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WASTE MANAGEMENT OPTIONS FOR THE END-OF-LIFE OF WIND TURBINE BLADES

9th International conference on Sustainable Solid Waste Management

Corfu, 15-18 June 2022

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CONTENT

1. INEGI
2. Turbine blade materials (and waste stream)
    2.1 State of the art
    2.2 The materials
    2.3 Issues
3. Technology trends
    3.1 New materials
    3.2 New manufacturing
    3.3 New uses
4. The EuReCOMP and FASTCOMP projects
5. Conclusions

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1. INEGI

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A Research and Technology Organization (RTO) focused on research and technology-based innovation activities, technology transfer, consulting and technological services, oriented to the development of industry and economy in general.

A non-profit, private and recognized as a public utility entity.

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KEY NUMBERS

COMPOSITES

93
Researchers and research engineers

>50
Direct staff

2,5 M EUR
Turnover in 2021

44
Innovation Projects with Industry

2. Turbine blade materials (and waste stream)

2.1 State of the art

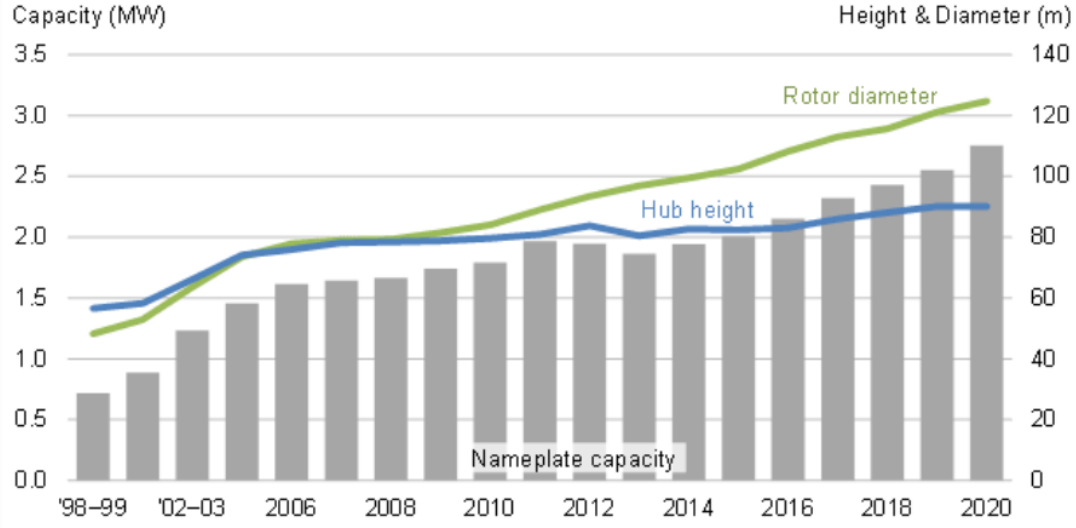
2.2 The materials

2.3 Issues

STATE OF THE ART in WIND TURBINE BLADES

TURBINE SIZE

As energy harvested by a wind turbine is proportional to the area of the rotor (or the square of the diameter) there is a physical incentive to grow rotor diameters as technology allows. That is one of the trends observed internationally:

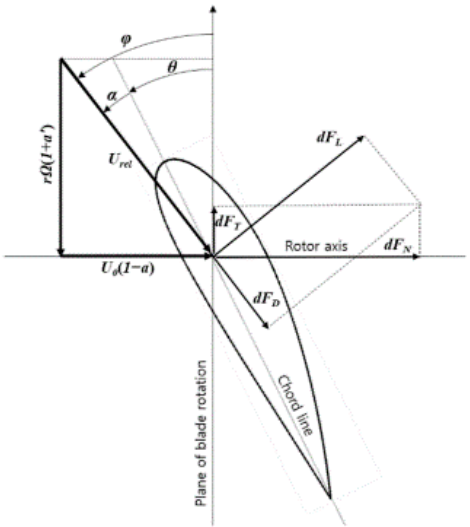


Average turbine hub height, rotor diameter, and nameplate capacity for land-based wind projects from the Land-Based Wind Market Report: 2021 Edition

WIND TURBINE BLADE MECHANICAL REQUIREMENTS

These considerations point to the dominant engineering requirements in turbine design: high stiffness to prevent flap-bending of the increasingly svelte structures (so that they do not collide with the towers). Low structural mass to reduce the intensity of gravity loads and of fatigue (as the blades rotate around the hub). And both low mass and high stiffness increase the natural frequency of the structure (and improve aerodynamic flutter response in variable winds). Finally, a long fatigue life.

a = Axial induction factor
a' = Angular induction factor
r = Section radius
α = Angle of attact
φ = Inflow angle
θ = Twist angle
Ω = Angular velocity of rotor
U_0 = Free stream wind velocity
U_{rel} = Relative wind velocity
F_D = Drag force
F_L = Lift force
F_N = Normal force
F_T = Tangential force



Yang, K. (2020). Geometry Design Optimization of a Wind Turbine Blade Considering Effects on Aerodynamic Performance by Linearization. Energies 2020, Vol. 13, Page 2320, 13(9), 2320. https://doi.org/10.3390/EN13092320

WIND TURBINE BLADE MATERIALS

MATERIALS

Material selection, follows the requirements that were discussed, as well as the manufacturing (vacuum infusion) and integration approach (adhesively joining) that has become standard within the industry. This is done to comply with the requirements but also due to manufacturing quality, cost considerations, complexity of the shapes that one wishes to produce, assembly process, abrasion, and impact resistance.

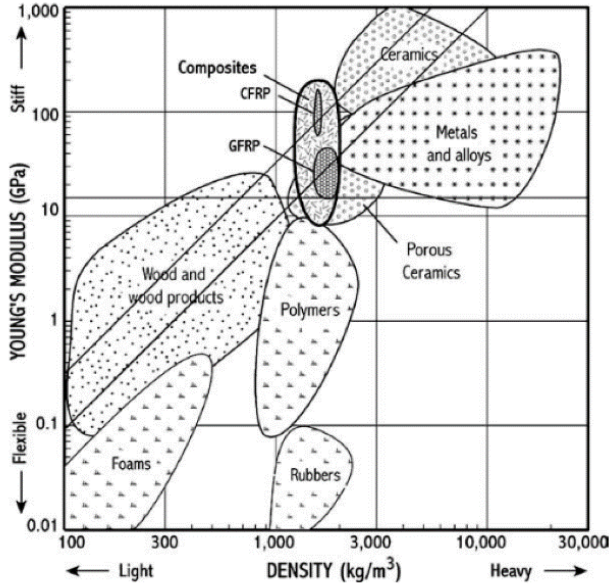
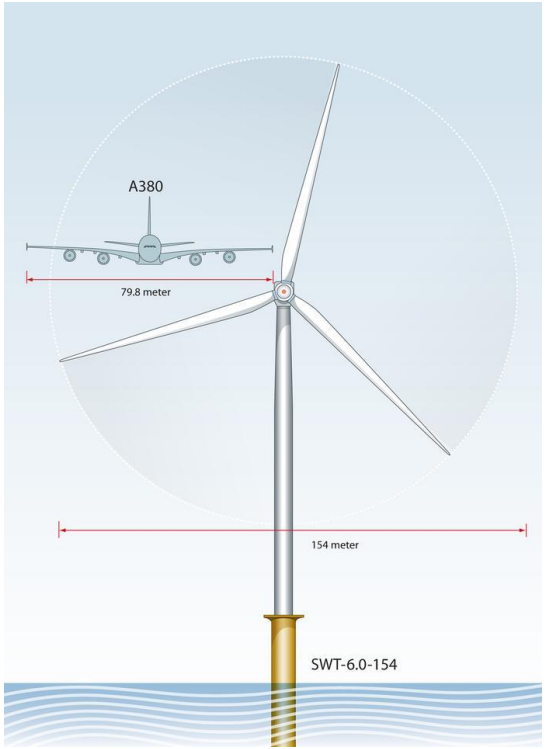


Figure 4 Diagram showing stiffness versus density for all materials. The merit index for a beam $M_b = E^{1/2}/\rho$ is represented by sloping lines with M_b equal to 0.003 (*lower line*) and 0.006 (*upper line*). The criterion for absolute stiffness E = 15 GPa is indicated by the horizontal line (4).

Brøndsted, P., Lilholt, H., & Lystrup, A. (2005). Composite materials for wind power turbine blades. In Annual Review of Materials Research (Vol. 35, pp. 505–538).

WIND TURBINE BLADE MATERIALS

Siemens B75 blade in its mould.



Schematic of the B75 wind turbine

SG 7.0-154 = 7,00 MW
3000 – 7000 homes

STATE OF THE ART in WIND TURBINE BLADES

MATERIALS USED ARE EXTEMELY RESISTANT TO ABRASION AND TO CHEMICAL AND BIOLOGICAL AGRESSION

Necessarily the composite materials which are used in wind turbine blades are extremely resistant to degradation mechanisms (mechanical, chemical and biological). The glass and polymer matrix elements of these composites are both responsible for this behaviour. This results in a waste stream that that does not degrade effectively and that is not possible to landfill appropriately with an expectation of a significant reduction in volume.

ISSUES

WIND ENERGY IS CENTRAL TO THE “HIGH RENEWABLES”

In the European Commission’s “high renewables” scenario for 2050, the EU will see wind energy provide more electricity than any other technology, with an ever increasing size of wind turbines to improve wind capture.

Although estimates vary substantially, a central estimate in the glass and carbon fibre composites used in wind turbine blades by 2050 points to a number in the of more than 480.000 tons of accumulated waste, in Europe alone.

Today decommissioned wind turbine blades are sent to landfills. However, a European Union ban on landfilling of this waste stream is foreseen to take place in 2025. This ban is accompanied by the pledge of the European industry to not decommission its blades outside Europe. And, therefore, a solution for the materials in this waste stream is necessary.

ISSUES

LIFE EXTENSION AND REPOWERING

Another issue which emerged recently, as the first wind turbines reach the end of their 20 year service life, is the unwillingness of some regulatory agencies to allow repowering and to extend the life of wind turbines.

While possible in many cases to extend the equipment's service or even to re-power (extend blade length to increase the potential output of the system) it is possible already to observe that some European nations are unwilling to accept refurbishing of existing wind turbines.

This can be explained by the need to repurpose existing sites with turbines which are significantly more powerful than what existed in the early 2000's.

Refurbishment and continued use of wind turbine blades may not be an option, at least for the wind energy intensification scenario.

ISSUES

LIFE EXTENSION AND REPOWERING

With the commitments to more wind energy, larger and more powerful turbines, and the end of landfills, Europe requires an intensification of research into new ways of addressing the end of life of wind turbine blades.

This research may take the form of

- advances in manufacturing processes,
- reduction of waste and defects during manufacturing,
- advances in materials and in their recyclability, such as the introduction of thermoplastic composites and de-polymerizable resins,
- and advances in reuse and re-purposing of large composite components which have reached their end of their primary purpose.

3. Technology trends

3.1 New materials

3.2 New manufacturing

3.3 New uses

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NEW MATERIALS AND THEIR RECYCLING

Use of thermoplastic matrices, which allow for direct use of the waste stream as new feedstock for other processes/products.

Use of thermosets which can be depolymerized, allowing the reuse of the fibres and cores as new materials. Removal of can take different forms:

- Solvolysis
  - Plasma-assisted Solvolysis
- Hydrothermal Solvolysis
  - Hydrothermal Solvolysis
  - Others

Finally, there is also an avenue available in pyrolysis.

DIGITAL MANUFACTURING TOWARDS REDUCED WASTE

Zero-defect towards zero-waste → control solutions capable of identifying defects in manufacturing and determining what corrective actions should be adopted for zero-defects less waste.

Human-oriented solution & skilled workforce → integrate user/operator's needs, requirements and suggestions in the technical development phase as well as skill development.

Real time monitoring → Diagnostic methods, non-destructive inspection and monitoring instruments to feed the digital twin model.

Preventive actions suggestion → "Intelligent" decision support systems will suggest corrective actions to prevent defects and or their further propagation.

PYROLYSIS

Although both glass and carbon are recoverable by pyrolysis, glass fibres are less valuable than Carbon fibres (by a factor of 10x) – and for this reason it has been easier to justify pyrolysis for carbon. Nevertheless, glass is the dominant fibre in wind turbine blades (and most of the mass of the blade) and is the main form of material that needs to be recovered.

Thermal recycling, pyrolysis in particular, achieves the highest mechanical property retention of all recycling processes but the use of high temperature ovens (500-600 °C) results in both higher cost and environmental impact. The polymer breaks down to fundamental components leaving the fibres for reuse.

This process still requires optimization, and further study, especially in order to allow its economic / environmentally sound application to glass fibre composites.

REUSE

Reuse is also an important avenue of research. Entire wind turbine blades need to find uses, as a whole, or fractionally, or as chip. These large structures have a significant possibility of finding value in products which require size, strength and number.

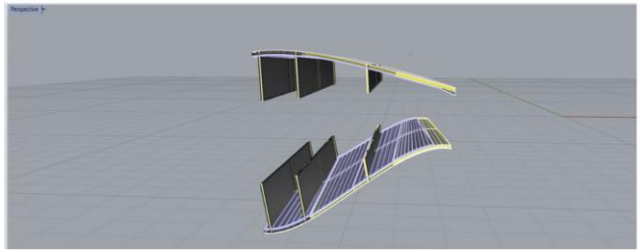
Examples of these uses are building roofs, facades and structural elements, as well as bridges.

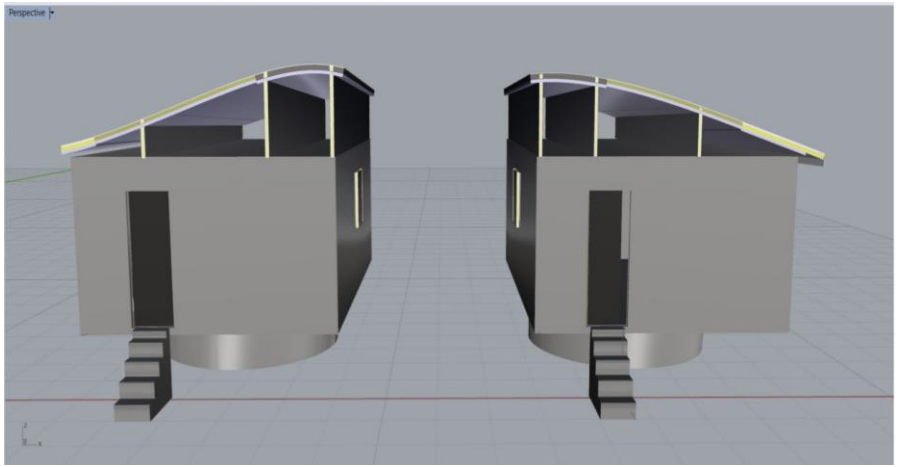
The fractional wind turbine blade uses that are being considered include urban furniture as well as smaller bridges and passageways.

As chip materials, wind turbine blades can also be incorporated in new composites as a filler, or in resins as moulding compounds. Naturally, as fibres tend to be much shorter, these (re)uses are far less structural than those which use continuous fibres.

TECHNOLOGY TRENDS

REUSE





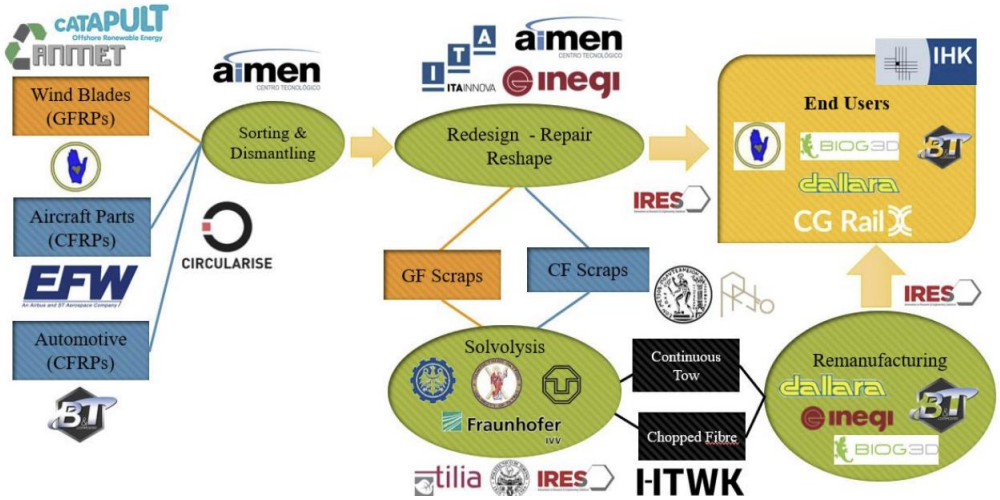
Bank, L. C., Arias, F. R., Yazdanbakhsh, A., Gentry, T. R., Al-Haddad, T., Chen, J. F., & Morrow, R. (2018). Concepts for reusing composite materials from decommissioned wind turbine blades in affordable housing. Recycling, 3(1). https://doi.org/10.3390/recycling3010003

4. The EuReCOMP and FASTCOMP projects

EURECOMP

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. The main pathways to achieve circularity will include the R6 strategy: Reuse, Repair, Refurbish, Remanufacture, Repurpose and Recycling of parts from end-of-life large scale products. The Reclamation of the materials used in such parts will accomplish a reduction of waste, due to transformation to high-added value products

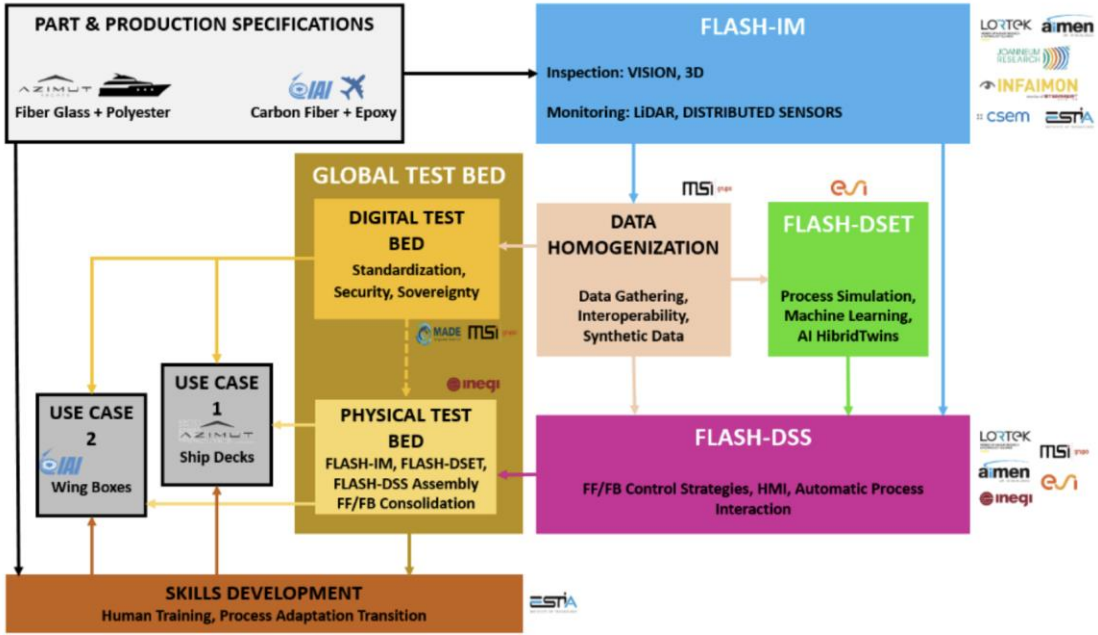
The work-structure of the 20 partner EURECOMP project



FlashCOMP

FLASH-COMP aims to avoid defects in manufacturing of large composite parts and determine if corrective actions should and could be adopted, in order to optimize the process, reach zero-defects and consequently, reducing the generation of wastes, both process- and product-related.

The work-structure of the 14 partner FLASH-Comp project



6. Conclusions

CONCLUSIONS

Waste from wind turbine blades needs research.

There are a number of really important studies before ours (see for example RE-Wind).

Glass fibres are less valuable than carbon fibre (1 order of magnitude less) and therefore it is less straightforward to justify recycling technology research, as well as its implementation. But this must be overcome.

We propose to go further: to establish protocols to ensure maximum reuse, and especially to establish protocols which allow an in-depth understanding of the residual mechanical properties of WTBs.

There is a range of opinions on solvolysis, pyrolysis, etc. However, it is the waste management research community who needs to address the issues of the technology, the cost, availability, embedded energy and possibility of reuse.

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