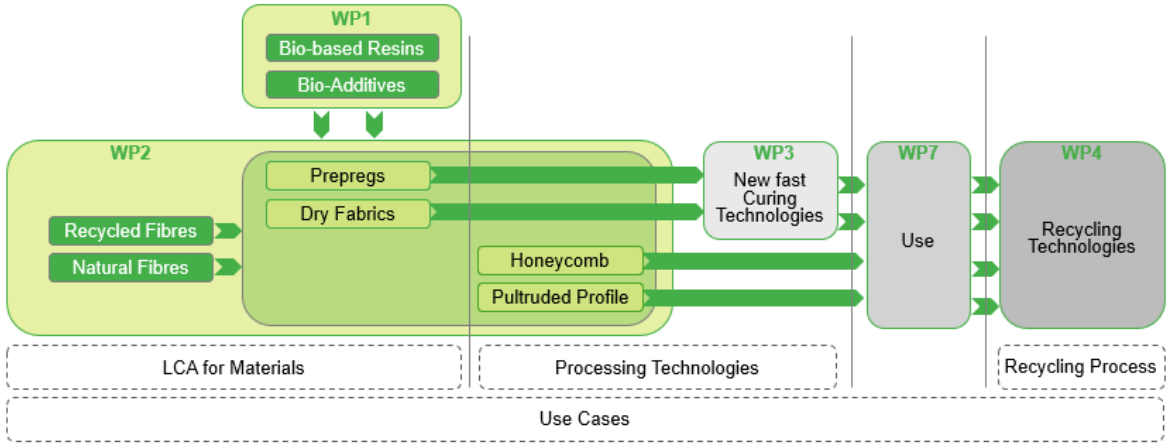
r-LightBioCom

Development Areas

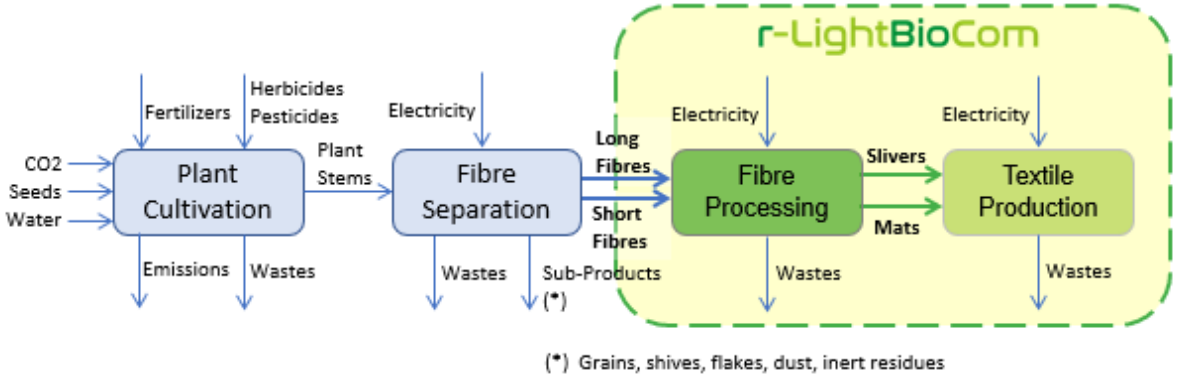
METHODS & TOOLS

Life Cycle Assessment (LCA)

- Environmental impact of r-LightBioCom solutions (materials, curing technologies and recycling processes)
- Comparison against conventional products and processes
- Decision making to choose eco-friendlier alternatives



r-LightBioCom's LCA



Natural Fibres Processing Stages for LCA

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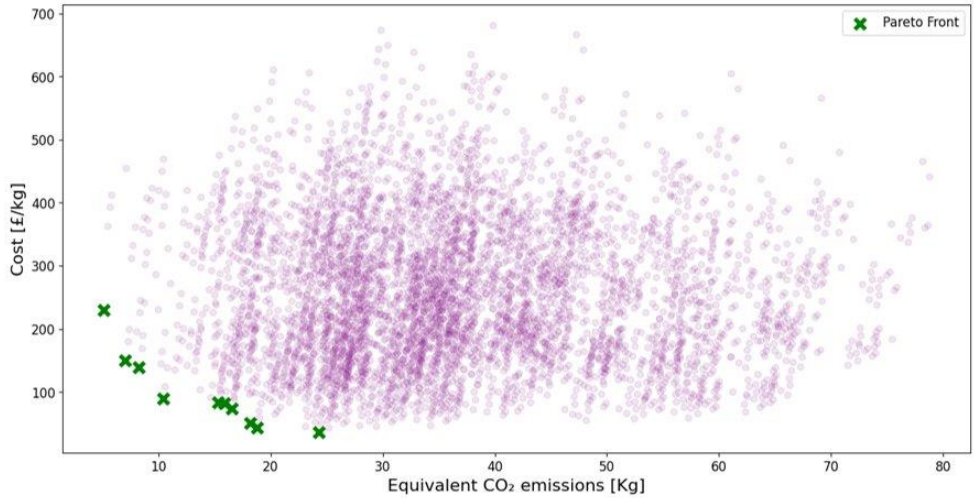
r-LightBioCom

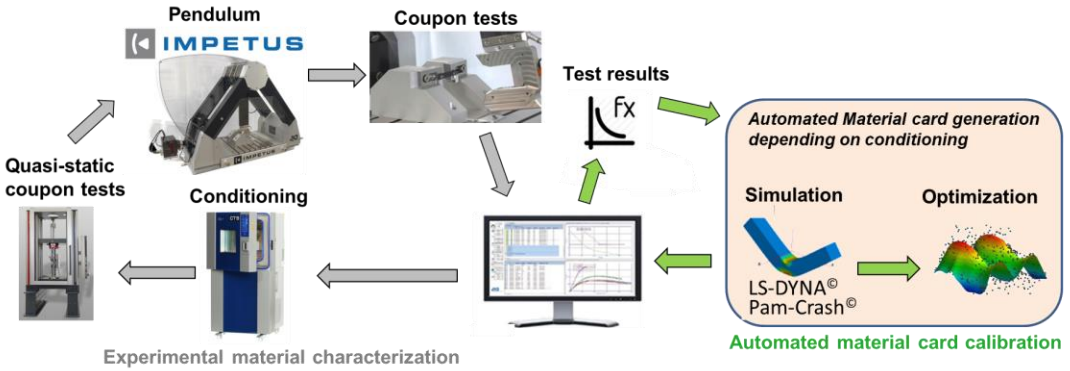
Development Areas

METHODS & TOOLS

Optimization framework for composite modelling, sustainability and validation

- Development of a **Coupled Ecological Optimization (CEO) Framework** to facilitate the implementation and impact of the sustainable material solutions.
- Optimized r-LightBioCom solutions relating to production cost, structural integrity and environmental impact will be developed through the advanced CEO.
- Automated material characterization and calibration utilizing digital twin, Reduced Order Modelling, homogenization and automated reporting will aid structural optimization and analysis





Funded by the European Union

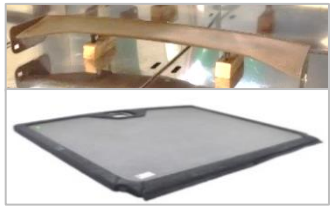
r-LightBioCom

Validation via Use Cases

r-LightBioCom's results will be validated in use cases.

a) Automotive sector:

- Application 1: Spoiler (exterior)
- Application 2: Trunk floor (interior)



b) Infrastructure sector:

- Application: Composite pultruded profiles for tunnel lining

c) Aeronautical sector:

- Application: Leading Edge (movable surface)

Funded by the European Union

Validation via Use Cases

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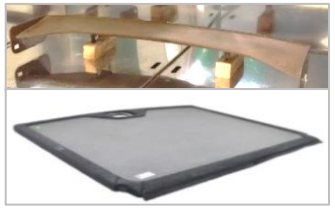


b) Infrastructure sector:

- Application: Composite pultruded profiles for tunnel lining

c) Aeronautical sector:

- Application: Leading Edge (movable surface)

Natural organic and inorganic fibres + Bio-epoxy resin

Manufacturing via Hand Lay-up

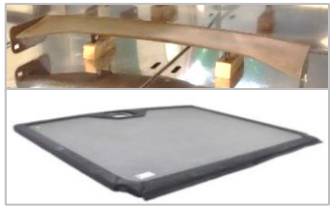
Funded by the European Union

Validation via Use Cases

r-LightBioCom's results will be validated in use cases.

a) Automotive sector:

- Application 1: Spoiler (exterior)
- Application 2: Trunk floor (interior)



b) Infrastructure sector:

- Application: Composite pultruded profiles for tunnel lining

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- Application: Leading Edge (movable surface)

Honeycomb core from natural/recycled fibre non-wovens + Natural organic non-wovens as skin layers + Bio-based resin

Manufacturing via Semi-automated Pultrusion

Funded by the European Union

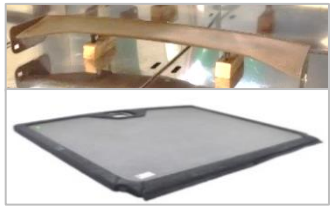
Validation via Use Cases

r-Aramid + Basalt fibre and/or r-CF + PA6 + Bio-benzoxazine and/or bio-epoxy resin

r-LightBioCom's results will be validated in use cases.

a) Automotive sector:

- Application 1: Spoiler (exterior)
- Application 2: Trunk floor (interior)



b) Infrastructure sector:

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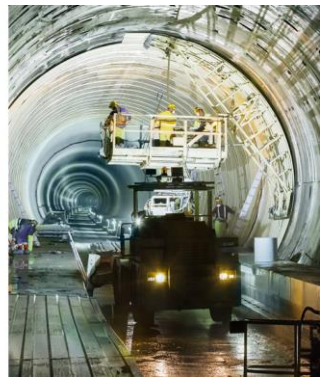

Manufacturing via Pultrusion Process

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Validation via Use Cases

r-LightBioCom's results will be validated in use cases.

a) Automotive sector:

- Application 1: Spoiler (exterior)
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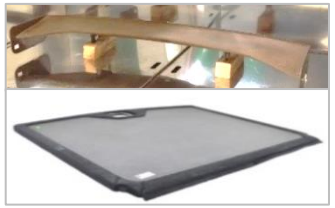

b) Infrastructure sector:

- Application: Composite pultruded profiles for tunnel lining

c) Aeronautical sector:

- Application: Leading Edge (movable surface)

Hybrid fabric from r-CF + PA6 + p-CF filament + Bio-benzoxazine

Manufacturing via RTM or infusion

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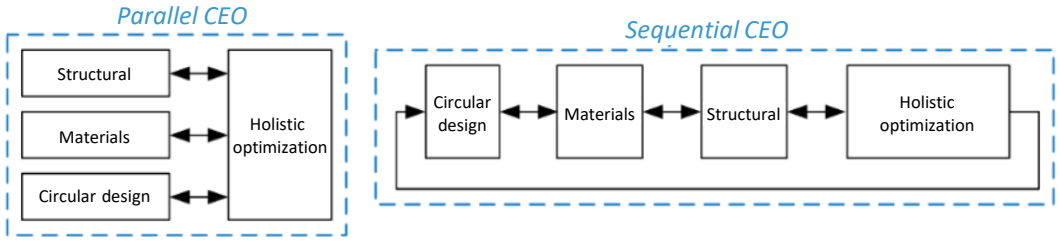
Summary

Sustainability results

- New bio-based resins and sustainable fabrics
- Sustainable manufacturing and recycling technologies
- Holistic optimisation tools for sustainable composite structures
- Tools for composite material modelling and validation

Further results

- Life Cycle Assessment (LCA) study
- Guidelines for standardised production processes & sharing best practices
- New business models



Coupled Ecological Optimization (CEO) Flowchart

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Contact us

Project Coordinator

Aitex

Info-r-LightBioCom@dlr.de

Technical Manager

Eduardo Fages

efages@aitex.es

Dissemination Manager

Dorothea Weber

dorothea.weber@dlr.de

Visit us

Project website

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Advanced lightweight materials FOR Energy-efficient STructures

Rocío Ruiz Gallardo, AIMPLAS & FOREST

Open Innovation Workshop

Processes and methods for recycling, reuse, and recovery of advanced composite materials in the transport sector

REPOXYBLE - Depolymerizable bio-based multifunctional closed loop recyclable epoxy systems for energy efficient structures
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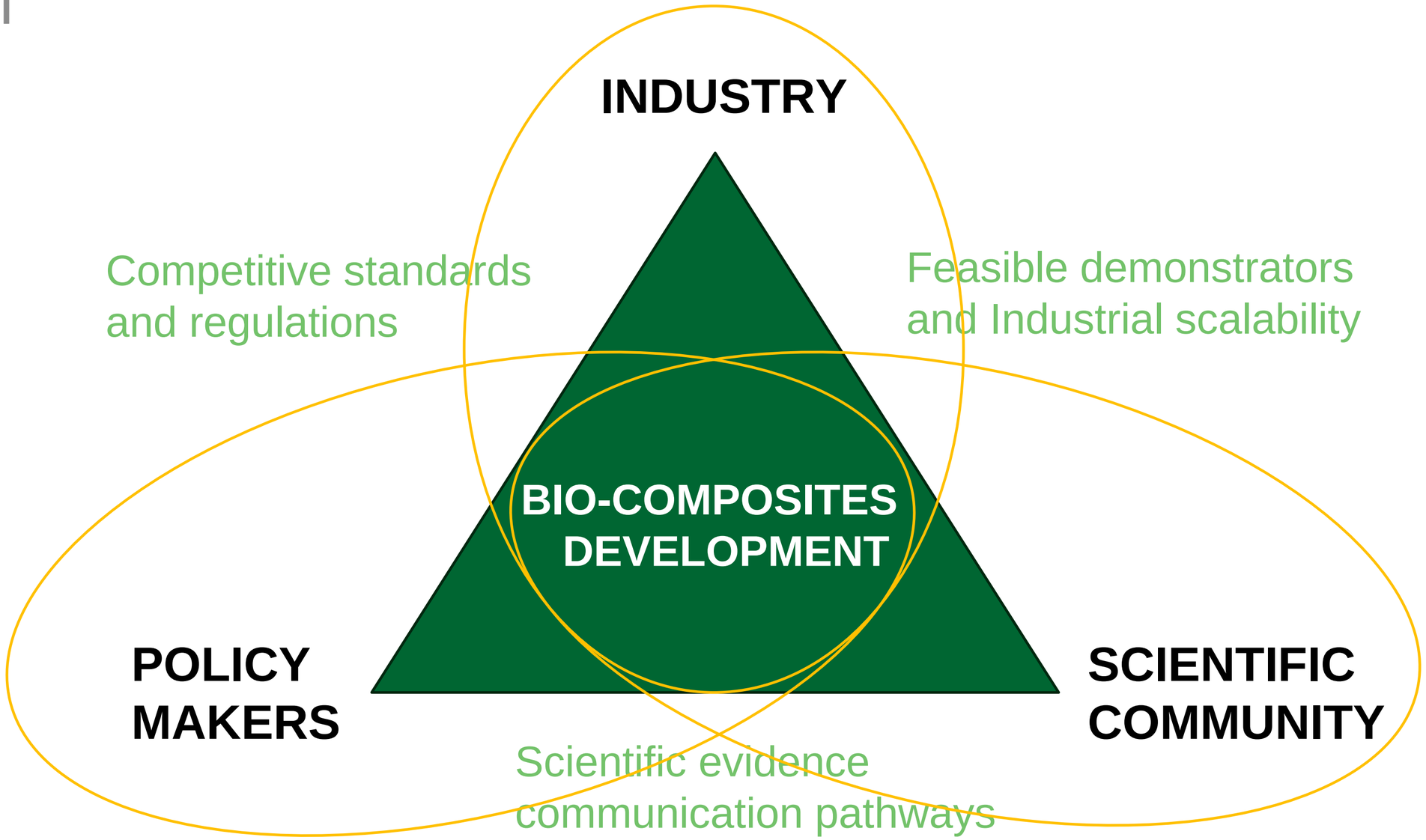
repoxyble
BIO-BASED MULTIFUNCTIONAL RECYCLABLE COMPOSITES

ADVANCED LIGHTWEIGHT MATERIALS FOR ENERGY-EFFICIENT STRUCTURES

Rocío Ruiz – Sustainable and Future Mobility Leader Group
rruiz@aimplas.es

Funded by the European Union

INLAY HINT


INDUSTRY
Competitive standards and regulations
Feasible demonstrators and Industrial scalability
BIO-COMPOSITES DEVELOPMENT
POLICY MAKERS
SCIENTIFIC COMMUNITY
Scientific evidence communication pathways

ABOUT FOREST

FOREST is a European Union research project under the topic of **Advanced lightweight materials FOR Energy-efficient STructures** funded by the European Union's Horizon Europe research and innovation programme.

The **FOREST** project will contribute to the decarbonisation of the transport sector by developing and implementing innovative **bio-based polymers & additives** and **recycled carbon fibres**. The goal will be achieved by combining three key drivers: **Reduce, Recovery,** and **Reshape.**

START: **December 2022**
END: **May 2026**
DURATION: 42 months

GOALS

REDUCE

Structural weight reduction in mobility

Using lightweight carbon fibre (CF)-based composites

Developing new highly-biobased polymers and additives

Fossil sources dependency reduction

GOALS

REDUCE

Structural weight reduction in mobility

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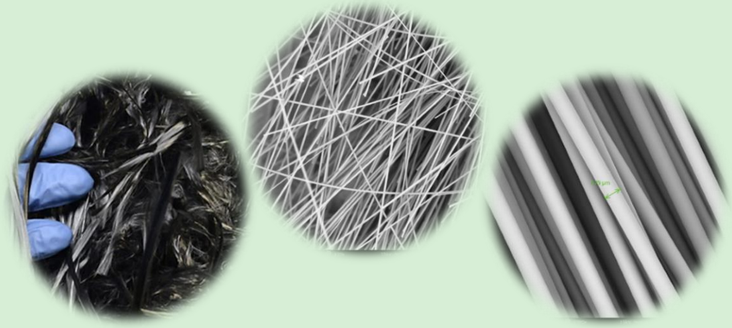
Fossil sources dependency reduction

RECOVERY



Implementing efficient methods to recover 100% CF waste

Incorporation in fully sustainable biocomposites

GOALS

FOREST

REDUCE

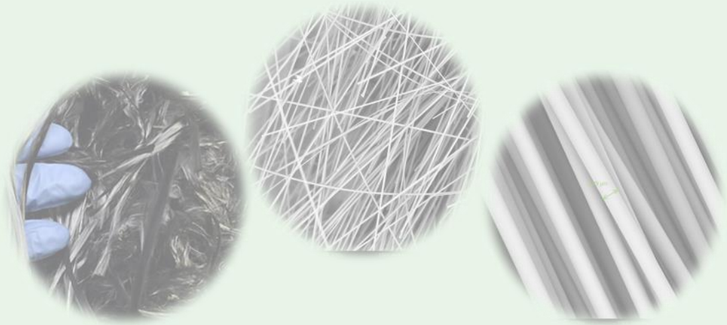
Structural weight reduction in mobility

Using lightweight carbon fibre (CF)-based composites

Developing new highly-biobased polymers and additives

Fossil sources dependency reduction

RECOVERY



Implementing efficient methods to recover 100% CF waste

Incorporation in fully sustainable biocomposites

RESHAPE

Research on the influence of the multifunctional additives

Combine biobased, recycled, and multifunctional materials

Incorporate sustainable solutions in the bus, aeronautic, and automotive sectors

CONCEPT

FOREST

SUSTAINABILITY

- Bio-based composites
- Lightweight materials
- Positive life cycle assessment

CHALLENGES

- Recycling technologies
- Circular economy

CONCEPT

FOREST

SUSTAINABILITY

- Bio-based composites
- Lightweight materials
- Positive life cycle assessment

CHALLENGES

- ➢ Recycling technologies
- ➢ Circular economy

MULTIFUNCTIONALITY

- EMI-shielding
- Flame-Retardants
  - ➢ Bio-based PECs
  - ➢ Efficient DOPO synthesis

CONCEPT

FOREST

SUSTAINABILITY

- Bio-based composites
- Lightweight materials
- Positive life cycle assessment

CHALLENGES

- ➢ Recycling technologies
- ➢ Circular economy

MULTIFUNCTIONALITY

- EMI-shielding
- Flame-Retardants
  - ➢ Bio-based PECs
  - ➢ Efficient DOPO synthesis

MANUFACTURING & SECURITY

- Out-of-Autoclave processes
- Self-monitoring
- Joining techniques
  - ➢ metal-biocomposite
  - ➢ biocomposite-biocomposite
  - ➢ welding (laser, ultrasonic)
  - ➢ adhesive bonding

PARTNERS

Funded by
the European Union

FOREST

Cooperation of **14 partners** from
8 European countries.

Spain, France, Germany, Turkey,
Italy, Poland, Czech Republic and
England

AIMPLAS PLASTICS TECHNOLOGY CENTRE
ARKEMA INNOVATIVE CHEMISTRY
CLARIANT
Fraunhofer IFAM
MBHA Group Crafting Innovation
STELIA
FENIX.TNT tvořivost nad technologií
IRT JULES VERNE
ANGAZ TECH
STELLANTIS CRF
Bitrez
Mercedes-Benz
BASF
GEN2 CARBON

VALUE CHAIN

FOREST

BIOPOLYMERS & ADDITIVES

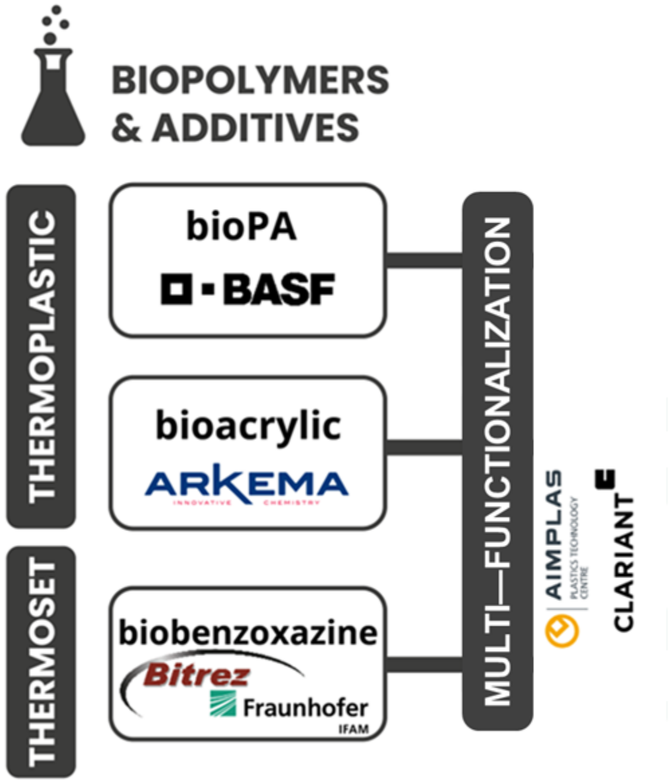
THERMOPLASTIC

- bioPA — BASF
- bioacrylic — ARKEMA

THERMOSET

- biobenzoxazine — Bitrez, Fraunhofer IFAM

VALUE CHAIN


BIOPOLYMERS
& ADDITIVES
THERMOPLASTIC
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bioPA
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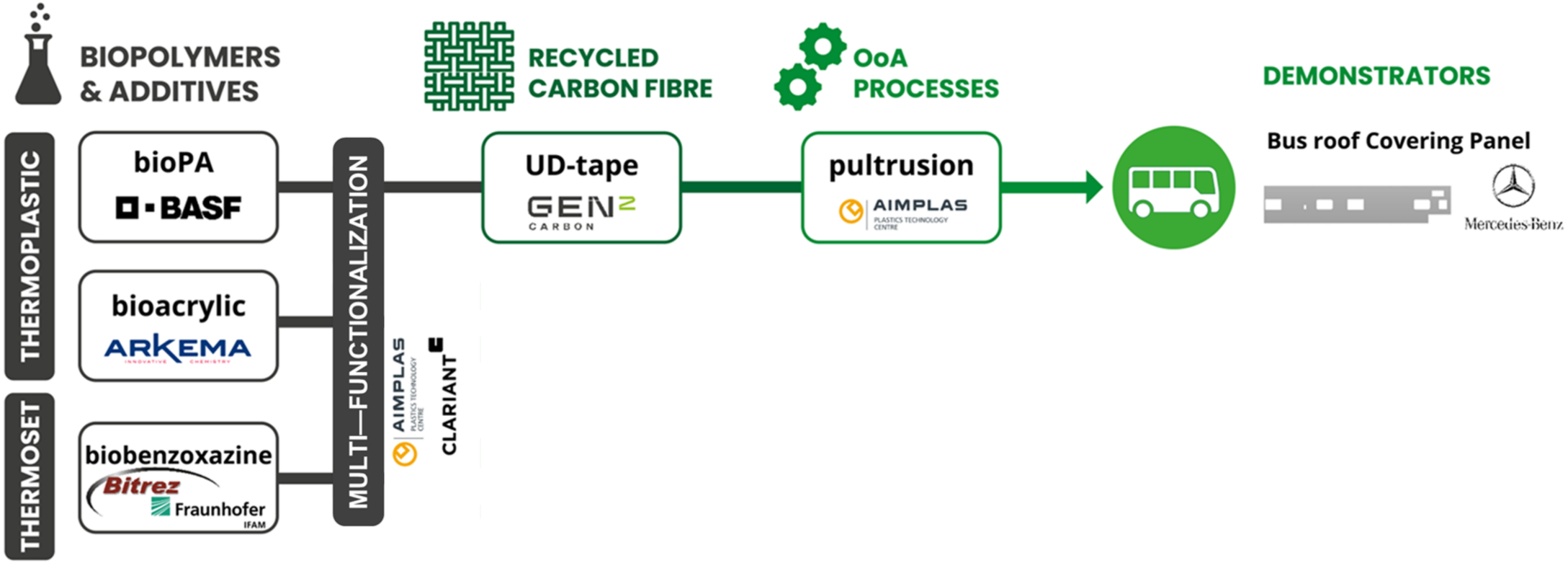
Bitrez
Fraunhofer
IFAM
MULTI—FUNCTIONALIZATION
AIMPLAS
PLASTICS TECHNOLOGY CENTRE
CLARIANT

VALUE CHAIN


BIOPOLYMERS & ADDITIVES
RECYCLED CARBON FIBRE
OoA PROCESSES
DEMONSTRATORS
THERMOPLASTIC
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BASF
bioacrylic
ARKEMA
biobenzoxazine
Bitrez
Fraunhofer IFAM
MULTI—FUNCTIONALIZATION
AIMPLAS PLASTICS TECHNOLOGY CENTRE
CLARIANT
UD-tape
GEN2 CARBON
pultrusion
AIMPLAS PLASTICS TECHNOLOGY CENTRE
Bus roof Covering Panel
Mercedes-Benz

VALUE CHAIN

FOREST

BIOPOLYMERS & ADDITIVES

RECYCLED CARBON FIBRE

OoA PROCESSES

DEMONSTRATORS

THERMOPLASTIC

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bioPA — BASF

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biobenzoxazine — Bitrez, Fraunhofer IFAM

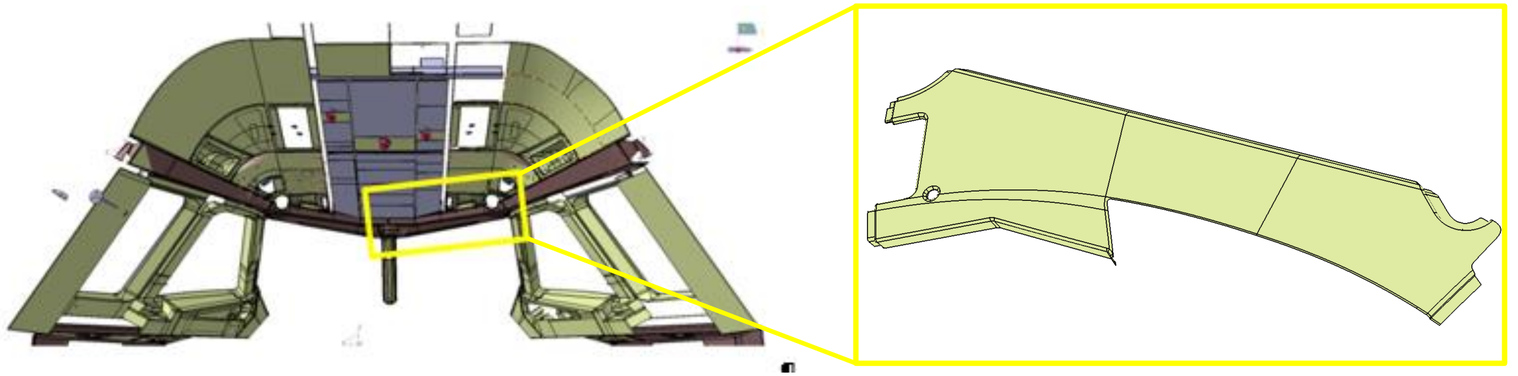
MULTI—FUNCTIONALIZATION — AIMPLAS, CLARIANT

UD-tape — GEN2 CARBON — pultrusion — AIMPLAS

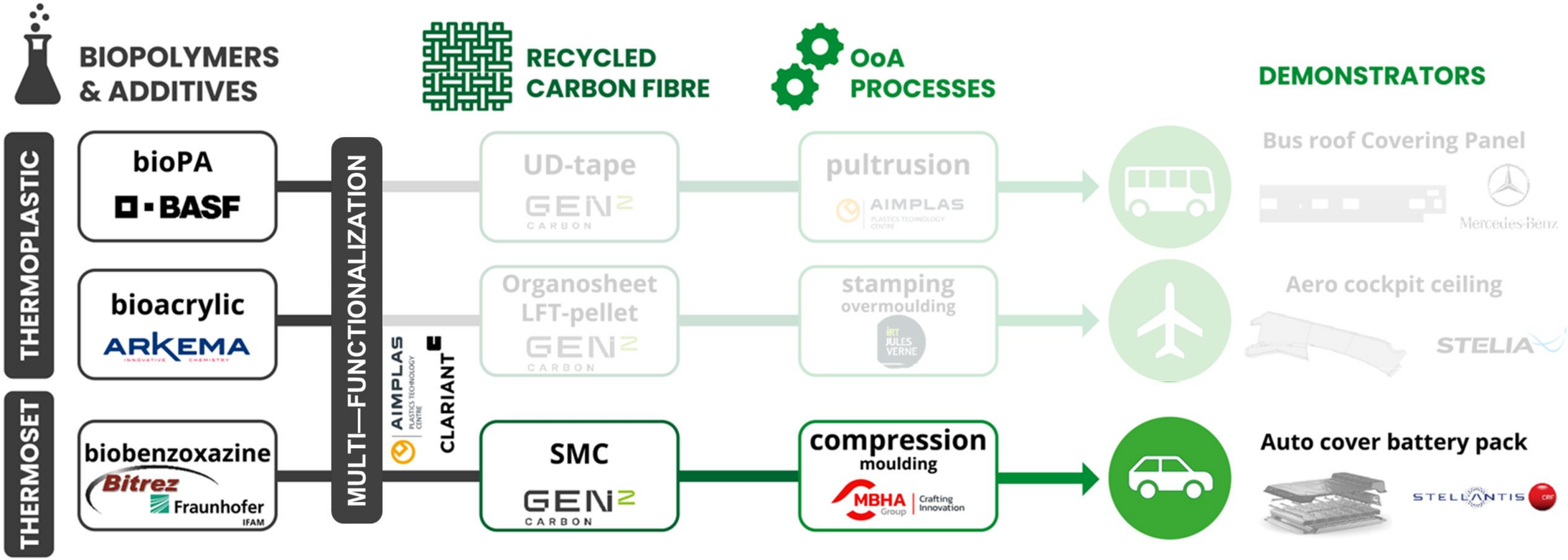
Organosheet LFT-pellet — GEN2 CARBON — stamping overmoulding — IRT JULES VERNE

Bus roof Covering Panel — Mercedes-Benz

Aero cockpit ceiling — STELIA



VALUE CHAIN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GEN2 CARBON
SMC
GEN2 CARBON
pultrusion
AIMPLAS
stamping
overmoulding
IRT JULES VERNE
compression
moulding
MBHA Group
Crafting Innovation
Bus roof Covering Panel
Mercedes-Benz
Aero cockpit ceiling
STELIA
Auto cover battery pack
STELLANTIS

PROGRESS M18

BIOPOLYMERS & ADDITIVES

THERMOPLASTIC

bioPA — BASF

- High MFI PA6 for continuous carbon fibre melt impregnation: **DONE**
- High bio-content bioPA6 up to 40 wt%: **DONE**
- Higher bio-content PA6s (>80 wt%): **ONGOING**

bioacrylic — ARKEMA

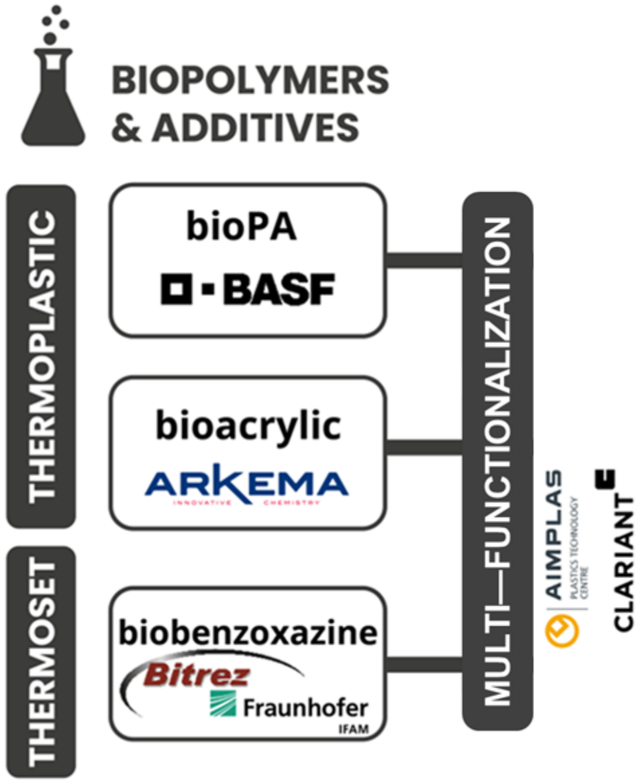
- Bio-based Elium resin up to 25 wt% bio-content: **DONE**
- Increase bio-content preserving mechanical properties: **ONGOING**

THERMOSET

biobenzoxazine — Bitrez, Fraunhofer IFAM

- High bio-content bio-benzoxazine formulations
- Increased green curing rates of bio-benzoxazines

PROGRESS M18



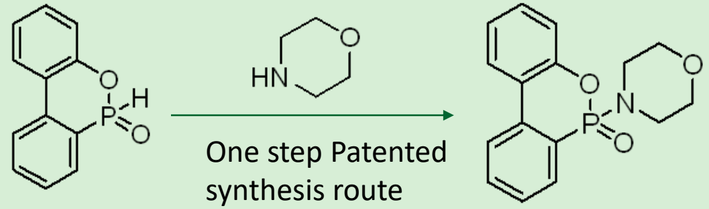
- **Multifunctional fire-retardant additives developed from:**

- Bio-based precursors → Poly Electrolyte Complex (PEC)

PHYTIC ACID

CHITOSAN

- More sustainable and cost-effective routes (non-Cl) → DOPO



→DOPO-morpholine

- **Multifunctional EMI-shielding particles:**

- Carbon-based particles with improved EMI-shielding properties added in mass to the bio-based resin.

PROGRESS M18

RECYCLED CARBON FIBRE

- UD-tape GEN2 CARBON
- Organosheet LFT-pellet GEN2 CARBON
- SMC GEN2 CARBON

- **Non-woven 100% recycled carbon fibre (rCF) mat : DONE**

  - Different grammages: 50/100/200/300 GSM

- **Recovery of continuous rCF for pultrusion thermoplastic UD-tape: ONGOING**

  - 10 m segments achieved. To be converted in longer threads

PROGRESS M18

FOREST

OoA PROCESSES

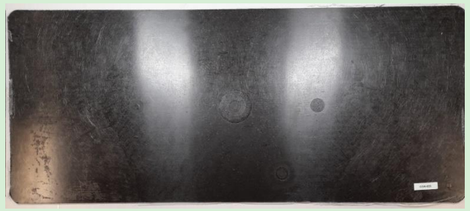
pultrusion
AIMPLAS PLASTICS TECHNOLOGY CENTRE

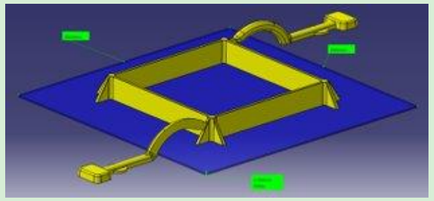
stamping
overmoulding
IRT JULES VERNE

compression
moulding
MBHA Group | Crafting Innovation

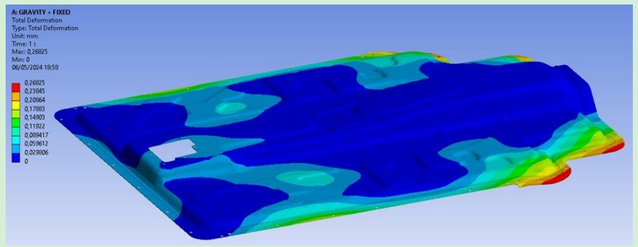
- **Compression moulding layups for characterization: ONGOING**
  - UD-tapes and rCF sandwiched panels
  - Pultrusion system design and simulation

- **C-RTM and Overmoulding trials: ONGOING**





- **Process and mould design modelling: ONGOING**



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EURECOMP- European recycling and circularity in large composites components

Dionisis Semitekolos, National Technical University of Athens – R-NanoLab & EuReComp

Open Innovation Workshop

Processes and methods for recycling, reuse, and recovery of advanced composite materials in the transport sector

REPOXYBLE - Depolymerizable bio-based multifunctional closed loop recyclable epoxy systems for energy efficient structures
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repoxyble
BIO-BASED MULTIFUNCTIONAL RECYCLABLE COMPOSITES

EURECOMP Project: European recycling and circularity in large composite components

Repoxyble open innovation workshop

07/06/2024

Dionisis Semitekolos / R-Nano NTUA

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R-NANO

EuReComp in a nutshell

DURATION
48 months

9 EU countries

COORDINATOR
Prof C. Charitidis

STARTING DATE
01/04/2022

20 partners

BUDGET
~9 M euros

PROJECT ACRONYM/TITLE
EuReComp
European recycling & circularity in large composite components

GA NUMBER
101058089
CALL: A digitized, resource-efficient and resilient industry 2021

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EuReComp Consortium

20 Industrial and **academic partners** with **complementary and multidisciplinary expertise!**

- ✓ **2 IND**
- ✓ **11 RTO**
- ✓ **7 SME**

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EuReComp Mission

The **cumulating composite wastes** are more prominent than the needed new composites. The **aircraft** and **wind energy** sectors contribute to a major share.

Across all industries about 60% of waste **fibre reinforced** composites is **landfilled**, causing severe **societal and environmental issues**.

EU's **Circular Economy plan** seeks to reduce the landfill down to 10% by increasing the rate of **recycling.**

Stakeholders seek **advanced technologies** and **end-of-life options**, which promote the **recycling** of carbon fibres.

EuReComp project has a strong focus on **circularity**, setting out to provide **sustainable methods towards recycling and reuse of composite materials**, coming from components used in various industries, such as aeronautics and wind energy.

EuReComp pathways towards circularity:

- Repairing, repurposing and redesigning parts from end-of-life large scale products and
- Recycling and reclamation of the materials used in such parts

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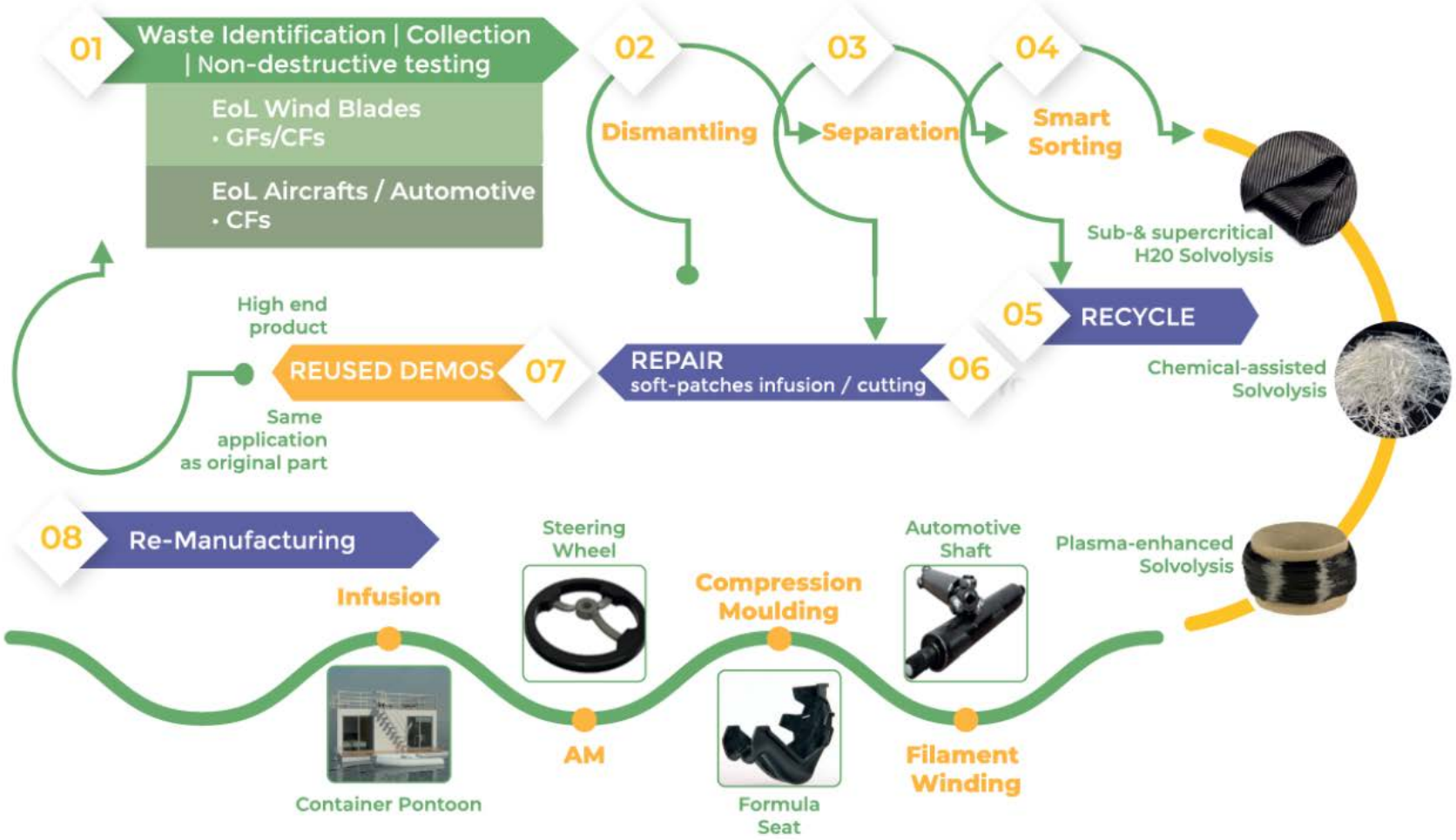
EuReComp Concept



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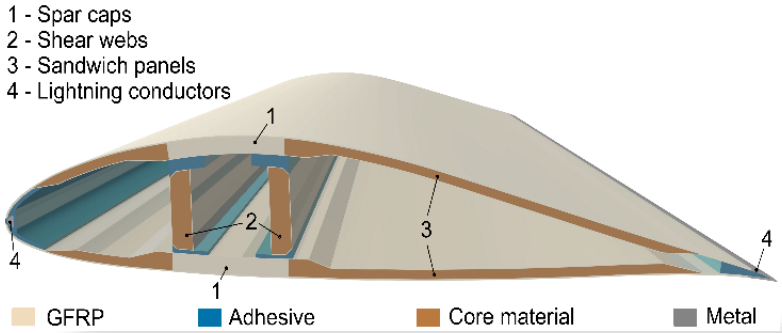
RE-use cases

Watertank cutting areas

Tables from an EoL watertank (TU Dresden – Institute for Lightweight Engineering and Polymer Technology)



Float test with PV-floating system

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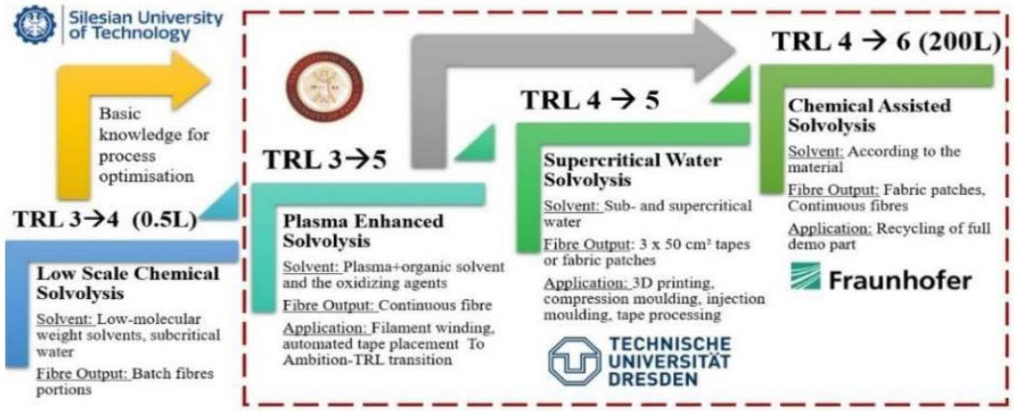
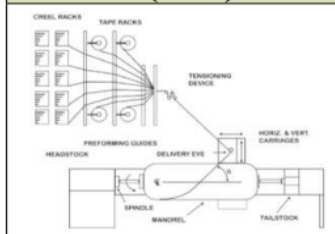
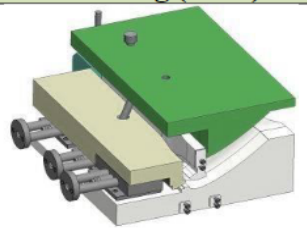
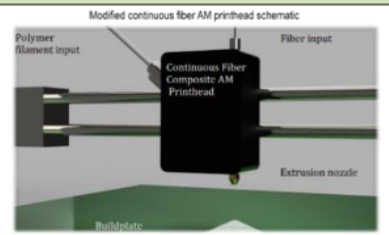
Demos with recycled materials



- *Continuous fibres*
- *CFs fabric patches*
- *Chopped CFs*

Filament Winding (B&T)	Compression Moulding (DAL)	3D printing (BIO)	Vacuum Infusion (APM)
			
Automotive Shaft 	Formula Seat 	Steering Wheel 	Container Pontoon 

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Recycling progress

Recycling progress

Composite specimen manufactured with Filament Winding

Plasma Treatment

Continuous Carbon Fibre Reclamation through Plasma Treatment

Fibre rearrangement

Fibre winding

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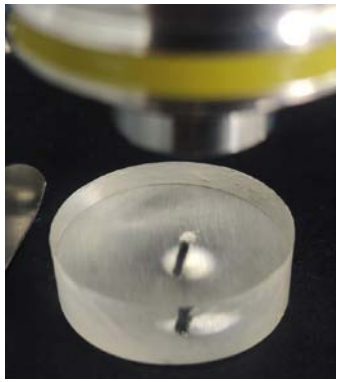
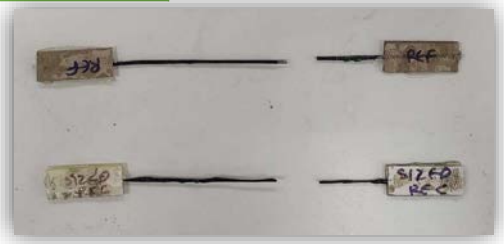
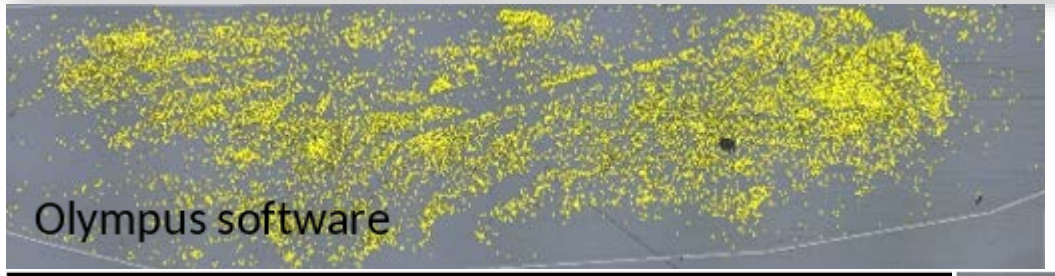
Fibre upgrading

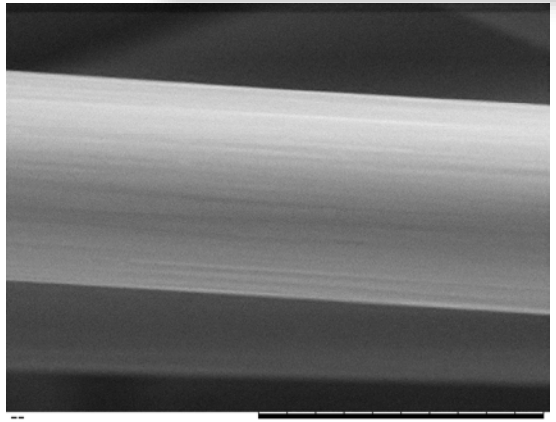
	Tensile Strength (GPa)
Reference	3.45 ± 0.41
Recycled	2.71 ± 0.32
Sized Recycled	3.12 ± 0.28



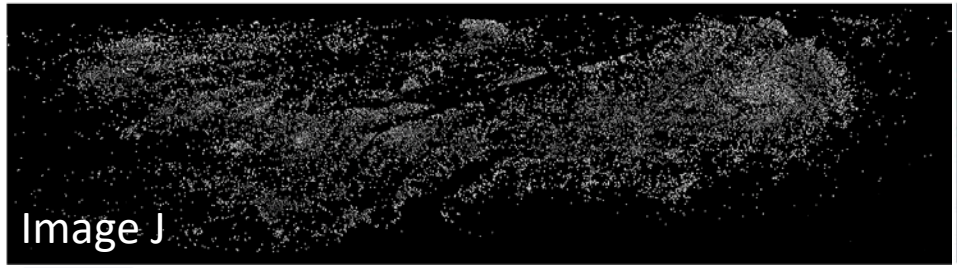
Impregnated fibre discs for optical microscopy

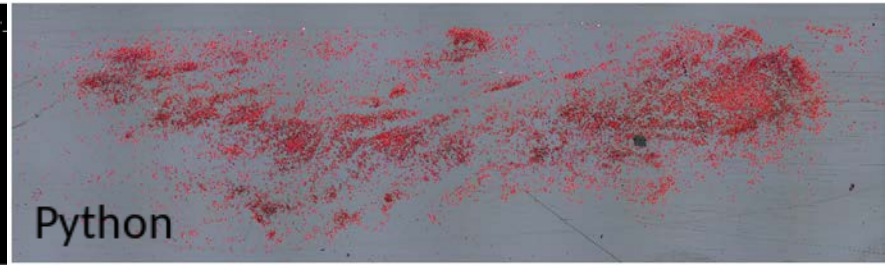






Recycled Fibre x9000





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Acknowledgment

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Thank you!

Dionisis Semitekolos

diosemi@chemeng.ntua.gr

R-Nano NTUA

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Carbo4Power - New generation of offshore turbine blades with intelligent architectures of hybrid, nano-enabled multi-materials via advanced manufacturing

Tatjana Kosanovic Milickovic, National Technical University of Athens – R-NanoLab & Carbo4Power

Open Innovation Workshop

Processes and methods for recycling, reuse, and recovery of advanced composite materials in the transport sector

REPOXYBLE - Depolymerizable bio-based multifunctional closed loop recyclable epoxy systems for energy efficient structures
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repoxyble
BIO-BASED MULTIFUNCTIONAL RECYCLABLE COMPOSITES

CARBO4POWER

NEW GENERATION OF OFFSHORE TURBINE BLADES WITH INTELLIGENT ARCHITECTURES OF HYBRID, NANO-ENABLED MULTI-MATERIALS VIA ADVANCED MANUFACTURING

Open Innovation Workshop (Repoxyble)

Process and methods for recycling, reuse and recovery of advanced composite materials in the transport sector

June 7th, 2024, Brussels

"This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 953192".

R-NANO

Project ID:

- **Full title:** New generation of offshore turbine blades with intelligent architectures of hybrid, nano-enabled multi-materials via advanced manufacturing
- **Acronym:** **Carbo$_4$Power**
- **Call identifier:** H2020-NMBP-ST-IND-2018-2020
- **Topic:** LC-NMBP-31-2020 Materials for offshore energy (IA)
- **Number of partners:** 18
- **Duration:** 48 months (1.11.2020 – 31.10.2024)
- **Funding:** ~7M €
- **Coordinator:** NTUA, R-NanoLab, Prof. C. Charitidis

Carbo4Power Concept

- Robust **new material architectures,** **hybrid nano-engineered multi-materials** with tailored **diverse functionalities**.
- Feedstock for **composites**, **adhesives** and **coatings** manufacturing technologies for offshore energy applications.
- **Digital tools**: **multi-scale modelling**, **design**, **topology optimization** and **data analytics**

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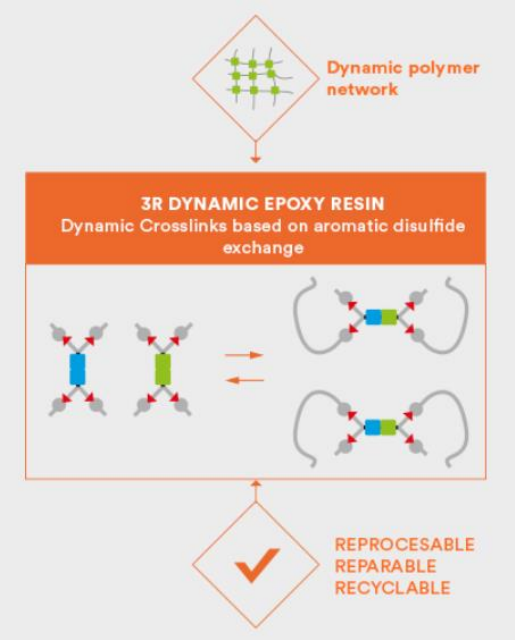
Sustainable materials for offshore wind and tidal blades

cidetec
surface engineering

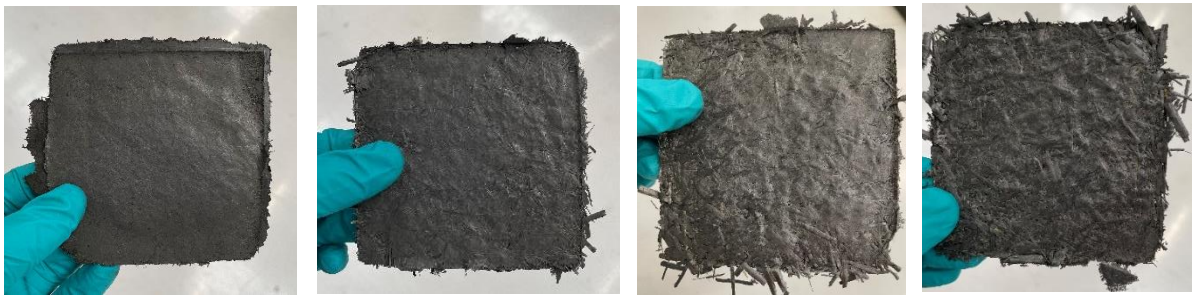


C4P's R3 Resins:

Reprocessing, **R**epairing, **R**ecycling resins due to dynamic hardeners

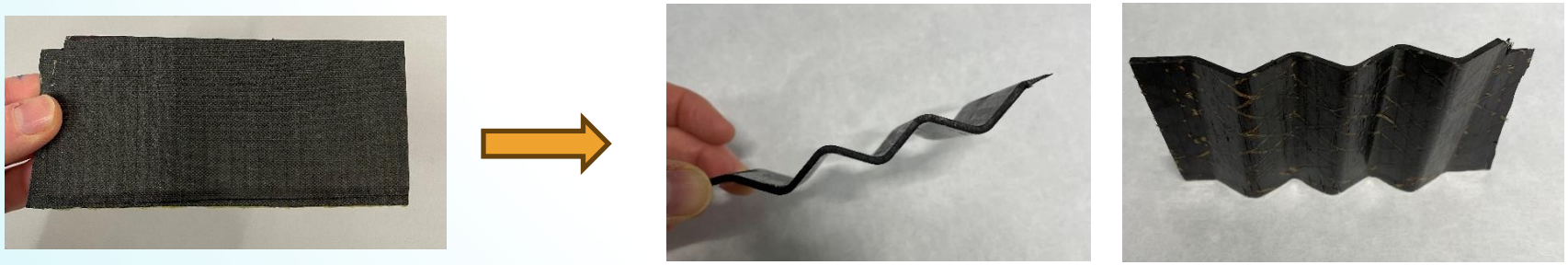
MECHANICAL RECYCLABILITY OF 3R COMPOSITES

1. Recycling of 3R GFRP and CFRP composite powder.



0,5 mm **1 mm** **2 mm** **4 mm**

2. Recycling via thermoforming of 3R composites.



https://www.cidetec.es/en/top-achievements/3r-leading-technology

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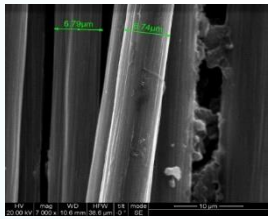
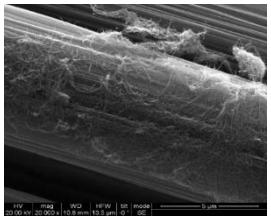
Innovative materials for offshore wind and tidal blades

Fiber surface Functionalisations

- Plasma treatment
- Electropolymerisation
- Nanoenhanced C-based sizing

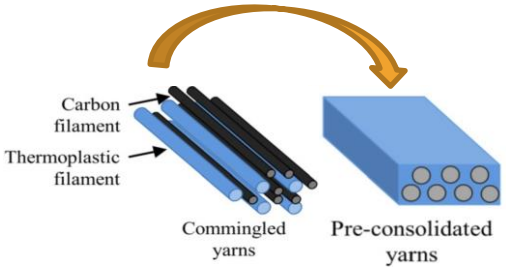




- Pilot line for NE sizing

Hybridization of conventional fibres, in the form of CY or tapes

- Successful & stable production of PPS/Cf commingled yarns
- Novel UD TP tapes with CY produced via pultrusion and hot-melt process



Novel non-intrusive quantum sensors (QRS):

- monitor different thermal/ mechanical events during fabrication & operation
- Strain sensing → SHM
- pQRS, tQRS, fQRS and hQRS for process health monitoring

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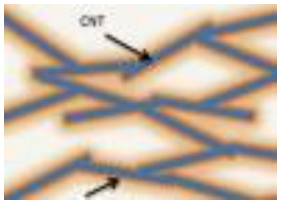
Functional materials for offshore wind and tidal blades

Functional resistive heaters for de-icing

- Graphene-based nanocomposite layers
- Embedded on the composite for active de-icing



Functional prepregs for Lightning Strike Protection

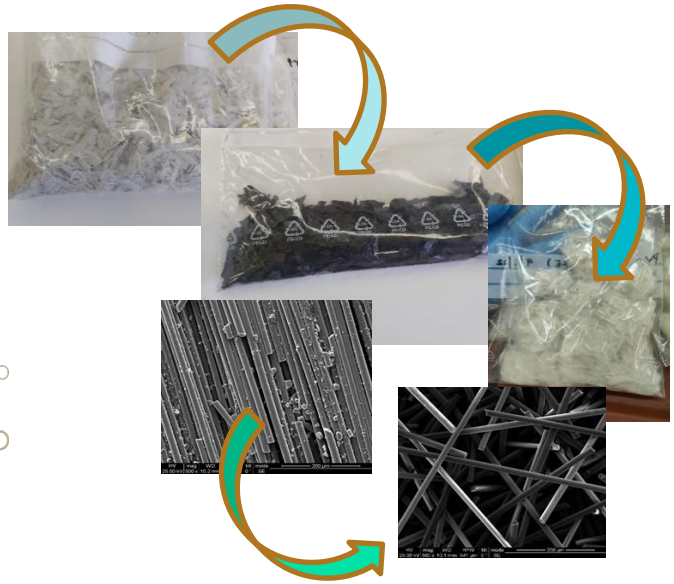
- Conductive C-based nanomaterials
- Prepregs manufactured with 3R resin

Adhesive joints with debonding on demand capabilities

- Adhesive modifications with thermo-expandable particles (TEP)
- Adhesive modifications with Magnetic Nanoparticles
- Introduce a damage mechanism for the disassembly

Functionally graded recycled fibre adhesive carrier

- Recycling of WTB blades for GF reclamation
- Manufacturing of FGA mat



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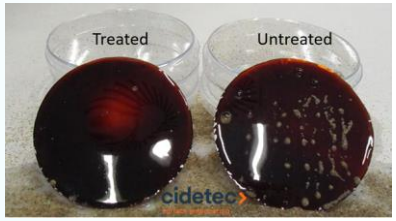
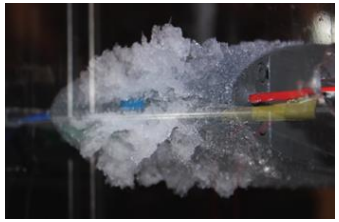
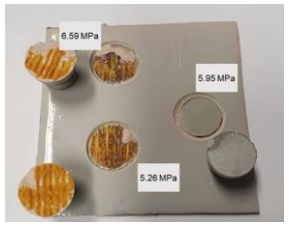
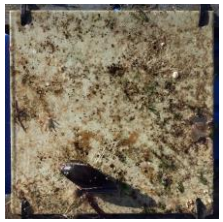
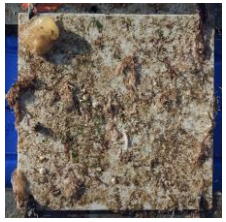
Multifunctional surface protective coatings - improved durability

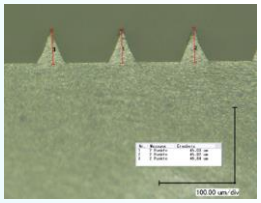
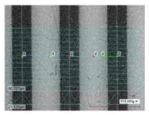
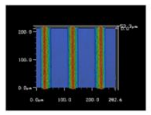
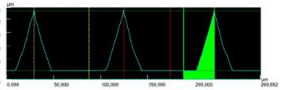
Low surface energy coatings with self-cleaning properties to reduce surface contamination / corrosion effects (incl. ice, biofouling, soiling, water)

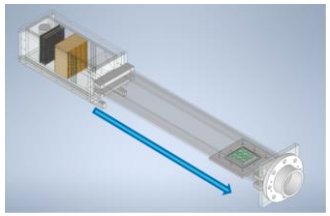


Drag-reducing riblet and lift increasing surfaces for improved energy harvesting



LE erosion protection coatings considering high strength / self-healing properties

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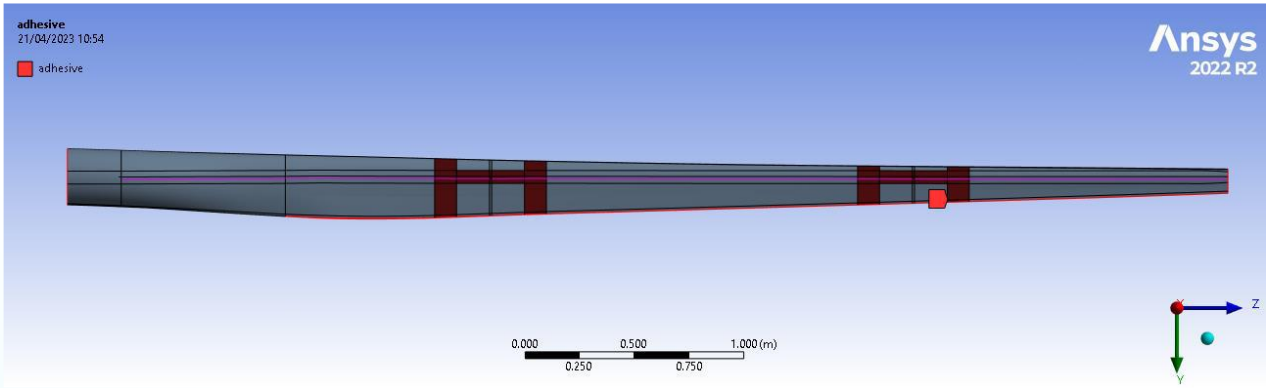
Wind turbine modular blade demo

Scale down 1:20 (>15MW turbine, 104m) wind turbine blade demonstrator (infusion & ATL/AFP manufacturing)



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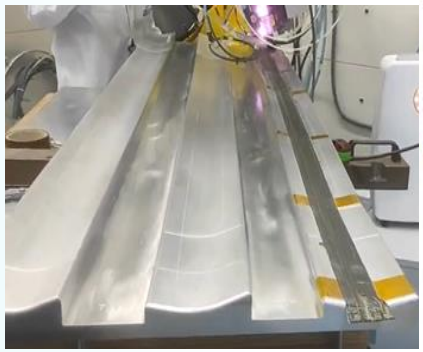
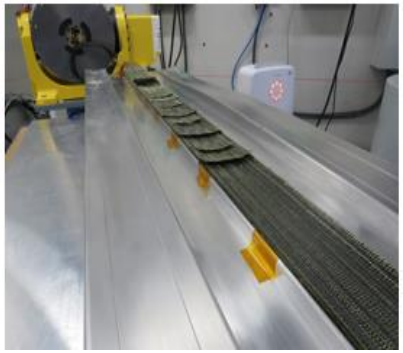
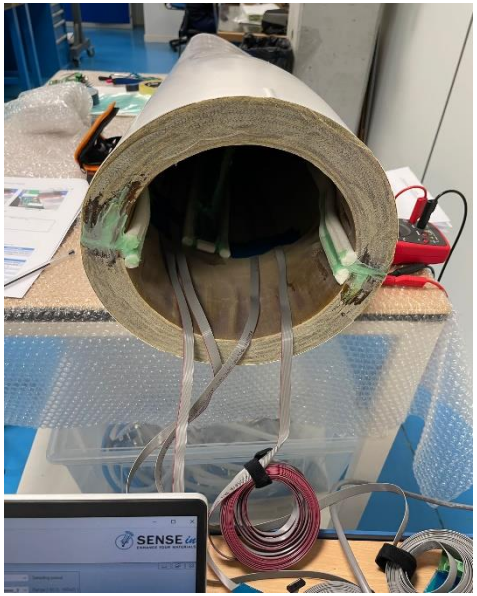
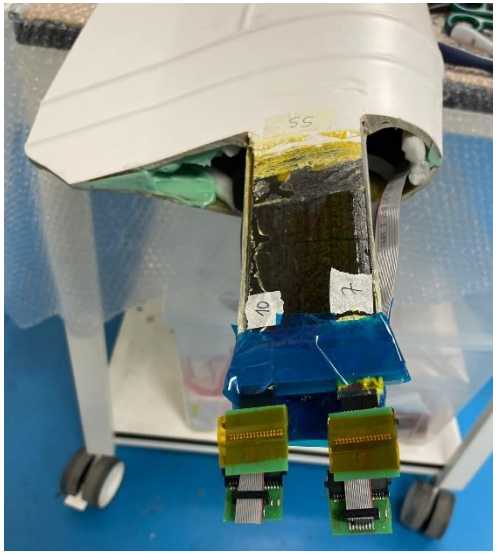
Scale down 1:20 modular blade (>15MW turbine, 104m) wind turbine blade demonstrator ((infusion & ATL/AFP manufacturing)









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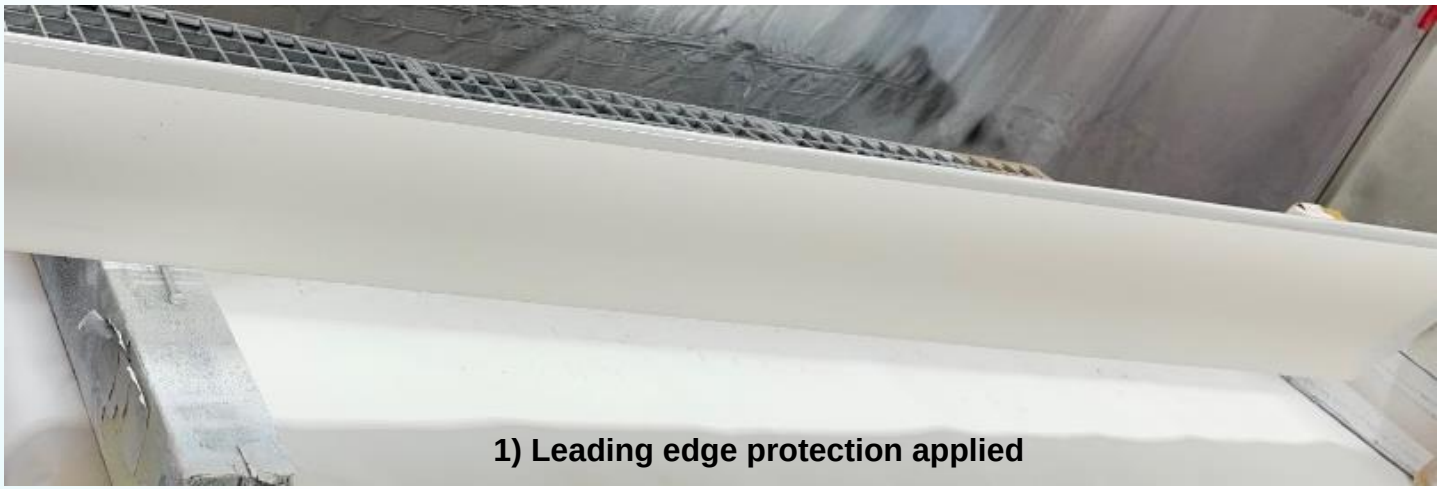
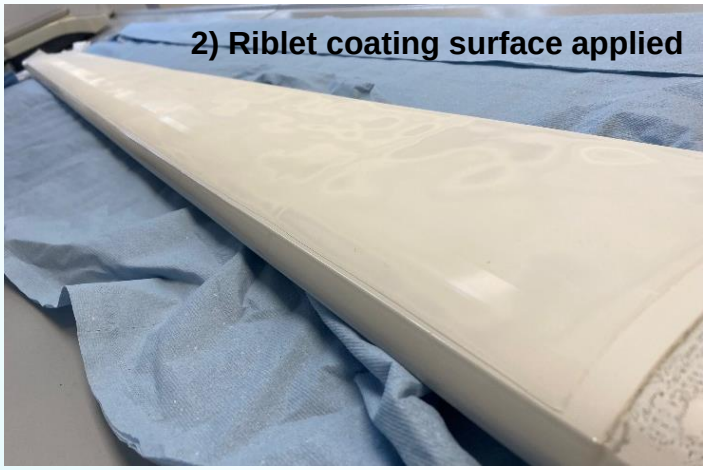
Wind turbine modular blade demo

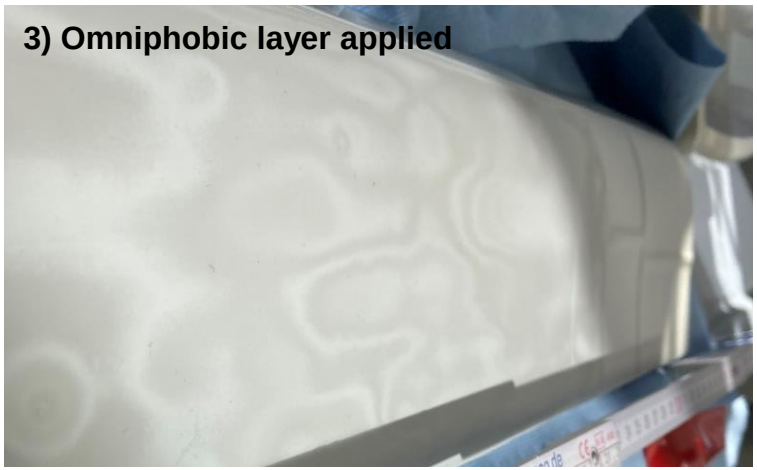
Scale down 1:20 15MW wind turbine blade demonstrator – coating application



1) Leading edge protection applied



2) Riblet coating surface applied



3) Omniphobic layer applied

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Tidal turbine blade demo

MADRAS demonstrator: Scale 1 tidal turbine blade D12 truncated, Sabella (half-shell); NCF/DFP/infusion manufacturing

Final Weight: ~ 220 kg
Length: ~ 4 m

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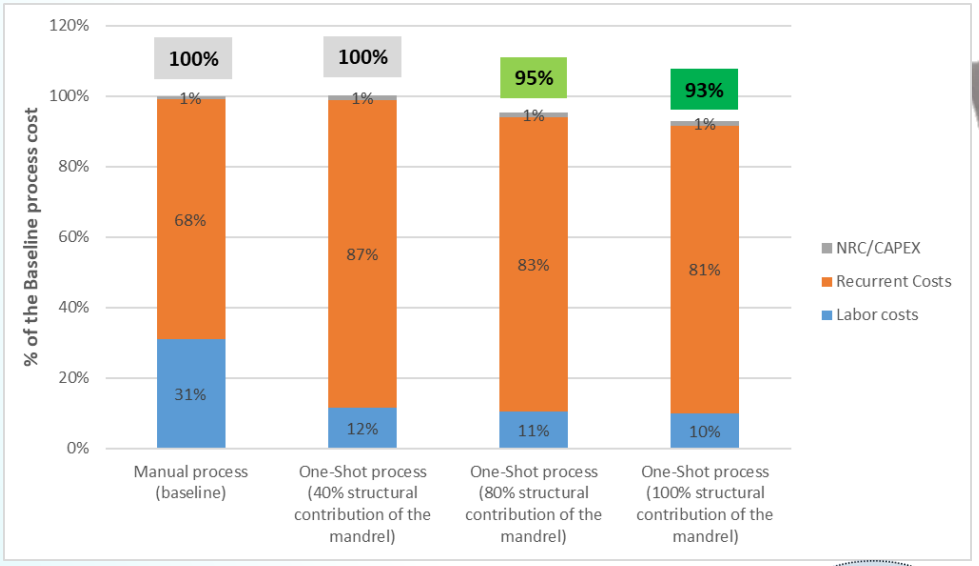
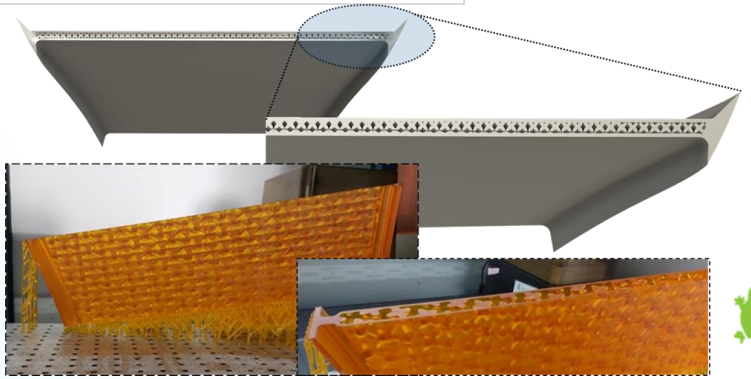
Tidal turbine blade demo

ONE-SHOT DEMONSTRATOR – Scale 1 root section (0.7m)

- Cost depends on the structural contribution of the mandrel
- -5% (on total cost/blade with depreciation) if considering 80% structural contribution
- Iso-cost with 40% structural contribution





BIOG3D

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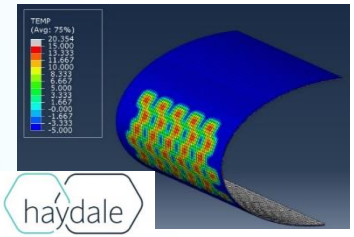
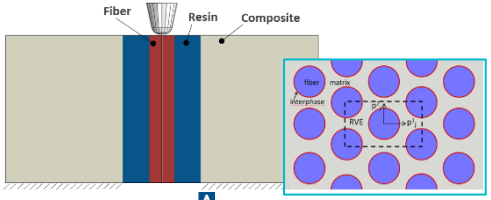
Modeling and Design to support developments

Design of Nanomaterial-enhanced heater system for de-icing



Study of carbon fibre treatments to improve CFRP properties



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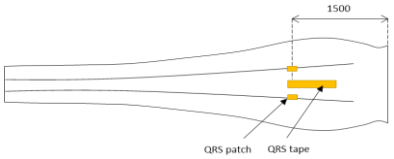
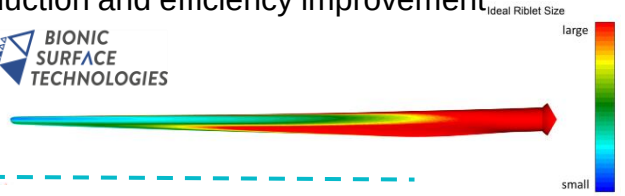


Localization of QRS sensors

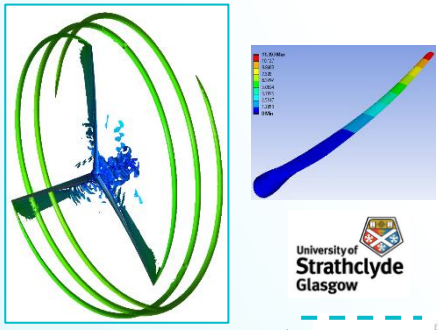
SENSE in ENHANCE YOUR MATERIALS

Design of Riblets introduction for drag reduction and efficiency improvement

BIONIC SURFACE TECHNOLOGIES



Coupled CFD-FEM simulations for accurate evaluation of blade operation



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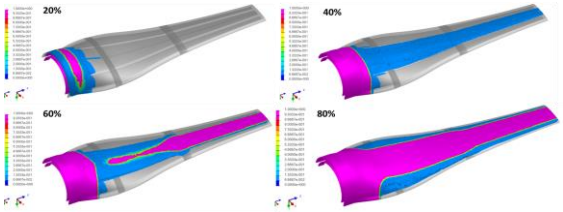
Support in TTB demo infusion process definition



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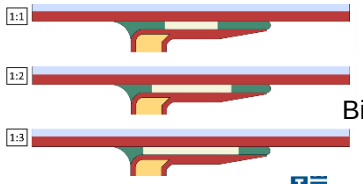
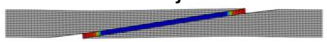
Analysis of innovative bonded joints solutions



Scarf-joints



Bi-adhesive joints

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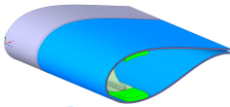
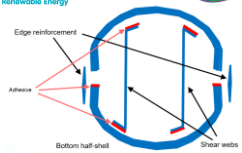
CATAPULT Offshore Renewable Energy





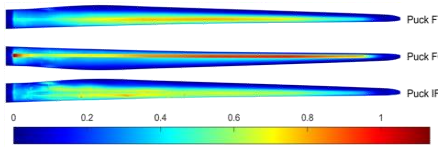
Demonstrators design

sabella

Optimised Bladelet design

BIOG3D

Structural analysis of blades at full and demo scales



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Impact

Operational & Maintenance Costs

Significant reduction of life cycle costs maintaining or improving other performance properties

Significant reduction of maintenance cost

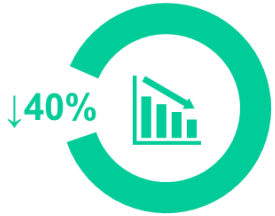
Production and Acquisition costs **< 30%.**

Installation and Commissioning costs - reducing transportation costs from the production factory to the port of **~ 60%.**

Operation and Maintenance (O&M) **< 50%.**

Decommissioning and Disposal **~ 15% reduction.**

Levelized CoE



Optimised materials cost & improved durability

↓ 40% Levelized Cost of Energy

<10 ct€/ kWh for wind

<15 ct€/kWh by tidal stream

Increase in the **annual energy** >6%.

Overcome durability-related issues affect the in-service life of offshore turbine blades .

Increase the lifetime of blades by 100% and decrease maintenance costs by approx. 50% (OPEX).

Overall cost of blades which is expected to be reduced by at least 40% (CAPEX).

Environmental impact

Reduction of environmental impact by 35% based on life cycle assessment (LCA) and eco-design:

Thermo-mechanically **reprocessable** composites.

High rate of **recyclability** at EoL

Enhanced repairability.

Environmentally-friendly nature (no chemicals used) coatings.

Focus on **on-demand debonding** functionality in joints.

Cost-effective transportation - new modular blade design.

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Consortium

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aimen CENTRO TECNOLÓGICO
cidetec surface engineering
IRES Innovation in Research & Engineering Solutions
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inegi driving science & innovation
BIOG3D
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THANK YOU!

Contact details:

info@carbo4power.eu

Carbo4P

Carbo4Power

Contact

Twitter

LinkedIn

carbo4power.net

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BIO-BASED MULTIFUNCTIONAL RECYCLABLE COMPOSITES

Thank you for participating!

We will keep you updated on

www.repoxyble.eu

LinkedIn: REPOXYBLE project

REPOXYBLE - Depolymerizable bio-based multifunctional closed loop recyclable epoxy systems for energy efficient structures
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