EURECOMP Project: European recycling and circularity in large composite components

1st EuReComp Workshop

20 April 2023, Dresden

NTUA Coordinator

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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 Objectives

To propose innovative **dismantling** and **sorting** systems enabling reuse and recycling of complex composite materials

To develop and integrate novel solutions for a **higher reuse** of whole products and components

Pilot demonstration of reuse/recycling approaches of composites & secondary raw materials

To develop tools to demonstrate the **circularity** and the **environmental benefits** of the solutions tested

To consider the **co-design of learning resources** together with local and regional educational organizations for current and future generations of employees

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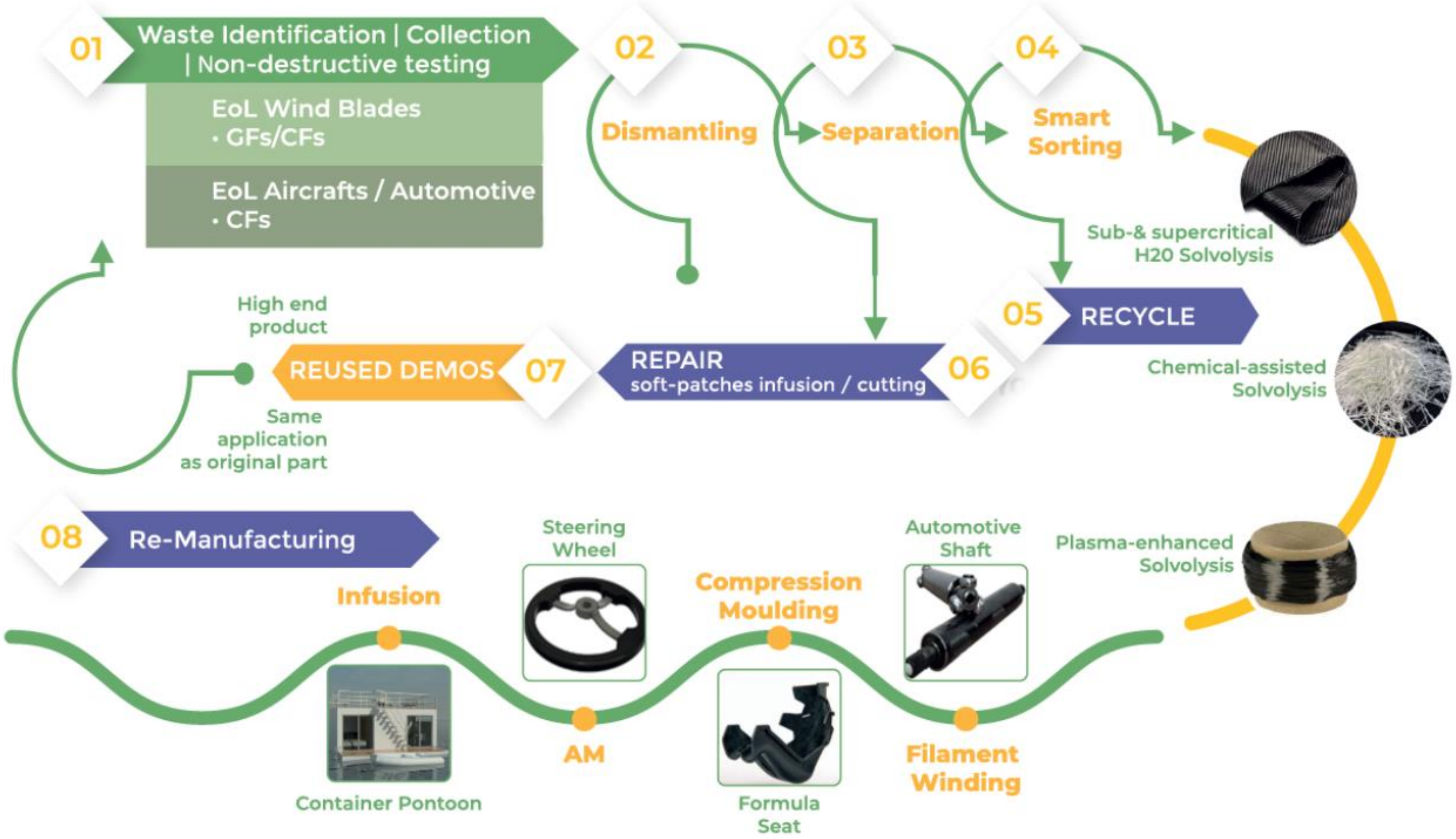
EuReComp Concept



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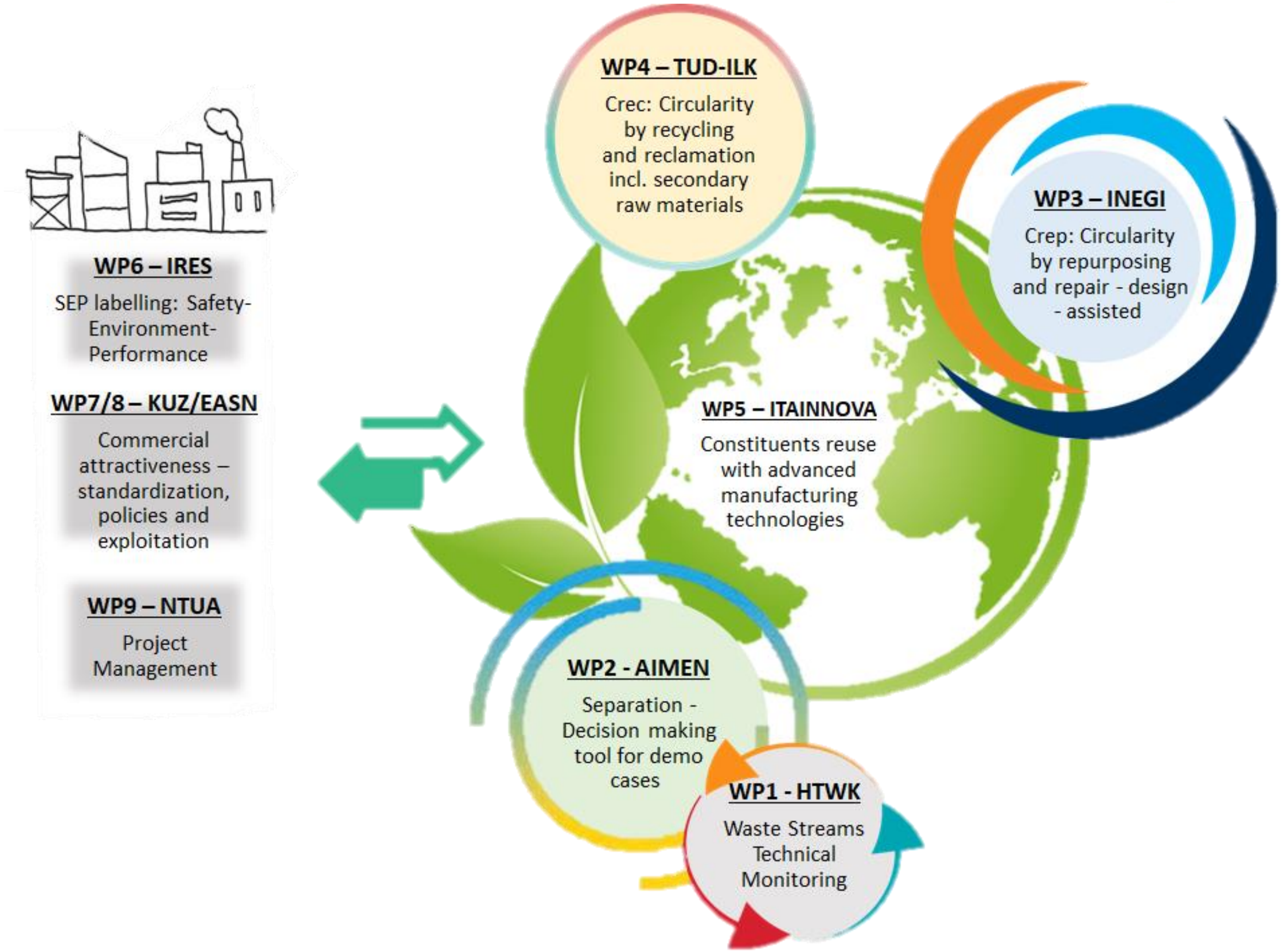
Work Plan



WP6 – IRES
SEP labelling: Safety-Environment-Performance
WP7/8 – KUZ/EASN
Commercial attractiveness – standardization, policies and exploitation
WP9 – NTUA
Project Management
WP4 – TUD-ILK
Crec: Circularity by recycling and reclamation incl. secondary raw materials
WP3 – INEGI
Crep: Circularity by repurposing and repair - design - assisted
WP5 – ITAINNOVA
Constituents reuse with advanced manufacturing technologies
WP2 - AIMEN
Separation - Decision making tool for demo cases
WP1 - HTWK
Waste Streams Technical Monitoring

Acknowledgment

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Thank you!

Dionisis Demitekolos

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National Technical University of Athens

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EoL Composite Materials Market Analysis

EuReComp Workshop, Dresden

20th of April 2023

STRATAGEM

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101058089.

EoL composite materials – Facts & figures

- Relatively new market
- The majority end-of-life composite materials are currently sent to landfills or incinerated
- Increasing interest in the last few years due to environmental concerns
- Expected CAGR of 6.6% from 2020 to 2027, reaching a market size of $5.2 billion by 2027

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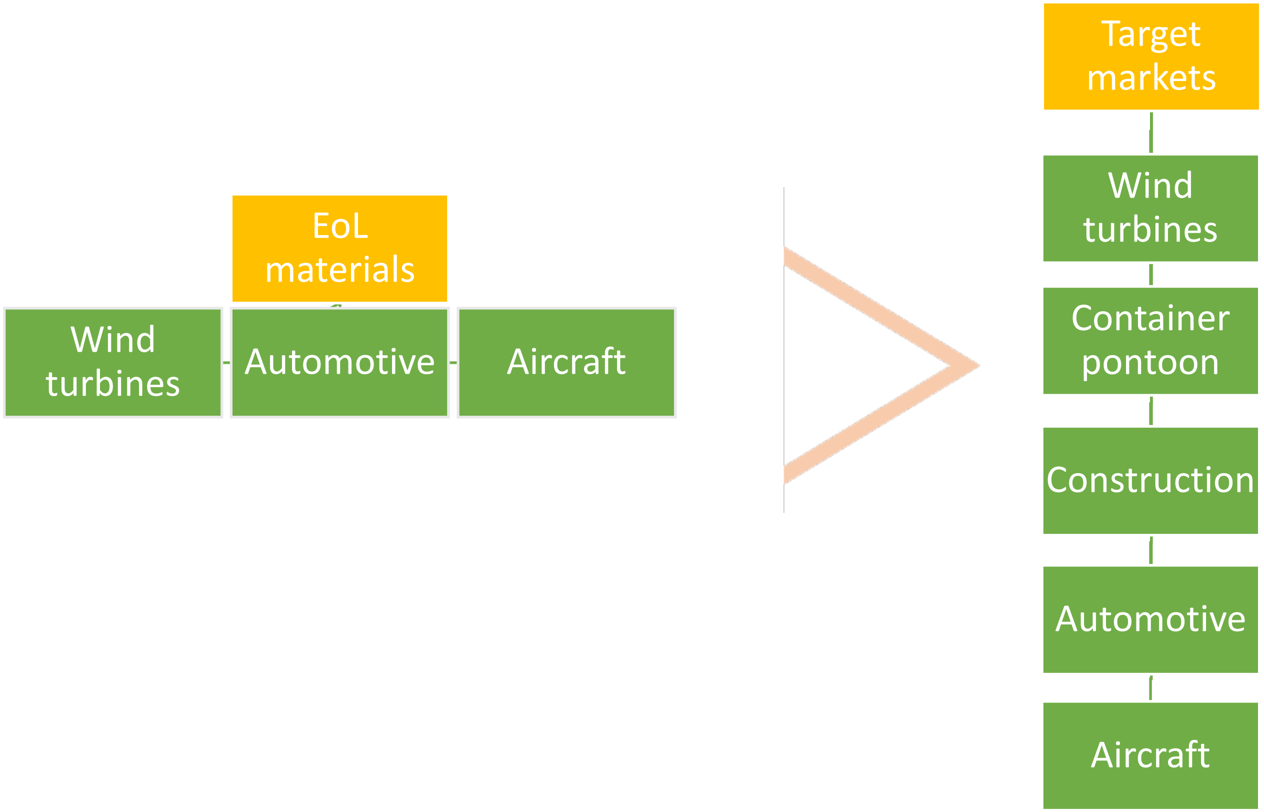
EoL composite materials – Facts & figures



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EoL composite materials – Facts & figures

Vevox Poll on EoL composite materials

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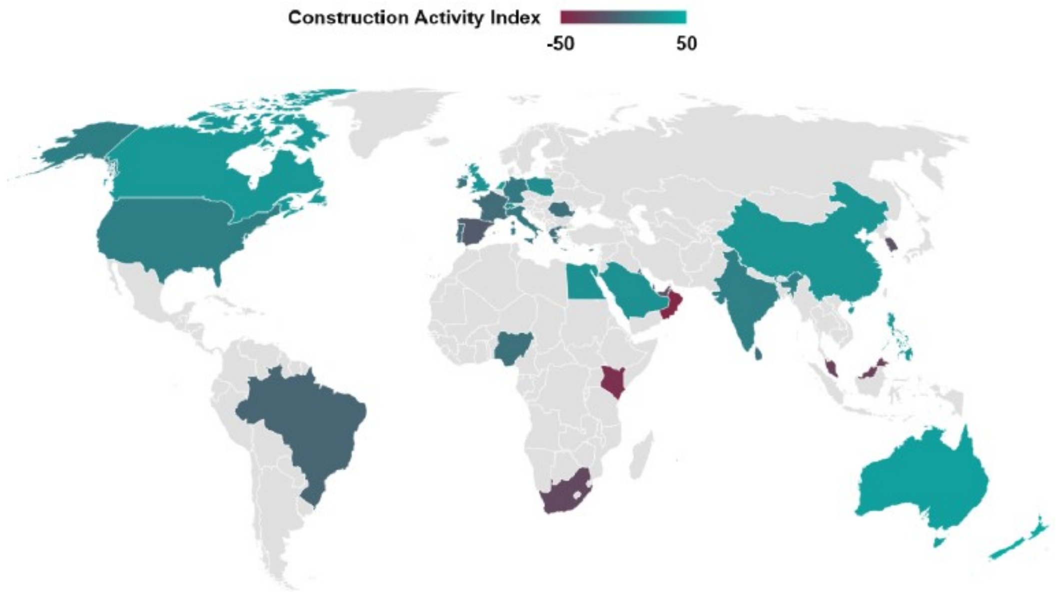
Current and Projected value

Construction market

$12.74 in 2022

CAGR 6.5%

- Growing global population
- Rapid urbanisation
- Rising disposable incomes
- Increasing modernisation of transportation infrastructure
- Increasing private sector investments,
- Increased investment in construction activities
- Growing housing demand.



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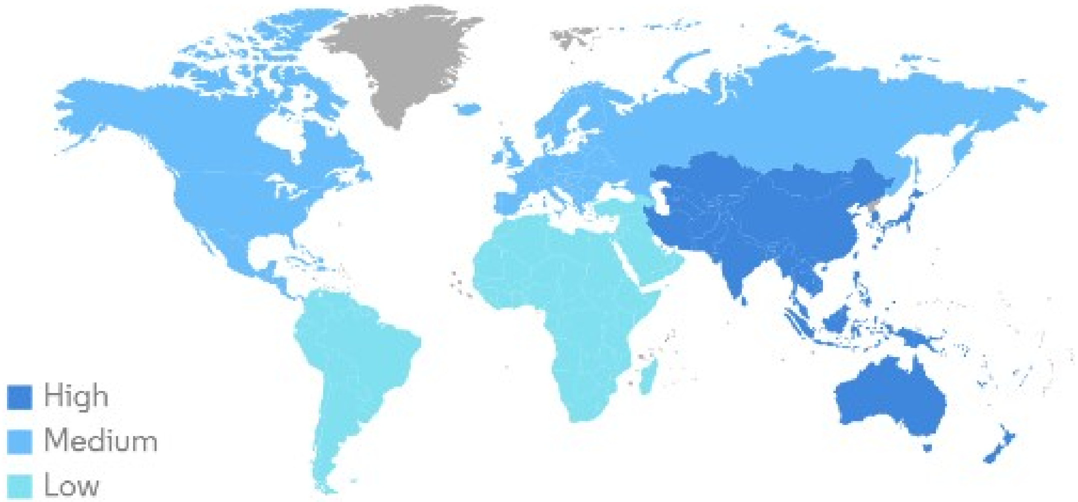
Current and Projected value

Wind turbine market

$53.4B in 2020

CAGR 6.3%

- Constant and rapid industrialization and
- Ambitious government targets for decarbonisation
- Growing energy demands
- Rise in domestic manufacturing



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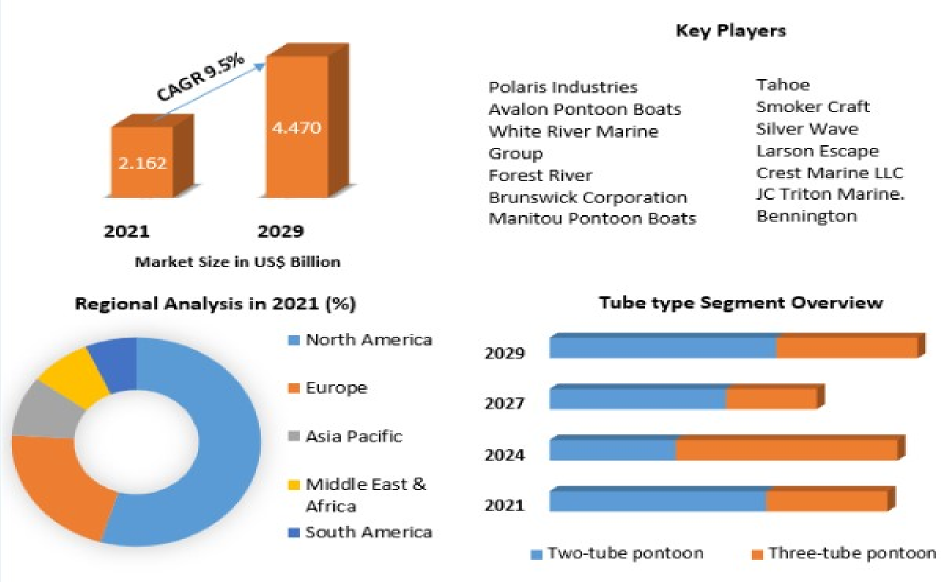
Current and Projected value

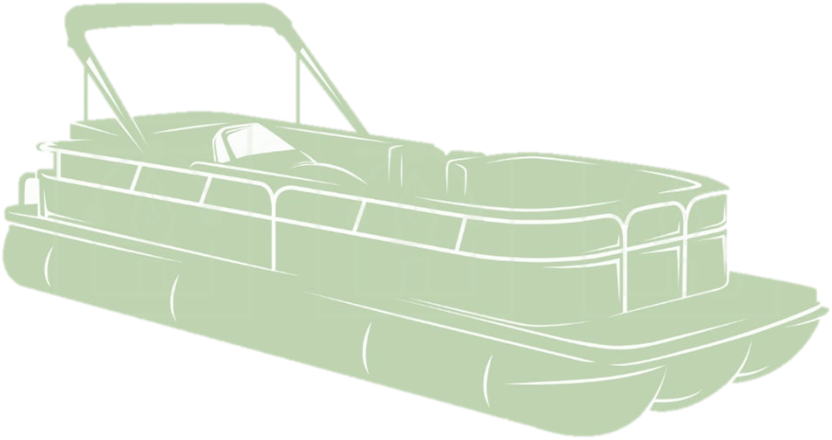
Pontoon market

$2.1B in 2020

CAGR 9.7%

- Boat industry and especially the recreational boating growth leads to this market’s expansion
- IoT technologies will upgrade pontoons into “smart boats” and facilitate real time tracking and smart boating.





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Current and Projected value

Aircraft market

$413.5B in 2021 CAGR 3.7%

- Investments in aircraft market are increasing
- Growing need to connect outer cities with prime aviation hubs
- Focus towards reducing environmental pollution along with the increasing need to improve fuel efficiency

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Current and Projected value

Automotive industry market

- Growing demand for lightweight materials including high strength, stiffness, and durability
- Increased adoption of electric vehicles
- EU legislation in the automotive sector mandated that 85% of a car has to be recyclable

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Challenges and opportunities

Challenges	Opportunities
High Initial Investment Costs	Growing Demand for Sustainable Materials
Lack of Standardization	Cost-effectiveness
Limited Supply of Feedstock	Advancements in Manufacturing Technologies
Regulatory and Environmental Issues	Increased Government Support

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Thank you!

Evangelos Koulis

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R^6 strategy within EuReComp

Philipp Johst

20th April 2023, Open Workshop, Dresden

HTWK – Leipzig, 9:10 – 9:35

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HTWK
Leipzig University
of Applied Sciences

Structure of the presentation

- Problem / Motivation

- Definition of various R-strategies

- Systematized R^6-strategy & Example E40 WTB

- Conclusion

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Problem / Motivation

- Demand for composites increased significantly
- Composites are often used in aerospace-, wind energy- and transportation- industry

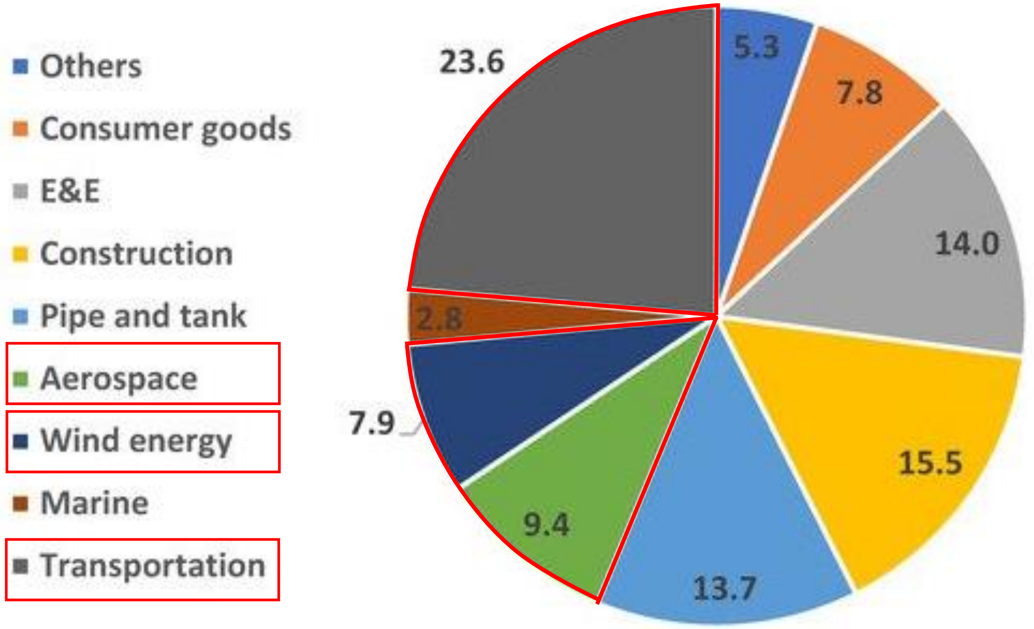

Figure: Global composite materials‘ market size distribution, by application, in 2020

Reference: Amaechi 2020 et al

Reference: https://www.auto-motor-und-sport.de/technik/bmw-i3-technik-mit-spannung-erwartetes-e-auto/

Reference: https://www.bam.de/Content/EN/Standard-Articles/Topics/Energy/article-inspection-of-rotor-blades.html

Reference: https://www.aerotelegraph.com/airlines-sollen-boeing-787-auf-wasserlecks-ueberpruefen

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Problem / Motivation

Aerospace sector

Reference: https://fing.htwk-leipzig.de/forschung-transfer/leichtbau-mit-verbundwerkstoffen/

By 2035, a value of **23.360t/year** of aircraft composite **waste** is estimated.

Reference: Karuppannan 2020

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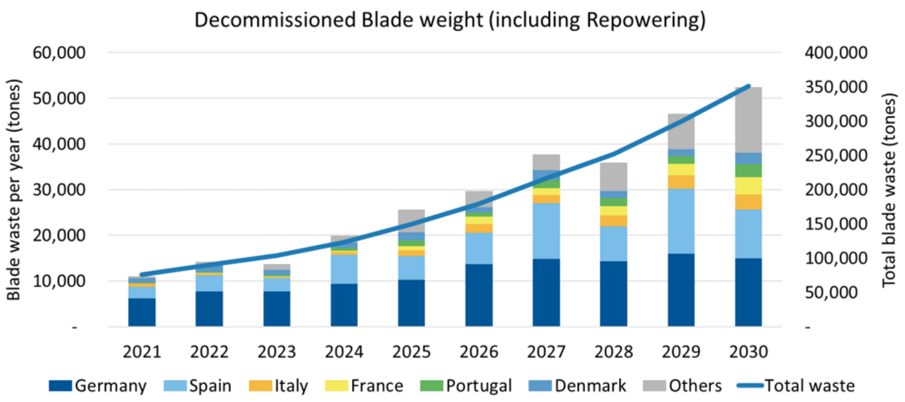
Wind energy sector

Reference: own figure



Reference: WindEurope

By 2030, a value of **50.000t/year** of wind turbine blade composite **waste** is estimated.

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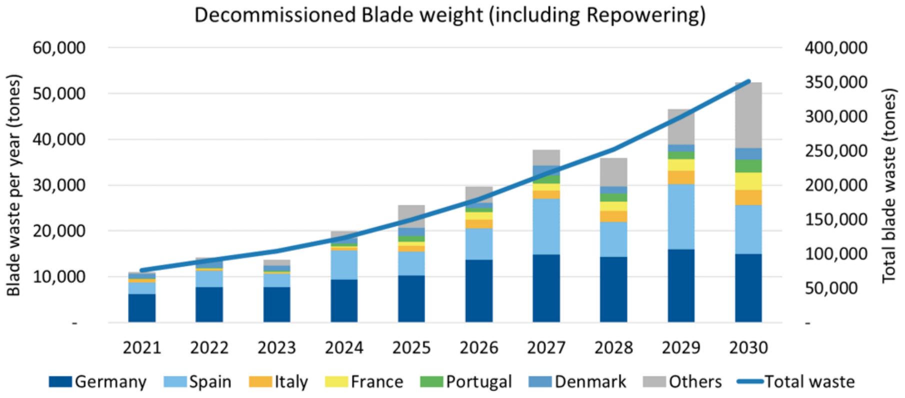

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Reference: WindEurope

- *Recycling technologies* for composite components are not sufficiently developed yet.
- Transition to a Circular Economy model → **waste** becomes a **valuable resource**

- Lower resource and material consumption
- Less generation of waste
- Extending the lifetime of products

- **New pathways are required to ensure an effective multiple use of End-of-life (EoL) components!**

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Definition of the various R‘s – Potting et al.

- 10 different R‘s → Some refer to product planning or imply incineration

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Definition of the various R‘s – Potting et al.

- 10 different R‘s → Some refer to product planning or imply incineration

- Systematized R^6 strategy consists of six different R-strategies:

Repair: “*Repair and maintenance of defective product so it can be used with its original function.*”

Reuse: “*Reuse by another consumer of discarded product which is still in good condition and fulfils its original function.*”

Refurbish: “*Restore an old product to bring it up to date.*”

Remanufacture: “*Use parts of discarded product in a new product with the same function.*”

Repurpose: “*Use discarded product or its parts in a new product with a different function.*”

Recycling: “*Process materials to obtain the same (high grade) or lower (low grade) quality.*”

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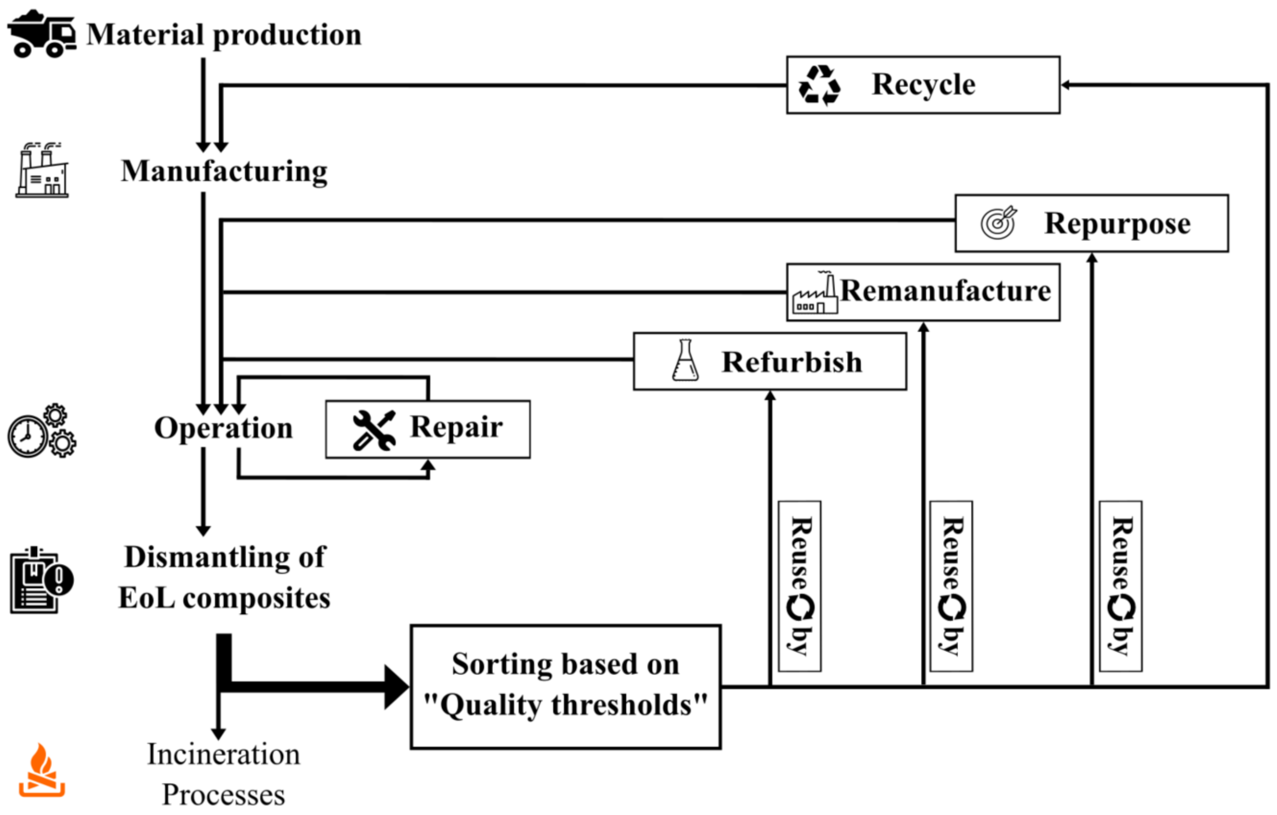
R^6 strategy



Reference: Johst et al. 2023

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R^6strategy – Repair

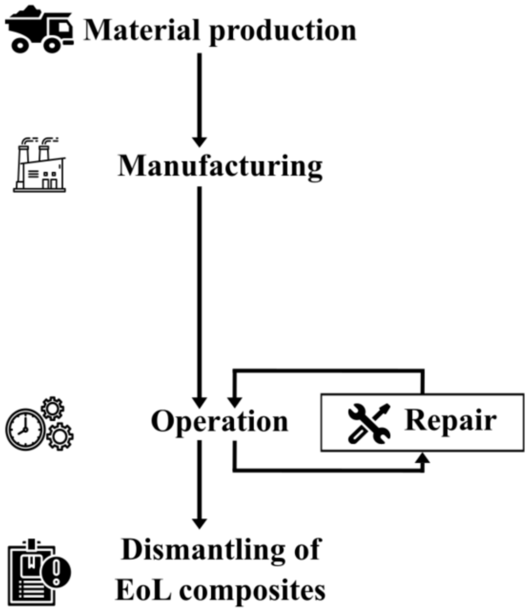
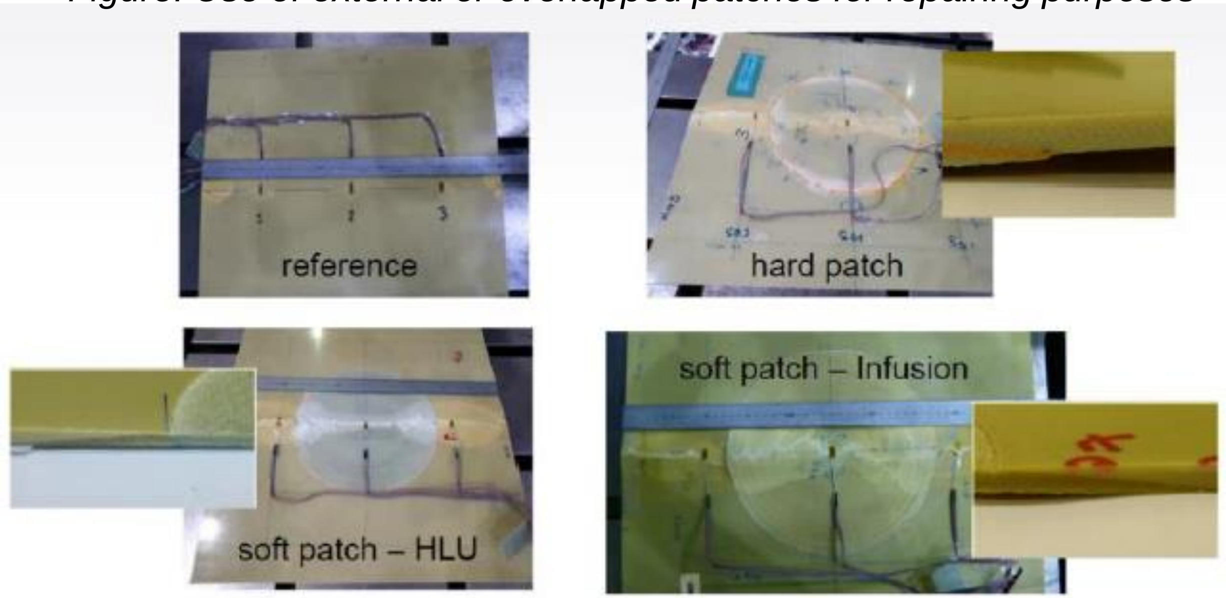


Figure: Use of external or overlapped patches for repairing purposes



Reference: Proposal

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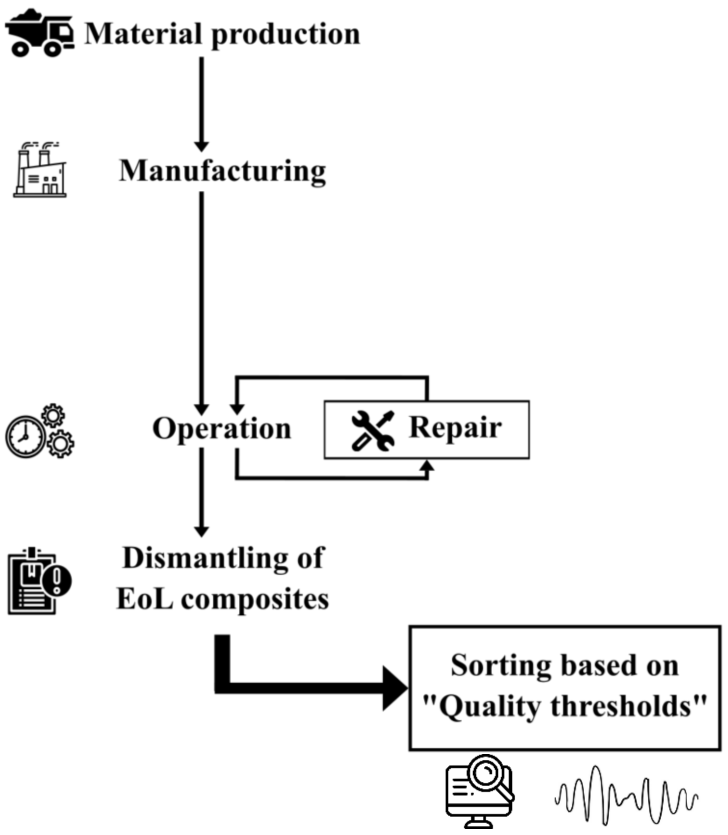
R^6strategy – Sorting



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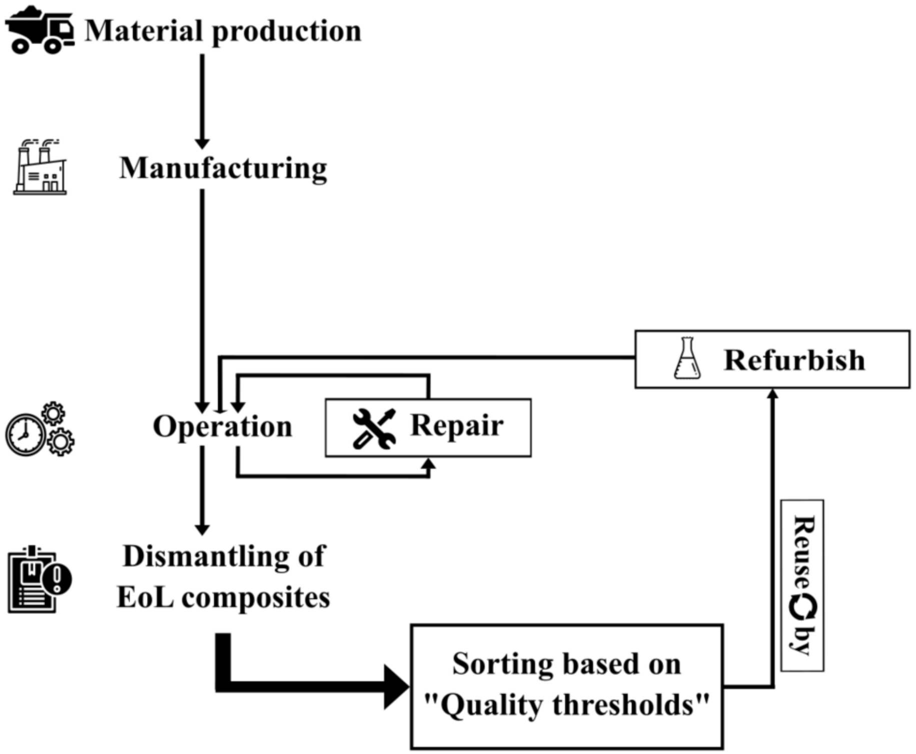
R^6 strategy – Refurbish



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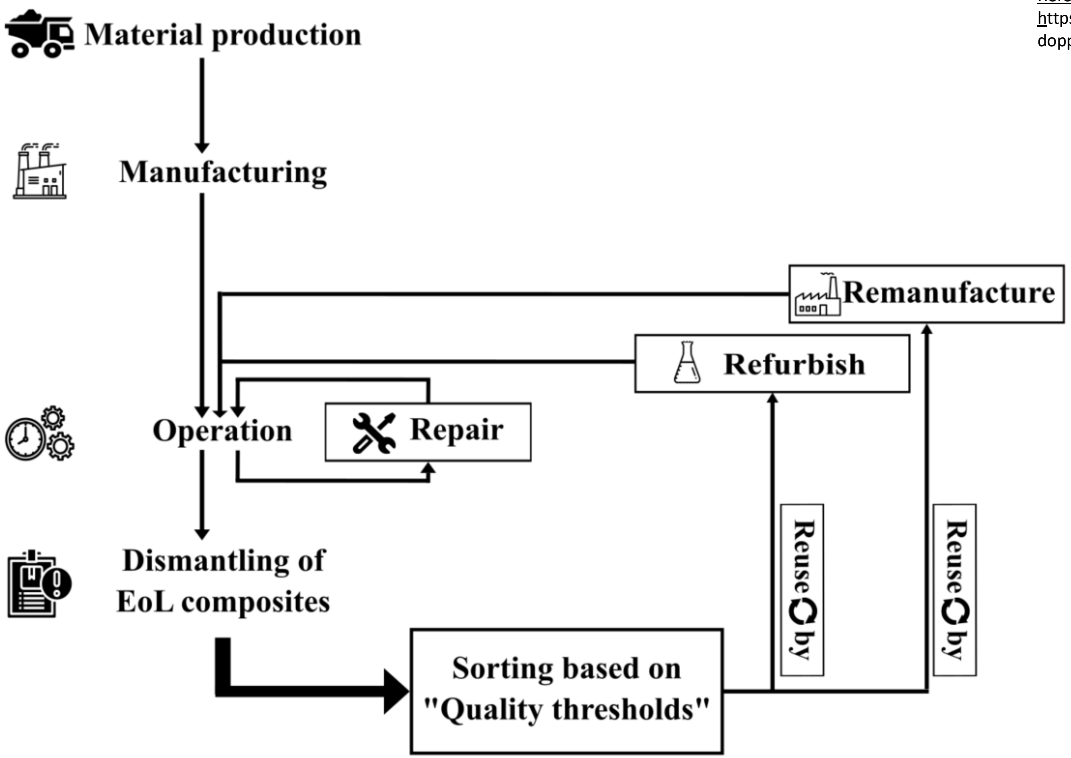
R^6 strategy – Remanufacture



Reference:
https://wingdesign.com/shop/flugzeugmoebel/flugzeugfenster/doppel-flugzeugfenster-wandelement/

Reference:
https://www.aerotime.aero/articles/31236-second-life-of-retired-plane

Reference: https://www.aerotelegraph.com/airlines-sollen-boeing-787-auf-wasserlecks-ueberpruefen

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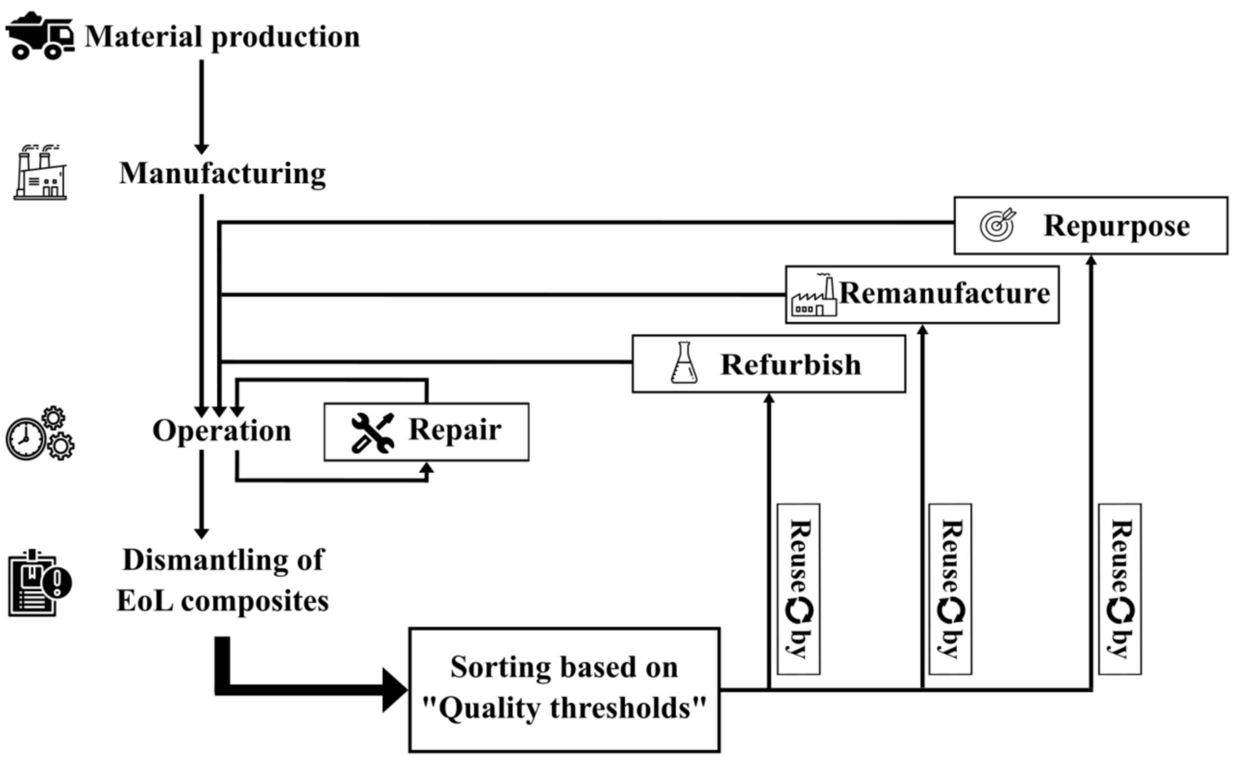
R^6 strategy – Repurpose



Reference: Hotels.com

Reference: https://www.rte.ie/brainstorm/2022/0804/1287943-what-can-you-do-with-used-wind-turbine-blades/

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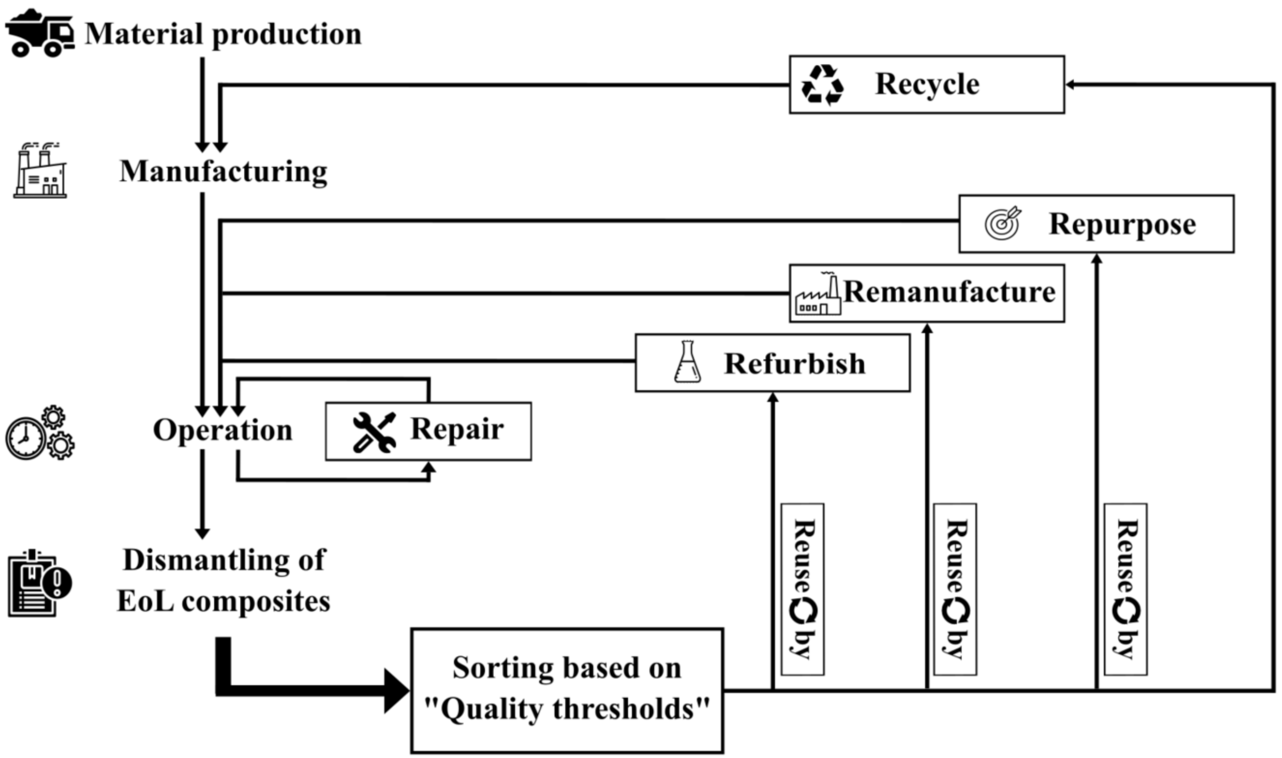
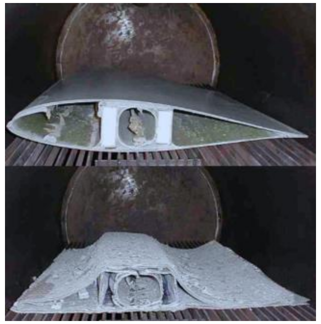
R^6 strategy – Recycle



Thermal



Reference: Larsen 2009

Chemical

Reference: https://prozesstechnik.industrie.de/

Mechanical

Reference: https://www.eurecum-gmbh.de/galerie/

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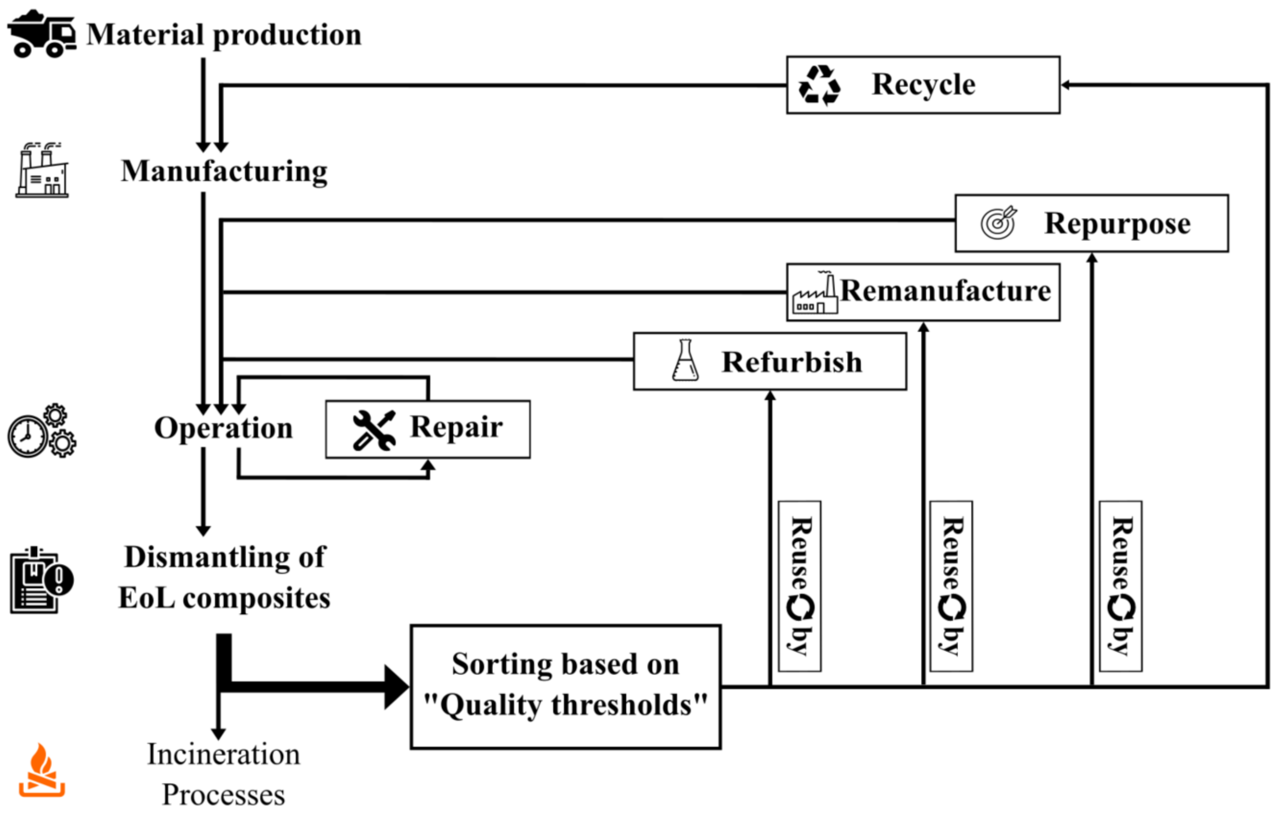
R^6 strategy



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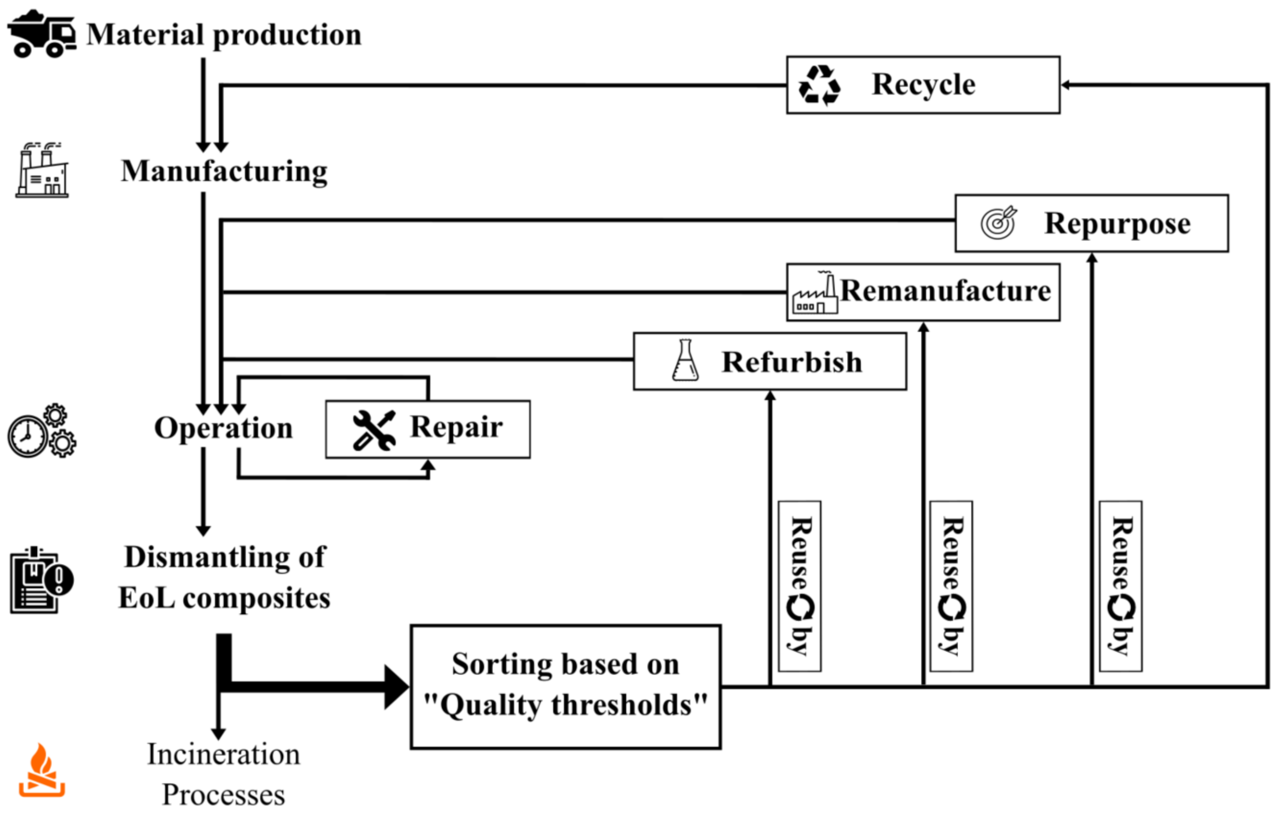
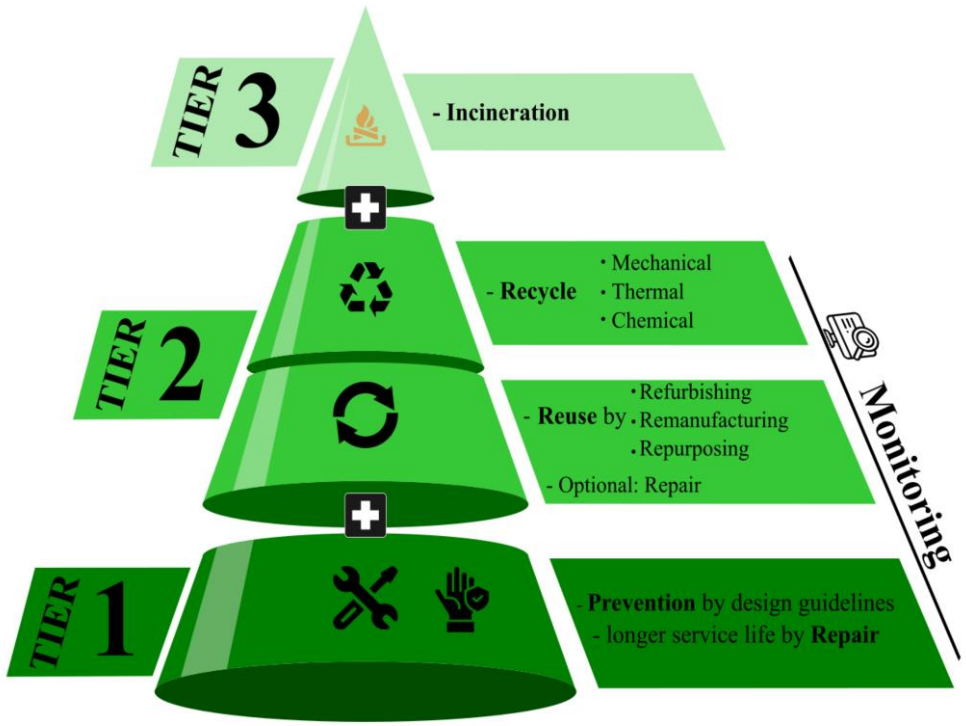
Systematization of R^6- strategy





<u>Reference:</u> *Johst et al. 2023*

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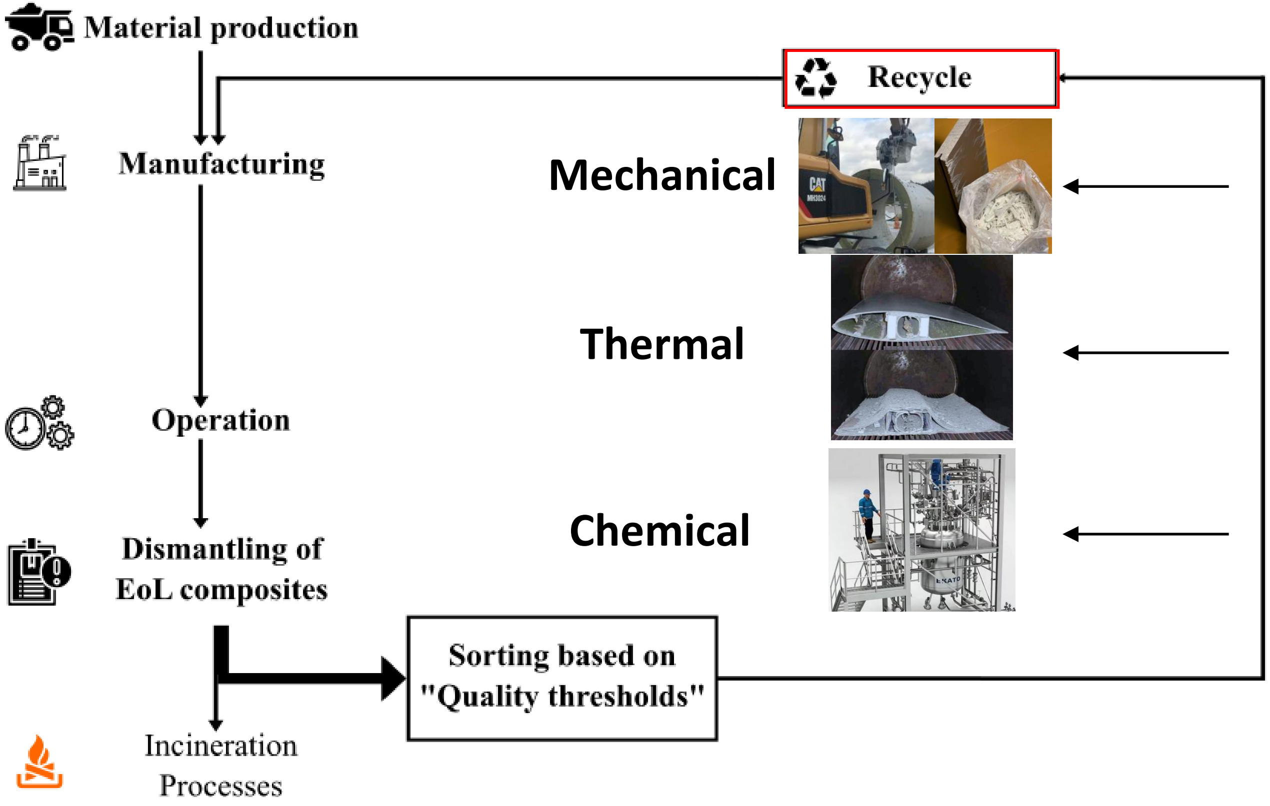

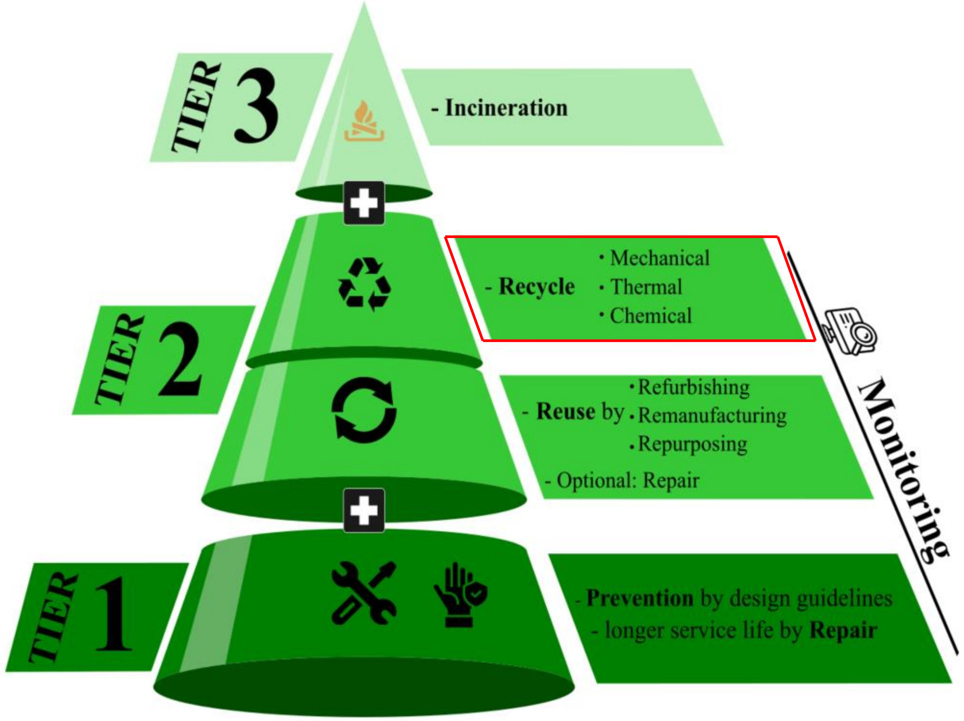

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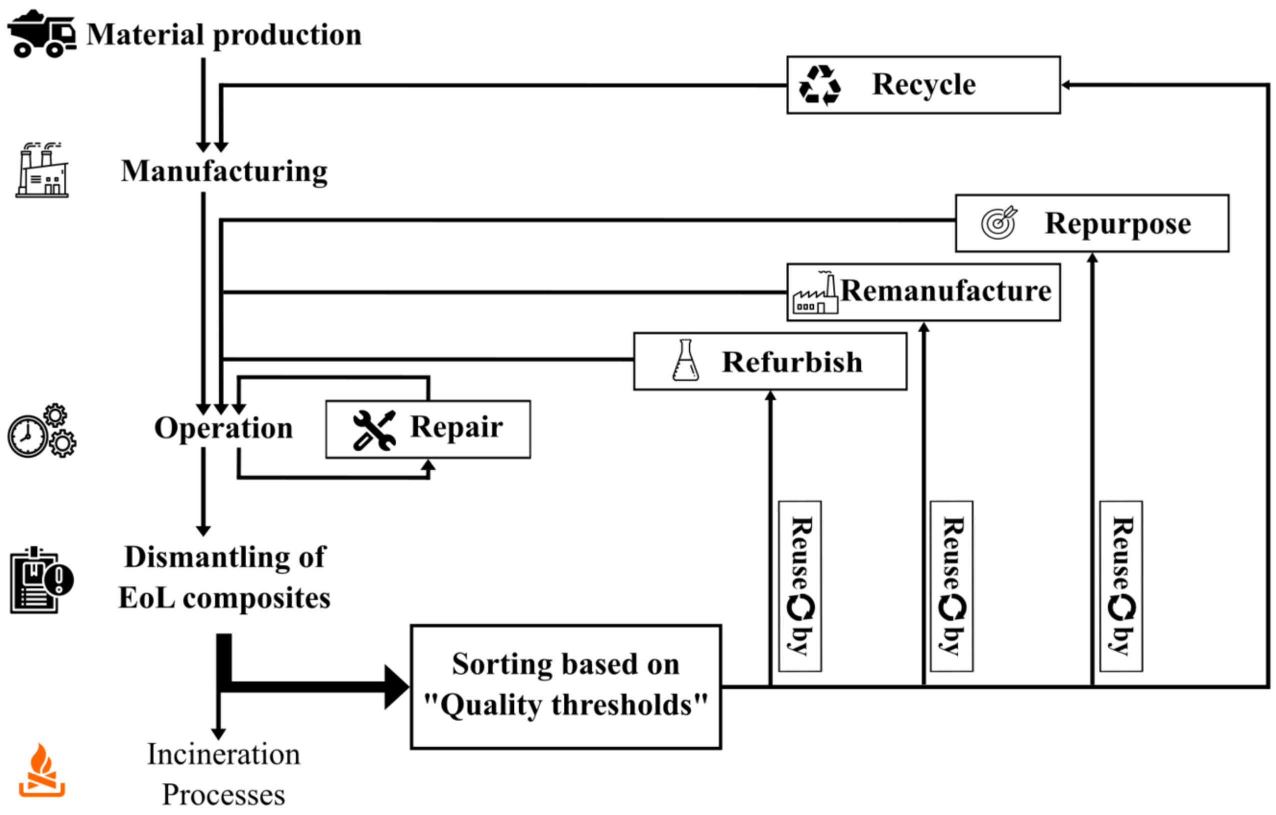

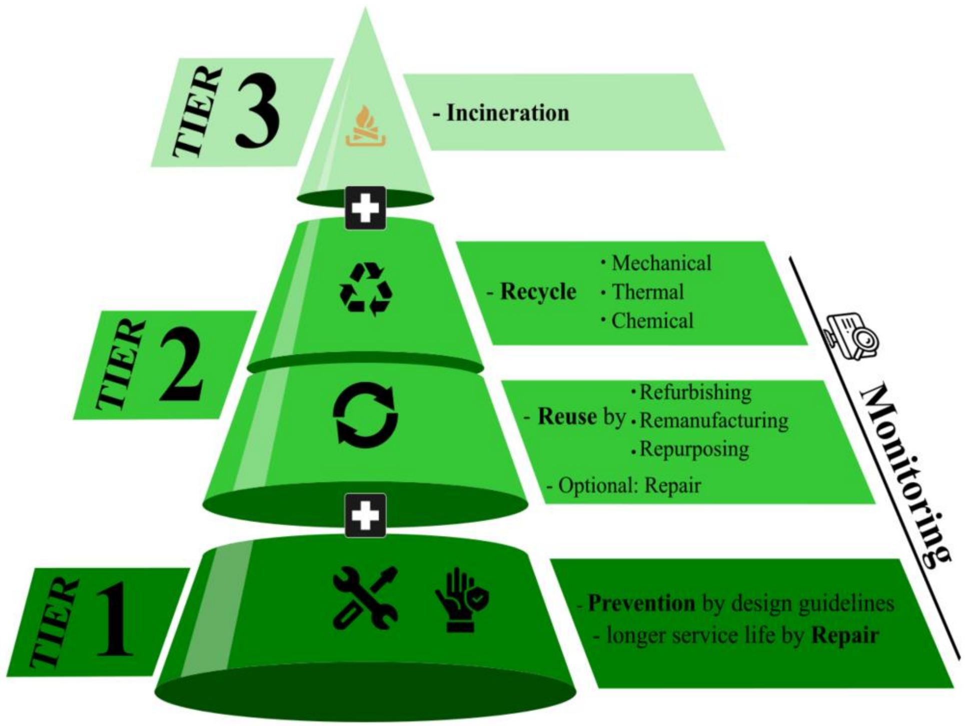

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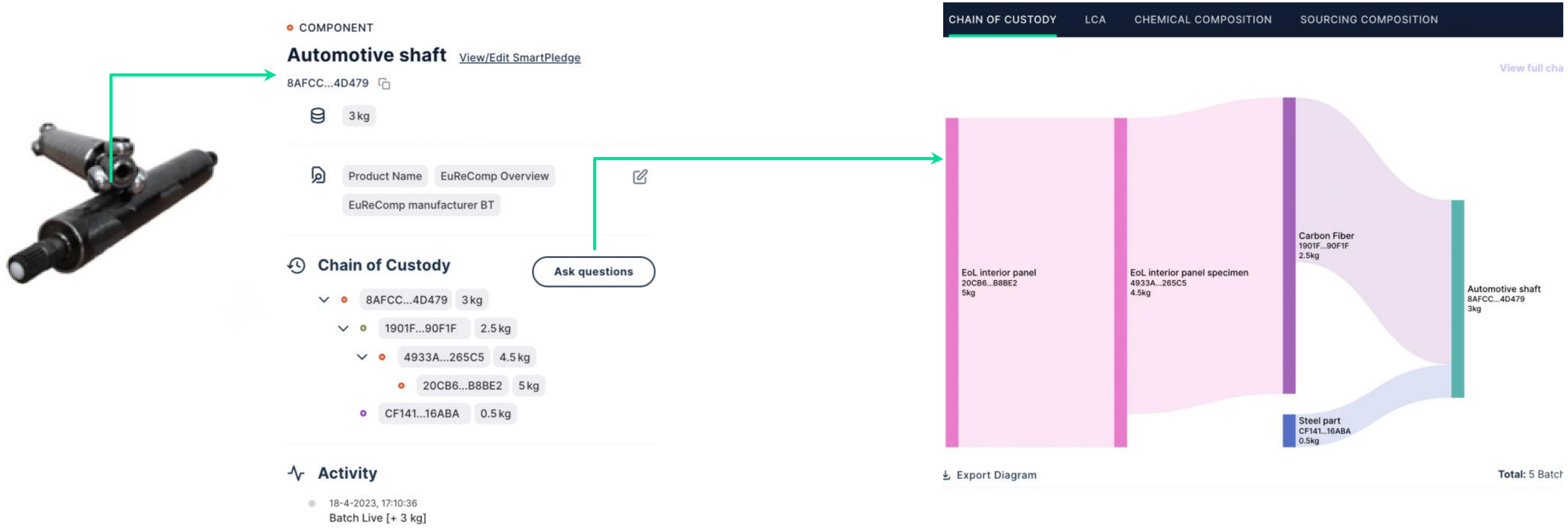
R^6- strategy – information flow



1. **Showcase innovation and sustainability efforts** to strengthen your brand
2. **Incentivise sustainable behaviour change** e.g. to support take-back systems
3. **Differentiate your sustainable products** to grow your revenue
4. **Share information** e.g. user or repair guides to support maintenance and product life time extension

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CIRCULARISE

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Example: EoL E40 WTB

E40 wind turbine

Reference: https://wind-turbine.com/

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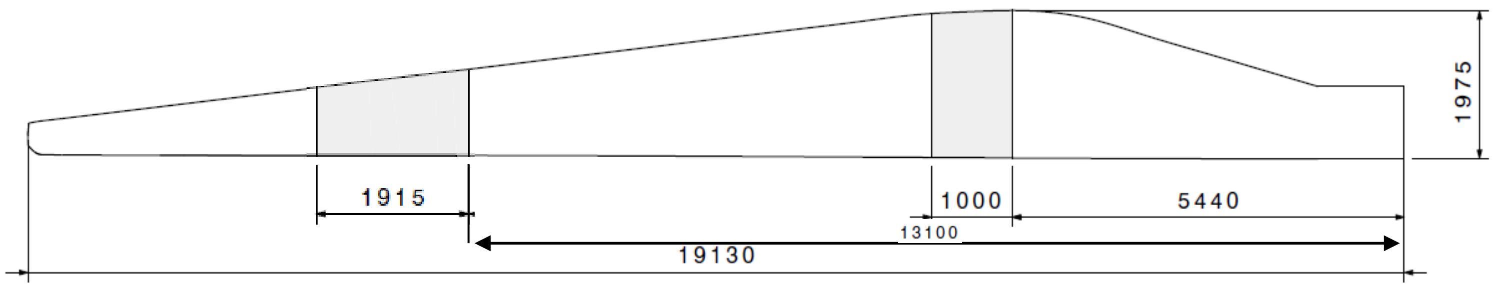

Reference: Bühl 2023

feature	value (kg)	
total mass	**946.75**	100%
glass fiber	**568.1**	60%
Thermoset resins	**217.8**	23%
Core material (kg)	85.2	9%
Metals (kg)	75.7	8%

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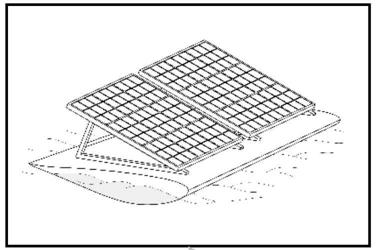
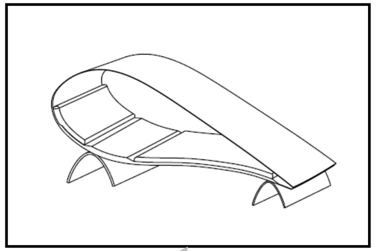
Example: EoL E40 WTB

E40 wind turbine

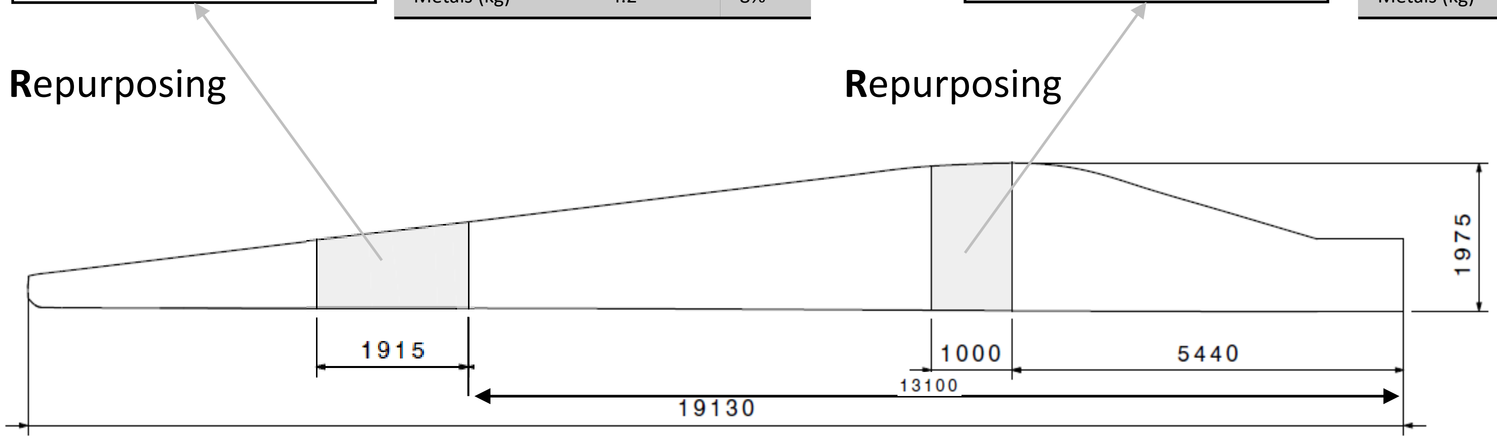
Reference: https://wind-turbine.com/



feature	value (kg)	
total mass	52.2	100%
glass fiber	31.3	60%
Thermoset resins	12	23%
Core material (kg)	4.7	9%
Metals (kg)	4.2	8%



feature	value (kg)	
total mass	32.2	100%
glass fiber	19.3	60%
Thermoset resins	7.4	23%
Core material (kg)	2.9	9%
Metals (kg)	2.6	8%



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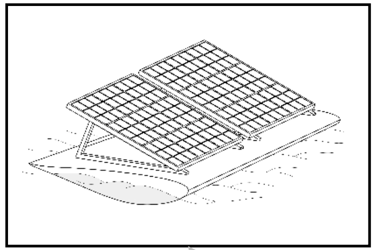

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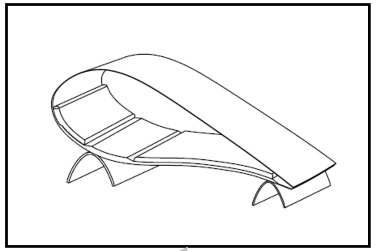
Repurposing



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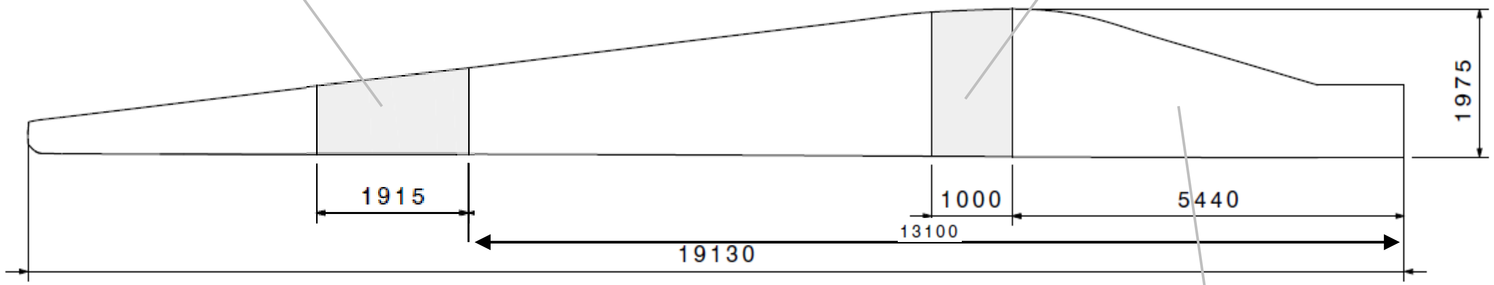

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mech. **R**ecycling

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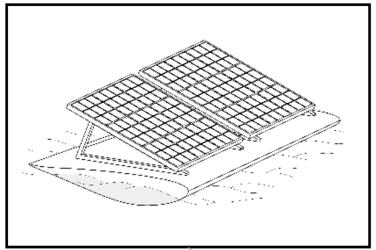

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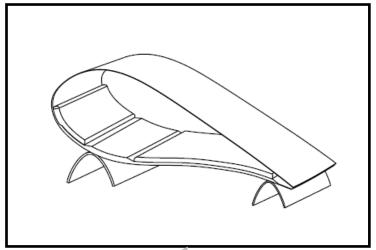

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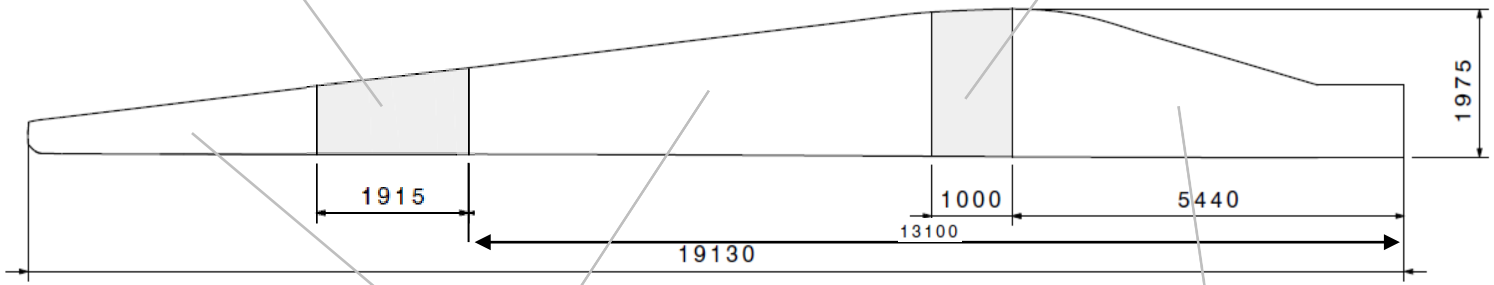

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ch. **R**ecycling

mech. **R**ecycling

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Conclusion

- Systematized R6 strategy aims for waste reduction and energy/emission savings

- Framework consists of: **Re**use, **Re**pair, **Re**furbish, **Re**manufacture, **Re**purpose, and **Re**cycling

  → *The* ***R-strategies*** *are harmonizing strategies supporting each other.*

- Legislative framework is not convincing to encourage such an economic circularity in Europe

- Comprise closed loops, starting with the sorting based on quality thresholds

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Thank you!

Philipp Johst

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HTWK – Leipzig

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Acknowledgment

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Consortium

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rethink rotor
OX2 architekten
Ina-Marie Orawiec Marcin Orawiec
Fachbereich
Architektur


Motivation
mineral raw materials consumption
90%
CO2
Greenhouse gas emissions
ca. 41 %
Volume of waste
55%
Gray energy, which is contained in every manufactured product, is irretrievably lost if we do not reuse the parts.

7500
rotorblades
yearly

Did you know?

wind power
21,7 % gross power / Germany

strongly growing market

What happens after 20 years?


250 m height
Kölner Dom, 157,22m height
Commerzbank Tower, Frankfurt am Main, 259m height

Participants:
Darmstadt University of Applied Sciences

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Prof. Marcin Orawiec
Prof. Thorsten Helbig
LB Jasmina Herrmann
Niklas Murmann // Student

Department of Structural Engineering
Dr. Markus Schmidt

Department of Environmental Engineering
Prof. Dr. Iris Steinberg
Leon Liebeskind // Student

Department of Mechanical engineering and plastics technology
Prof. Dr. Andreas Büter

The project was supported by
Fraunhofer-Institut für Windenergiesysteme IWES

Results

University of applied sciences Darmstadt

Exhibition

„BAULAB“- real labs of the h_da

awarded by Hessischen Wirtschaftsminister

Zukunftspreis des Großen Frankfurter Bogens 2022

roof trusses

stadiums, indoor swimming pools, sports halls warehouses, industrial buildings

large components - beltet segments

supports, beams, cantilevers

fiber structures, yarns

lightweight construction

reuse

repair

recycle

roof trusses

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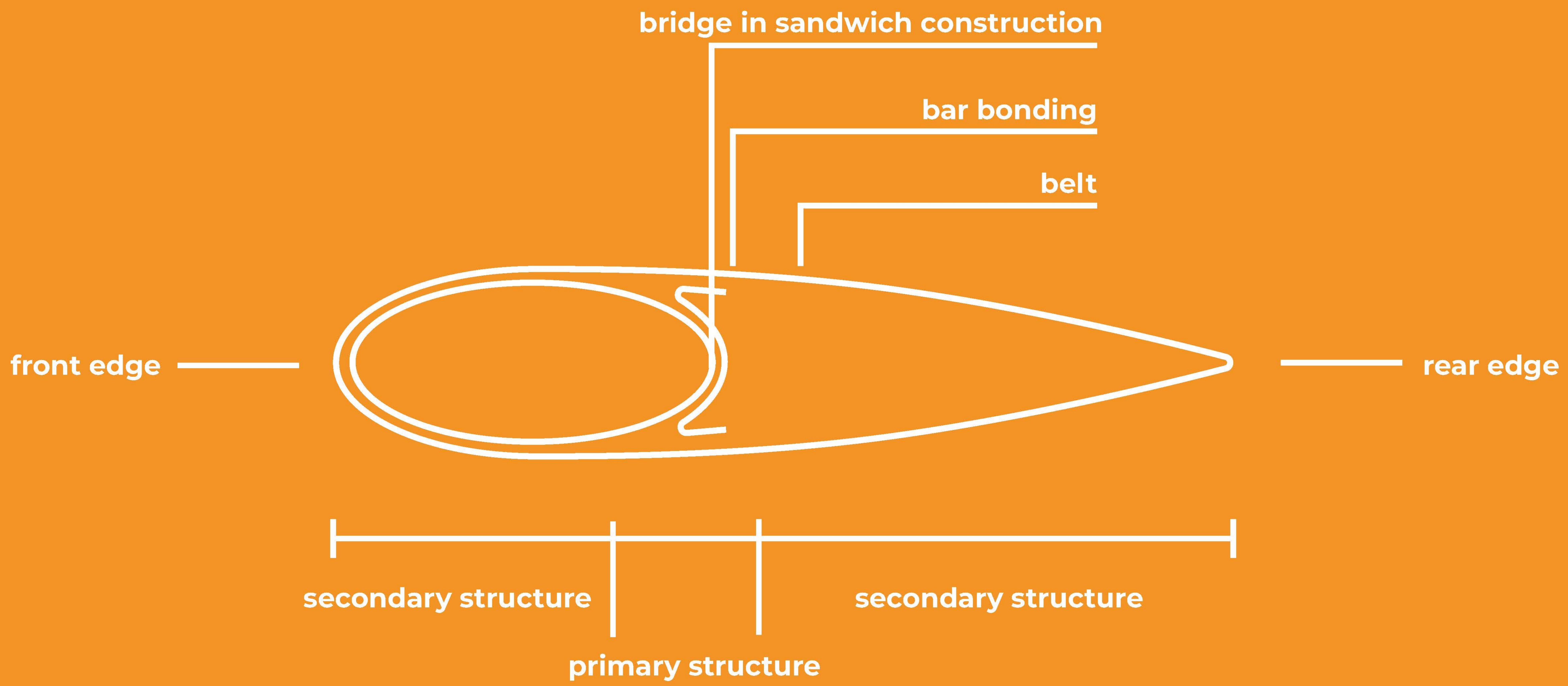

bridge in sandwich construction
bar bonding
belt
front edge
rear edge
secondary structure
primary structure
secondary structure

Hollow body with various stiffening ribs.

dimensionally stable
light
hollow
corrosion
resistant
functional
...

beautiful

function

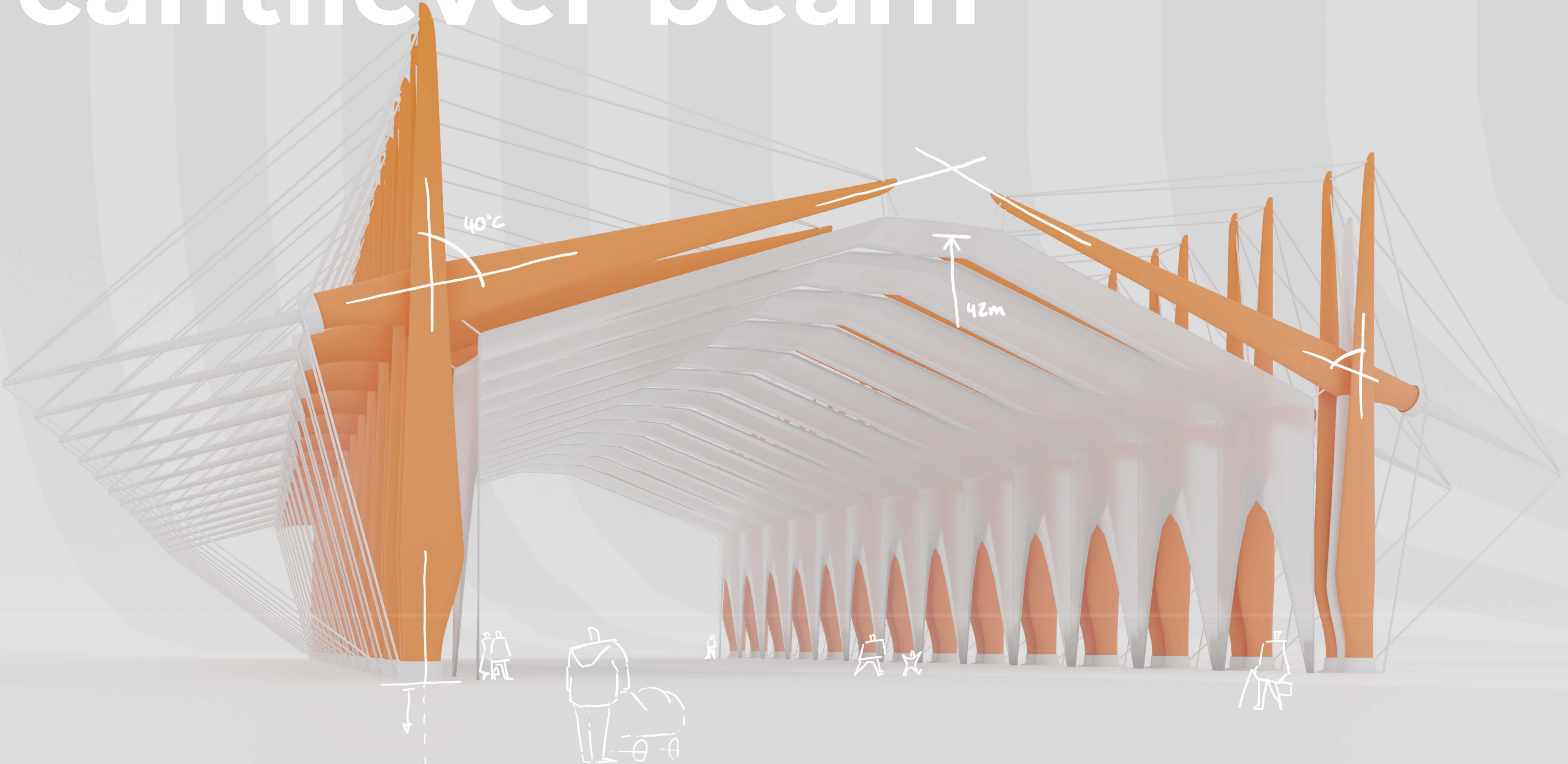
pontoon construction


Pacific
Tuvalu

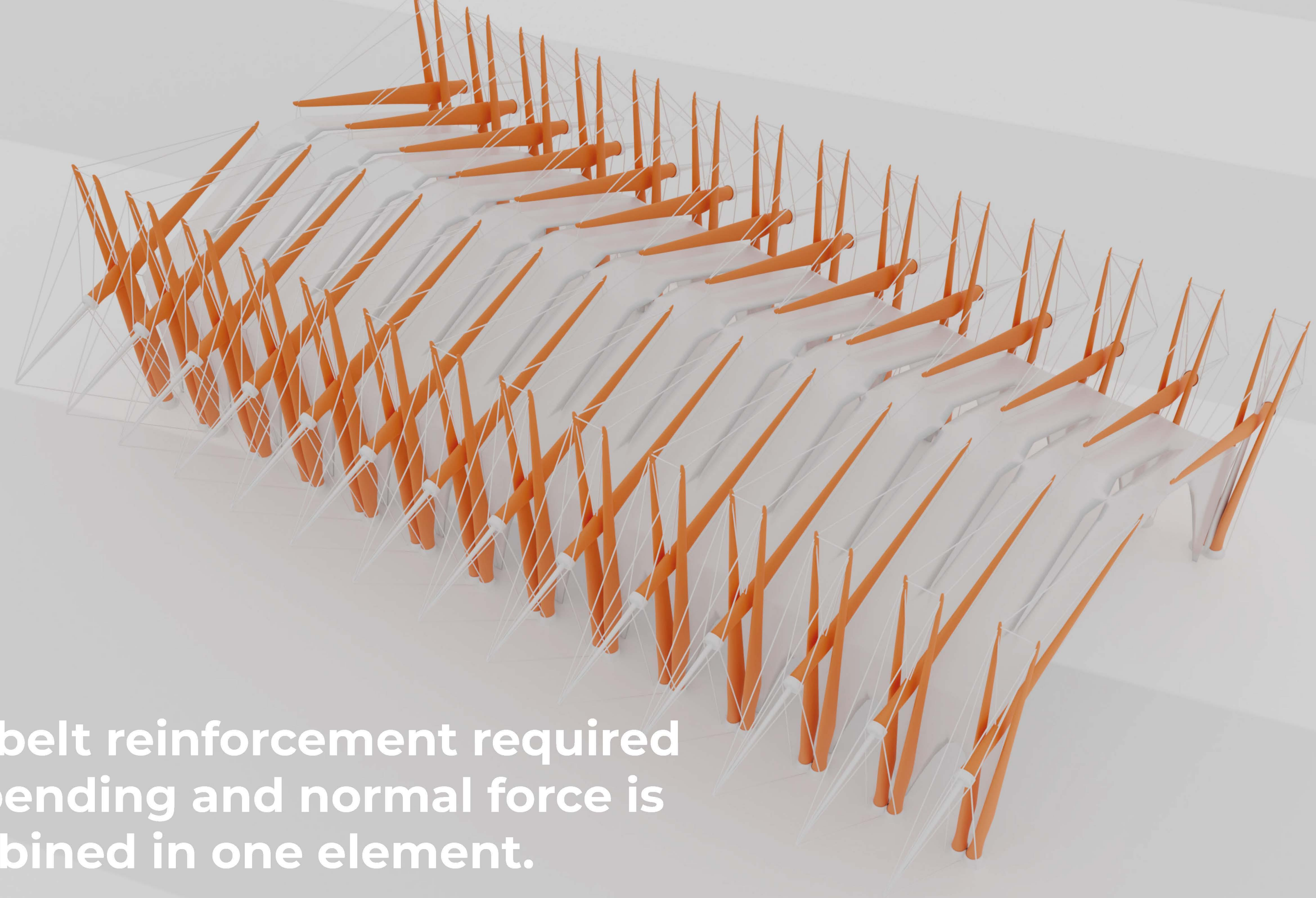
coastal protection

noise barrier

cantilever beam



retrim rotor OX2architekten Fachbereich Architektur



The belt reinforcement required for bending and normal force is combined in one element.


40°


Lightshaft
Structure
Stiffness Ring
Shaded
Area
Performance
Lighting
Passthrough
Entrance

stadium

shukhov tower

To be continued...

NDT and spectroscopic techniques for EoL composites

1st EuReComp workshop

April 20th 2023, Dresden

David Castro, Camilo Prieto (AIMEN)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101058089.

OUTLINE

- NDT TECHNIQUES
  - MOTIVATION
  - TYPE OF DEFECTS
  - THERMOGRAPHY, ULTRASOUNDS (UT),..

- SPECTROSCOPIC TECHNIQUES
  - MOTIVATION
  - HYPERSPECTRAL IMAGING
  - LASER-INDUCED BREAKDOWN SPECTROSCOPY (LIBS)

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1. MOTIVATION

- ❑ Why composite inspection?

  - ➢ Much higher percentage of composites in today’s world.
  - ➢ Need to detect discontinuities that can lead to catastrophic failure
  - ➢ To assess EoL components integrity to decide R6 strategy

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What causes defects in composites?

- **Incorrect design:**
  - can cause unevenly distributed stresses or loads among the layers.
- **Incorrect manufacturing processes:**
  - as incorrect material mixing, poor layer placemen, poor curing.
- **Mechanical damage:**
  - repeated mechanical loads or exposure to impacts.
- **Exposure to environmental factors:**
  - humidity, temperature, radiation, pressure.
- **Improper use:**
  - loads or stresses that exceed its capacity

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2. COMPOSITE DEFECTS

TYPES OF DEFECTS:

Delamination:

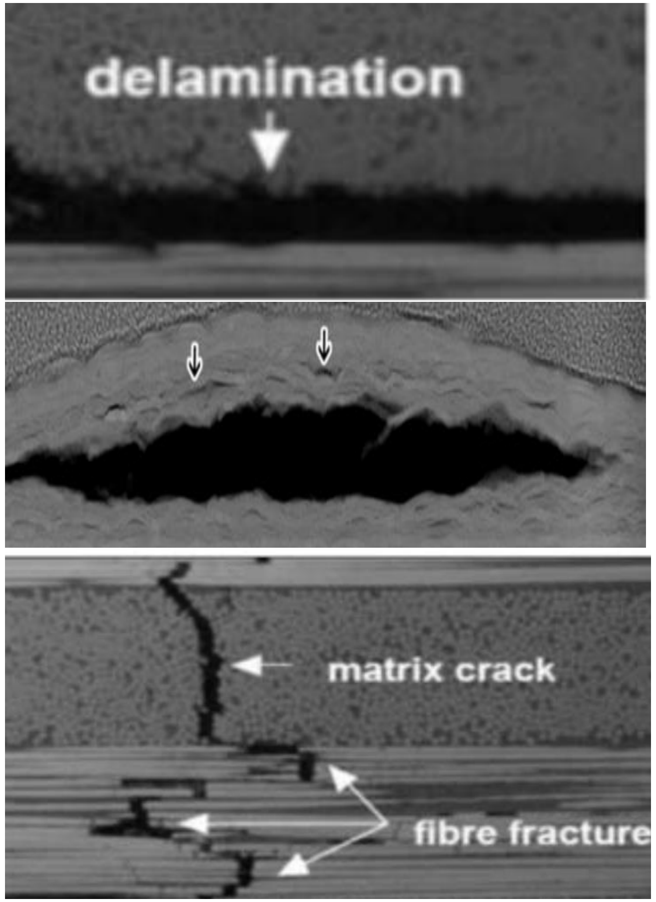
- Layers of the matrix and fiber of the composite are separated.

Blisters:

- Are small air pockets
- Inclusions of foreign material

Cracks:

- Fissures , fractures and breaks.



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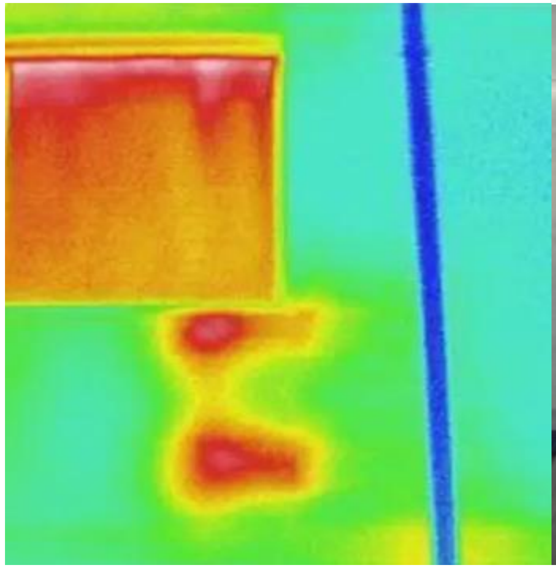
3. NON-DESTRUCTIVE TESTING (NDT)

- Applicable to materials without destroying their propiertes
- Evaluate change in physical propiertes of the material.
- TYPES
  - Visual
  - Eddy Currents
  - Ultrasounds (UT)
  - Thermography
  - Radiography

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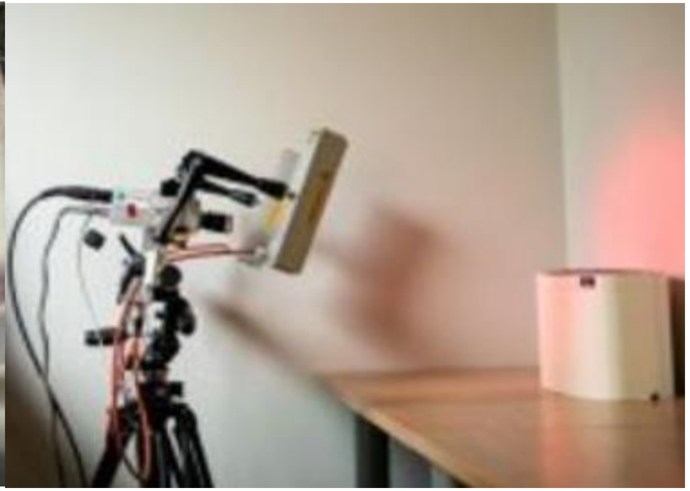
3. NON-DESTRUCTIVE TESTING

❑ VISUAL INSPECTION

- It is low cost but not very accurate
- Disadvantages:
  - Limitations of human vision
  - Subjective
  - Inadequate internal defects
- TYPES:
  - Visual inspection with ultraviolet light
  - Penetrant testing(PT)
  - Visual inspection with lasers



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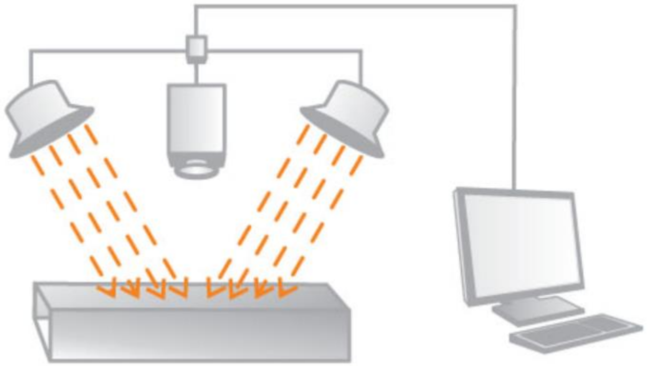
THERMOGRAPHY

- Measure the distribution of infrared radiation emitted by a material.

- Two Types:
  - PASSIVE
    - Without external sources
  - ACTIVE
    - With external sources (laser, flashlamps)



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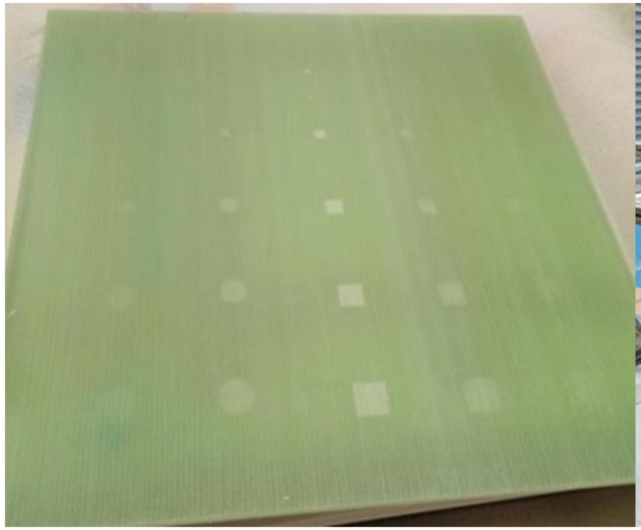
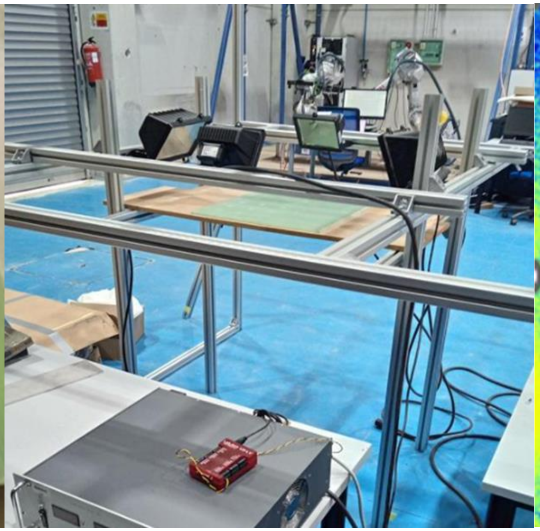
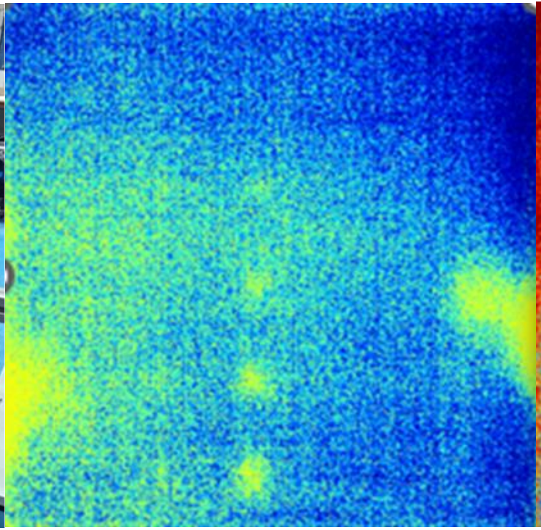
3. NON-DESTRUCTIVE TESTING

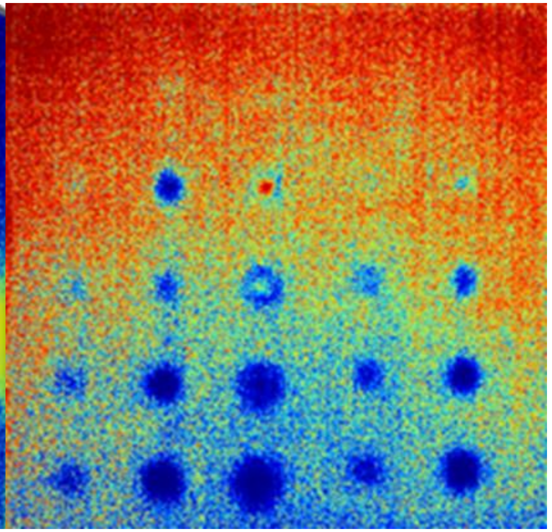
❑ ACTIVE THERMOGRAPHY

- GF-composite specimen
- Source
  - Flashlight lamps
- Types
  - Thermal pulses
  - Lock-IN
- ALGORITHMS
  - FFT
  - WAVELETS
  - PCA









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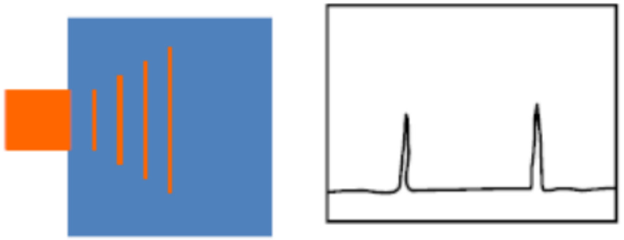
3. NON-DESTRUCTIVE TESTING

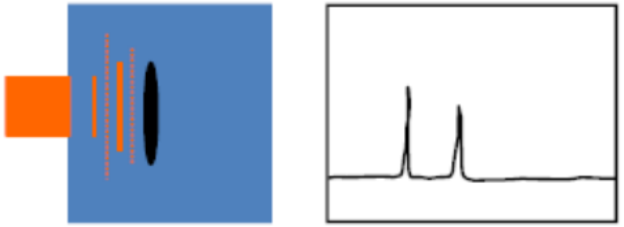
ULTRASOUNDS

- Source: ultrasonic waves (50 kHz - 10 MHz)
- The material and the discontinuities in the composite are detected by the variation of the signal's amplitude

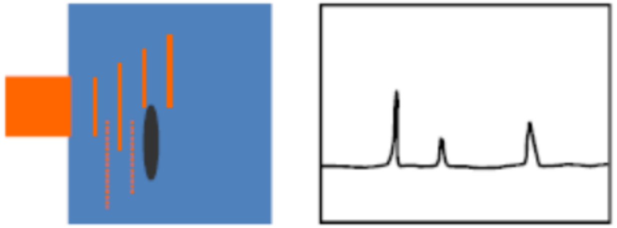
DEFECTS



- NO DEFECT: Pulse Echo with a probe and water as a coupling medium between the probe and the part.



- DELAMINATION: detected by the receiving signal which decreases considerably or even disappears if the delamination is large compared to the input signal.



- POROSITY: detected because noise appears between the input and output signals, but unlike a delamination, the signal is not lost as long as the porosity is not too high.

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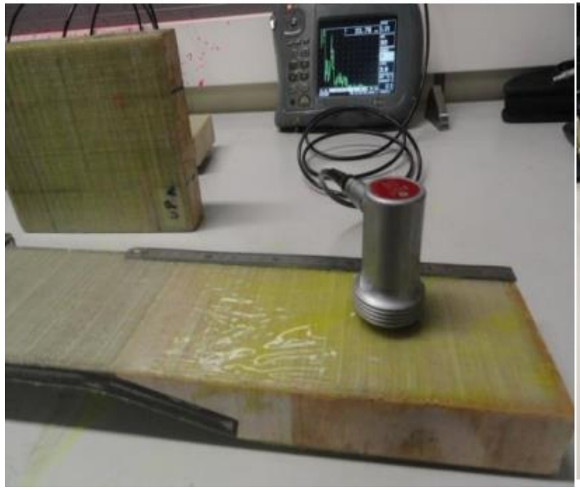
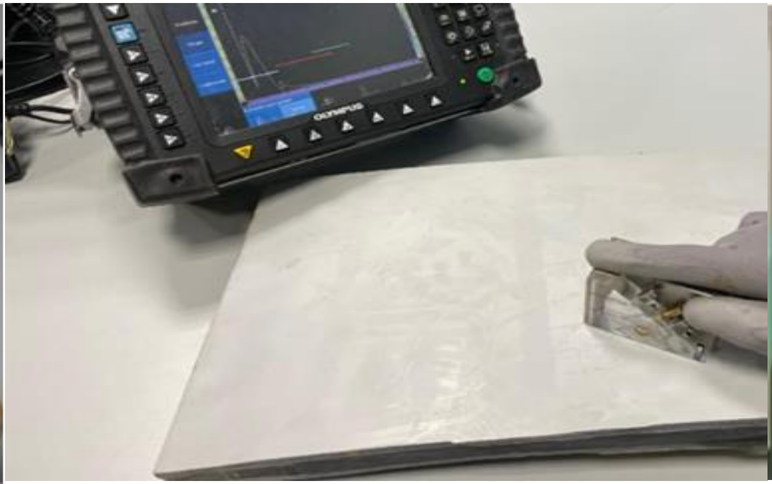
3. NON-DESTRUCTIVE TESTING

❑ CONFIGURATION

- Frequency is very important: Higher frequencies have better resolution but lower penetration
- Standard test specimens are used
- A coupling medium (such as water, oil, grease, glycerin) is used as a transmitting medium.





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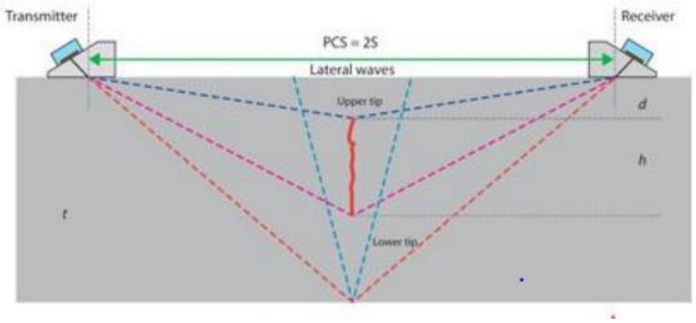
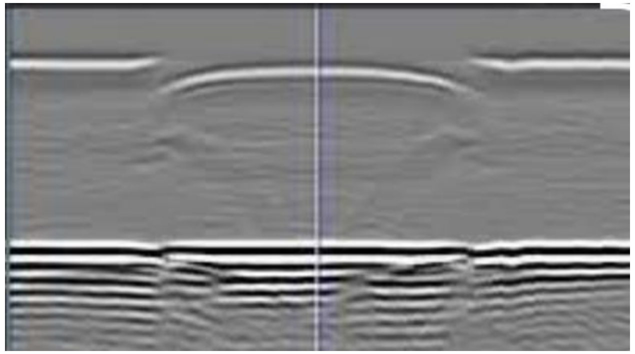
3. NON-DESTRUCTIVE TESTING

❑ TOFD (Time of Flight Diffraction)

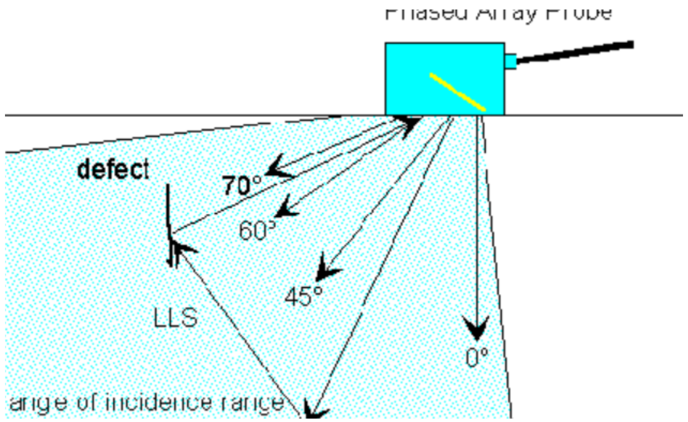
- Two ultrasonic probes are used: a transmitter and a receiver
- Generates an Image
- Fast and precise
- Dead zones

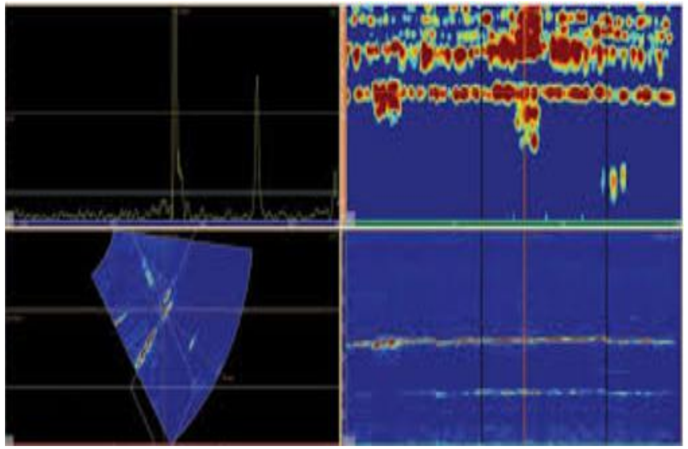




❑ PHASE ARRAY

- An array of transducers
- Flexibility
- Generates imaging
- Higher resolution





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3. NON-DESTRUCTIVE TESTING

❑ RADIOGRAPHY

- Use a radiation source(X or gamma tays)
- Based on the difference in absorption of materials
- 2D image

❑ TOMOGRAPHY

- Based in the same principle as radiography
- 3D reconstruction

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4. MOTIVATION

EUReCOMP aims to **provide sustainable methods towards recycling** and reuse of composite materials, coming from components used in various industries, such as aeronautics and wind energy.

SORTING / MATERIAL IDENTIFICATION to enable, ease and add value to the current recycling processes, considering their interaction with upstream/downstream processes; thus improving the efficiency of existing composite recycling processes, separation and quality control methods.

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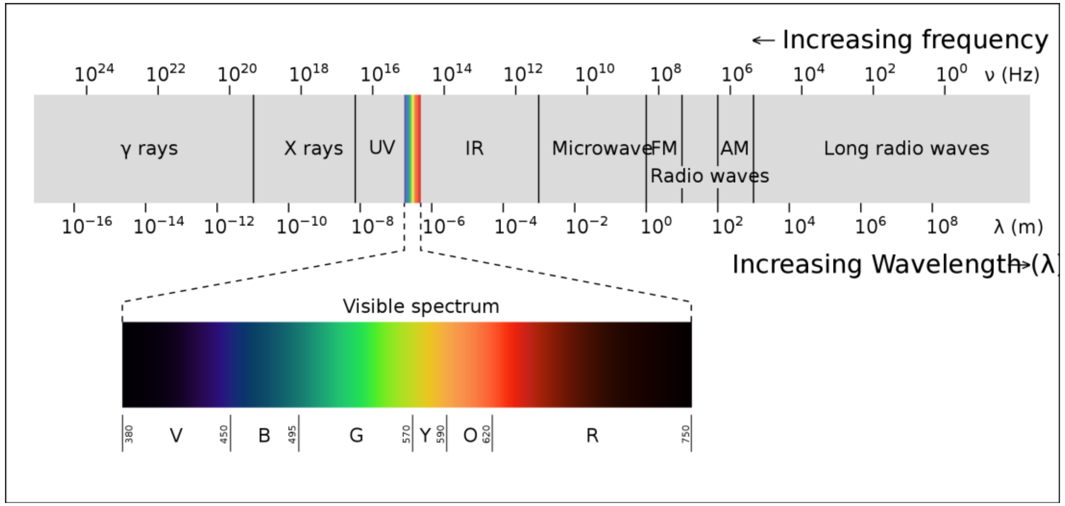
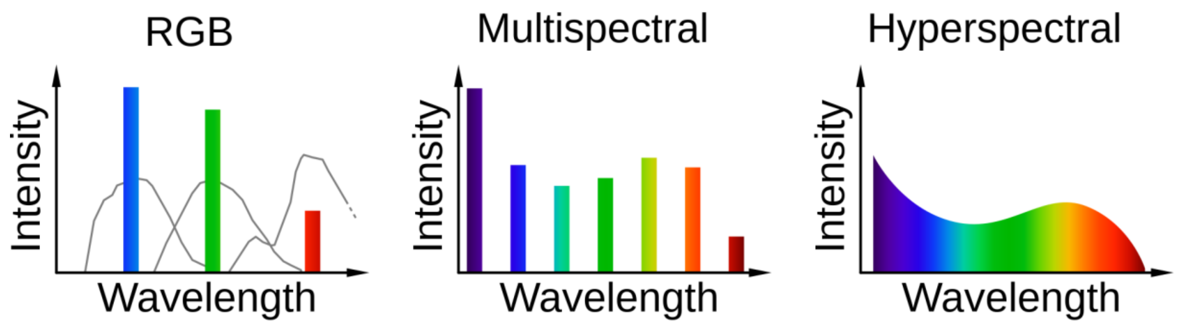
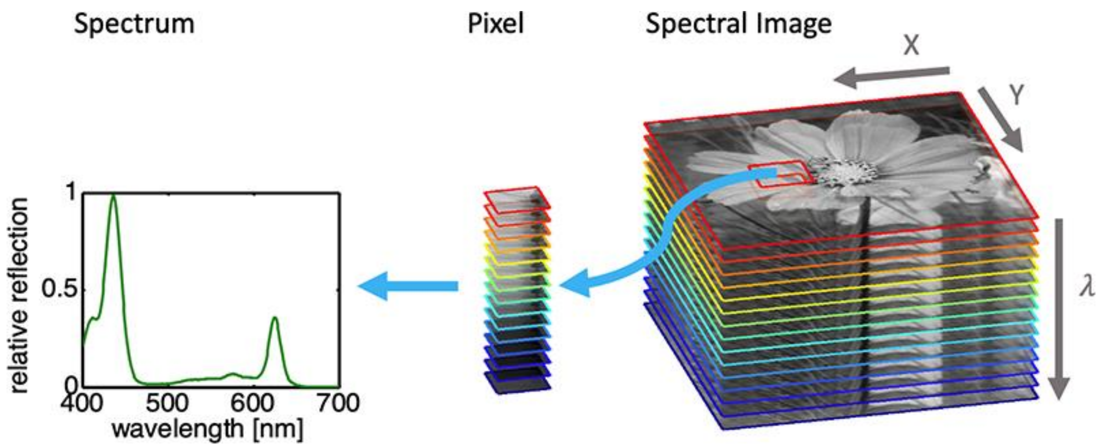
5. HYPERSPECTRAL IMAGING (HSI)





Multispectral / hyperspectral combines the power of digital imaging and spectroscopy.

Every pixel in the image provides local spectral information across a large number of spectral bands.



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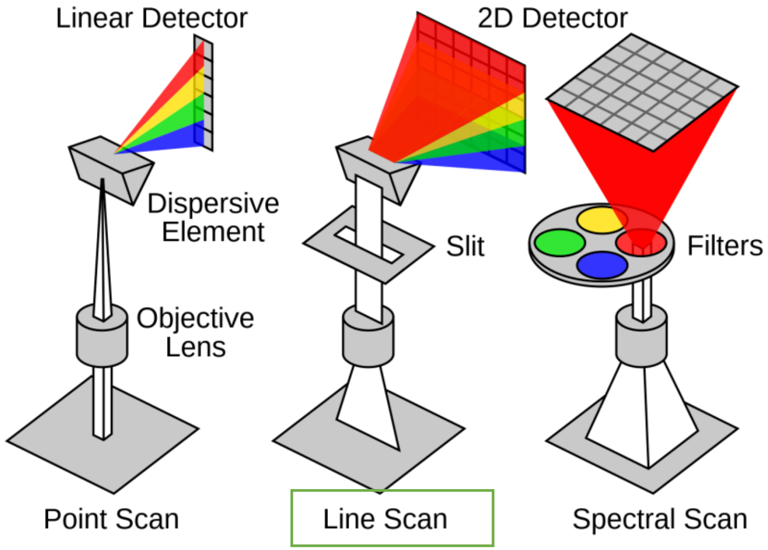
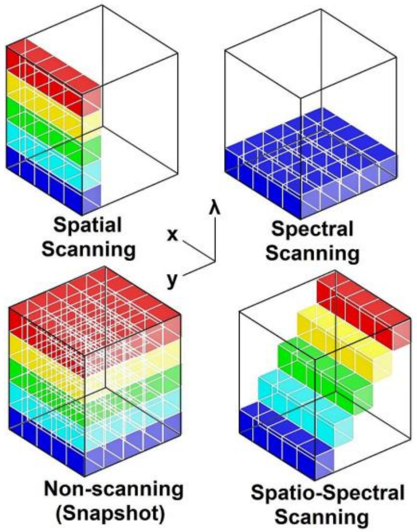
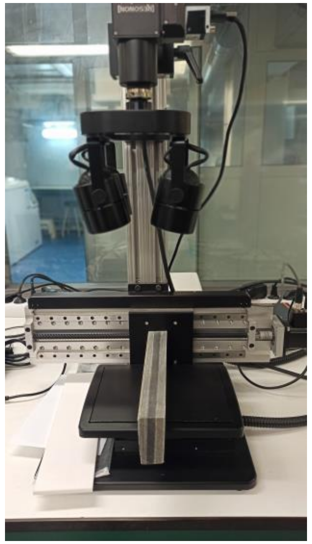
➢MULTI/HYPERSPECTRAL IMAGING SCANNING TECHNIQUES







- 300 spectral bands
- 400-1000nm
- 2,1nm spectral resolution

➢RECYCLING APPLICATIONS:

Hardware configuration selection depends on material variations, handling of the waste streams, processing speed of collected data versus further on-line actions (sorting)

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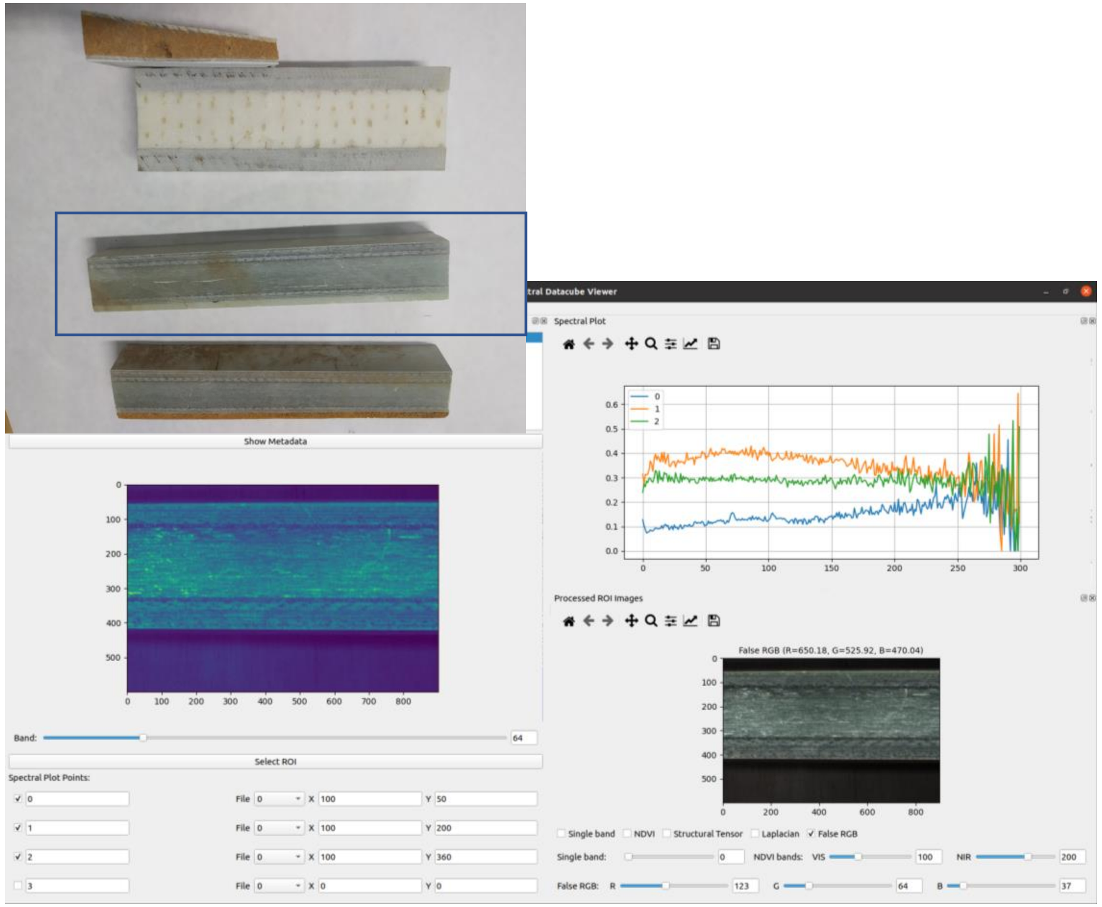
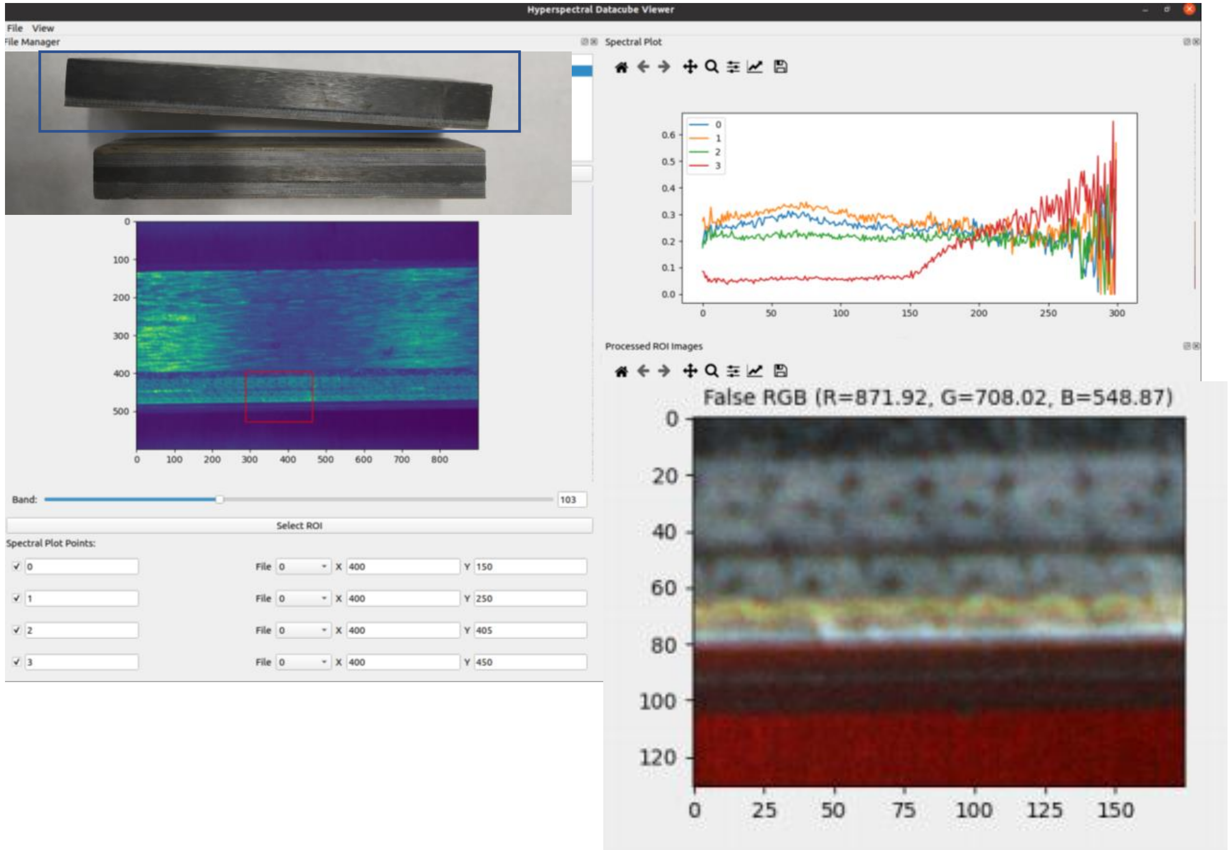
5. HSI - COMPOSITES

❑ GF-COMPOSITES (WTB):

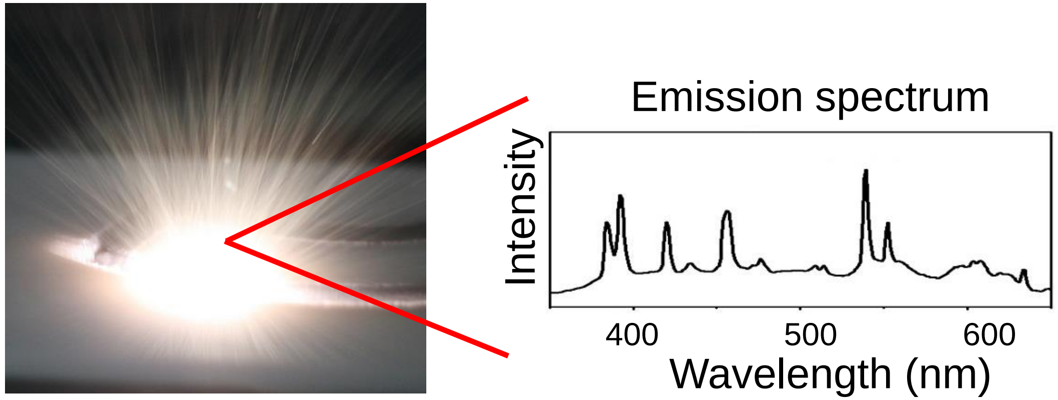


❑ CF-COMPOSITES (WTB)



This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101058089.

❑ LASER INDUCED BREAKDOWN SPECTROSCOPY



Laser ablation

- Analysis of plasma generated during laser ablation
- Atomic emission spectroscopic technique for elemental analysis
- Provides information about chemical composition of sample

➢ FEATURES

- Little sample preparation
- (Almost) non-destructive
- Works on solid and fluid samples
- Multiple element detection
- In-situ and real-time analysis
- (Possible) portability and low-cost

➢ LIMITATIONS

- High Limit of Detection (compared with pure lab analytical techniques)
- Matrix effects can cause interference
- Local /surface measurement (sub-mm)

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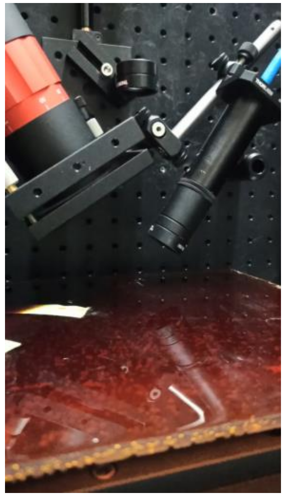
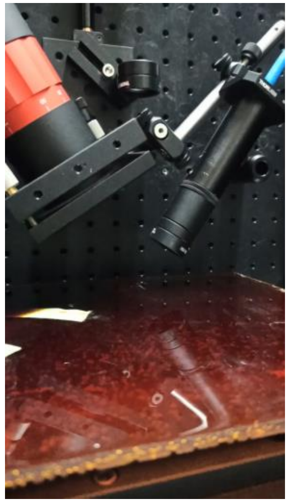
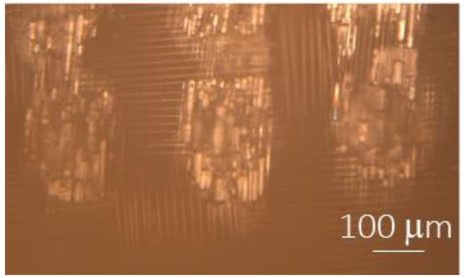
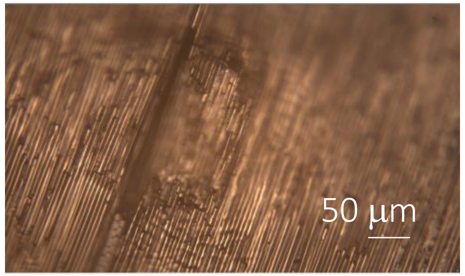
6. LIBS DEVELOPMENT

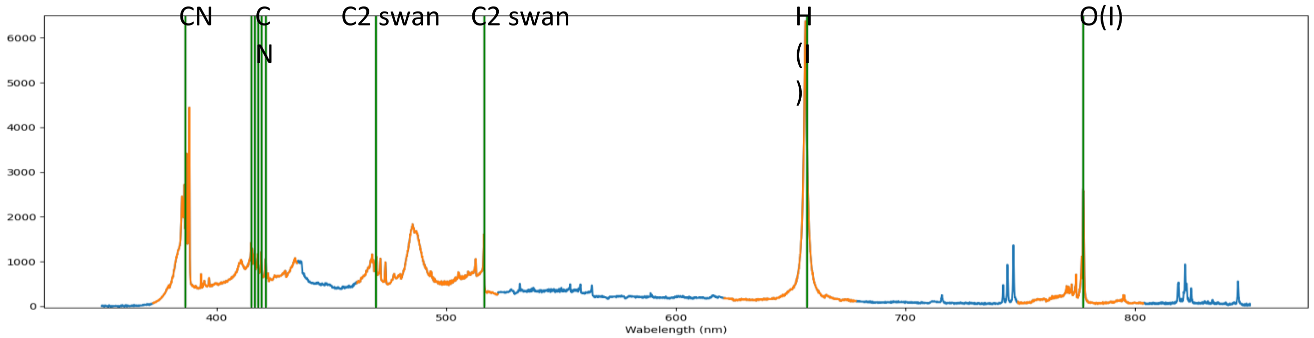
- Multi-wavelength nanosecond laser
- motorized 4-turret spectral gratings
- iCCD for temporal resolved plasmas signal acquisition











MATERIAL COMPOSITION

Fibers: glass/carbon

Resin types: epoxy, polyester, vinilester,..

hardeners/curing agents

->Spectral descriptors, chemometrics and machine learning implementation

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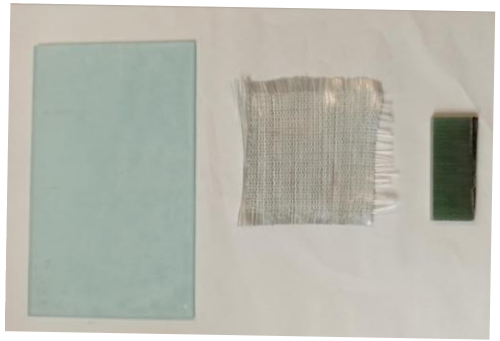
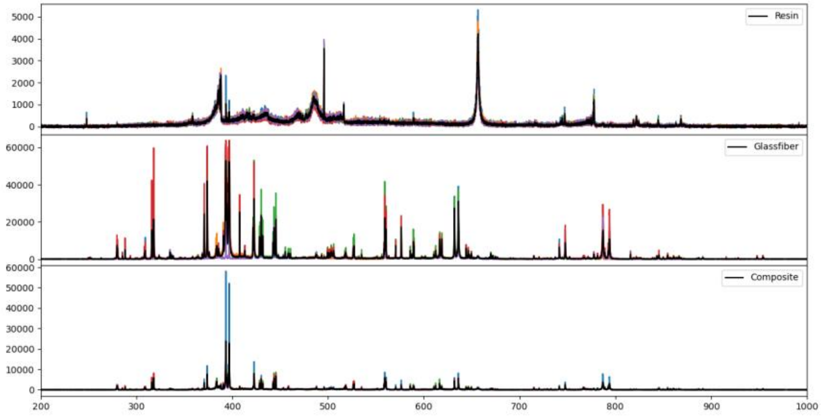
6. LIBS - RESINS AND COMPOSITES

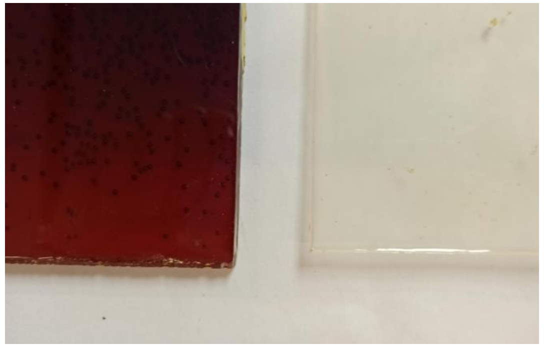
❑ MATERIALS, SPECTRA ANALYSIS AND CHEMOMETRICS

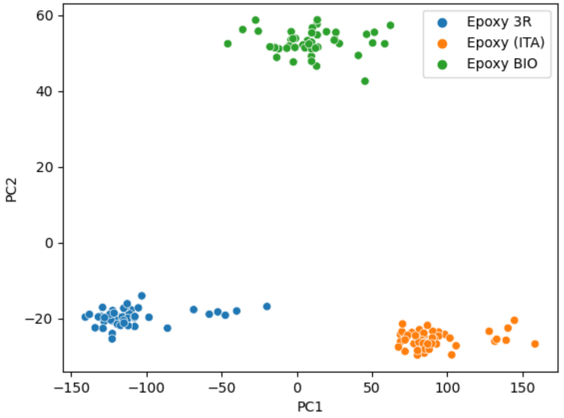
GFRP



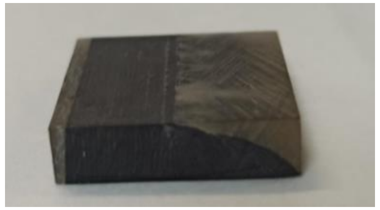


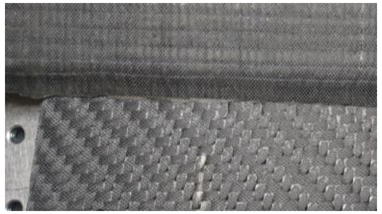
RESINS

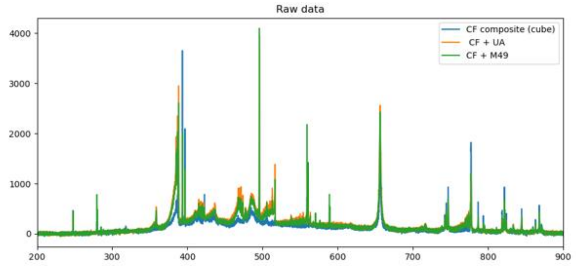


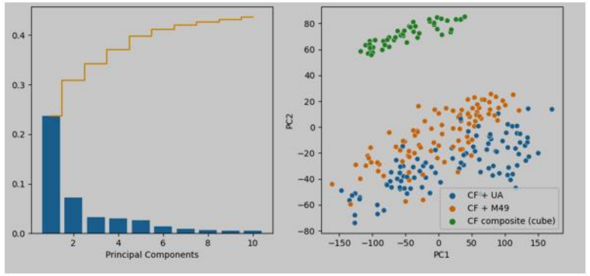


CFRP









This project has received funding from the European Union’s Horizon Europe research and innovation programme under grant agreement No 101058089.

NDT (Thermography, Ultrasounds Testing) spectroscopic (HSI, LIBS) techniques for EoL composites

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Camilo Prieto
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AIMEN TECHNOLOGY CENTER

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Thank you!

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Acknowledgment

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Solvolysis Technologies within EuReCome

1th EuReComp Workshop

20.04.2023 / Dresden, Germany

Paul Schulz, Robert Kupfer / TU Dresden

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TECHNISCHE UNIVERSITÄT DRESDEN

Content Overview

Introduction

Solvolysis within EuReComp Project

- Sub- and Supercritical Water Solvolysis
- Chemical Assisted Solvolysis
- Plasma Enhanced Solvolysis

Fibre treatment

Physical Simulation-Modelling

Summary and Discussion

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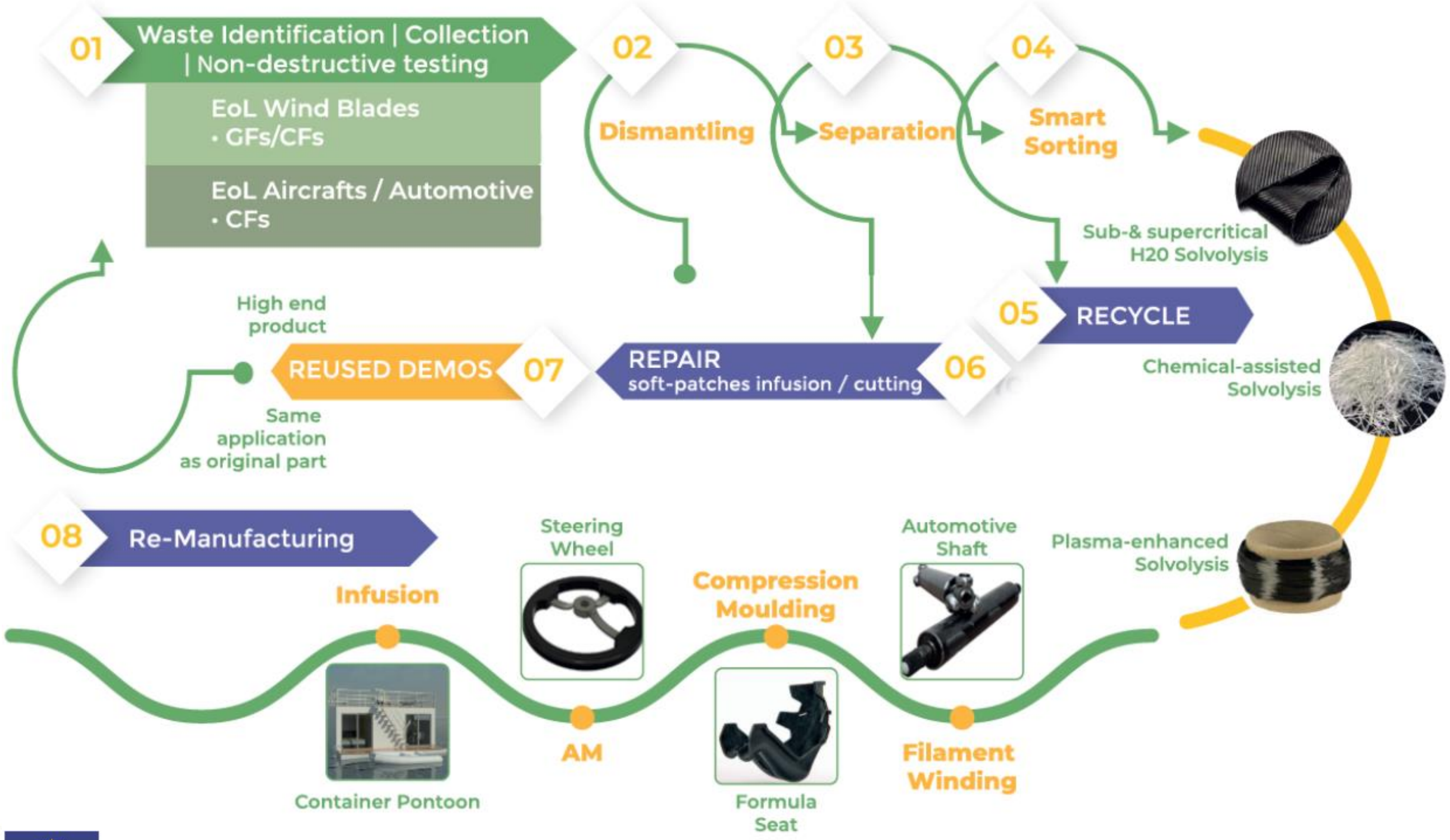
Introduction

EuReComp's material stream concept



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Introduction

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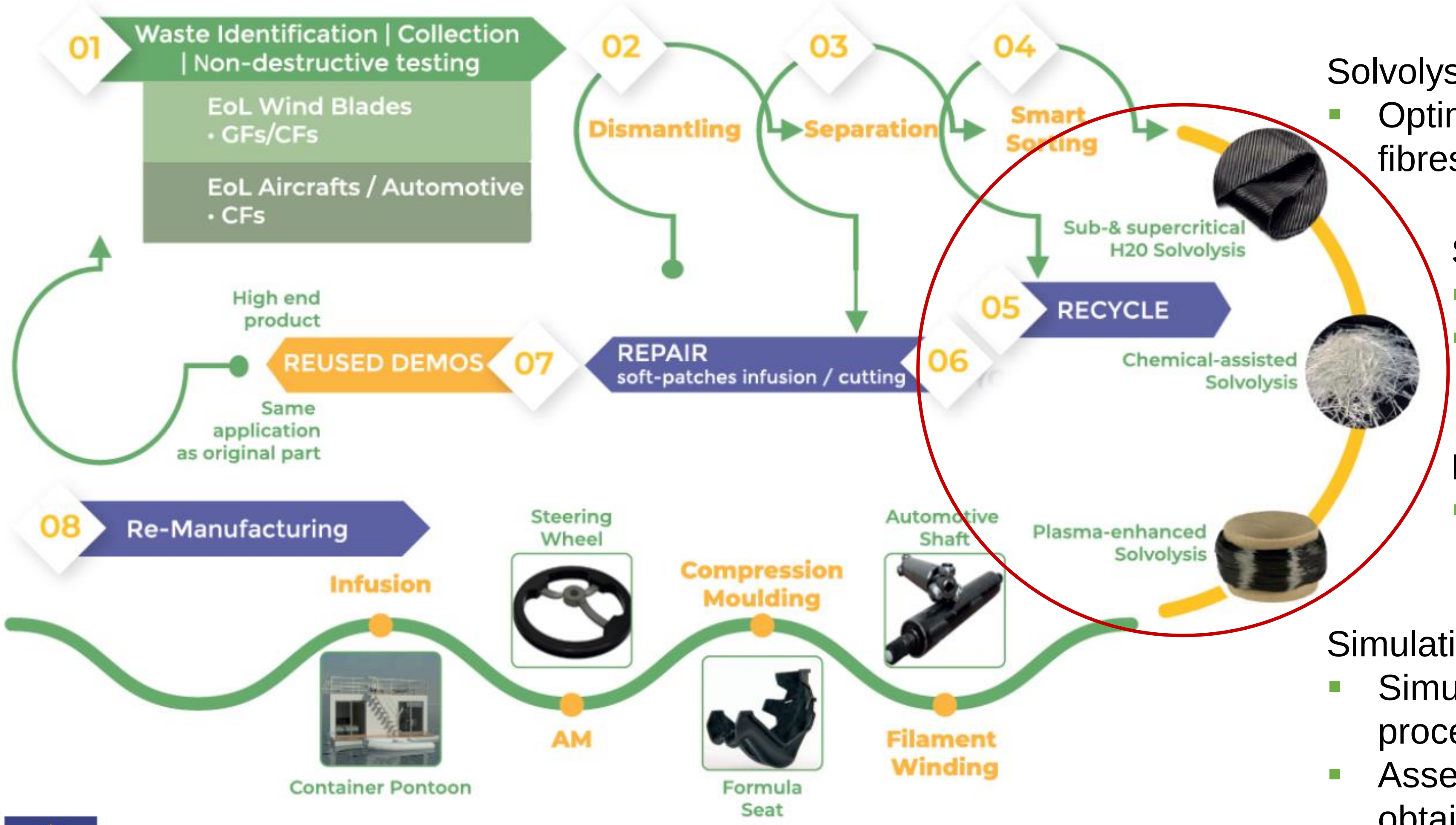

Goals of EuReComp recycling process

Solvolysis process
- Optimised solvolysis conditions for fibres/matrix separation

Solution
- Fractionation dissolved matrix/solvents
- Treatment-recycling / reuse assessment

Fibre treatment
- High-value long fibres for textile fabrics and continuous yarns

Simulation
- Simulation of dissolution and waste treatment processes
- Assessment structural mechanical potential of obtained fibre materials

Funded by the European Union

Working package 4 - Circularity by recycling and reclamation incl. secondary raw materials

Tasks of WP 4

4.1 Solvolysis → 4.2 Solution analysis → 4.3 Fibre treatment → 4.4 Physical Simulation

[1] Beghetto et al. 2021

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Introduction

Working package 4 - Circularity by recycling and reclamation incl. secondary raw materials

Solvolysis

- Reaction with a solvent whereby the chemical bond breaks (chemical depolymerisation)
- Reverse reaction of polycondensation or a related reaction of this by incorporation of small molecules
- Process is specified according to the solvent
  - Glycolysis
  - Hydrolysis
  - Methanolysis
  - Ammonolysis

Example of depolymerisation of PET by different solvents [1]

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Introduction

Working package 4 - Circularity by recycling and reclamation incl. secondary raw materials

Solvolysis

- Reaction with a solvent whereby the chemical bond breaks (chemical depolymerisation)
- Reverse reaction of polycondensation or a related reaction of this by incorporation of small molecules

Three Solvolysis technologies in different scales are researched for recycling of fibre-reinforced plastic (FRP)

- ➞ Sub- & supercritical water solvolysis (low scale)
- ➞ Chemical-assisted solvolysis (low and pilot scale)
- ➞ Plasma enhanced solvolysis (low scale)

- ➞ Support through development of an atomistic solvolysis simulation model (especially sub- and supercritical water solvolysis)

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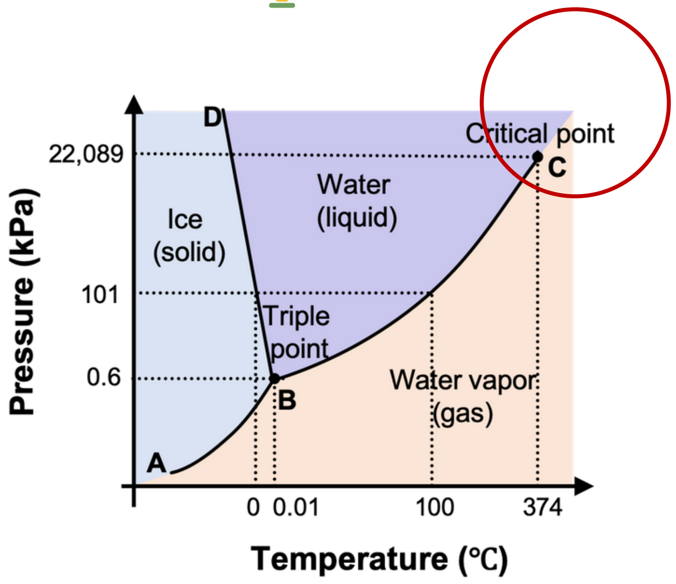
Sub- and Supercritical Water Solvolysis (T4.1.1)

Task, process principle

- Development of recycling approach to recover carbon fibres (CF), glass fibres (GF) and oligomers/monomers from resin matrix with water
- Solvent: Subcritical water
    - Temperature range 100 °C to 374 °C
    - Liquid through pressure
- Solvent: Supercritical water
    - Water in state above critical properties
    - T: > 647.14 K (374 °C), P: > 22.064 MPa, ρ: > 322 kg/m³
    - Distinction between liquid and gaseous phase not possible
- Process primarily for CF



P-T phase chart of water

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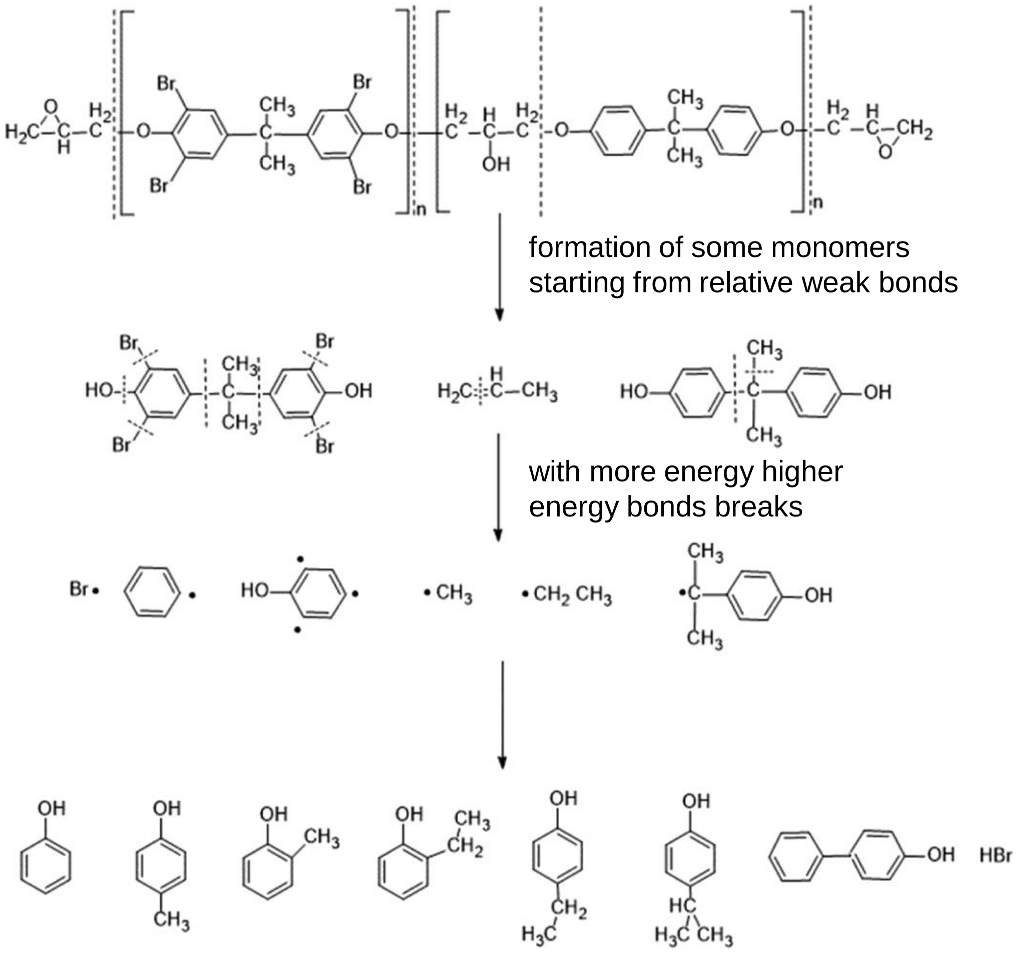

Proposed formation pathway of decomposition products of epoxy resin [2]

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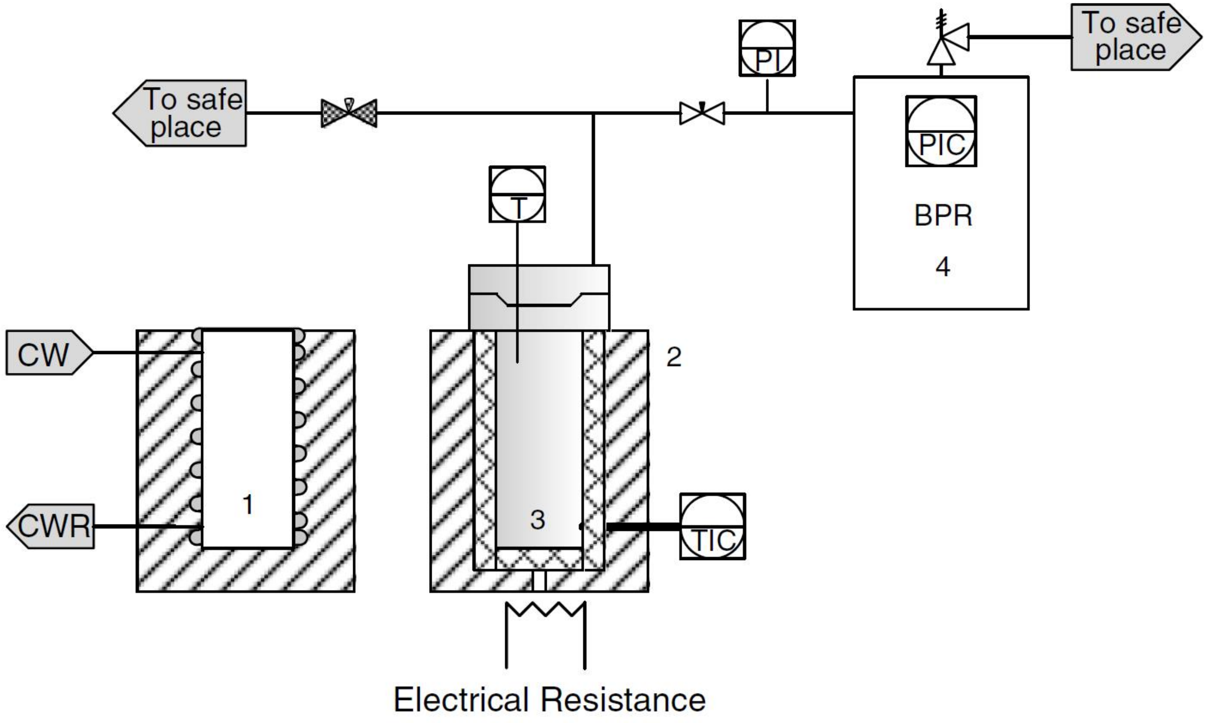
Sub- and Supercritical Water Solvolysis (T4.1.1)

Equipment

- Basic: Batch reactor, non-stirred
  - 1: Cooling block
  - 2. heating block
  - 3. Removable autoclave reactor
  - 4. Back pressure regulator (BPR)
- Procedure
  - Placing of the specimen
  - Filling with a defined volume of water
  - Closure of the reactor
  - Pressure depending on volume and temperature
  - Heating and Cooling through the system or separate



Schematic diagram of a bench scale reactor [3]

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Sub- and Supercritical Water Solvolysis (T4.1.1)

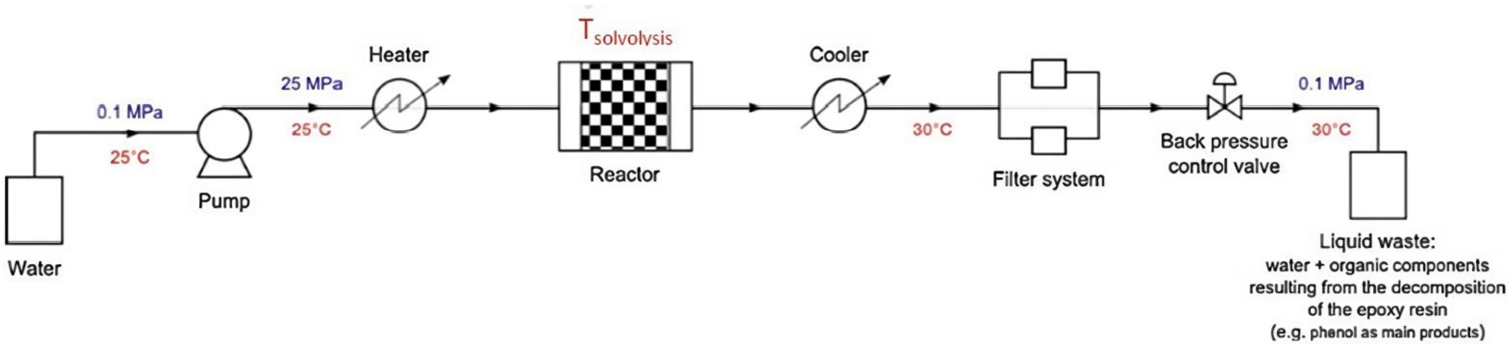
Equipment and outlook

- Advanced: semi-batch type reactor system
  - Single loading with subsequent flushing
  - Pressure and Temperature controlled by
    - HP pump with pressure valve at the outlet
    - Heating section
- Collecting tank, storage tank

- Procedure:
  - Charging of the tank with composites
  - Build-up of pressure and temperature by flowing of water
  - Continuous analysis of the reaction products in the exiting fluid possible
  - Cooling of the reactor and removal of the fibers with subsequent analysis

Outlook

- Next few month start of investigation on subcritical and supercritical water solvolysis on a batch system



Schematic diagram of the semibatch-type reactor [4]

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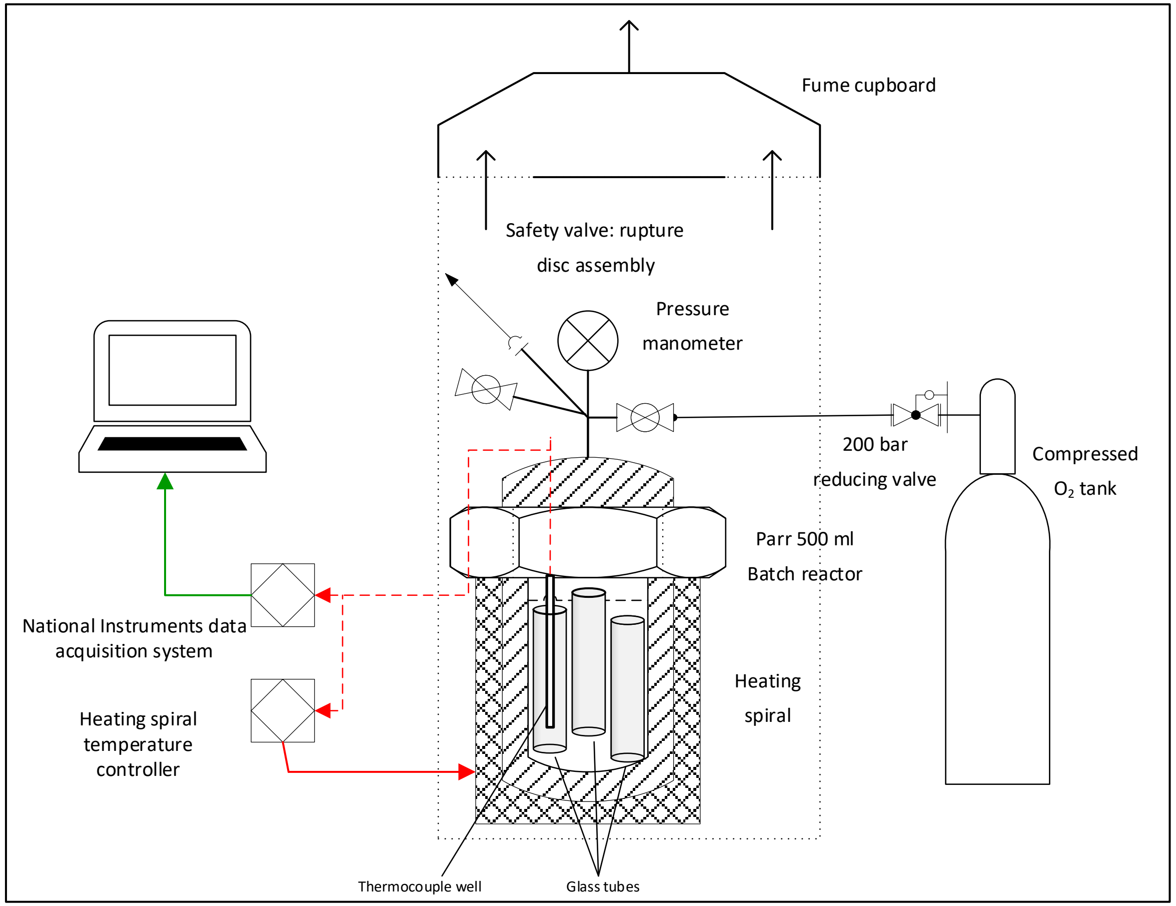
Low Scale Chemical Assisted Solvolysis (T4.1.2)

Task, process principle and equipment

- Development of recycling approach to recover CF, GF, and oligomers/monomers from resin matrix (especially with low molecular solvents)
- Solvent: Ethylene glycol with TBD catalyst (mixture), the study of the impact of different solvents and catalysts on the process.
- Solvolysis systems:
  - Parr 4650 500 ml high-temperature, high-pressure reactor
  - Self-designed 3 dm^3 reactor for upscaling the process for ambient pressure and 200°C
  - Measurements of process temperature, energy consumption, rate of the proces and process kinetics.

Responsible Partner: Silesian University of Technology



Lab scale equipment based on Parr 4650 system

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Low Scale Chemical Assisted Solvolysis (T4.1.2)

Results and outlook

- Successful experiments with CF and GF composites
- Obtained CF and GF washed with isopropanol and "brushed"
  - Brushing did not cause any difficulties, nor visible damage to the fibers
  - Fibre length: 50-60 mm avg., 600-650 mm max. for GF
- Experimental planning to account for and investigate
  - Different low-molecular solvents and catalysts
  - CF reinforced WTB parts
  - Continuous fibers recovery
  - Rate of the solvolysis process, and process kinetics

Responsible Partner: Silesian University of Technology



Recovered GF


Recovered CF

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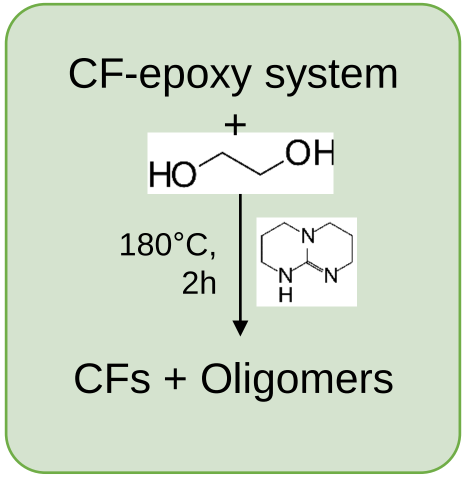
Pilot Scale Chemical Assisted Solvolysis (T4.1.3)

Task, process principle and equipment

- Development of recycling approach to recover CF and oligomers from resin matrix (especially with medium molecular sovents)
- Scale-up: small technical scale, ATEX proof of all equipment: EX II 2/3G ib IIB T3
- Testing of solvolysis systems and development at lab scale:
    - Solvents: polyvalent alcohols, polar aprotic solvents
    - Different catalysts
    - Conditions, stirring, pretreatment methods (e.g. swelling)


Small-technical scale



Lab scale assembly

Responsible Partner: Fraunhofer

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Pilot Scale Chemical Assisted Solvolysis (T4.1.3)

Results and outlook

- Different tested input materials from WTB (INEGI) and pi scrap (B&T, anhydride-cured epoxy + CF)
- Challenges depending on input material, i.e. solvolysis systems and conditions need to be adapted
- Scale-Up: extensive balancing needed regarding feasibility, economical and risk aspects

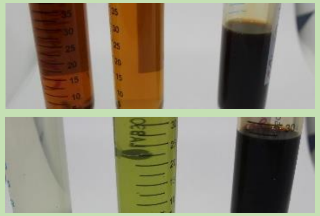
- Pending analysis of fiber and extract via SEM/REM, GC-MS and others
- Scale-Up tests by Q3 2023

Responsible Partner: Fraunhofer

B&T material

WTB pice

B&T material ✔



Extract color applying different solvent/cat. systems

WTB material ✔
By now no full fiber recovery

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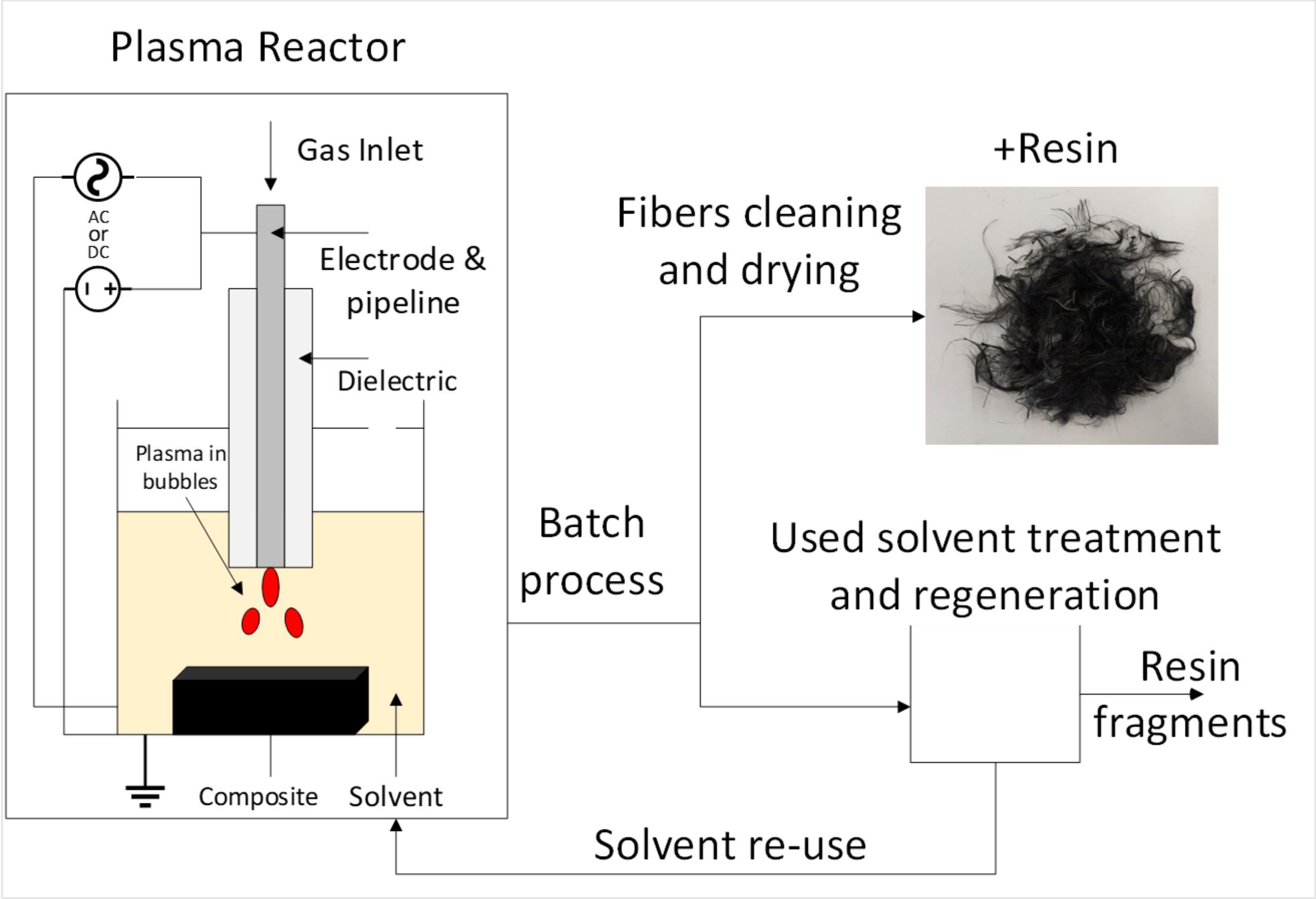
Plasma Enhanced Solvolysis (T4.1.4)

Task, process principle and equipment

- Implementation of novel plasma enhanced solvolysis process for the separation of CFRP and GFRP
- Solvent: Plasma in bubbles or in contact with liquid is used for solvent activation
- Strong oxidative species produced from plasma combined to plasma induce shockwaves enhance composite dissolution
- Advantages
  - Low temperature
  - Atmospheric pressure
  - Low power consumption for plasma ignition
  - Treatment times



Schematical overview of the process

Responsible Partner: ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ UNIVERSITY OF PATRAS

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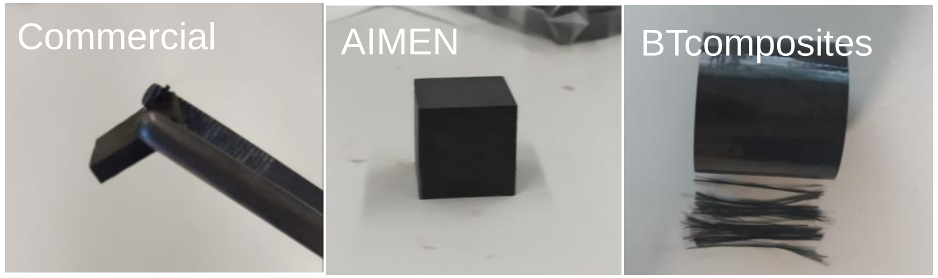
Plasma Enhanced Solvolysis (T4.1.4)

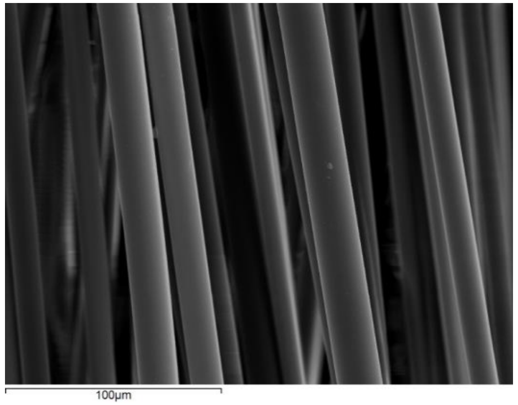
Results

- Short fibres recovery
  - Successful retrieval of short fibers (1, 3 and 7 cm) from different composites (treatment times 15-120 min)
  - In general, after cleaning and drying fiber surface almost free of residuals
  - Single fiber mechanical test of fibers are promising. ~90 % of tensile strength is preserved
- Continuous fibers recovery
  - Successful retrieval of continuous fiber (6m and 12m, treatment times ~ 60 min)
  - Good quality fibers, surface free of residuals (SEM pictures)

Responsible Partner: ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ UNIVERSITY OF PATRAS



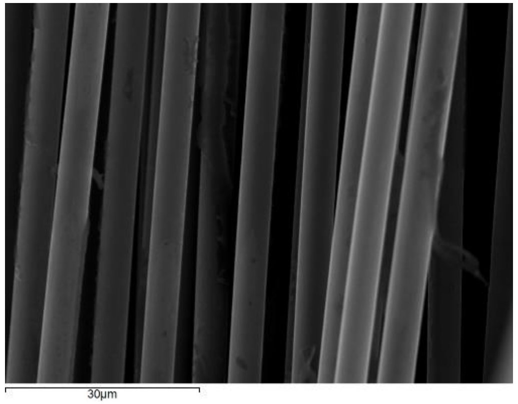
Different Sources for short fibres



After optimizing cleaning step fiber surface almost free of resin residuals


Source for continuous fibres


60 min treatment



Resulting fibre quality

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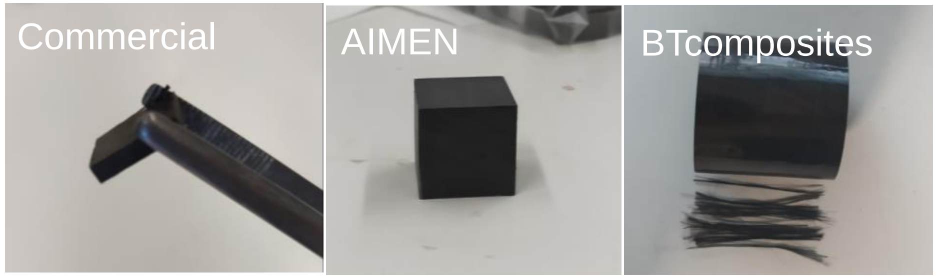
Plasma Enhanced Solvolysis (T4.1.4)

Outlook

- Re-optimise the process for the samples received from AIMEN (reduce the treatment time)
- Mechanical testing of fiber tows (ASTM standard)
- Regenerate and re-use solvents (first tests successful), treat process exhausts (small amounts, scrabbing)



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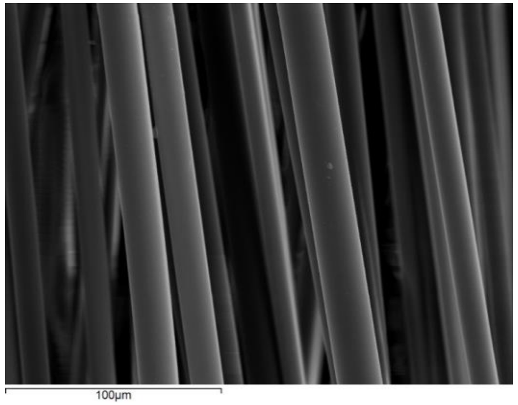

After optimizing cleaning step fiber surface almost free of resin residuals

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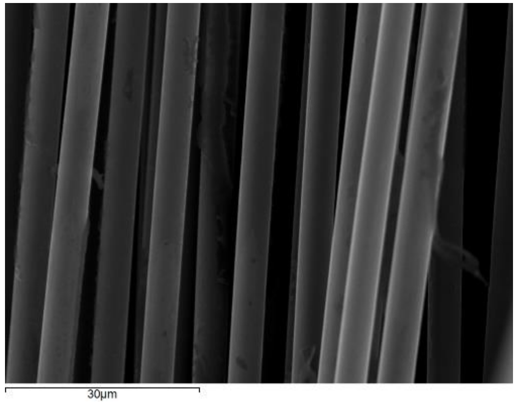

Resulting fibre quality

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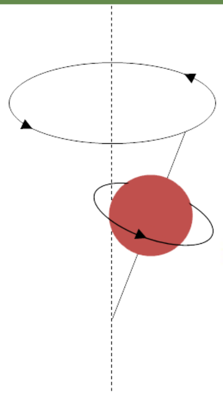
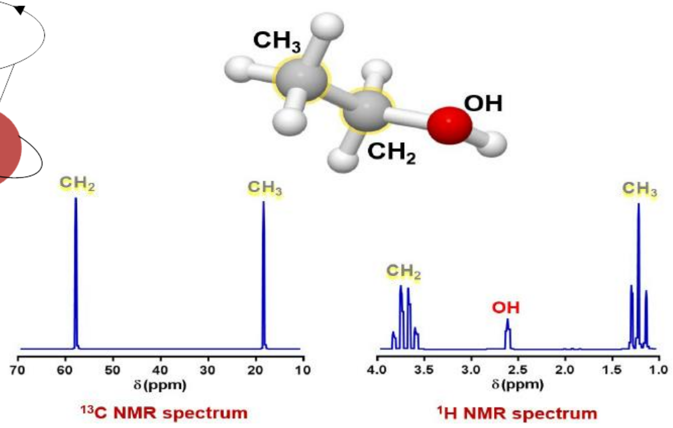
Solution Analysis (T4.2)

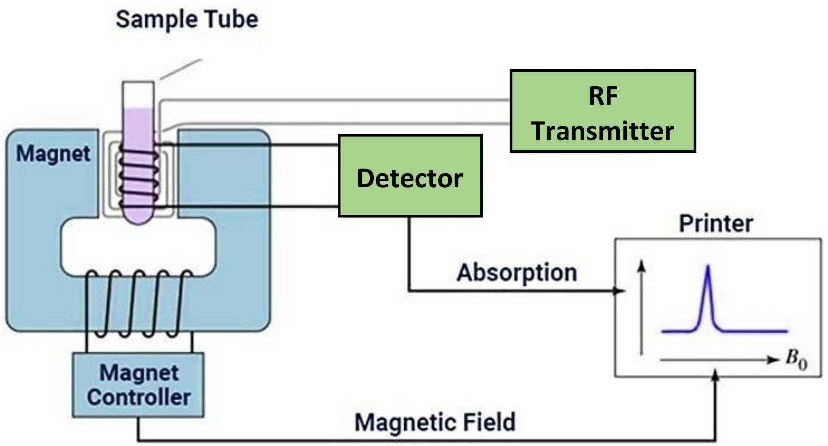
Task, process principle and equipment

- Characterisation and composition analysis of resulting liquid products after solvolysis
  - Measurement system: Nuclear magnetic resonance spectroscopy
  - Determination of the efficiency of solvolysis based on the composition of the solutions via **1H NMR** by the proton ratios of the components' characteristic signals (e.g. bisphenol A oligomers, solvents: ethylene glycole, NMP; etc.)
  - Optimising the conditions for recording spectra
- Assessment of possible re-use scenarios

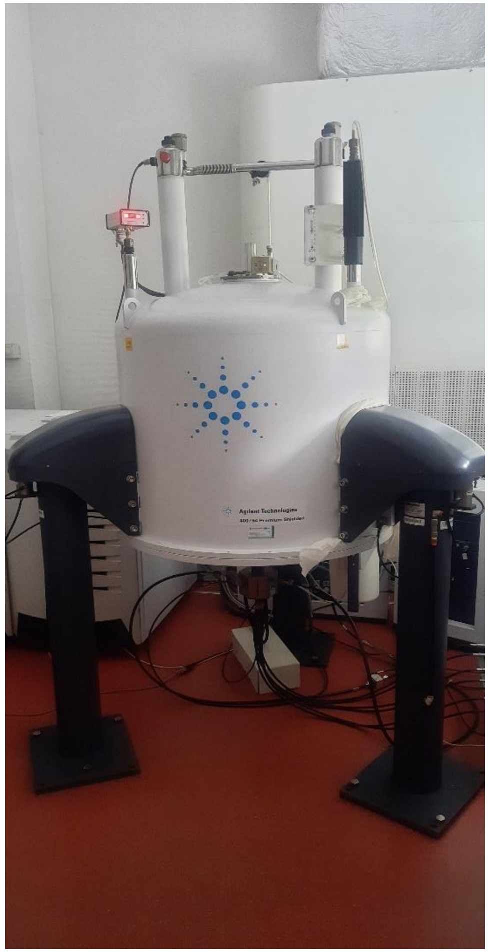




Example of NMR spectra of ethanol [4]



Instrumentation
Nuclear magnetic resonance spectroscopy [5]



NMR Agilent Magnet 400

Responsible Partner: Silesian University of Technology

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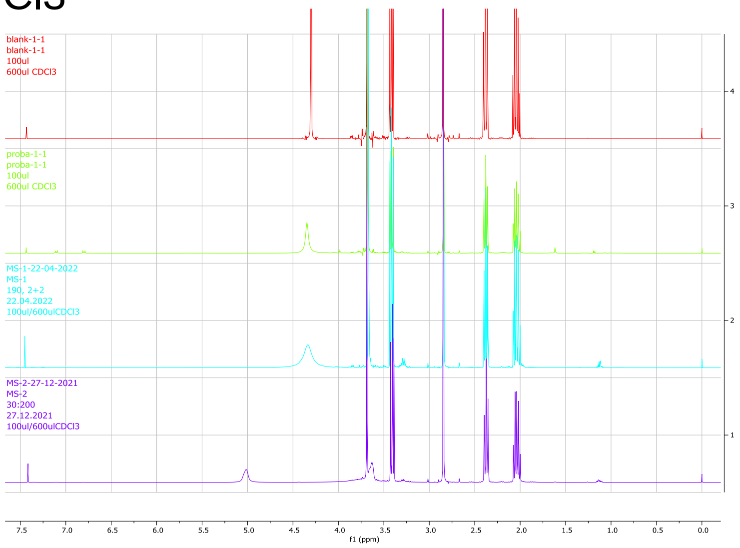
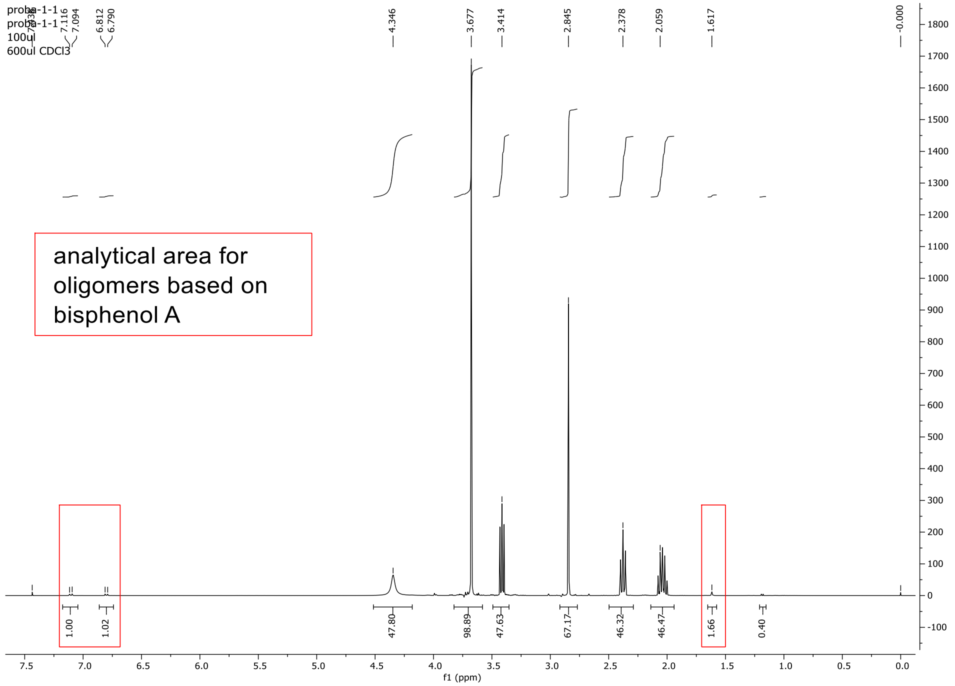
Solution Analysis (T4.2)

Results and outlook

- 1H spectra were recorded in CDCl3 on an Agilent Magnet 400 spectrometer at operating frequencies of 400 MHz
  - 100µl of sample/600 µl of CDCl3
  - Temperature: 25°C
- Analyses shows that it is possible to determine the efficiency of solvolysis and control its course using 1H NMR
- Next activities: Investigating liquid products from solvolysis process



Comparison of ^{1}H NMR spectra from different solvolysis processes



1H NMR spectrum of the solution after solvolysis with marked signals characteristic for bisphenol A-based oligomers

Responsible Partner: Silesian University of Technology

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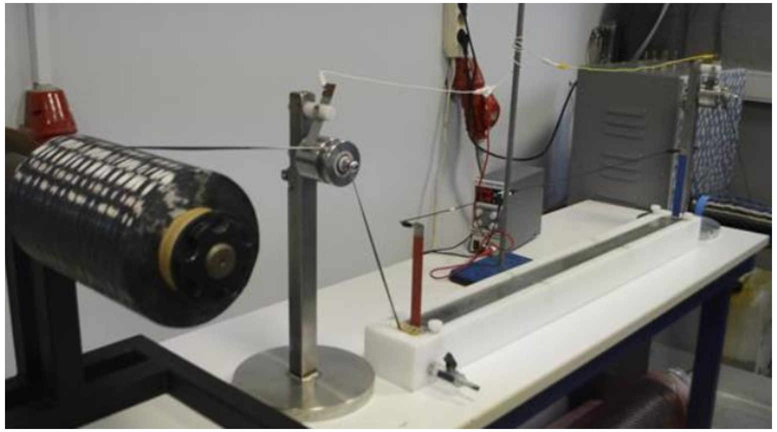
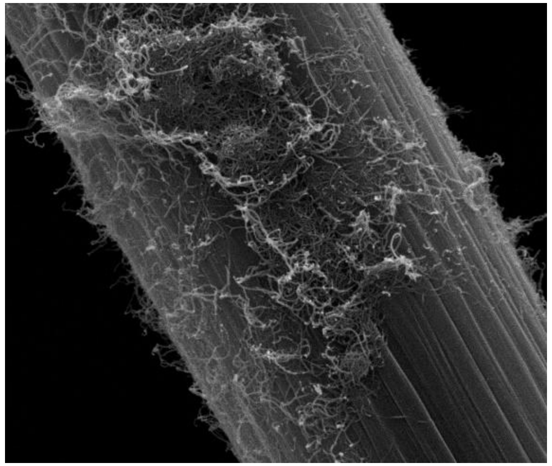
Fibre treatment for upgrading (T4.3)

Task, process principle and equipment

- Evaluation of fibre quality as well as functionalisation of CF by electrochemical treatment and subsequent electropolymerisation (2 stage process)
  - 1st: Anodic oxidation that creates oxygen groups on the surface of the fibres
  - 2nd : Electropolymerisation of monomer
- Solvent-based sizing/coating formations with nanoadditives

Continuous process for the functionalisation of CFs to improve mech. properties





SEM image from functionalised CF

Continuous process for the sizing of CFs to improve handling after recycling process

Responsible Partner: NATIONAL TECHNICAL UNIVERSITY OF ATHENS

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Physical simulation-modelling (T4.4)

Overview of the research partner

The **multi-Scale ModeLing Laboratory - SMaLL -** is an engineering research group launched at Politecnico di Torino (**POLITO**)

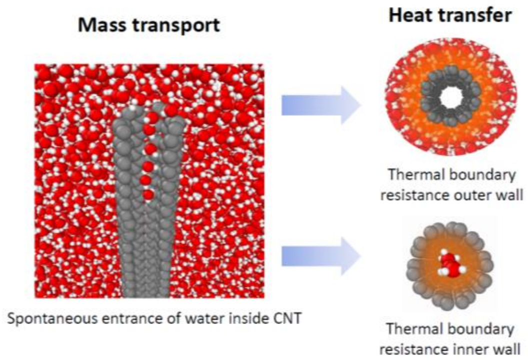
Our Goal: propose and promote innovative solutions for applications related to the energy sector.

Our Activities: modeling, numerical simulations and experimental tests for sea water desalination and purification, composites recycling, batteries and materials discovery.

Our Expertise: materials modeling techniques at different scales (from atomistic to continuum), model-order reduction techniques, coarse-graining (up-scaling).

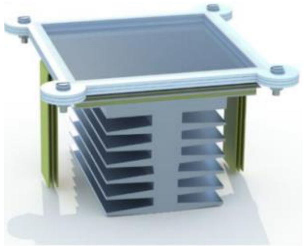
Responsible Partner: Politecnico di Torino 1859; SMaLL multiScale ModeLing Laboratory

Atomistic: DFT, Classical MD, Reax MD



[7]

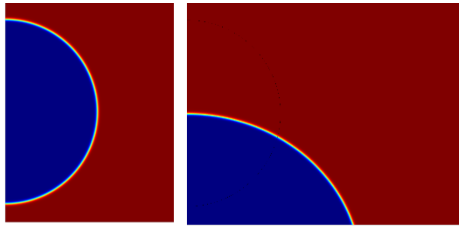
Mesoscopic: CG MD



[9]

[8]

Continuum



[6] Picture from j.ijheatmasstransfer.2023.123868
[7] Picture from J. Phys. Chem. B 2021, 125, 43, 12020–12027
[8] Picture from *Nat Sustain* **1**, 763–772 (2018)

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Physical simulation-modelling (T4.4)

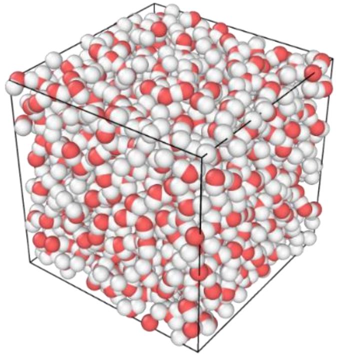
Task, simulation approach and outlook

Task: Develop numerical simulations to design and assist nanocomposites recycling driven by solvolysis.

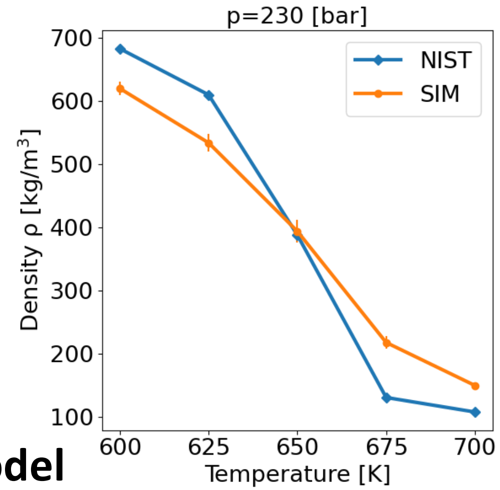
Our Solution: Classical and reactive molecular dynamics simulations to reproduce the solvolysis process of nanocomposites materials under different operative conditions.

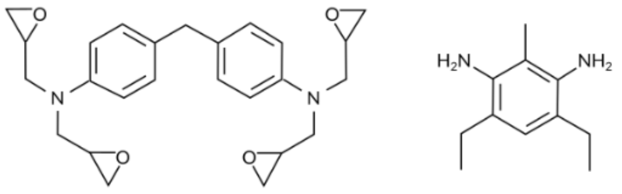
Expected Outcomes:

- Understand the crucial characteristics of composite/solvent interfaces under sub- and supercritical conditions;
- Propose a reliable and fast model-driven design of the solvolysis process, to limit the degradation of recycled secondary products.



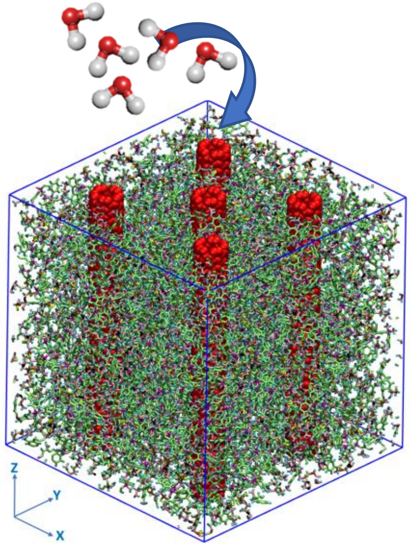
SPC-E water model





TGDDM
Resin

DETDA
Hardener



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Summary

Key-facts

- Three different types of solvolysis technologies are investigated
- Scale-up approach is planned in the project
- First successful experiments approve the general technical feasibility
- Associated atomistic simulation enables deep comprehension of the solvolysis process
- Business case / LCA analysis still pending €
  - High potential for CF expected
  - Potential for GF still uncertain due to the low virgin material price

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Thank you!

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TU Dresden

Questions?

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Acknowledgment

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Consortium

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WP7: Training & Life-long learning

1st EuReComp Workshop

April 20th 2023

Thomas Wagenknecht (KUZ Leipzig)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101058089.

Status of Current Activities

Objectives

- Professional qualification and life-long learning is the key to establish new technologies
- Development and establishment of a life-long learning concept
- Generation of modular training courses on the recycling of large composite structures
- Insurance of the recruitment and qualifying of skilled workers from current and future employee generations - depending on technical / qualification level - from career changers to post-graduates
- Integration of innovative learning and teaching methods

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101058089.

Basic concept setup

Long life learning concept

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Basic concept setup

Long life learning concept

Physical training

- Powerpoint (-like) presentations
- Text, pictures, (interactive) animations, videos, animated effects, AR, VR
- Oral information

- Hands on experiences
- Demonstration of processes
- Scripts, w/ glossary

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Basic concept setup

Long life learning concept

Physical training

- Powerpoint (-like) presentations
- Text, pictures, (interactive) animations, videos, animated effects, AR, VR
- Oral information
- Hands on experiences
- Demonstration of processes
- Scripts, w/ glossary

Online training / E-learning

- Learning management system (LMS)
- On-demand contents
- Text, pictures, animations, (explanatory) videos
- Interactive animations (realtime 3D content)
- Downloadable files (instructional materials)
- Quizzes, tests, glossaries, surveys, chats, presentations, checklists, inclusion of external tools, …

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101058089.

Status of Current Activities

Basic structure for the Learning Management System

Overview / General information

- Description of the EuReComp project: motivation, aim, duration, partners, …
- State ofe the art: General situation about waste (data)
- Possible solutions
- R6 strategy

Mechanical Recycling

Downcycling

Incineration: Thermal and energy recovery

WTB / Aircraft / Automotive

- Manufacturing
- Properties
- Materials
- Data
- Regulations (industry-specific)

Sorting criteria

Decommissioning

Specification for segmentation

Setting the threshold for reusing, repairing or recycling

Prevention

Design guidlines

Reverse engineering approach

Condition analysis

Screening of available materials (consumption, dimensions,...)

Documentation of screened materials

NDT

Dismantling

Separation

Smart sorting

Compositional identification assessment

Business guidance on the conformity assessment

Repair

= Longer operating time

Technologies

Advanced calculation / optimisation tools for the repair design

Development of novel repair strategies

- Requirements
- Detection
- Substeps
- Tests
- Specifications

Upgrade properties through sizing / surface treatment

Demo use cases?

Reuse

Repurpose

Structural reuse

Non-structural reuse

Demo use cases

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Status of Current Activities

Basic structure for the Learning Management System

Repair
- = Longer operating time
- Technologies
- Advanced calculation / optimisation tools for the repair design
- Development of novel repair strategies
- Requirements
Detection
Substeps
Tests
Specifications
- Upgrade properties through sizing / surface treatment
- Demo use cases?

Reuse
- Repurpose
- Structural reuse
- Non-structural reuse
- Demo use cases

Chemical Recycling / Solvolysis
- Chemical-assisted solvolysis
- Plasma-enhanced solvolysis
- Characterisation of CF & GF
- Fibre treatment for upgrading
- Physical simulation / modelling

End user technologies
- 3D printing
- Filament winding
- Compression moulding
- Infusion
- Demo use cases

Safety–Environment–Performance
- Risk assessment
- LCA
- Economic and socio-econ. assessment

Conclusion
- Summary of the project results

Miscellaneous
- Glossary

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Status of Current Activities

Learning Management System *Moodle*

- Decision for **Moodle** (moodle.org):
    - One of the most popular learning management systems worldwide (50% of the LMS market share in Europe, Latin America, and Oceania)
    - Free and open-source
    - Used for blended learning, distance education and other online learning schemes in schools, universities, workplaces and other sectors
    - <https://moodle.kuz-leipzig.de/>

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Status of Current Activities

Learning Management System *Moodle*

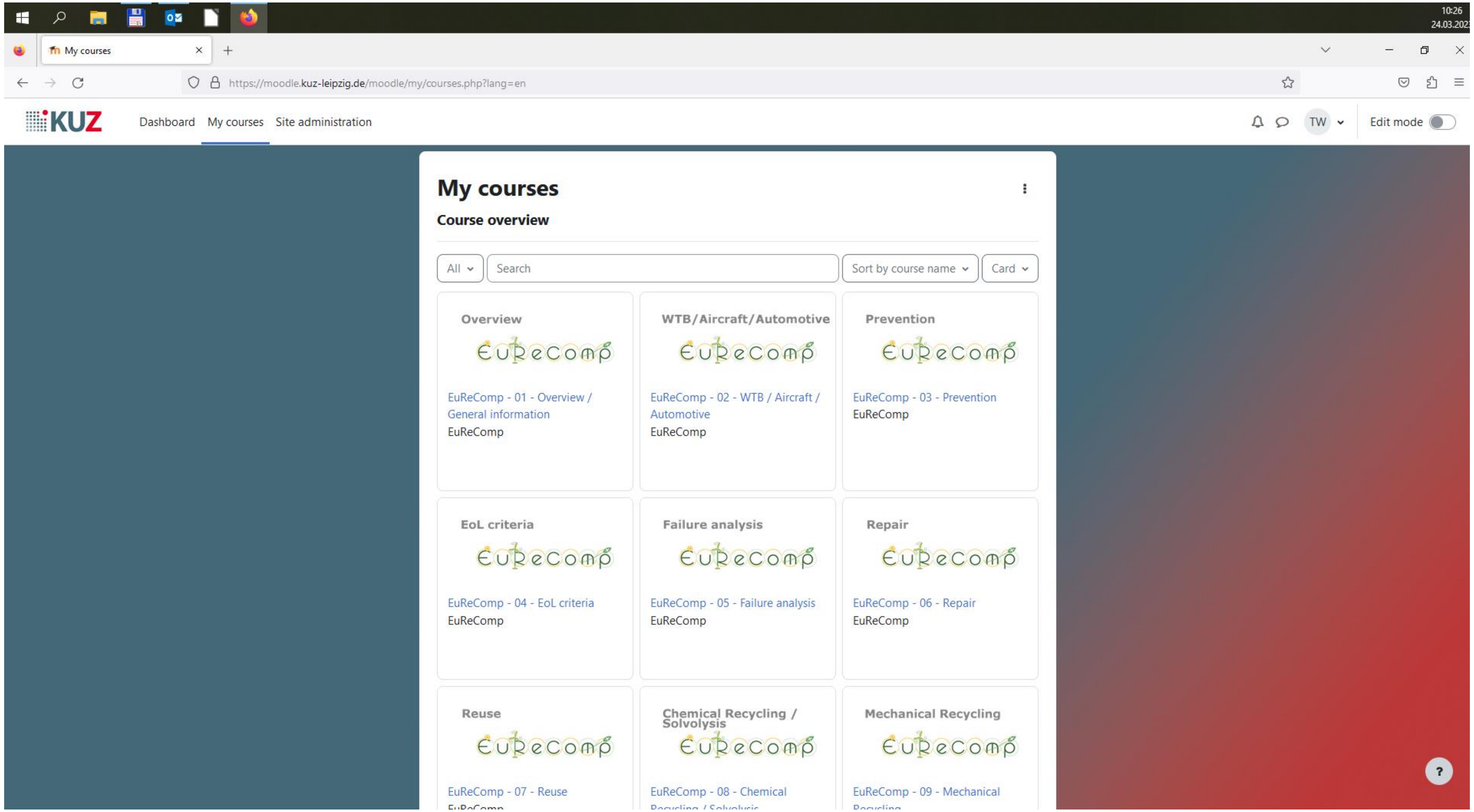
- Covering of current training trends
  - Blended learning
  - Micro learning
  - Incremental learning
  - Video based learning
  - Mobile learning
  - Gamification

Empowering educators to improve our world

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101058089.

Status of Current Activities

Learning Management System *Moodle*



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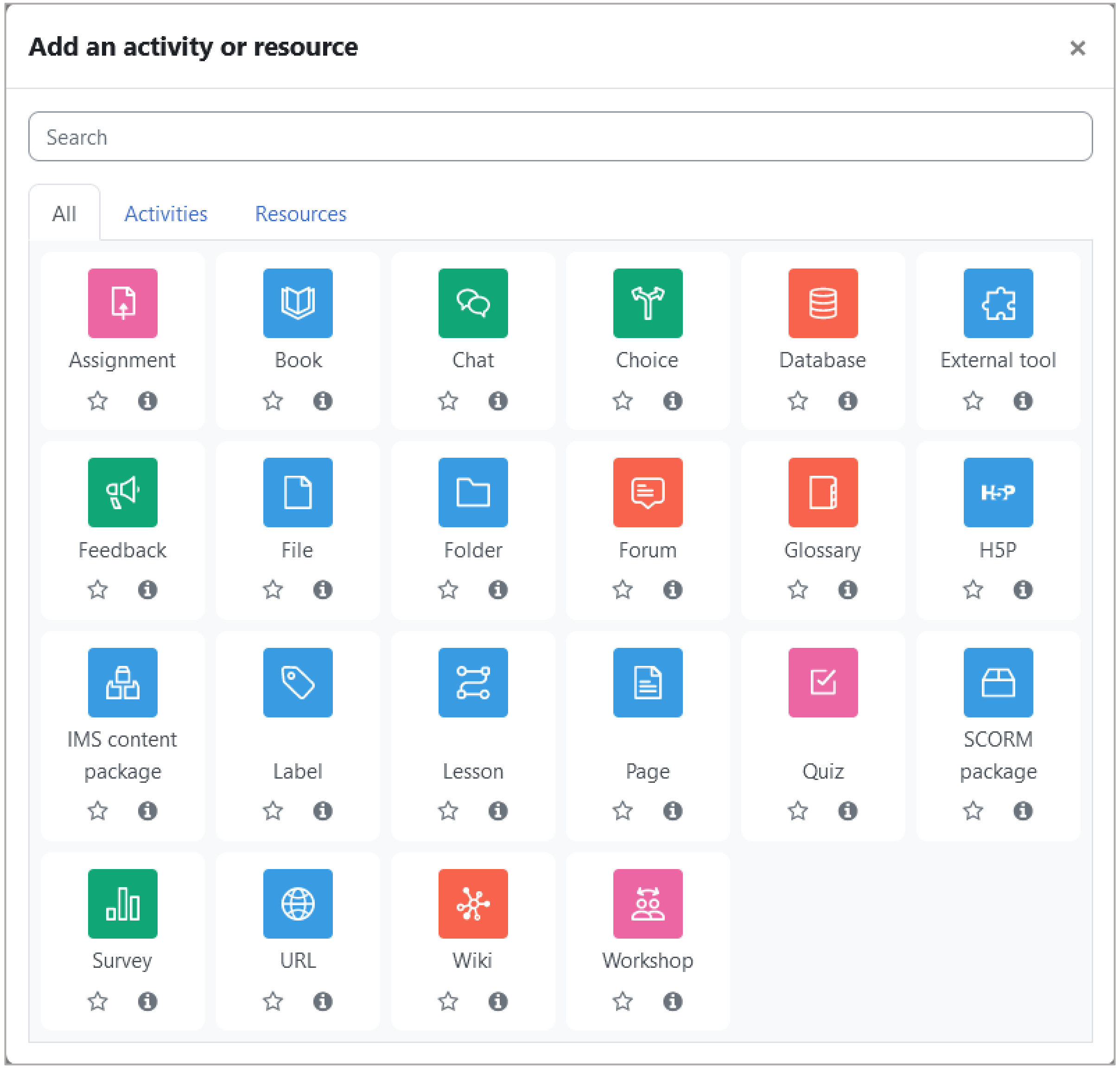
Status of Current Activities



Learning Management System
Moodle

moodle
Empowering educators to improve our world

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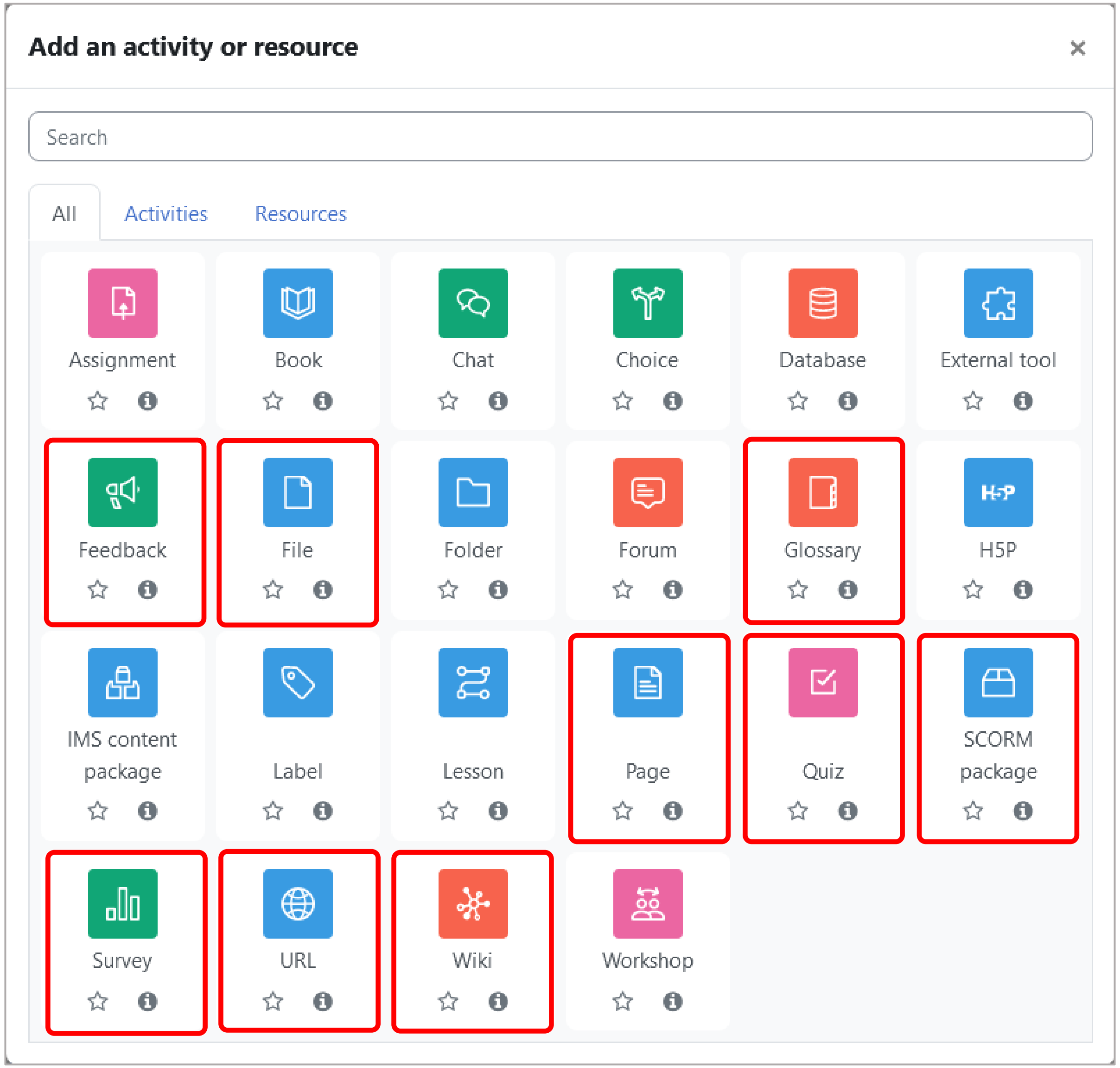
Status of Current Activities



Learning Management System
Moodle

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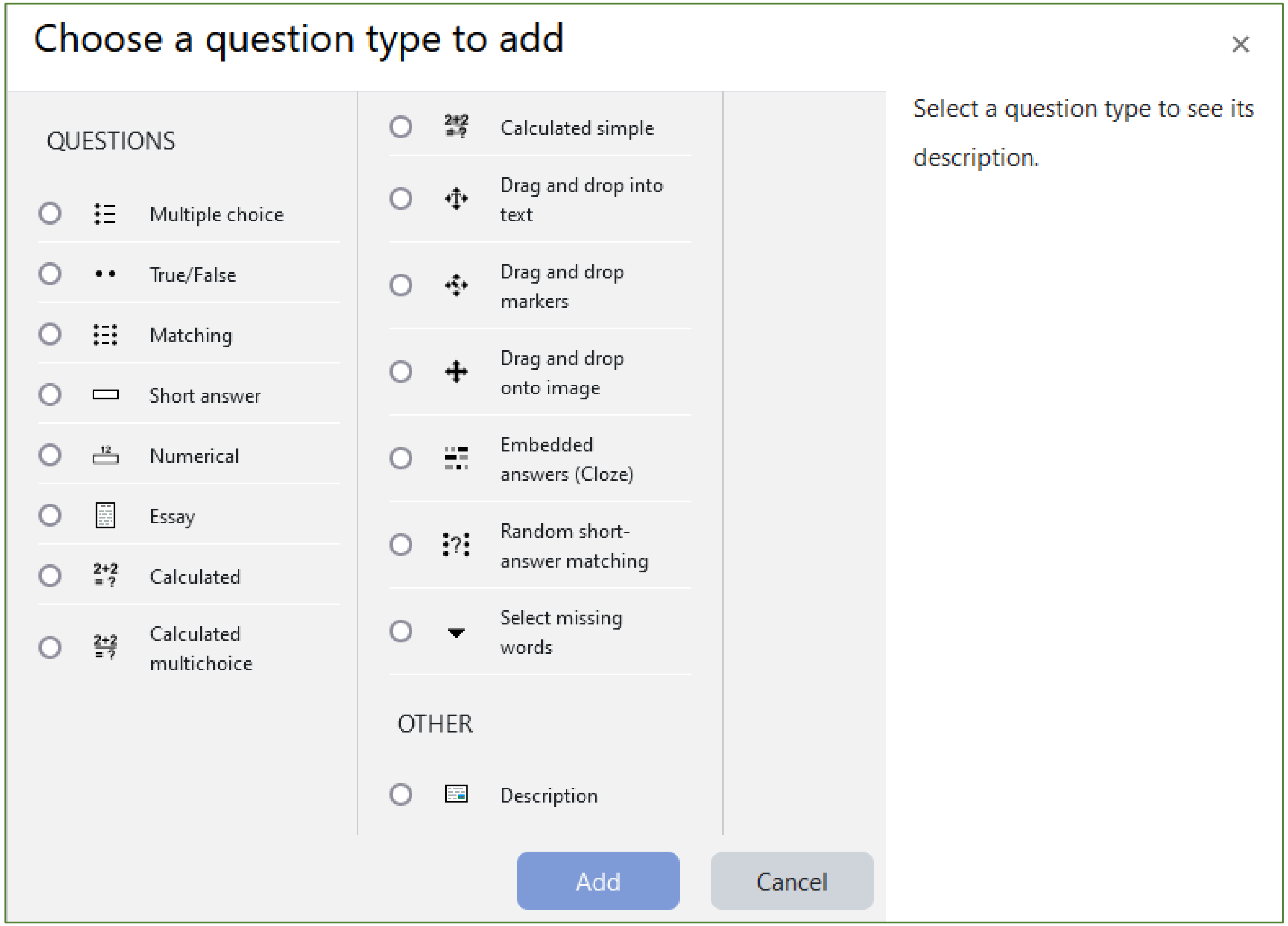
Status of Current Activities



Learning Management System
Moodle

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Thank you!

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