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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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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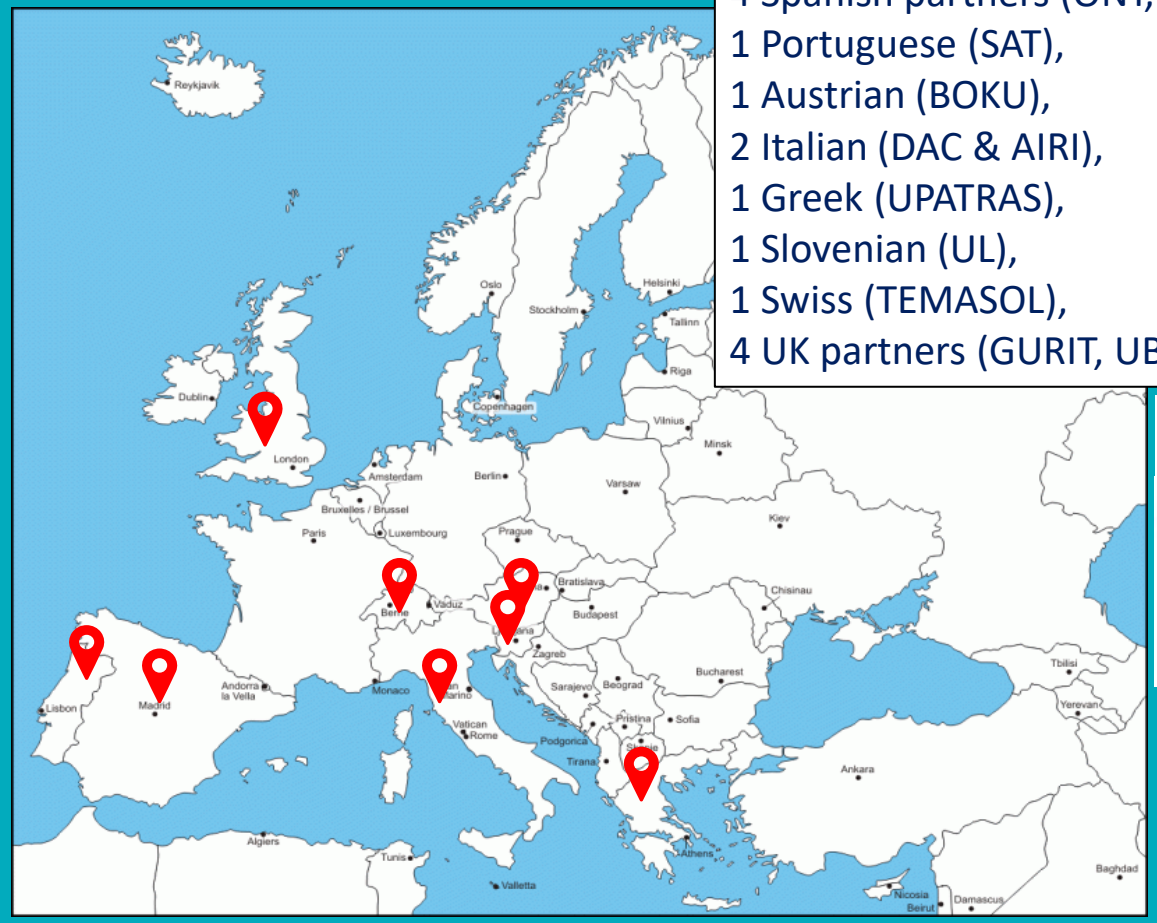
REPOXYBLE goals & objectives

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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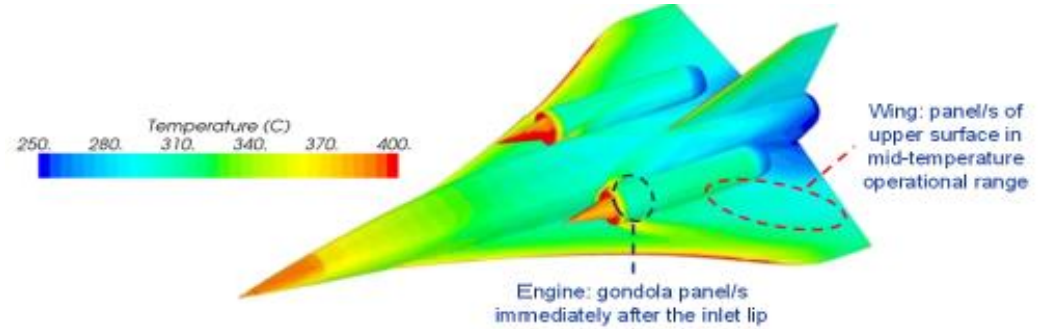
REPOXYBLE case studies



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.

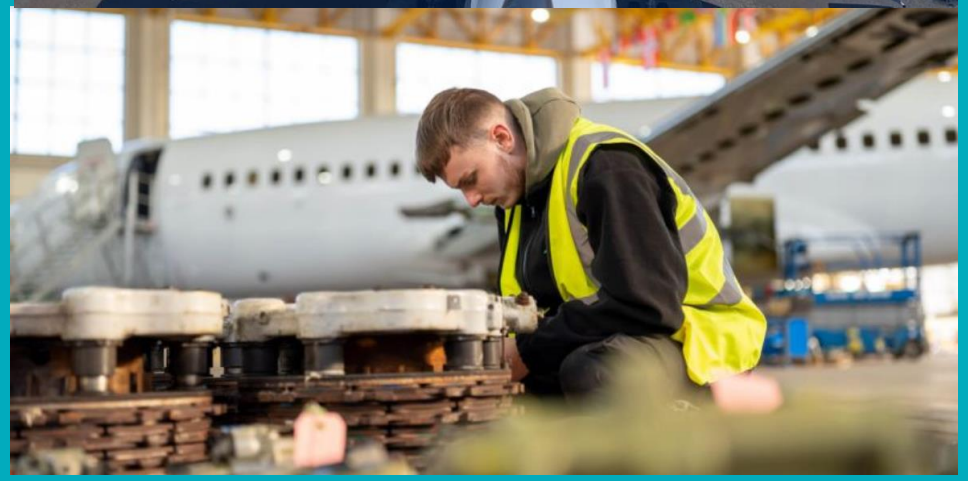
- However the simple mixture of resin and curing agent rarely provides a material with the desired properties for a specific application therefore other materials are added, forming a **composite.**

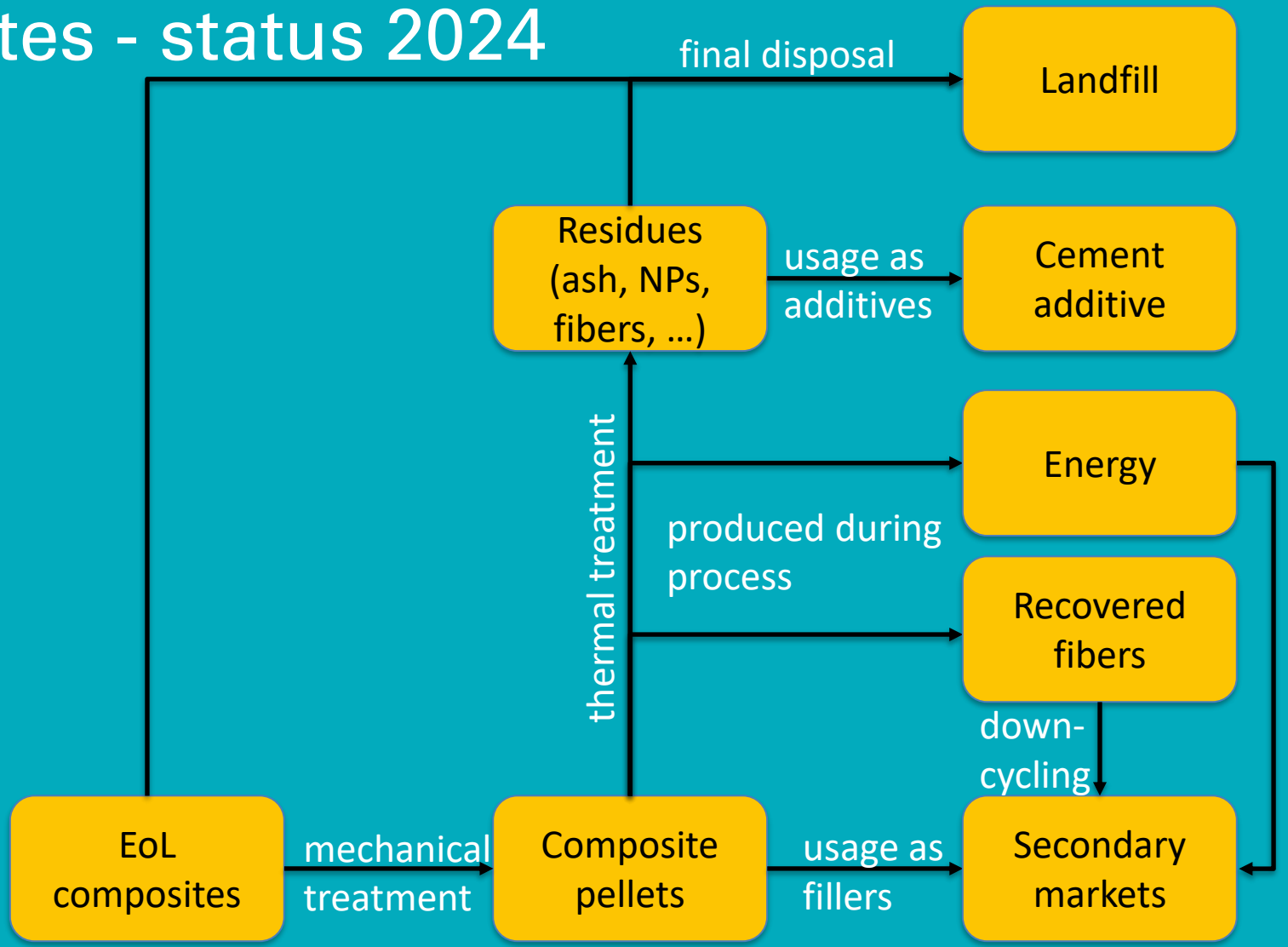
Source: *Plastics Europe; 2006; Epoxy resins and curing agents – toxicology, health, safety and environmental aspects*

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:

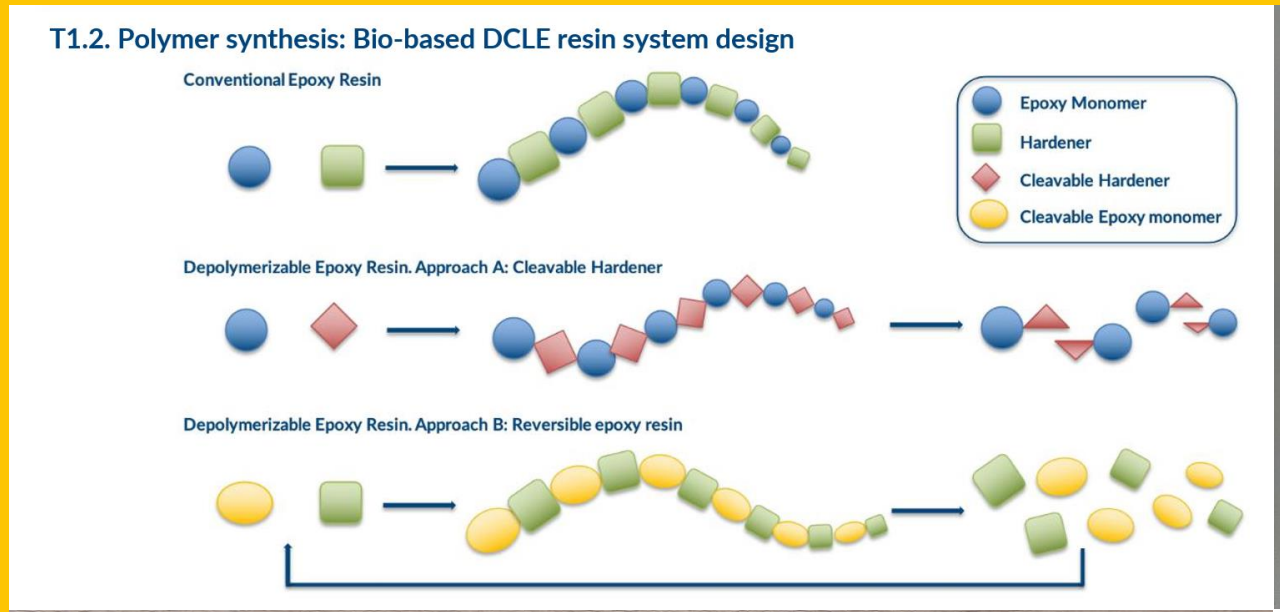
Solvolysis (Hydrolysis, Aminolysis, Supercritical)

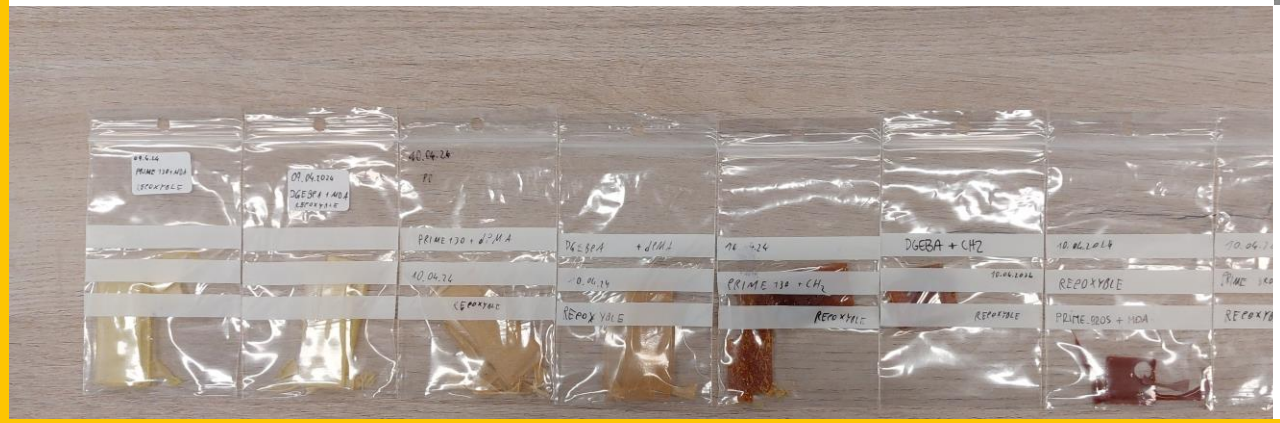
Pros	Cons
High recovery rate (lab scale)	Moderate TRL (< 6)
Enables recovery of most base materials	Usage of hazardous substances
„Good quality“ of recycled material	Market for recycled products not established on larger scale
Depending on method, not energy intensive	

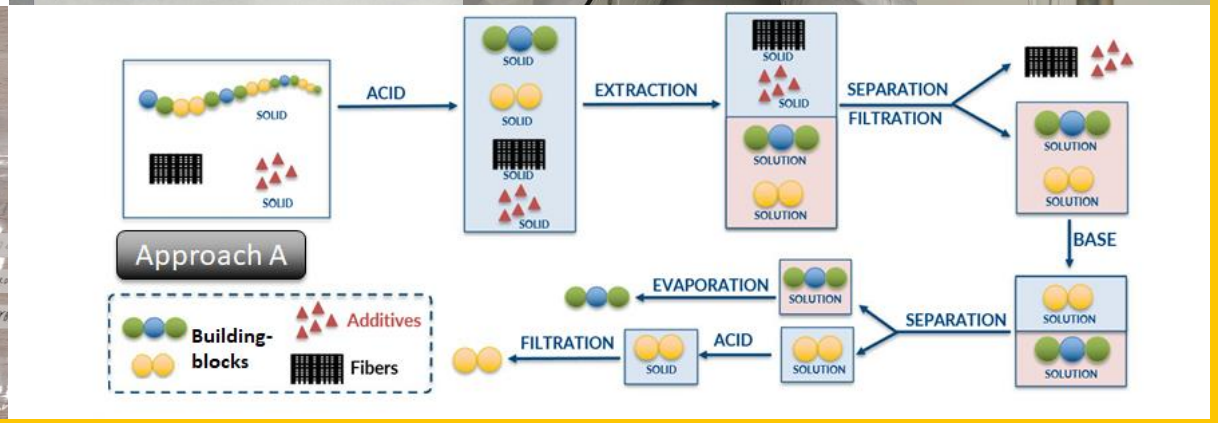
👉Conclusion from recycling comparison

- **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:

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