End-of-life of wind turbine blades
Value chain, recycling and composite materials

22.06.2023

Justine Beauson
DTU Wind Energy

Illustration by: Marie Boye Thomsen

Can wind turbine blades be recycled?

PART 1 Recycled materials

What type of material can be obtained from blade? What can these materials be used for? What is the potential of recycled in the production of new polymer composite?

Bloomberg Green

Wind Tu… Can't Be… Recycled, So They're Piling Up in Landfills

Companies are searching for ways to deal with the tens of thousands of blades that have reached the end of their lives.

By Chris Martin

February 5, 2020, 11:00 AM GMT+1 Updated on February 7, 2020, 8:54 PM GMT+1

PART 2 The value chain

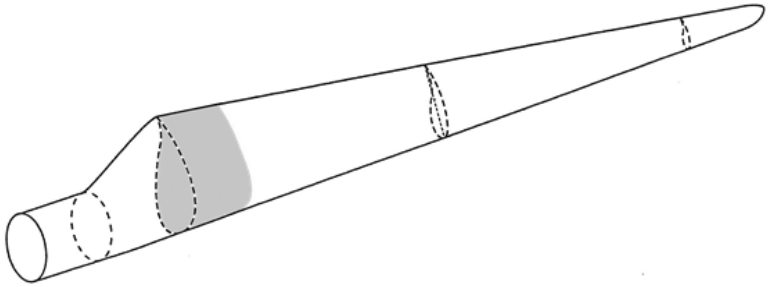
Why is the value chain perspective important? What are the steps before recycling and how do these impact the recycling process? What are the conditions for a successful recycling?

PART 3 Future materials

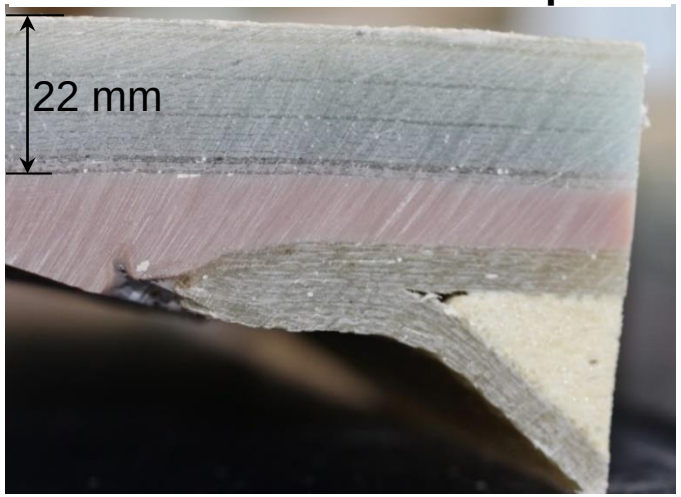
Can wind turbine blades be produced so they are more easily recycled?

Photographer: Benjamin Rasmussen for Bloomberg Green

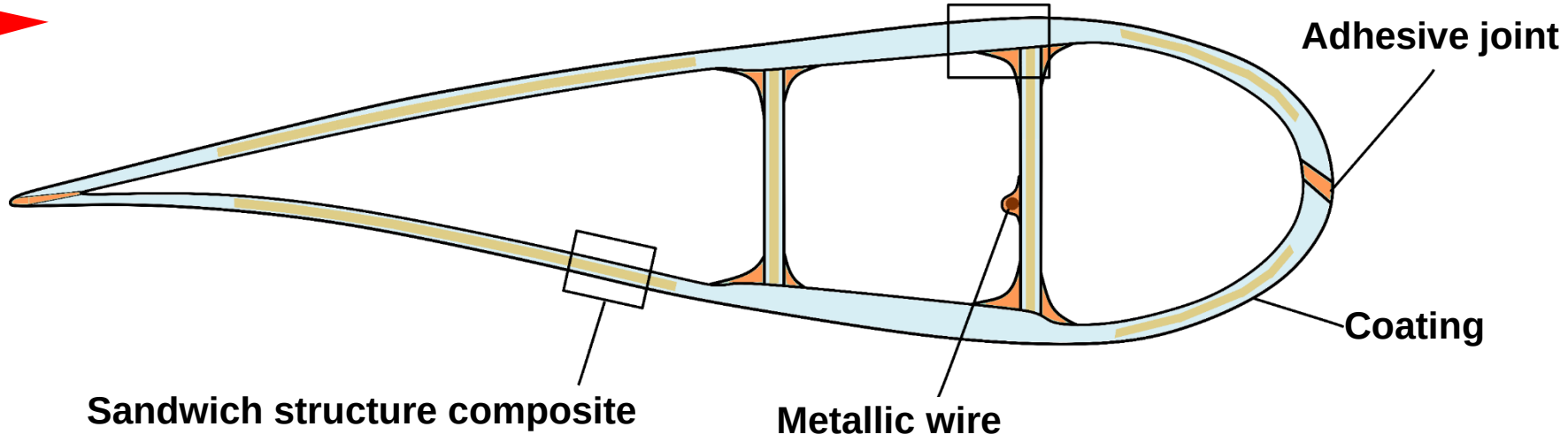
Wind turbine blades are complex structures



Glass fibre composite



The complex structure and the diversity of materials are challenges for recycling

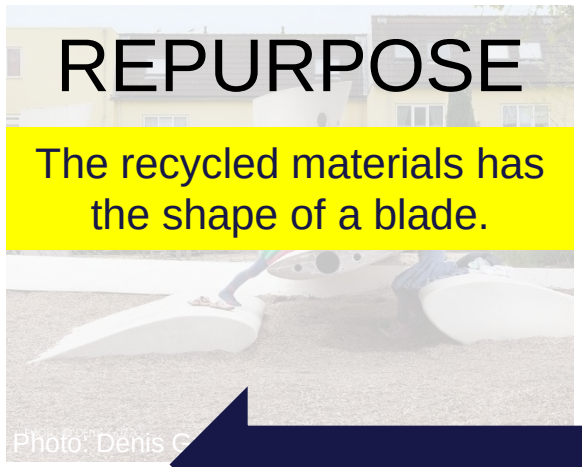


A variety of recycled materials can be obtained from wind turbine blades

Solutions are complementary

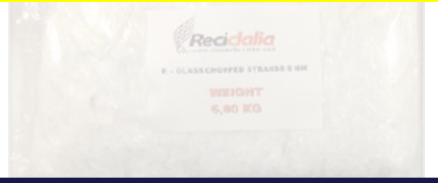
REPURPOSE

The recycled materials has the shape of a blade.



RECYCLING

Size of the material is small cm-scale. Can be mixed with more than one source of waste.



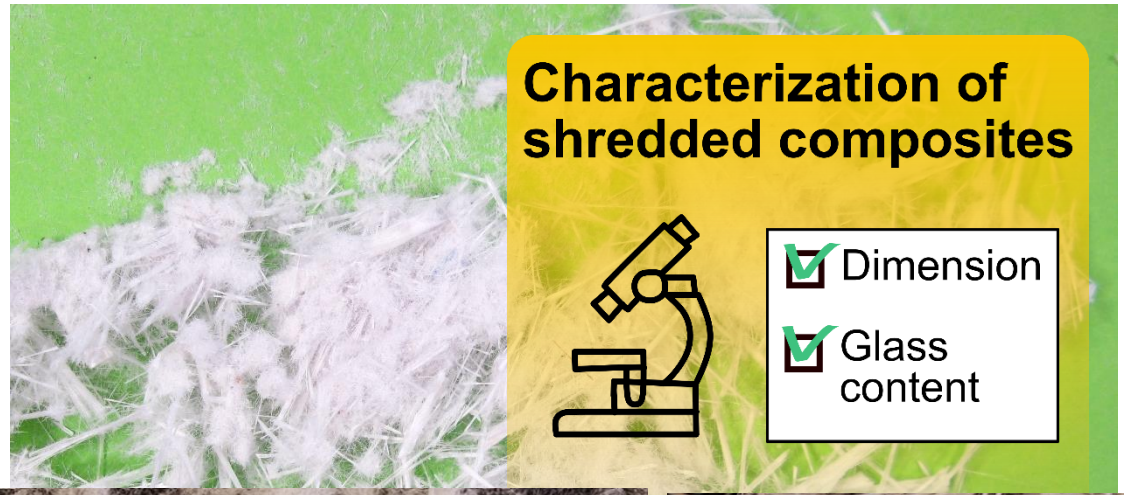
RECOVERY

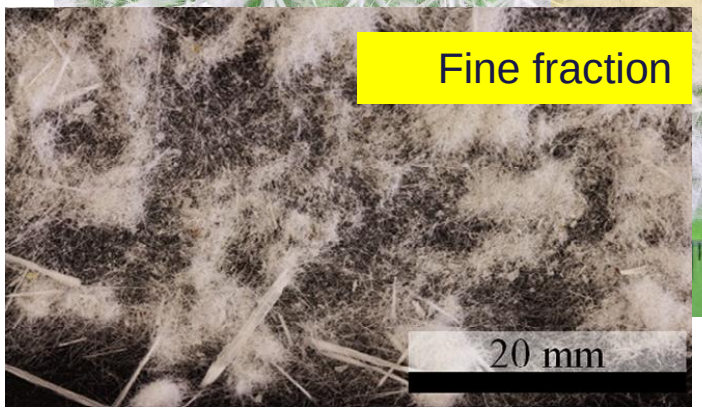
Fewer processing steps

More processing steps

What is the potential of recycled materials as reinforcement in new polymer composite applications?

Shredded composite





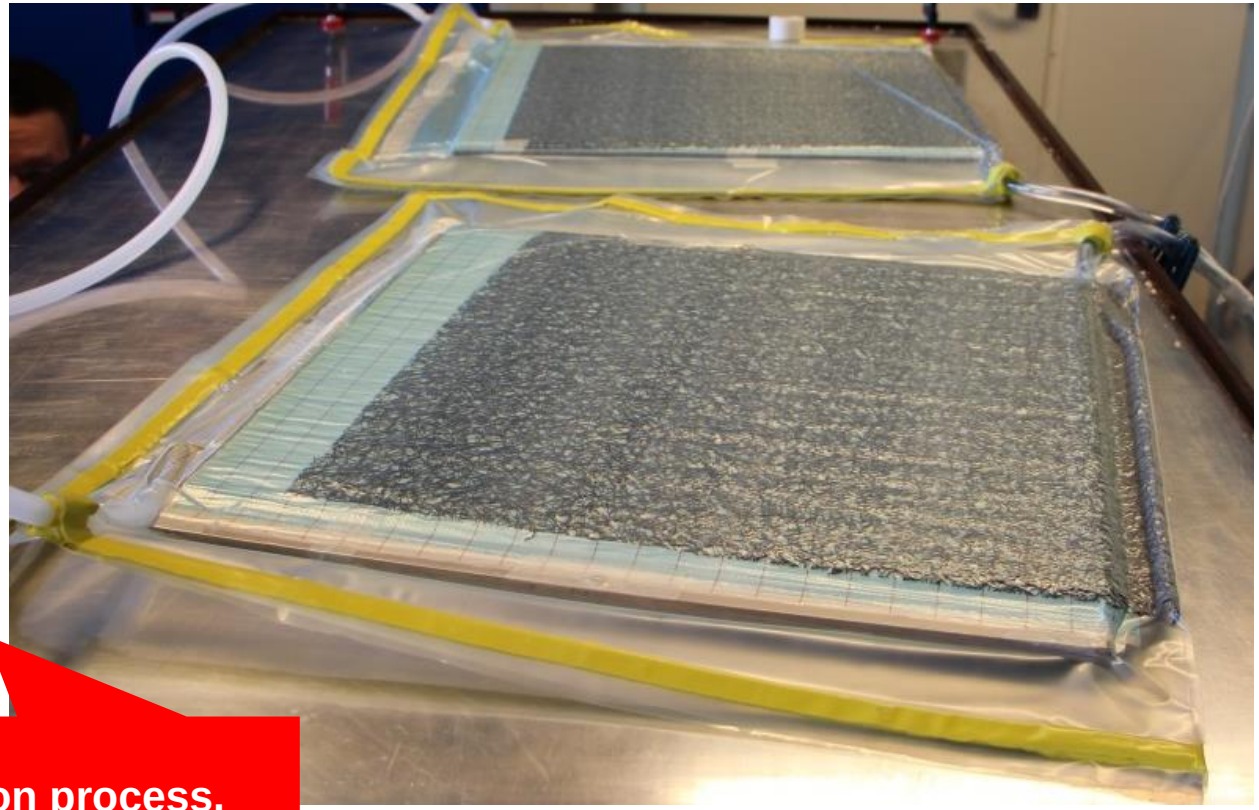
Recycled glass fibre

Shredded composite made of different fractions. Recycled glass fibres brittle, but stiff.

What is the potential of recycled materials as reinforcement in new polymer composite applications?

Polymer composite with Shredded composite

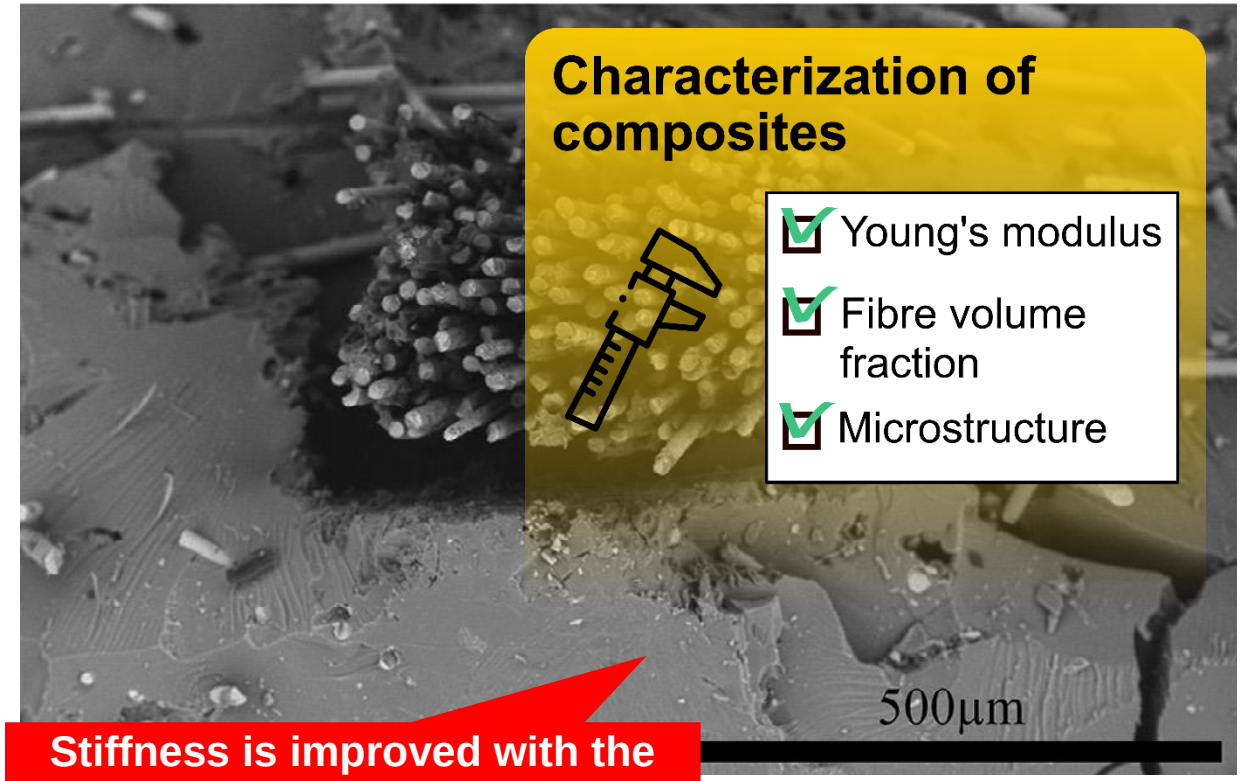
Polymer composite with Recycled glass fibre



Vacuum infusion process.

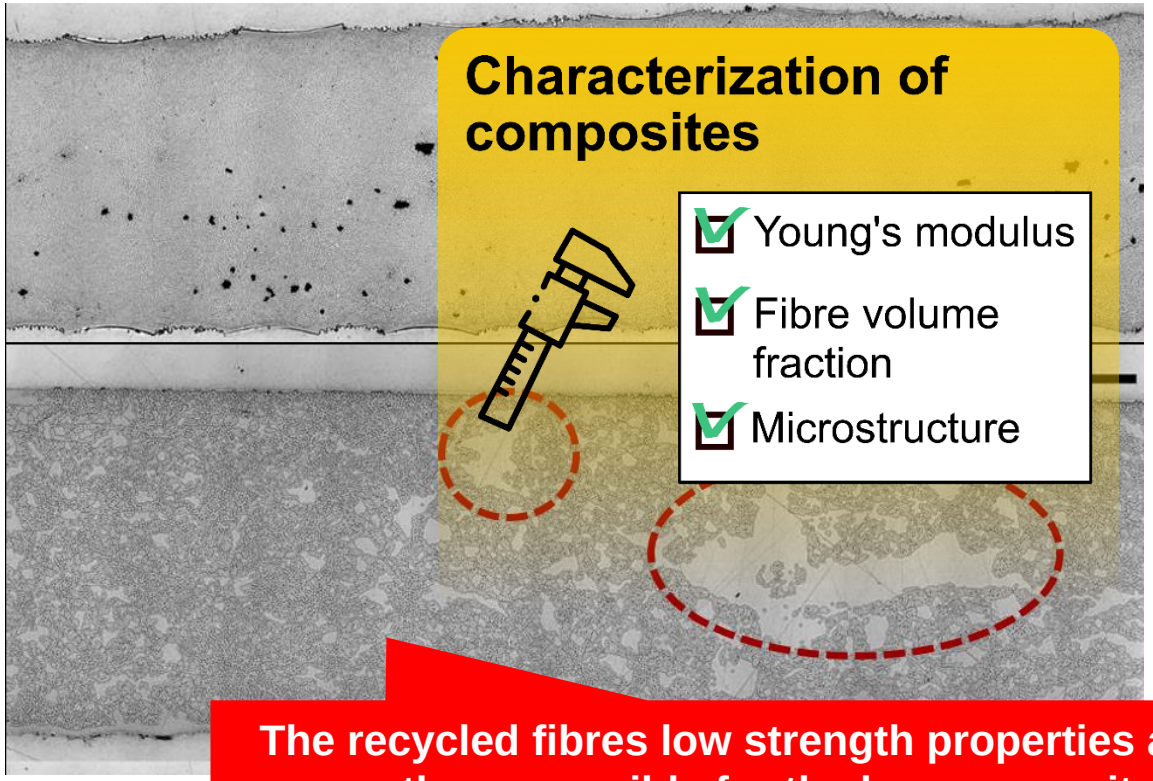
What is the potential of recycled materials as reinforcement in new polymer composite applications?

Polymer composite with Shredded composite



Stiffness is improved with the addition of shredded composite, but fails prematurely

Polymer composite with Recycled glass fibre



The recycled fibres low strength properties are mostly responsible for the low composite strength measured

What is the potential of recycled materials as reinforcement in new polymer composite applications?

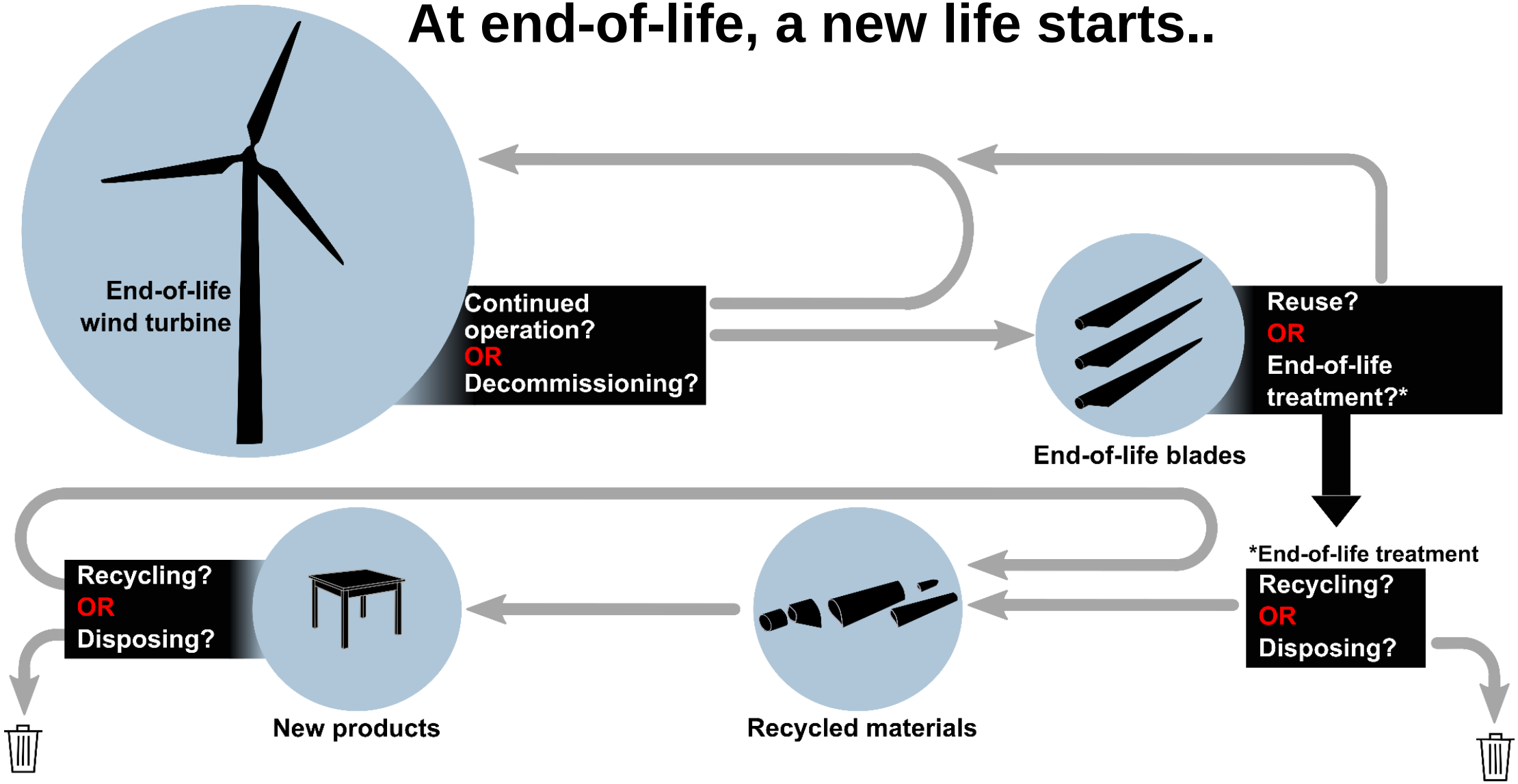
Conclusions

- Both recycled materials have some reinforcing effects…
- However, replacement of virgin reinforcement, like E-glass fibres with recycled glass fibres or shredded composites is not realistic.

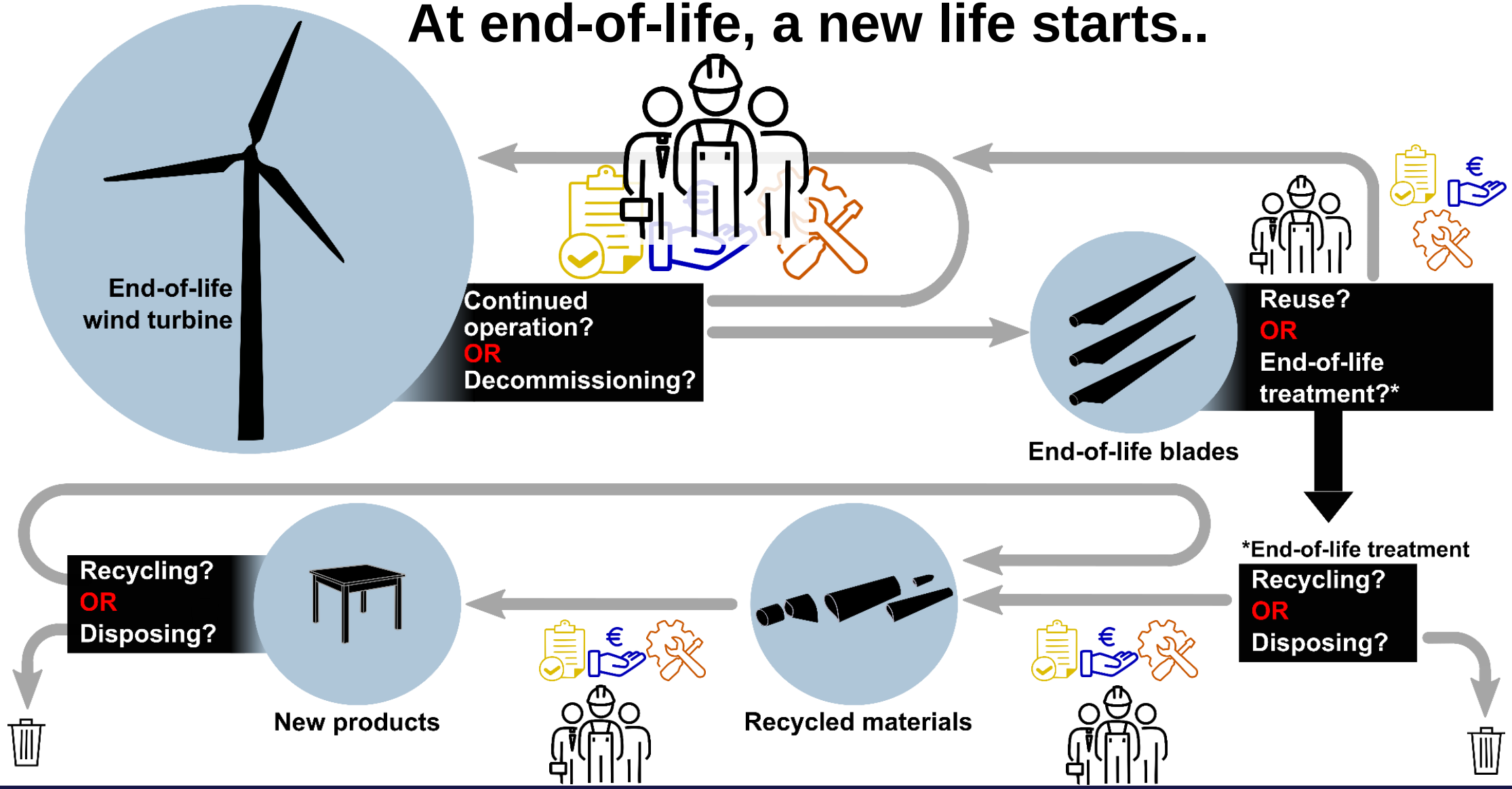
Next steps

1. Can we **take advantage** of the “weaknesses” of these recycled materials?
2. Can we produce recycled materials with **better properties?**
3. **How to recycle** products with recycled materials?
4. How to upscaling to larger industrial **scale?**
5. Does the recycling process make sense from **environmental point of view?**

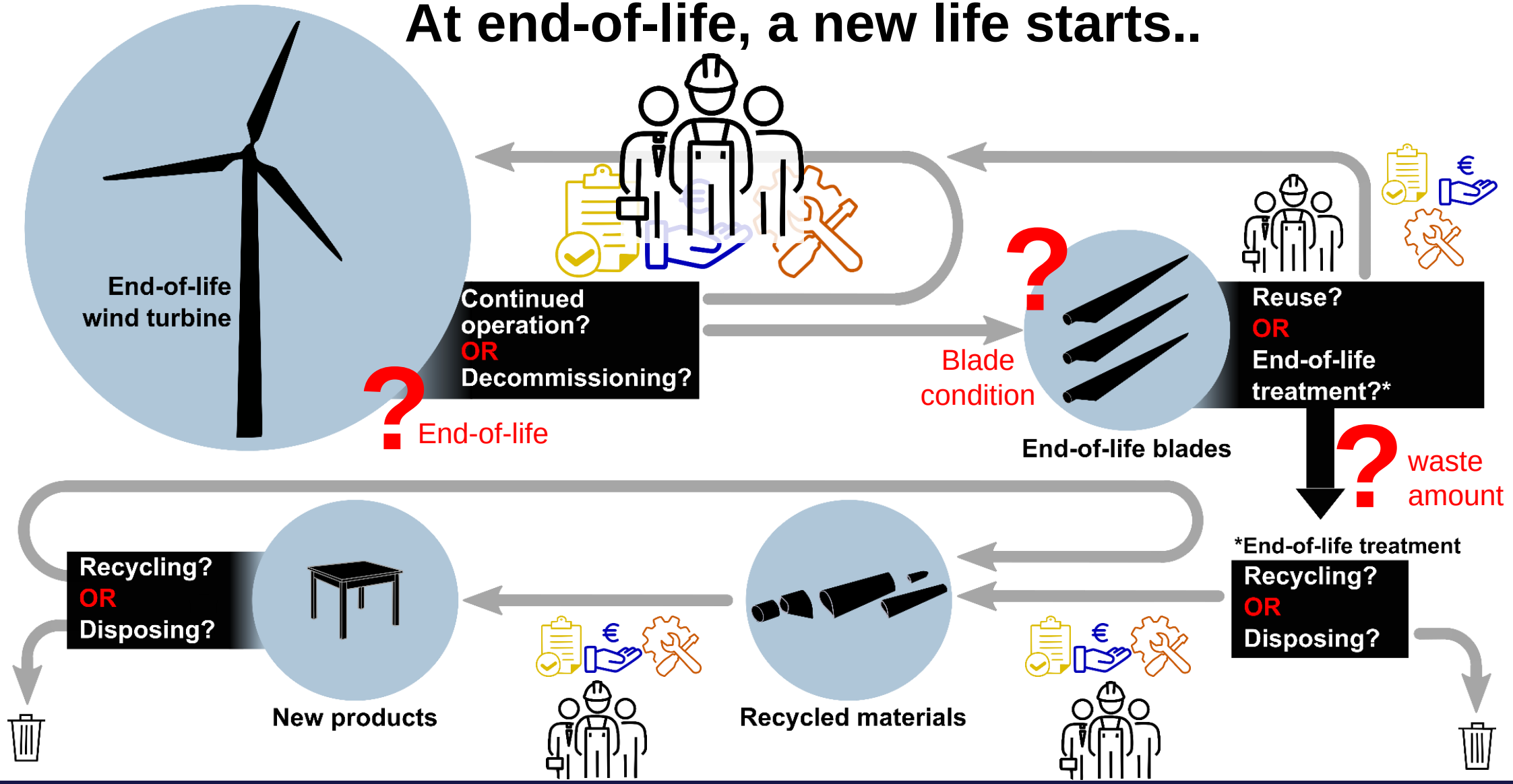
At end-of-life, a new life starts..



At end-of-life, a new life starts..



At end-of-life, a new life starts..



Can wind turbine blades be recycled?

Recycling is complex, and not only from a technical point of view.

PART 1 Recycled materials

Shredded composite and recycled glass fibres have a some reinforcing effect in new polymer composite, however these are limited effect. Future studies needs to look at ways to improve the production and quality of these materials and find alternative reuse applications.

PART 2 The value chain

For recycling solutions to be reliable and sustainable, a holistic and coordinated approach to the end-of-life of wind turbine blade is needed, considering economy, regulations, technical feasibility, environmental impact, social perception and acceptance..

PART 3 Future materials

Can wind turbine blades be produced so they are more easily recycled?

DecomBlades

The Circular Economy Value Chains for Decommissioned Wind Turbine Blades

Establish a functional, **sustainable value chain** to handle end of life wind turbine blades from decommissioning, to reprocessing and recycling in new Applications

Support Danish industry partners in becoming leaders in recycling polymer composites and wind turbine blades

Upscale the results achieved in DecomBlades with an international plan

- Detailed blade knowledge (design, content, volumes)
- **Shredding and logistics**
- **Recycled materials market**
- **Pyrolysis technology**
- **Cement co-processing**

3 year project – 2021 to 2024

Supported by: Innovation Fund Denmark

LM WIND POWER a GE Renewable Energy business

SIEMENS Gamesa RENEWABLE ENERGY

Vestas

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FLSmidth

Estimating end-of-life wind turbine blades in Denmark

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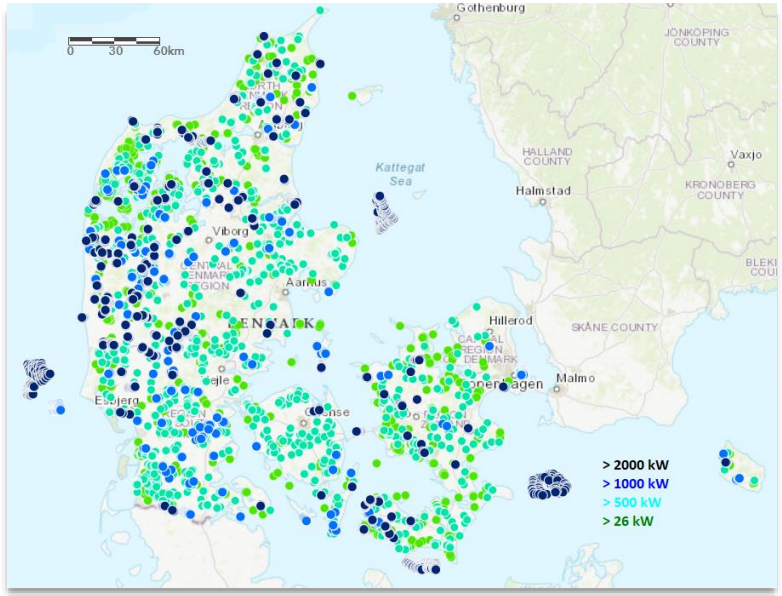
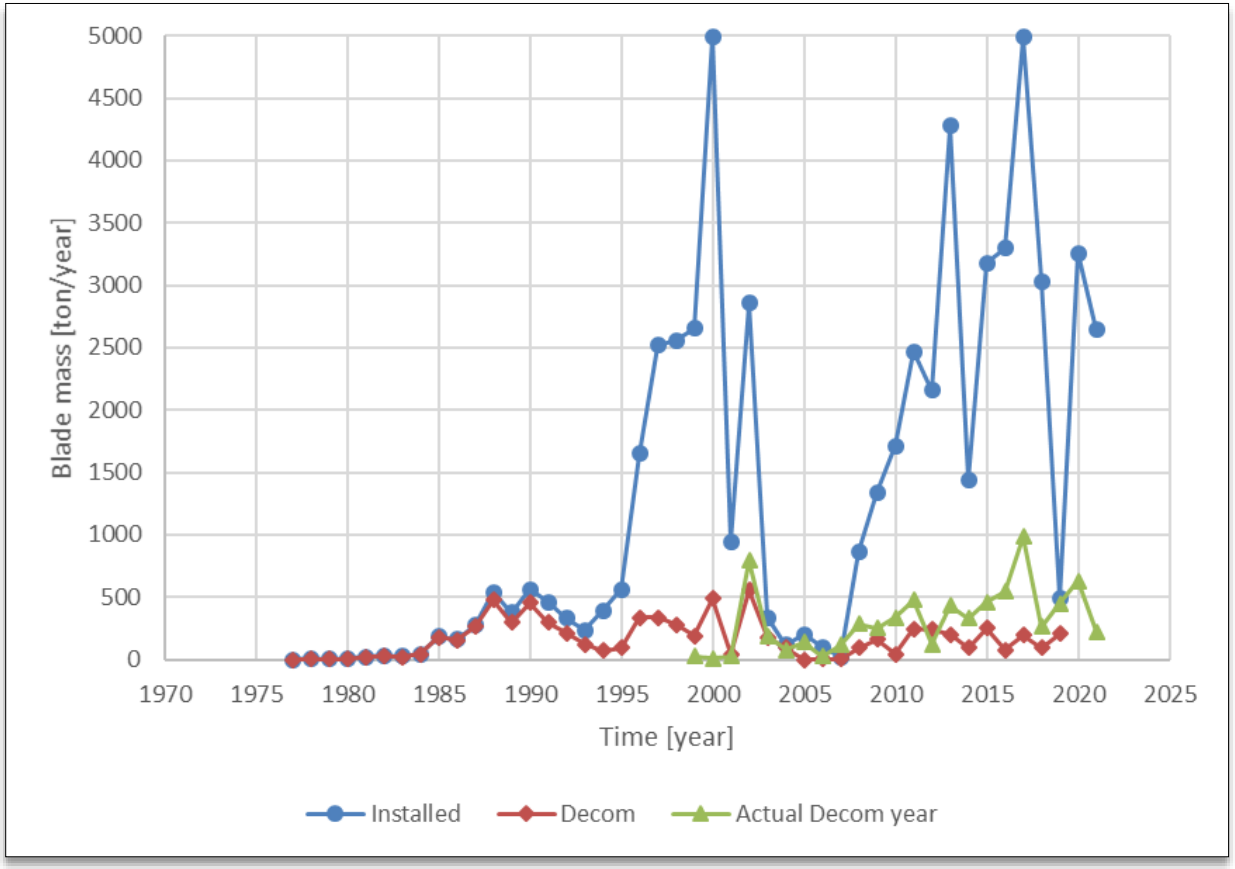
[3]Siemens Gamesa Renewable Energy A/S, DK-9220 Aalborg, Denmark

Essential to build business cases for the recycling industry!

We use stamdata register.





How to estimate?

We can look into the past, but how to predict the future?

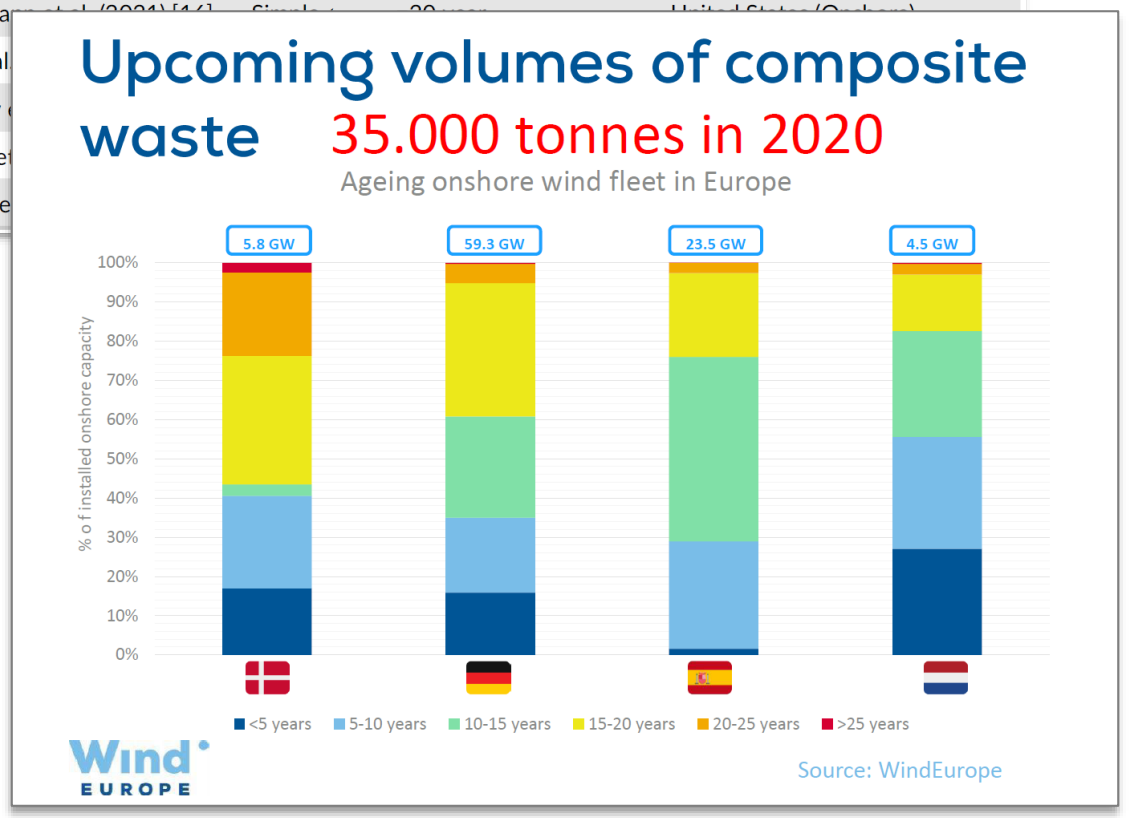
Many studies provides different numbers and uses different calculation methods!

Waste estimate assumptions in literature:

1. End-of-Life ~ Design Life time
2. **End-of-Life ~ Distribution of decommissioning age of turbines**

We model how wind turbines are being depleted.

Authors	Method for time of decommissioning	Geographical dispersion
Andersen et al. (2016) [23]	Simple t_{Decom}=20 year	Sweden and Denmark (Onshore)
Liu and Barlow (2017) [11]	Simple t_{Decom}=18, 21, 26 year	Europe + world (Onshore)
Sultan et al. (2018) [12]	Distribution t_0 = 25 year	Great Britan (On- and Offshore)
Tazi et al. (2019) [13]	Simple t_{Decom}=15 year	France (Onshore)
Lichtenegger et al. (2020) [14]	Distribution t_0 = 18 year	Europe (On- and Offshore)
Tota-Maharaj et al. (2021) [24]	Simple t_{Decom}=20 year	Great Britain (On- and Offshore)
Chen et al. (2021) [15]	Distribution t_0 = 14, 18 and 21 year	China (on- and Offshore)
Cooperma		
Heng et al		
Delanney		
Sommer et		
Lefeuvre e		

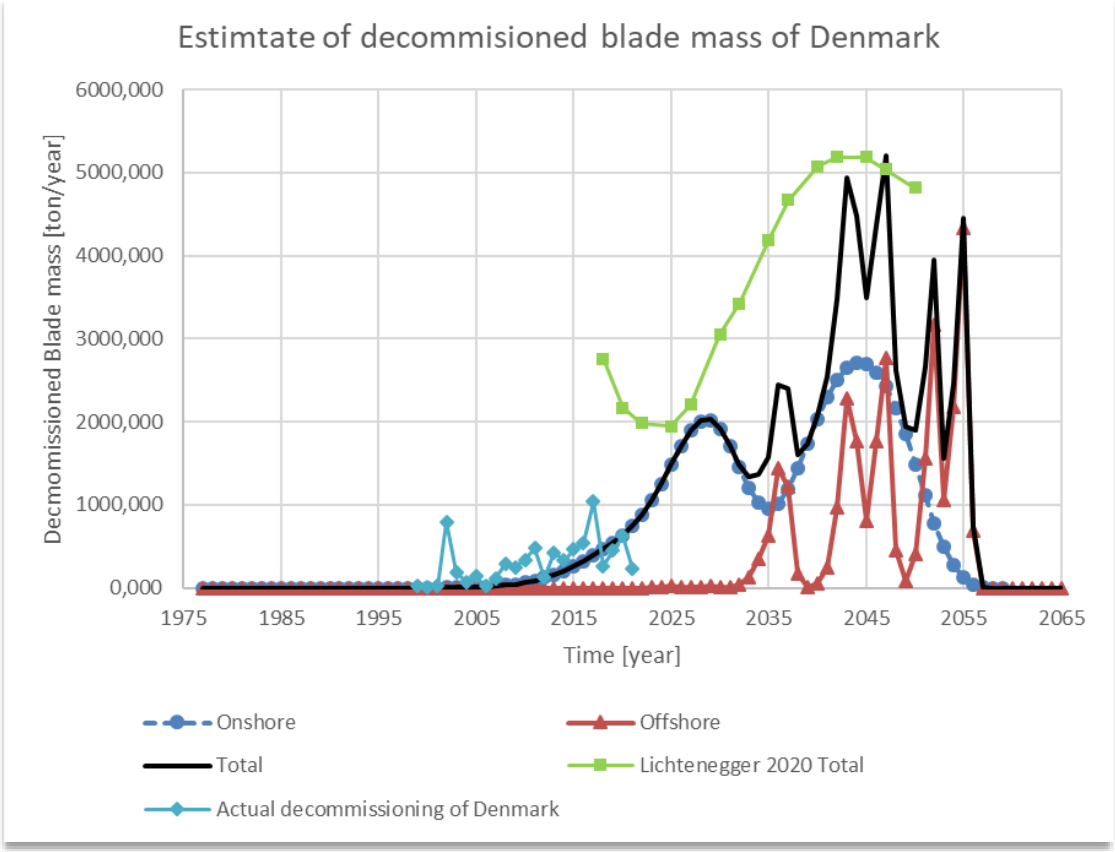


In 2029, we can expect 2000 metric ton/year

- **Onshore**
  - Average decommissioning time = 29 years

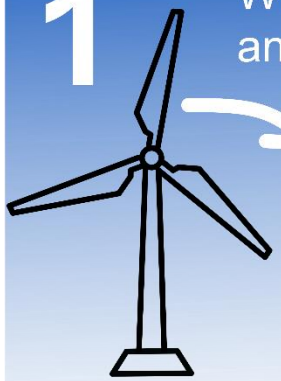
- **Danish decommissioned blade mass**
  - 2000 metric ton/year 2029
  - 5000 metric ton/year 2044-2046

- Upper limit to the amount of blade material arriving for recycling processes in Denmark, because it is not known if the blades are resold and reused after the decommissioning.
- The current high electricity price might further slow down the decommissioning of wind turbine blades, whereas incentives for upgrading older turbines with larger rotors may speed up the decommissioning.

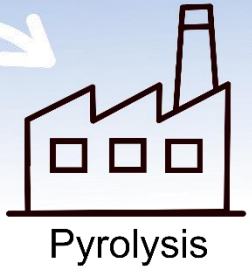


DTU

1 Wind turbine blade is shredded and material is sent for pyrolysis



Shredding



Pyrolysis

Recycled glass fibres

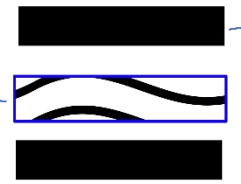
2 Fibre analysis

- ☑ Density
- ☑ E-modulus
- ☑ Tensile strength

3 Composite manufacturing

Sandwich structured composites

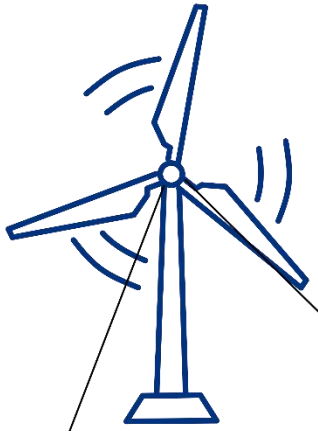
1. Fibre dispersion
2. Fibre mat preparation
3. Compaction
4. Vacuum infusion

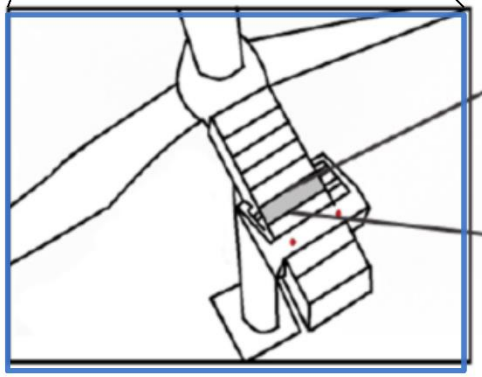


Virgin UD glass fibres

Recycled glass fibres

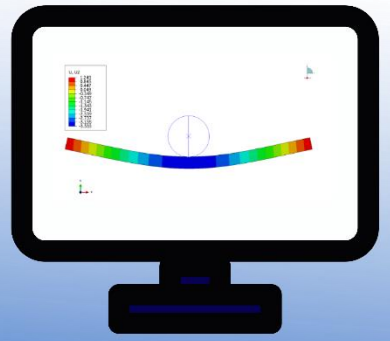
APPLICATION
Nacelle cover for a wind turbine





Sandwich composite

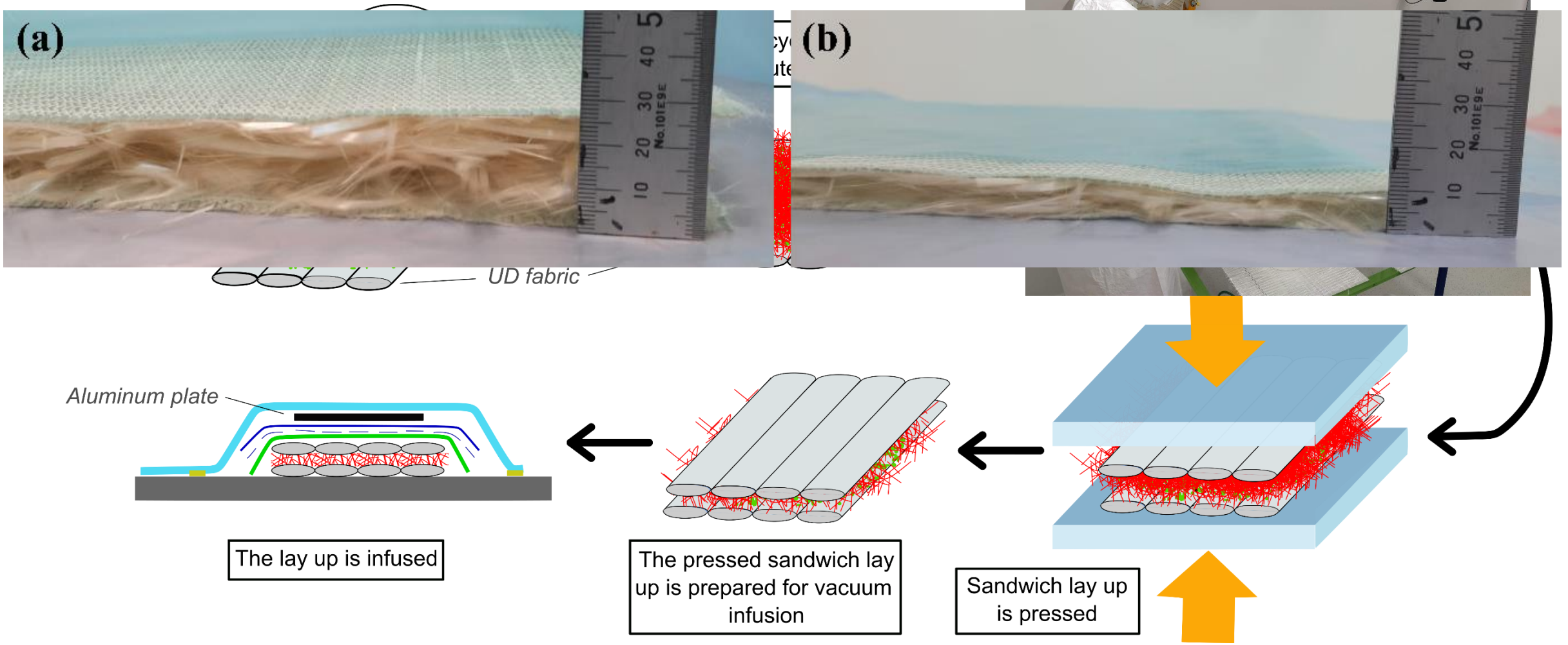
5 Composite modelling



4 Composite characterization

- ☑ Young's modulus
- ☑ Bending stiffness
- ☑ Fibre volume fraction
- ☑ Microstructure

Overview of the manufacturing ste



DecomBlades and 3B-Fibreglass are ready to unlock circular recycling of glass fibre in wind turbine blades

Blade material passport

Objective: let the recycler know what is inside the blade, where are the different materials? How much of the different materials to expect?

https://decomblades.dk/

Committed Blade Manufacturers

SIEMENS Gamesa RENEWABLE ENERGY

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Vestas

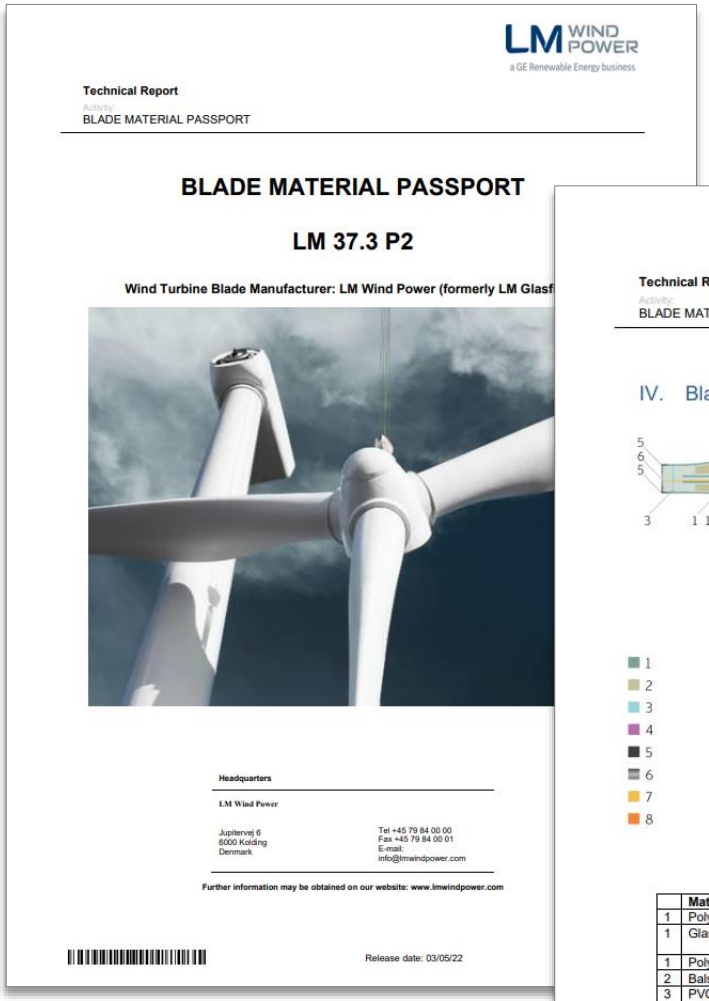
NORDEX

acciona Windpower

GE VERNOVA

ENERCON ENERGY FOR THE WORLD

Constructive dialogue with several other Blade Manufacturers



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Technical Report

Activity: BLADE MATERIAL PASSPORT

BLADE MATERIAL PASSPORT

LM 37.3 P2

Wind Turbine Blade Manufacturer: LM Wind Power (formerly LM Glasf

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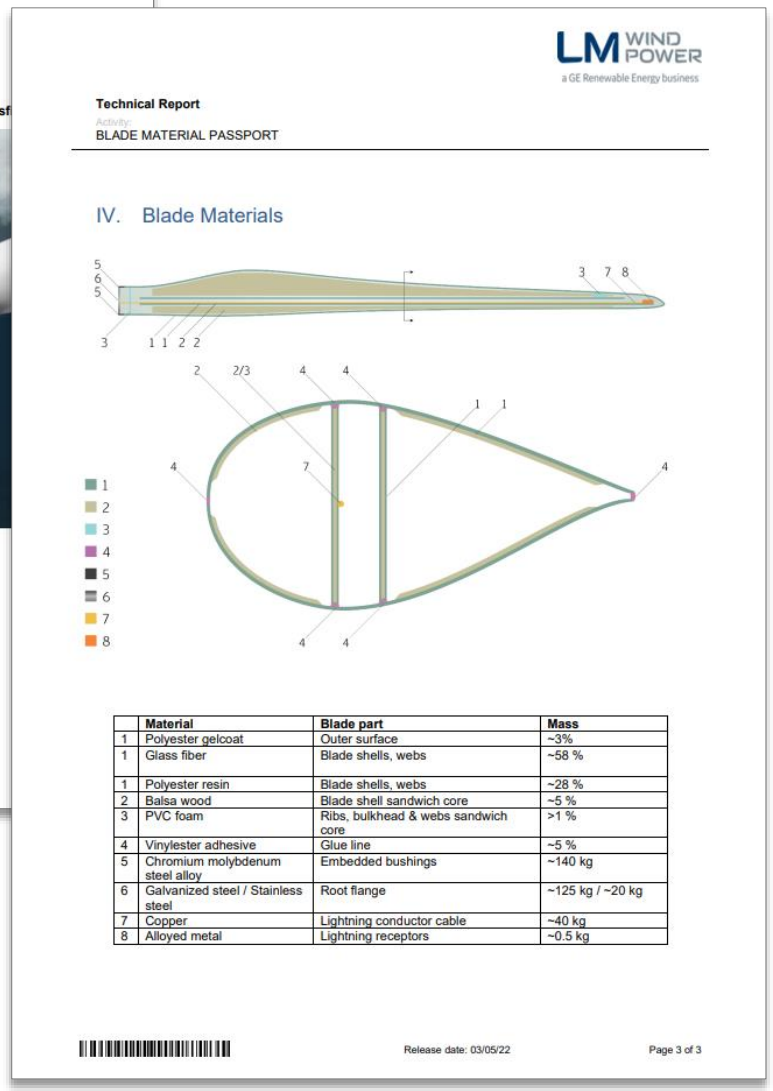
Release date: 03/05/22



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Technical Report

Activity: BLADE MATERIAL PASSPORT

IV. Blade Materials

	Material	Blade part	Mass
1	Polyester gelcoat	Outer surface	~3%
1	Glass fiber	Blade shells, webs	~58 %
1	Polyester resin	Blade shells, webs	~28 %
2	Balsa wood	Blade shell sandwich core	~5 %
3	PVC foam	Ribs, bulkhead & webs sandwich core	>1 %
4	Vinylester adhesive	Glue line	~5 %
5	Chromium molybdenum steel alloy	Embedded bushings	~140 kg
6	Galvanized steel / Stainless steel	Root flange	~125 kg / ~20 kg
7	Copper	Lightning conductor cable	~40 kg
8	Alloyed metal	Lightning receptors	~0.5 kg

Release date: 03/05/22

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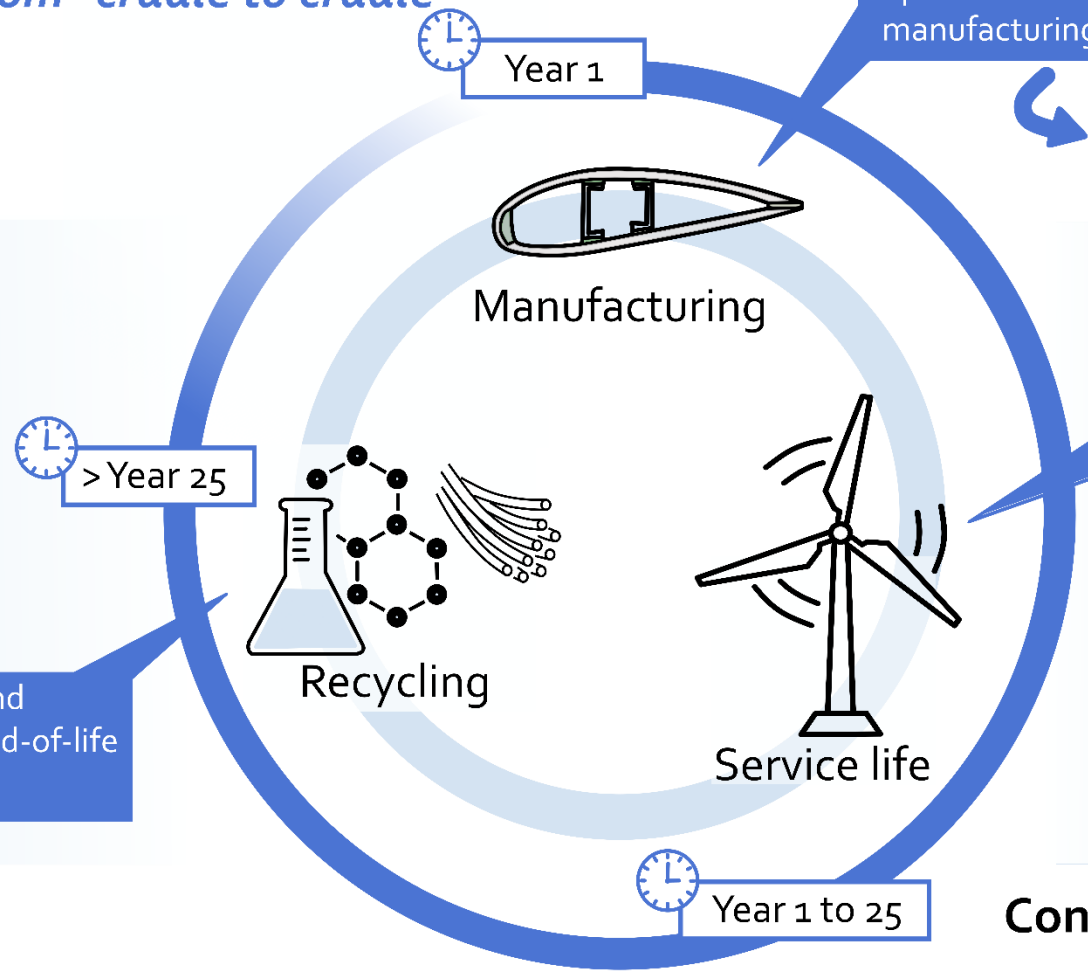
WISEWIND

neW generatIon of SustainablE WIND turbine blades

Digital Twin from "cradle to cradle"



Output

- **Digitial twin** of blade material from cradle to cradle
- **New generation of recyclable wind turbine blade**, with reworkable, recyclable and repairable resin
- **Demonstration of feasibility** and cost analysis of new recyclable blades

Duration

36 month
2023 - 2026

Budget

12.5 Mio.DKK

Partners

DTU Wind and Energy Systems

ReFlow®

SIEMENS Gamesa RENEWABLE ENERGY

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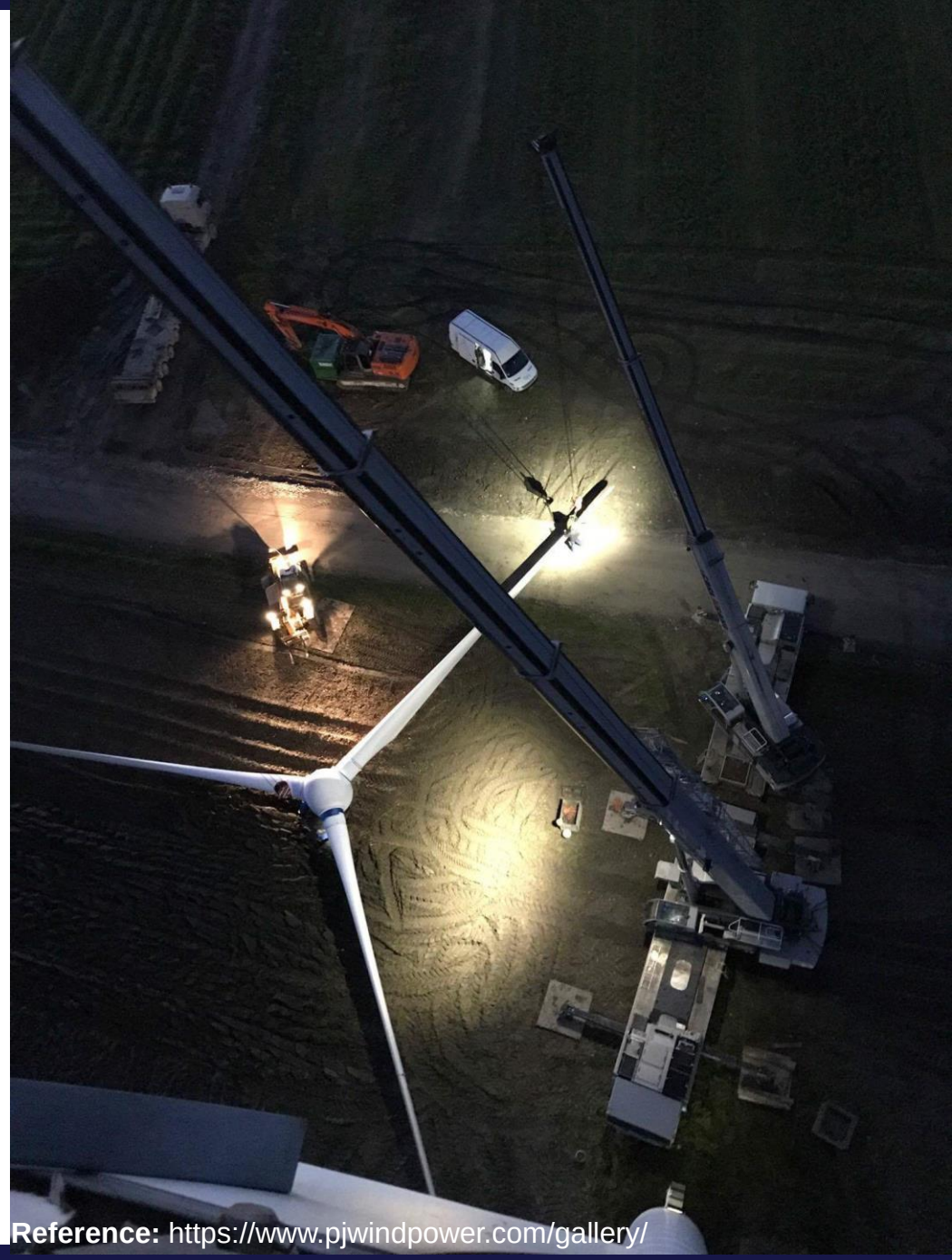
Take home messages

- Recycling is complex, and not only from a technical point of view.
- We need more coordination across the recycling value chain and transparency (blade information, blade tracing).
- Improved recyclability is good, but what about reusing wind turbine blades?



Reference: https://www.pjwindpower.com/gallery/

Thank you!
For your attention.

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