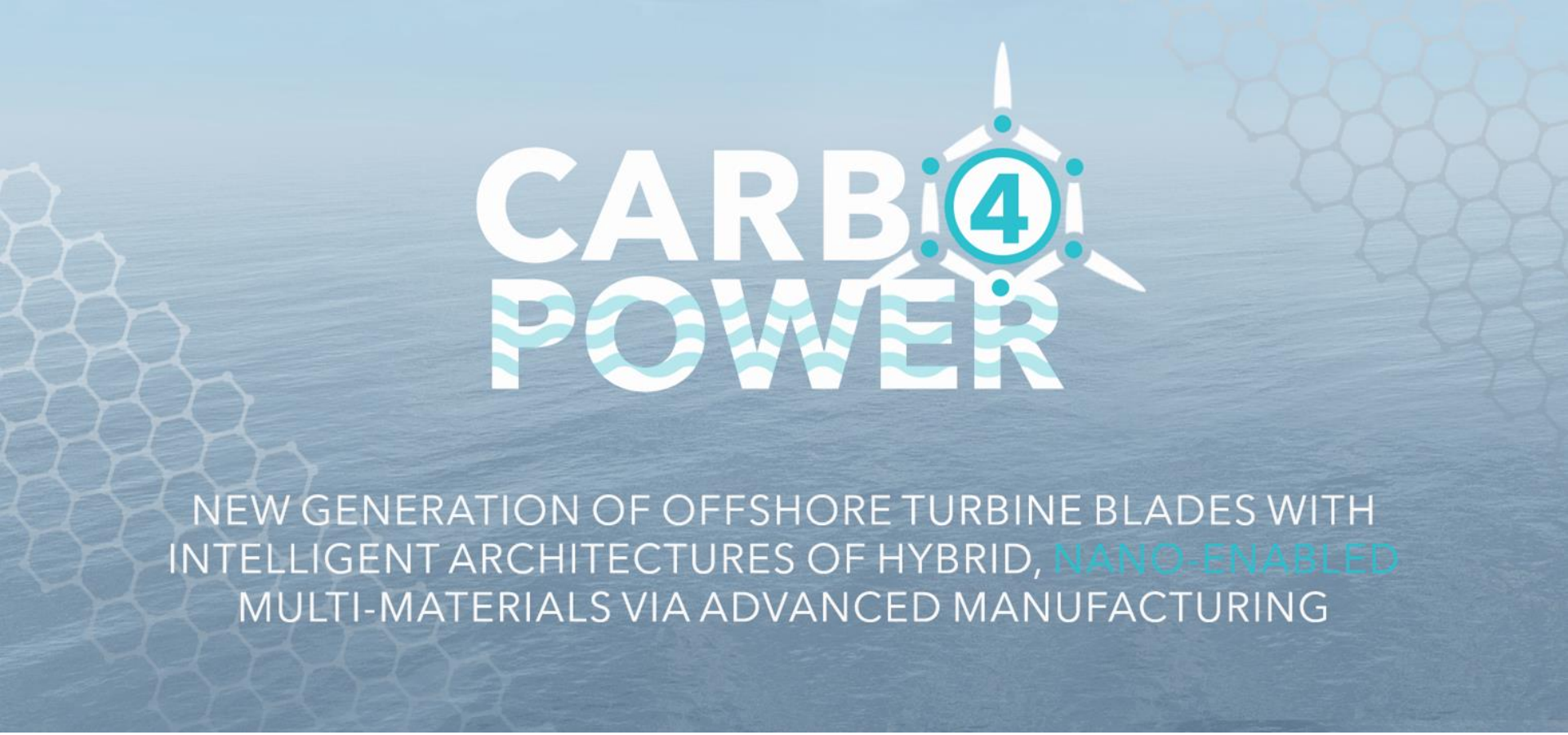


# Carbo4Power project: New generation of offshore turbine blades of nano-enabled multi-materials

Stefania Termine, Dr. Tatjana Kosanovic, Dionisis Semitekolos,
& Prof. Costas Charitidis

coordinator@carbo4power.eu

E-LASS #17, Las Palmas, Spain, May 3-4 2023

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

# 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 off shore energy (IA)
- **Number of partners:** 18
- **Duration:** 48 months (1.11.2020 – 31.10.2024)
- **Funding:** ~7M €
- **Coordinator:** NTUA, R-NanoLab, Prof. Costas A. Charitidis

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# Consortium


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# 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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# Project Targets

A **new generation** of **lightweight, high strength, multifunctional, digitalized multi-materials** for offshore wind / tidal turbine rotor blades.

**Increased operational performance and durability** while **reducing cost of energy production, maintenance** and **environmental impact.**

**- Nanocomposites based on dynamic thermosets** with inherent recyclability and repairability and tailored nano-reinforcements.

**- Multifunctional nano-enabled coatings** to improve turbine protection (e.g. against lightning and biofouling).

**- New Blade segments** designed and fabricated by advanced net-shape automated multi-material composite technologies (ca. ↓20% scrap).

**- Recycling of blade materials** - ↑ up to 95% - advanced functionalities of 3R resins & de-bonding on demand adhesives.

**N**ew pathways of **composites manufacturing** for multiple processing life cycles, and explore the emerging valorization opportunities in **offshore energy sector**.

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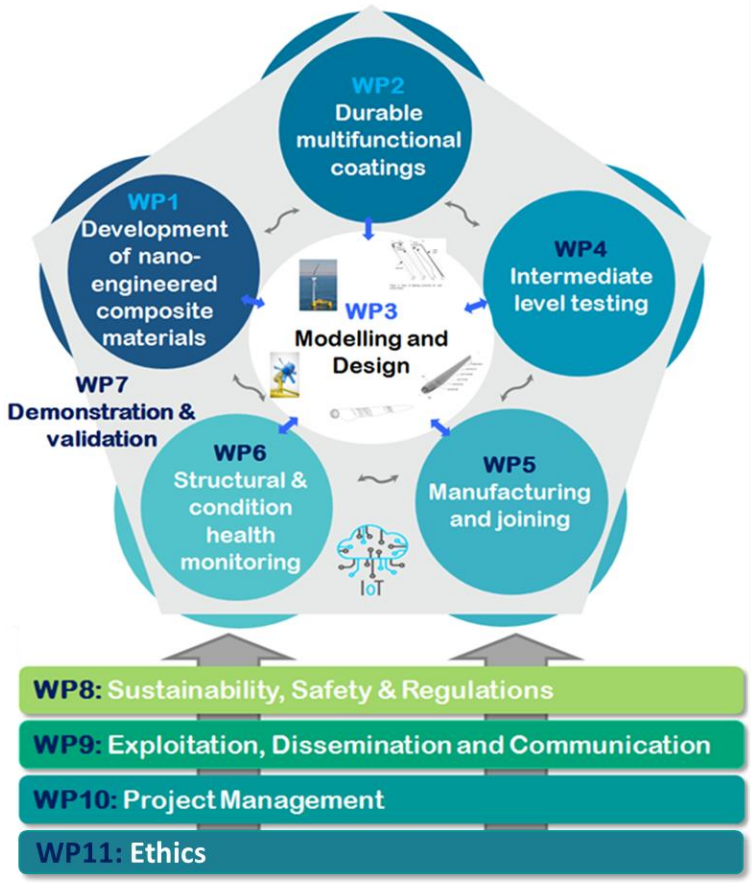
# Work Plan




## Phase 1

**WP1, WP2, WP3**

- R&D on the 3R resins, nano-additives integration in epoxies, fibres, coatings, adhesives, characterisation of their functionalities
- A portfolio of materials/process/joining technologies and techniques
- Validation at lab-scale - specific applications
- Multi-physical models

## Phase 2

**WP4, WP5**

- Intermediate level testing toward manufacturing of demo cases for validation of developed technology solutions (elements, joints)
- Realistic environmental condition test rigs (icing wind tunnel, seawater, accelerated UV chamber, thermal aging, among others)
- Optimization of materials combination - "right materials in right place"
- Manufacturing of demo scale blades.

## Phase 3

**WP6, WP7**

- SHM - materials and process information will be combined with the digital tools for demonstrating the achievement of the TRL6.
- Testing and validation two demo on WTB and TTB (TRL6).
- Capability of blade materials to undergo the recycling process.

## Horizontal

- Sustainability, safety and regulations
- Cost /benefit analysis of the novel materials & manuf. technologies
- Exploitation, Standardisation, Communication & Dissemination
- Project Management and Coordination
- Ethics

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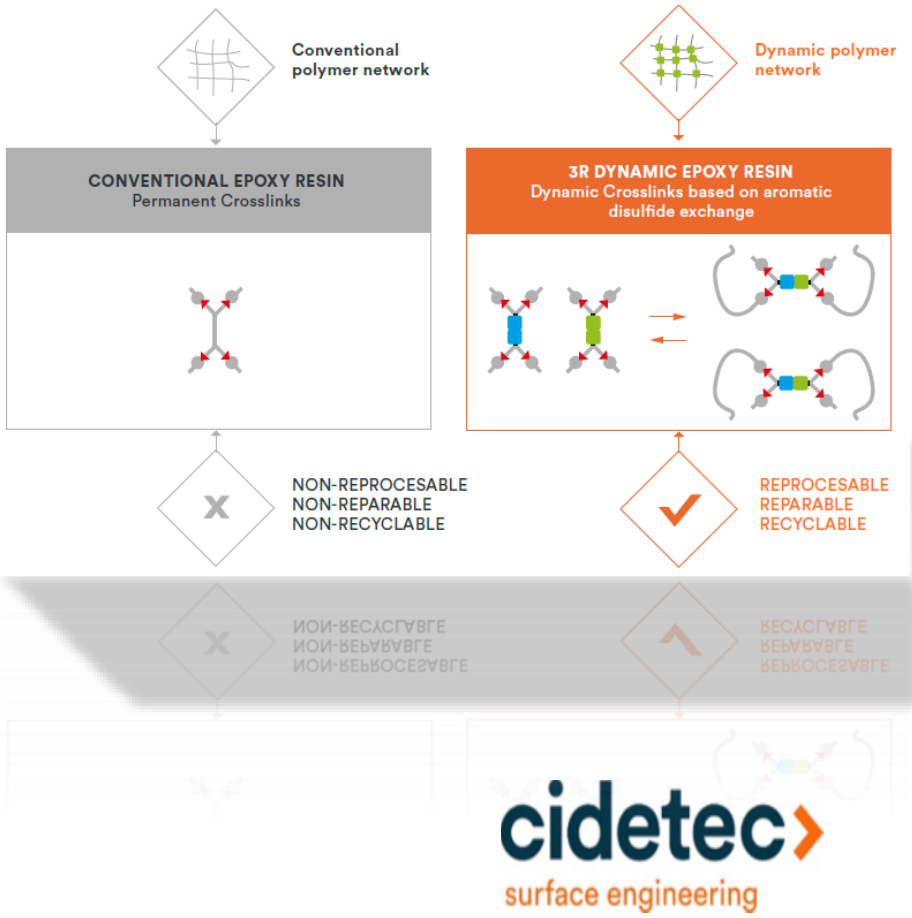
# Material Innovations

## 3R resin formulation for W/TTB




**3R resin**
**Reprocessing, Repairing, Recycling**

*Formulations were developed for blade manufacturing processes:*
*Infusion, prepregs for AFP/ATL*

cidetec
surface engineering

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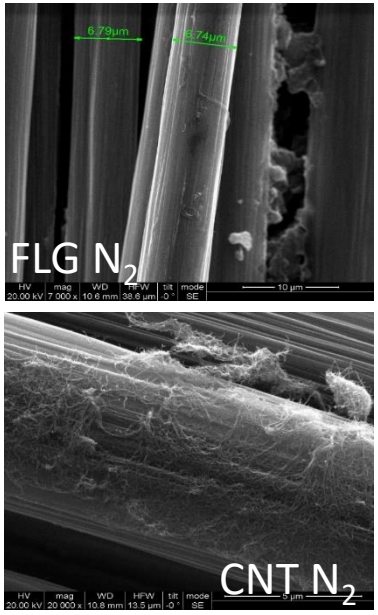
# Material Innovation

## Novel Multi-functional composite materials

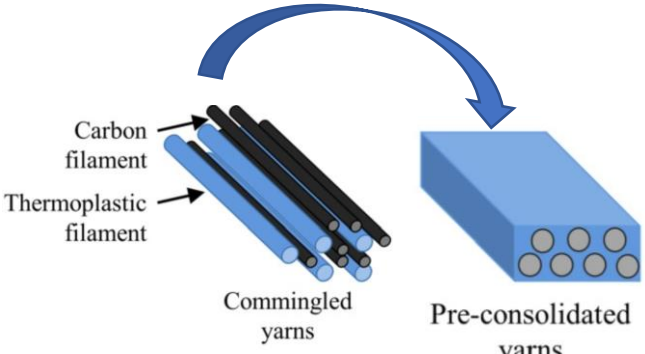
### Fiber surface Functionalisations

- Plasma treatment
- Electropolymerisation
- Nanoenhanced C-based 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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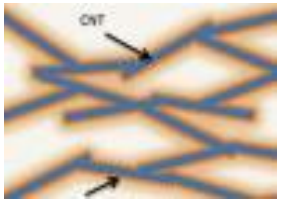
# Material Innovations

## Novel Multi-functional composite materials

### Functional resistive heaters for de-icing

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




haydale

### Functional prepregs for Lightning Strike Protection

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

cidetec surface engineering

haydale

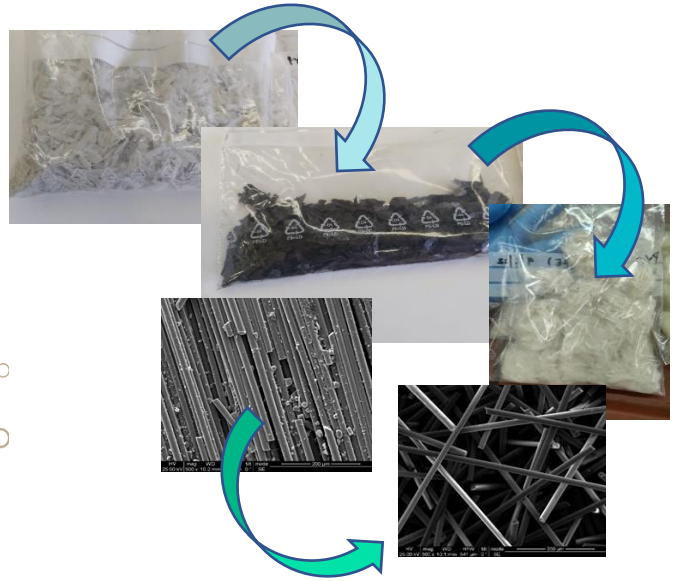
### Adhesive joints with debonding on demand capabilities

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

ITAINNOVA

### Functionally graded recycled fibre adhesive carrier

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



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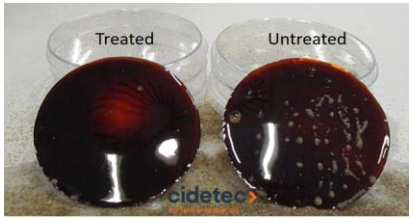
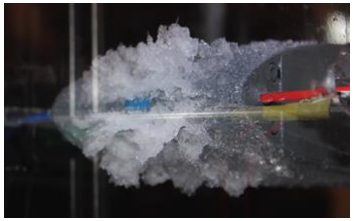
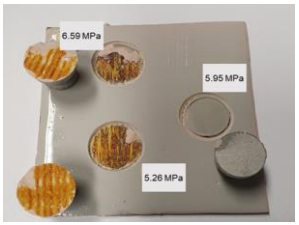
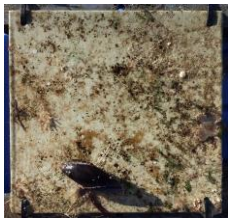
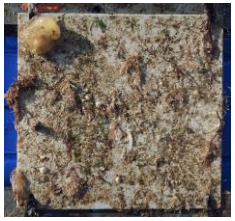
# Material Innovations

## Novel Multi-functional Coatings

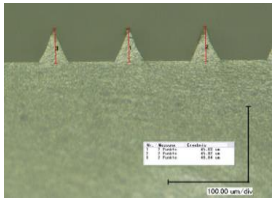
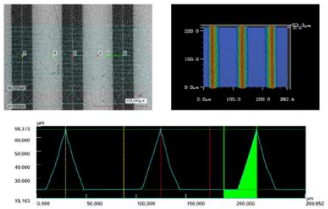
**Low surface energy coatings** with self-cleaning properties to reduce surface contamination / corrosion effects (incl. ice, biofouling, soiling, water)

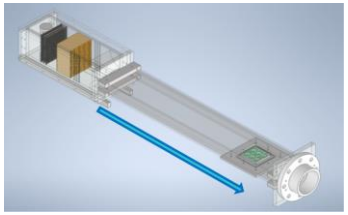


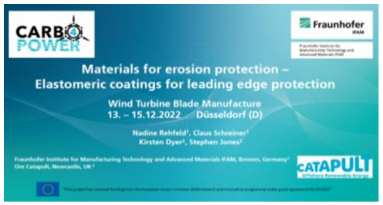
**Drag-reducing riblet** and lift increasing surfaces for improved energy harvesting




**Erosion protection coatings** for leading edge protection, considering high strength / self-healing properties

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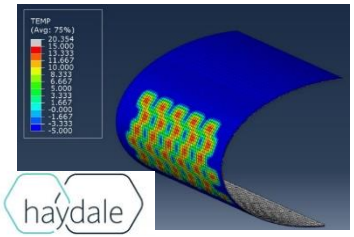
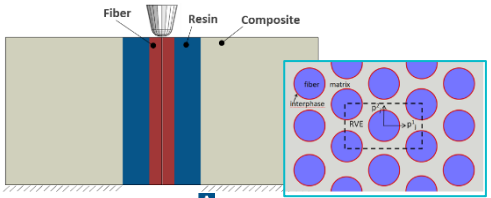
# Modeling Activities

## Modeling and Design

Design of Nanomaterial-enhanced heater system for de-icing




Study of carbon fibre treatments to improve CFRP properties

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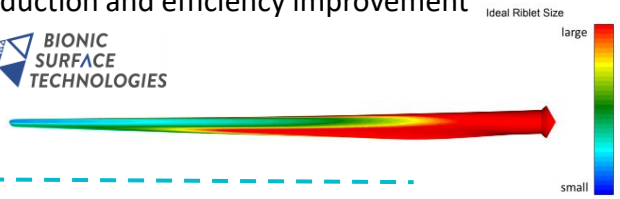
Localization of QRS sensors

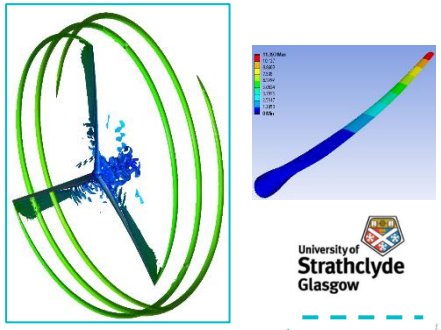
SENSE in ENHANCE YOUR MATERIALS

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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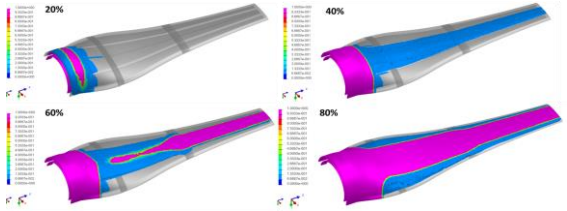
Support in TTB demo infusion process definition

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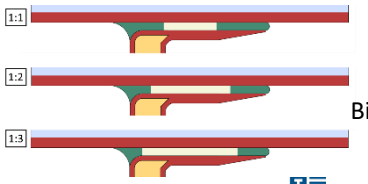
Analysis of innovative bonded joints solutions

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Scarf-joints

Bi-adhesive joints

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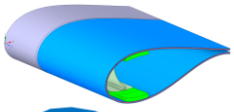
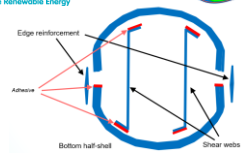




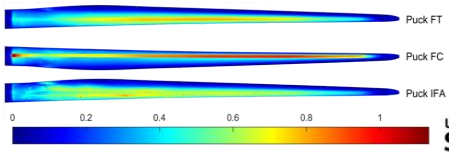

Demonstrators design

sabella

Optimised Bladelet design

BIOG3D

Structural analysis of blades at full and demo scales

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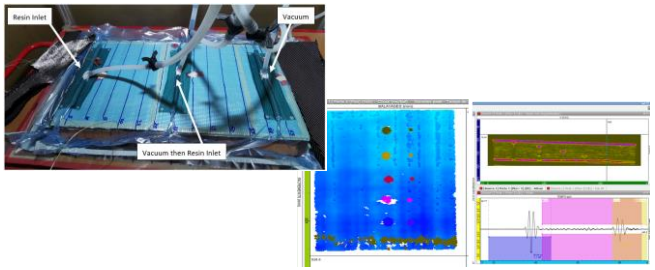
# Project Highlights

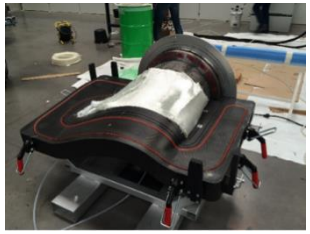
## Intermediate level testing

- Infusion of panels for intermediate mechanical testing
- Infusion of one thick reference panel with artificial defects to evaluate different NDT testing methods




## Manufacturing Processes

- 3R processability evaluation
- Infusion of W/TTB shells
- Advanced manufacturing:
  - ATL/ AFP (WTB spar)
  - NCF placement (TTB blades)



***Demonstrators***

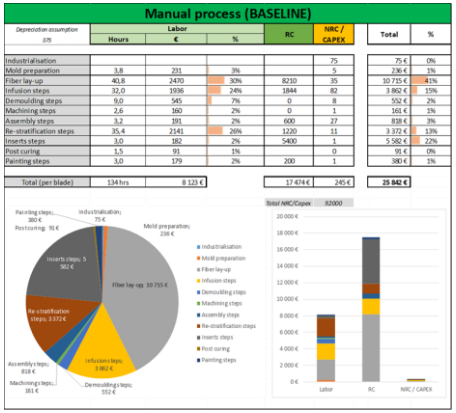
*WTB:*

- *scale-down 1:20 modular blade >15MW (infusion & ATL/AFP manufacturing)*

*TTB:*

- *1x D12 truncated (4m) scale 1 blade (NCF/DFP/infusion manufacturing)*
- *1 x Scale 1:2 truncated (0.7m) Tidal blade (One-shot manufacturing)*

Technical-economical study for manual/automated process

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# Project Highlights

## Horizontal Activities

- Sustainability, safety and regulations
- LCA/ LCC Analysis
- Liaison with Standardisation Bodies and Advisory Board
- Cost /benefit analysis of the novel materials & manuf. Technologies
- Exploitation, Standardisation, Communication & Dissemination

*From 1M – 48M of project implementation*

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# Expected Impact

**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.**

## Operational & Maintenance Costs


**Optimised materials cost & improved durability**

**↓ 40% Levelized Cost of Energy**

**<10 ct€/ kWh for wind**

**<15 ct€/kWh by tidal stream**

Increase of **energy production** for a given turbine size.

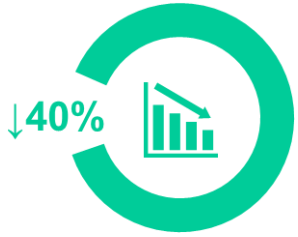
Increase in the **annual energy** >6%.

**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).

## Levelized CoE




**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.

## Environmental impact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# THANK YOU!

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