Discussion paper on managing composite blade waste

MARCH 2017

WindEurope

windeurope.org

1. CONTENTS

1. INTRODUCTION

The total wind power capacity installed at the end of 2016 was 153.7 GW which was enough to cover 10.4% of the EU's total electricity consumption in a normal wind year[1]. With a cumulative capacity of 153.7 GW and a project lifetime of 20 years, the total number of wind turbines installed in Europe is around 77,000 (assuming an average wind turbine capacity of 2 MW).

The EU's binding target for increasing the renewable energy share to 27% by 2030, and its commitments to cutting greenhouse gas emissions by 80-95% as of 2050, emphasizes wind power's important role in the future energy mix.

However, a growing amount of wind turbines will start to be decommissioned, considering that:

- The standard lifetime of a wind turbine is approximately 20-25 years;
- There are increasing repowering opportunities i.e. replacing old models with newer and more efficient models.

A sustainable process for dealing with wind turbines at the end of their service life is needed in order to maximize the environmental benefits of wind power from a life cycle approach. Most components of a wind turbine such as foundation, tower, components of the gear box and generator are already recyclable and treated accordingly. Nevertheless, wind turbine blades represent a challenge due to the materials used and their complex composition.

The objective of this research note is to provide an overview of the different methods used for sectioning and recycling wind turbine blades as well as practical examples and experiences from research and industry projects. Important sources have been obtained from researchers, the original equipment manufacturers (OEMs), operators and maintainers (O&Ms), waste handlers and those that use the recyclates from blade waste.

It is our hope to supply relevant and practical information on the subject and promote the sustainable management of composite blade waste. Research on the subject is ongoing and with this comes the challenge of keeping up-to-date with the state-of-the-art. If you have further input please notify us at Sustainability-Platform@windeurope.org.

2. COMPOSITES & THE WIND INDUSTRY

In this section the structure and material composition of wind turbine blades is explained. Following, a description of the current material markets for glass and carbon fibres, as well as the market forecasts for composite use in blades and decommissioning projections.

2.1 BLADE STRUCTURE & MATERIAL COMPOSITION

Wind turbine blades are considered a composite structure, consisting of various materials with different properties. Although material compositions vary between blade types and blade manufacturers, blades are generally composed of the following (see Figure 1):

- Reinforcement fibres e.g. glass, carbon, aramid or basalt;
- Polymer matrix e.g. thermosets such as epoxies, polyesters, vinyl esters, polyurethane, or thermoplastics;

[1] EWEA (2016) Wind in power. 2015 European statistics

- Sandwich core e.g. balsa wood or foams such as polyvinyl chloride (PVC), polyethylene terephthalate(PET);
- Coatings e.g. polyethylene (PE), polyurethane (PUR);
- Metals e.g. copper wiring, steel bolts.

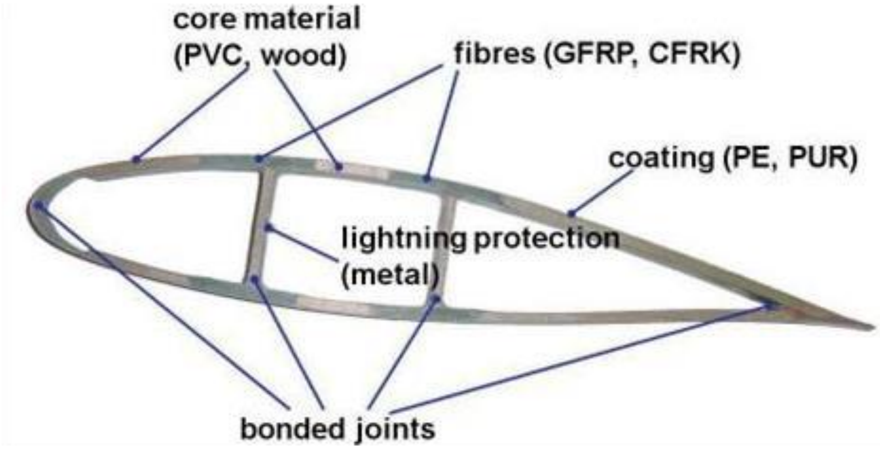


Figure 1. Material composition of a wind turbine blade cross section

The combination of fibres and polymers, also known as fibre reinforced polymer (FRP) composites, represents the majority of the blades material composition (60-70% reinforcing fibres and 30-40% resin by weight). In many respects, FRP composites are advantageous because they:

- Combine properties of high tensile strength with low density (high strength-to-weight ratio) to withstand the mechanical load requirements and to optimally perform aerodynamically;
- Provide resistance to fatigue, corrosion, electrical and thermal conductivity important for the long expected lifetime;
- Enable cost effective manufacturing of longer and lighter blade structures needed for increasing the generation of wind power;
- Can be easily affixed with add-on components (lightning protectors, leading edge protection, and heating systems) to improve performance.

When thermoset FRP composites are cured however, the polymers become cross-linked and undergo an irreversible process that makes recycling difficult.

2.2 MATERIAL MARKETS FOR GLASS & CARBON FIBRES

Glass fibre represents the primary material in wind turbine blades. According to a market report by the German associations AVK and CCeV[2], Europe's production volumes in glass fibre reinforced polymers (GFRP) steadily grew by 2.5% in 2015, reaching 1,069 million tonnes. This correlates to 25% of the world's total production volumes and represents the highest level in eight years. Further, 34% of Europe's production (363 million tonnes) is associated with the construction sector, in which the wind power industry is included.

Carbon fibre is also used in wind turbine blades, but to a lesser degree. Carbon fibre's superior strength and higher stiffness offers many advantages over glass fibre but its higher cost per volume is a key barrier to further deployment in the wind power industry. In the same market report, the global carbon fibre

[2] AVK & CCeV (2015) Composites market report 2015. Market developments, trends, outlook and challenges

demand in 2014 was 53,000 tonnes, which represents a growth of 14% over the previous year from the construction sector. The wind power industry specifically represented 14% of that demand (7,400 tonnes).

2.3 MARKET FORECASTS FOR COMPOSITE USE IN BLADES & DECOMISSIONING PROJECTIONS

The wind power industry is one of the fastest-growing consumers of FRP composites in the world[3], which correlates with the industry's rapid growth in recent years. Considering current and future developments in wind power, FRP composite waste amounts from the industry are expected to increase. Assuming that the amount of composite material used in wind turbines is between 12-15 tonnes per MW, Figure 2 projects the annual use of FRP composites until 2030.

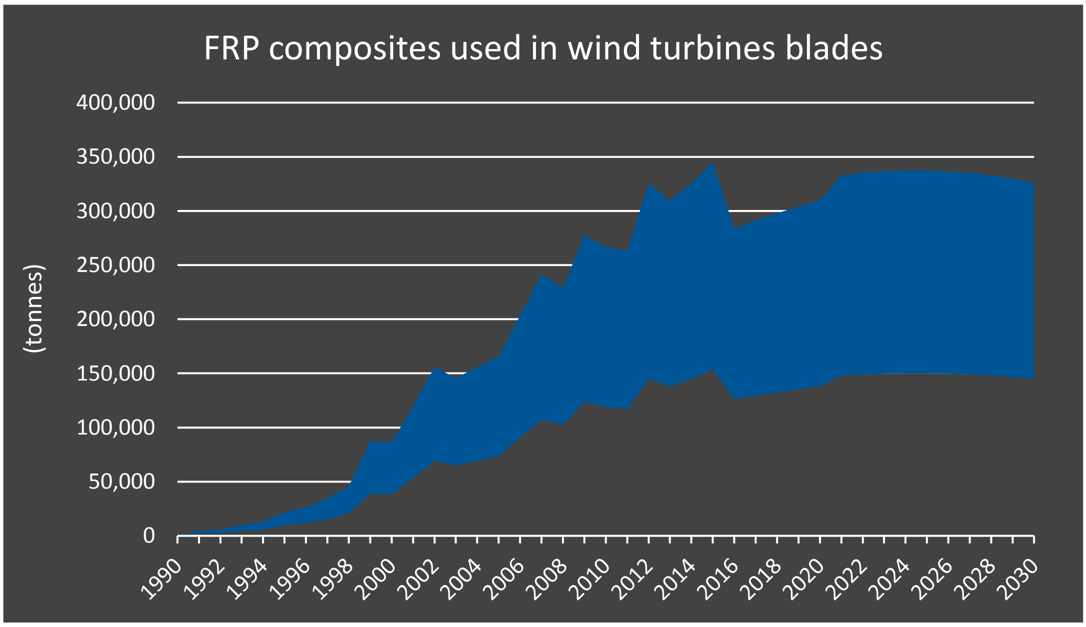


Figure 2. Annual use of FRP composites in wind turbine blades (WindEurope 2015)

Based on the installed capacity in 2000, the use of FRP composites for wind turbine blades was around 50,000 tonnes. The annual wind power capacity installed in Europe in 2016 attained 12.5 GW[4], bringing the use of FRP composites in blades to 150.000 - 186.000 tonnes[5], a threefold increase when compared to the 2000 figures.

With these projections, increasing amounts of FRP composites are expected to be recycled. Until now, the supply of composite waste from blades has been limited. However, recycling capacities have been increasing and recycling methods have been maturing in order to accommodate the expected amounts from blade waste. Further, waste policies and the demand for wider producer responsibility[6] are also increasing.

---

[3] Stewart, R. (January/February 2012) Wind turbine blade production – new products keep pace as scale increases. *Reinforced Plastics* 56(1), 18-25

[4] Wind in power: 2016 statistics

[5] The estimated usage of composites is calculated as the production of the EU annual wind capacity installed -12.5 GW, times the amount of composite material used in wind turbines per MW- 12-15 t/MW

[6] Cherrington, R., Goodship, V., Meredith, J., Wood, B., Coles, S., Vuillaume, A., Feito-Boirac, A., Spee, F. and Kirwan, K. (2012) Producer responsibility: defining the incentive for recycling composite wind turbine blades in Europe. *Energy Policy*, 47, 13-21

2.4 FUTURE TRENDS IN BLADE MATERIALS

Blade material challenges are related to stiffness optimization, fatigue life, damage prediction methods and the production of light weight blade structures. Further, materials selection is determined by design changes, geographical locations with more hostile environmental conditions and the demand for longer wind turbine blades. Active areas in materials research include:

- Optimising the formation of chemical bonds via the curing process;
- Incorporating automatized manufacturing processes to ensure consistent material qualities;
- Introducing nano-components as strengthening agents in the fibre-matrix[7,8];
- Investigating fibre architectures - combining high performance glass fibres, carbon fibres and nano-engineered fibres to make hybrid reinforcements;
- Investigating durable coating materials to ensure erosion-resistance e.g. gel-coats, paint systems and tapes;
- Promoting alternative manufacturing processes for carbon fibre to reduce costs, since the material provides better mechanical properties and is financially more attractive to recover compared to glass fibre;
- Researching alternative materials that are recyclable e.g. thermoplastics, cellulosic fibres and bio-resins.

Material innovations will inevitably have positive effects on the production, maintenance and life time of the blades. Design and material selection processes should consider the overall sustainability of the materials chosen including their impacts on recyclability and alignment with future recycling methods[9]. European technological platforms indicate that materials research for blades is an important research area[10] and see accounting for sustainability as a strategic issue[11].

3.BLADE SECTIONING METHODS

As a first step of blade decommissioning, the blades need to be dismantled from the rest of the wind turbine and cut into smaller sections before being transported for waste treatment. Sectioning wind turbine blades can be carried out in several ways, depending on the purpose or use, the local environmental requirements, and the size of the blade. The most common methods include:

3.1 WATER JET CUTTER

This method uses a very high-pressure jet of water, or a mixture of water and an abrasive substance. It can cut different blade materials, including metals. The process is somewhat environmentally friendly, regarding dust and noise emissions, but the use of water is high in comparison to the other methods listed below.

---

[7] Böger, L., Sumfleth, J., Hedemann, H., Schulte, K. (2010) Improvement of fatigue life by incorporation of nanoparticles in glass fibre reinforced epoxy. *Composities Part A: Applied Science and Manufacturing*, 41(10), 1419-1424

[8] Koziol, K., Vilatela, J., Moisala, A., Motta, M., Cunniff, P., Sennett, M., Windle, A. (2007) High-performance carbon nanotube fiber. *Science*, 318(5858), 1892-1895

[9] Conti-Ramsden, J., Dyer, K. (2015) Materials innovations for more efficient wind turbines. *Renewable Energy Focus*, 16(5-6), 132-133

[10] Asociación Eólica Empresarial. Observatorio Tecnológico (2016) Innovación en el desarrollo de palas

[11] Janssen, L. G. J., Arántegui, R. L., Brøndsted, P., Gimondo, P., Klimpel, B. B., & Thibaux, P. (2012) Strategic energy technology plan

3.2 WIRE SAW

The method uses a water cooled steel wire with diamond particles/teeth, which is wrapped around the wind turbine blade. The wire can cut different blade materials, including wood and metals. It can also section all blade sizes and is only limited by the length of the wire which can be extended indefinitely. The process is relatively environmentally friendly, regarding dust and noise emissions. The cooling water can be recycled and the cuttings can be collected. Additionally, the cuts are relatively smooth and well defined. The disadvantage is that the method is time consuming and the blade must be firmly affixed during the cutting to avoid pinching the wire.

3.3 CIRCULAR SAW

Different types and sizes of diamond tipped circular saws can be used. Sizes range from handheld saws to hydraulically driven saws with blade sizes up to 2 meters in diameter. The saw can make any size section but it is usually necessary to make several cuts. This increases the amount of dust/cuttings/emissions that are produced for each section. If done properly, the circular saw will produce relatively fine handling friendly cuts. It can be combined with different dust collecting systems, either by vacuum or water. The key advantage is that it is possible to make independent cuts in all directions. This gives the possibility to extract selected materials, like the main laminates or balsa for special purposes.

3.4 JAW CUTTER

The jaw cutter is the most common method for sectioning wind turbine blades. The hydraulically driven jaw produces a very rough cut through the material, and the material is crushed in the cutting zone. It is difficult to control the dust and fibre emissions therefore a water fog is needed to control the dust. It is also necessary to sanitize the area after completion. The sections are prone to emit dust and fibres during transport, which increases the demand for proper stowing and protection on the lorries.

Regardless of the tool, sectioning by means of a mechanical process (saw/cutter affixed to an excavator) is best practice compared to a manual process (handheld tools). Further, environment, health and safety aspects related to cutting and transporting blades should be risk assessed e.g. machinery and equipment, working at heights or with suspended loads, manual handling/ergonomics, personal protective equipment, noise and dust. Normally, blade cutting and transport activities are outsourced to contractors e.g. regional waste handlers. They should be consulted to obtain more specific information on facility requirements e.g. FRP taxes, FRP bans, dimensional requirements of blade sections, available capacity/volume.

4.BLADE WASTE TREATMENT METHODS

As a second step of blade decommissioning, the blades are transported to a waste treatment facility. There are a number of ways to treat the waste, depending on the intended application or end use of the FRP composites. Below the best available technologies in Europe are outlined (Figure 3). Each waste treatment method includes a brief description concerning the recovering process of FRPs and its commercial status (Table 1).

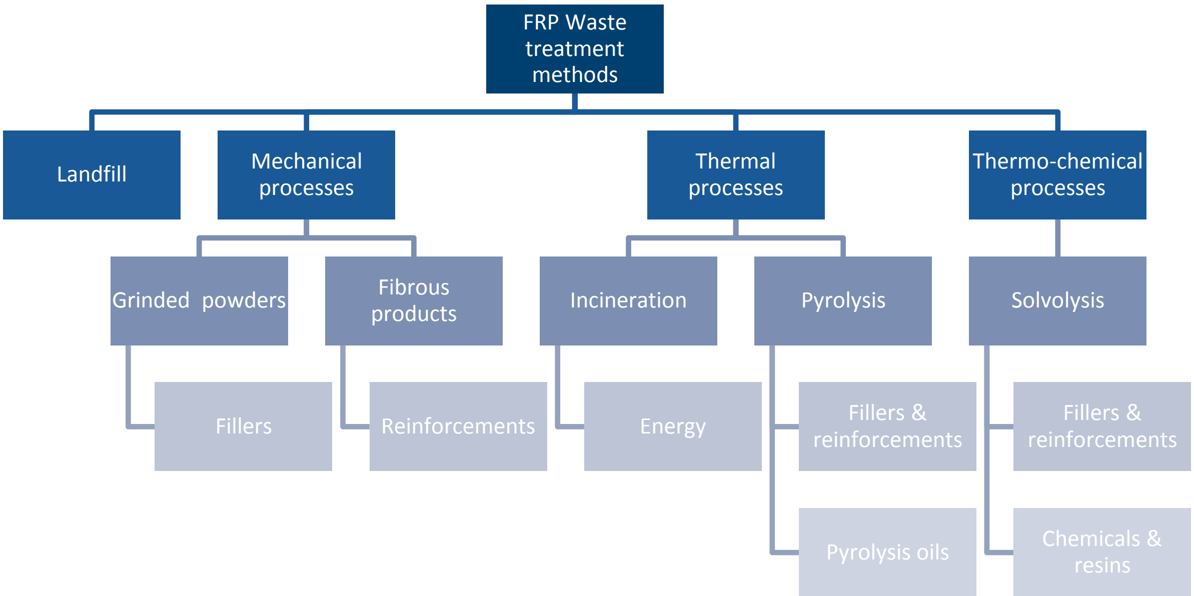


Figure 3. FRP composite waste treatment methods (adapted from Sacchi 2014[12] Composites UK 2016[13]; Skrifvars 2015[14])

[12] Sacchi, R. (2014) Best available technology report. Reusing, recycling, recovering fibre-reinforced thermoset plastics
[13] Composites UK (2016) Composites recycling – where are we now?
[14] Skrifvars, M. (2014) Recycling of thermoset polymer composites

Table 1. Description and status of FRP composite waste treatment methods (adapted from Mativenga et al 2016[15])

PROCESS	DESCRIPTION AND COMMERCIAL STATUS
Biotechnological	- Microorganisms used to degrade matrix - Limited availability even at laboratory scale
Chemical	- Solvents (water, alcohol, acid) used to break matrix bonds at usually elevated temperatures (300-650°C) and pressures - Among all the tested solvents, water appears as the most commonly used (hydrolysis) - Fibre materials recovered with similar strength applications and resins can be combusted for energy recovery - Most research at laboratory scale with focus on carbon fibres
Electrochemical	- Electrical current is applied through an electrolyte solution to degrade composite matrix - Limited availability even at laboratory scale
Fluidised bed pyrolysis	- Involves passing the size-reduced FRP composite through a bed of sand, fluidised by a stream of hot air - High energy consuming process with lower mechanical properties of the composite compared to other pyrolysis methods - Process investigated at a pilot scale
High voltage fragmentation (HVF)	- High voltage creates pressure waves along plasma channels to disintegrate materials in water - Laboratory and pilot scale machines available
Incineration	- Blade sections are incinerated at high temperatures (800°C) - Organic substances are combusted and converted into non-combustible material (ash), flue gas and energy (electricity and heat recovery) - The ash can also be used as a substitute for aggregate in other applications (material recovery) or landfilled - Principal alternative treatment method for composite waste to landfill in Europe
Landfill	- Blades are sectioned into suitable dimensions and placed in the regional landfill - No material recovery possible - Some national landfill taxes or complete bans on composites (Germany) - Commercial scale – one of the principal methods for composites
Mechanical	- Size reduction and separation into powder and fibrous fractions via cutting, crushing, shredding, grinding, or milling processes - Finer pieces (recyclate) are sorted and used as fillers or reinforcements or as fuel for thermal waste processes - Commercial scale with wide range of potential applications (material recovery) however lower cost for virgin fillers (calcium carbonate, silica) - Mechanical properties of the composite are reduced (stiffness, strength)

[15] Mativenga, P., Shuaib, N., Howarth, J., Pestalozzi, F., Woidasky, J. (2016) High voltage fragmentation and mechanical recycling of glass fibre thermoset composite. *CIRP Annals – Manufacturing Technology.* 65, 45-48

Microwave pyrolysis	- Decomposition of matrix using microwave heating in an inert atmosphere (heating from the inside out) - Thermal transfer is very fast, potentially energy saving compared to other pyrolysis methods - Limited availability even at laboratory scale
Pyrolysis	- Blades are sectioned into suitable dimensions and decomposed using conventional heating (ovens) in an inert atmosphere (450-700°C) - Material recovery in the form of fibres which can be used as reinforcements (glues, paints, concrete). Bi-products include syngas (later combusted for electricity and heat recovery) and char (recycled as fertilizer) - Industrial scale process commercially available

5. PRACTICAL EXAMPLES REUSING FIBRES BASED ON THE WASTE HIERARCHY

The European Waste Framework Directive (2008/98/EC) defines basic concepts related to waste management. It emphasizes the need for extended producer responsibility, increased recycling and reduced availability of landfill. It also establishes the waste hierarchy, which prioritises waste treatment methods into five sustainability categories: prevent; reuse; recycle; recover; dispose. The waste hierarchy model is shown in Figure 4 and is used to describe practical examples where recycled fibres have been reused.

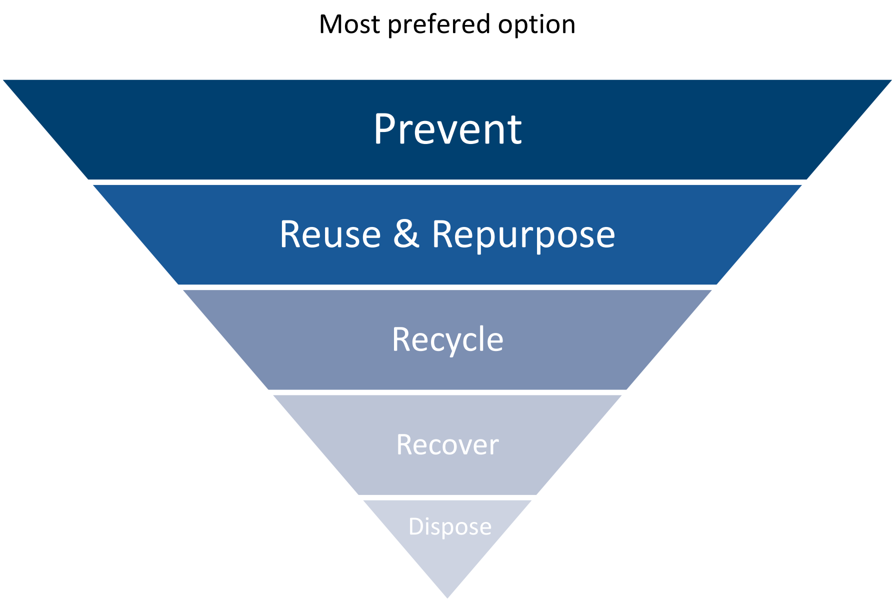


Figure 4. The waste hierarchy for sustainable blade waste management

In 2015 the EU's Circular Economy Package proposed changes to the Waste Framework Directive which could limit municipal waste to landfill to 10% by 2030. But it is still not clear how this will affect industrial/construction waste other than packaging (75% must be recycled by 2030)[16]. Regardless, a transition to more circular waste models is desired; below are some practical examples for FRP composite blade waste.

5.1 PREVENT

Prevent blade waste through reduction efforts in design. The lifetime of the blade can be extended through routine servicing and repair, thereby extending the time before waste treatment is needed. Blade refurbishment procedures can include visual inspection, ultrasonic inspection, and natural frequency measurements. The blades can also be repaired, repainted, weighed and balanced.

5.2 REUSE & REPURPOSE

Repairing a blade and installing it on an existing turbine or on a new turbine would be an example of true reuse as the blade maintains its original function.

Practical example(s): A number of European and North American companies have established businesses for selling refurbished turbines and components e.g. Green-Ener-Tech, Repowering Solutions, Enerpower, Spares in Motion, etc.

Repurposing a blade means it becomes a new product with a new function.

Practical example(s): Reusing the blades for artificial reefs[17], playgrounds or street furniture (see Figure 5 or Superuse Studios and partners [18] [19] [20] [21]). Specific structural parts of the blade could also be used in less demanding constructions like walkways, simple bridges, etc.

Both reuse and repurpose require minimal changes to the blade structure. This form of waste treatment is also referred to as *primary recycling*, where the new product has equivalent properties and similar value. However, these solutions are difficult to implement on an industrial scale.

Wikado playground from Superuse Studios

REwind Willemsplein public benches from Superuse Studios

Figure 5. Practical examples of reusing wind turbine blades

[16] Composites UK (2016) Composites recycling – where are we now?

[17] Rahnama, B. 2011. Chapter 5 Using wind turbine blades as artificial reefs constructions in reduction of environmental impact effect of disposing wind turbine blades. Gotland University, Maters Thesis

[18] http://superuse-studios.com/index.php/2012/08/rewind-erasmusplein/

[19] http://superuse-studios.com/index.php/2008/10/wikado-2/

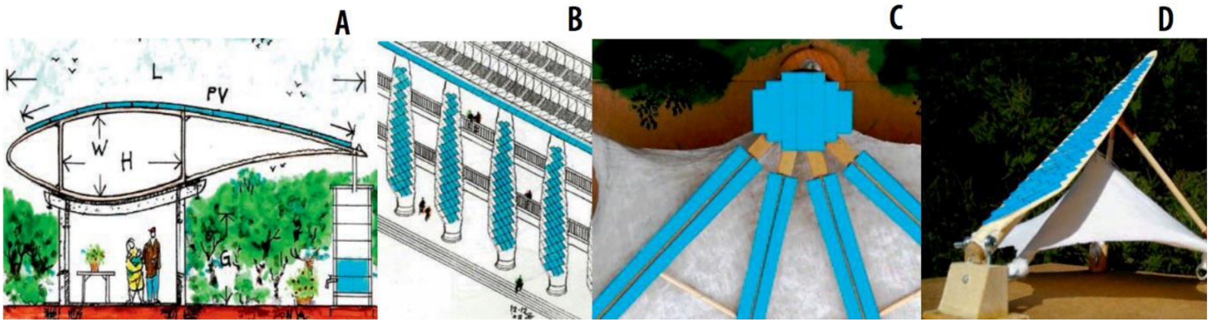
[20] http://superuse-studios.com/index.php/2011/12/kringloop-zuid-2/

[21] https://groenomstilling.erhvervsstyrelsen.dk/etablering-af-bro-bygget-af-genbrugte-vindmoellevinger

5.3 RECYCLE

Recycling means the blade becomes a new product or material with a different functional use. Recycling still requires energy and other resources in order to convert the blade waste into something else. Upcycling involves converting the blade into new products/by-products/materials with an improved material quality or functionality, while downcycling involves conversions with a reduced material quality or functionality. Downcycling is also referred to as *secondary recycling*, where the new product/by-product/material has inferior properties or lower value. These solutions can also be difficult to implement on an industrial scale.

Practical example(s): Upcycling wind turbine blades into construction or building structures. One example is a bridge that is currently being developed from old blades in Nørresundby, Denmark[22]. Another example is the architectonic re-purposing of blades for building structures (see Figure 6 or Goodman[23]).



Architectonic reuse

Figure 6. Practical examples of upcycling wind turbine blades

Downcycling wind turbine blades into furniture or skateboards are other practical examples (see Figure 7 or GetWasted[24]). Using finely shredded composite recyclate as a substitute for fuel in the production of cement is a second example of downcycling (see Holcim[25]).

Furniture from GetWasted   Skateboard from GetWasted

Figure 7. Practical examples of downcycling wind turbine blades

[22] Erhvervsstyrelsen (2016) Etablering af bro bygget af genbrugte vindmøllevinger
[23] Goodman, J. (2010) Architectonic reuse of wind turbine blades, SOLAR 2010 Conference, ASES, May 18-22, 2010, Phoenix, Arizona
[24] http://getwasted.dk/en/
[25] Holcim: Disused wind turbine blades can now be utilized in cement production http://www.holcim.com/de/referenceprojects/disused-rotor-blades-can-now-be-utilized-in-cement-production.html

5.4 RECOVER

Pyrolysis, solvolysis and incineration with energy recovery (heat, electricity or fuel) and waste by-products from blade waste all fall under the category of recovery. These forms of waste treatment can also be referred to as *tertiary recycling.*

Practical example(s): Insulation wool mats made from blade fibres via pyrolysis (see Figure 8 or ReFibre ApS[26]).

Insulation wool made from blade fibres via pyrolysis

Figure 8. Practical examples of wind turbine blade recovery including downcycling

5.5 DISPOSE

Disposing blades via landfill or incineration without energy recovery are the least favoured waste treatment methods because there is no material or energy recovery.

All categories in the waste hierarchy, excluding disposal, aim to prevent wasting potentially useful materials while also reducing the consumption of raw materials or energy. It is understood that some of these examples represent demonstration projects that are not a large scale solution - not all blade waste can be reused in such a way. However, these examples illustrate the innovation and creativity necessary for a transition towards a more circular economy. Further, they provide social value by raising awareness of important issues e.g. waste management or wind power. The street furniture and playgrounds in particular also help to create community spaces. Those scrapping a blade should thus consider the waste hierarchy and circularity principles to ensure the most sustainable option is selected.

More practical examples can be found as an outcome of the GenVind Innovation Consortium.

6. RESEARCH & INDUSTRY PROJECTS

Since the start of the 1980's, research has been carried out to investigate possible waste treatment methods for composites. Some of the more recent European research projects around composite waste from wind turbine blades include (Table 2):

[26] ReFiber ApS http://www.refiber.com/technology.html

Table 2. Publically funded research and industry projects

PROJECTS	SOURCE
Dreamwind Investigating new ways to recycle and manufacture reusable composite materials for wind turbine blades via bio-based resources and stimuli-responsive materials *Date:* 2016-2020	Link
LIFE BRIO Project Optimising procedures for the dismantling of wind farms, taking into account the proper management of composite waste from blades, as well as developing policy and legislative recommendations to the European Commission *Date:* 2014-2017	Link
Genvind Innovation Consortium Demonstrated how composite waste can be applied in different products, components and structures which were based on cradle-to-cradle philosophies *Date:* 2012-2016	Link
Recycling of Waste Glass Fibre Reinforced Plastic with Microwave Pyrolysis Recycling FRP thermosets via microwave pyrolysis *Date:* 2011-2012	Link
EURECOMP (Recycling Thermoset Composites of the SST) Recycling FRP thermosets via solvolysis *Date:* 2010-2012	Link
REACT (Re-use of Glass Fibre Reinforced Plastics by Selective Shredding and Re-activating the Recyclate) Recycling FRP thermosets via mechanical processes *Date:* 2003-2005	Link

7. IS THERE A BUSINESS CASE FOR RECYCLING COMPOSITES?

Technology exists to recycle composites

It is difficult to single out the key barrier to recycling composites, as there are many that are interlinked. Recycling composites is not a technological problem. But despite the fact that technologies for recycling composites exists, they are mostly deployed at small local and regional scales (see Blade waste treatment methods). In fact, there are an increasing number of companies that offer composite recycling services (see Appendix B. List of companies handling composite waste) based on a variety of forms, i.e. dry fibres, uncured prepreg pieces to cured components[27]. The most used processes at commercial scale today are mechanical, pyrolysis, incineration and landfilling.

[27] "Prepreg" is the common term for a reinforcing fabric which has been pre-impregnated with a resin system. This resin system (typically epoxy) already includes the proper curing agent. As a result, the prepreg is ready to lay into the mold without the

Lack of a robust secondary raw material market

One key problem however, lies in the use of the recyclate in other applications and processes – secondary applications and market development for composites is only in its infancy[28]. Today, there are no “host of applications” waiting for the projected amounts of recycled fibres. Processing methods vary in their effects on the fibre quality (length, strength, stiffness properties), thereby influencing the secondary application. Recycled fibres must first be tested and characterized and then the fibre properties must be matched up with potential applications. To date, too few potential applications of commercial scale using recycled composites have been investigated (see Practical examples using fibres based on the waste hierarchy).

Economies of scale

Another problem exists with economies of scale for commercial processing and recycling plants and their geographical distribution from the wind farms. When recycling, the impacts associated with sectioning and transporting must also be weighed. Also, there are difficulties securing a stable stream of feedstock (waste composite) as this is dependent on decommissioning decisions by wind farm owners. Further, the recyclate cannot compete with the price of virgin materials. Thorough product documentation (material specifications) must also be well maintained if waste is to be used as a resource after a long lifetime of turbine operation; also considering the differences between OEMs in a component’s material composition.

Legislative barriers

Legislation is also a decisive factor for composite recycling. Legislation regarding waste and recycling differ between regions. Landfill is a relatively cheap disposal option but it is the least preferred option under the European Union (EU)’s Waste Framework Directive[29]. Some Member States have imposed landfill taxes to dissuade disposal while other nations have forbidden composites in landfill all together, e.g. Germany, with other EU countries likely to impose taxes or disposal restrictions as well. Some indicate that trends in legislation tend to increase producer responsibility, increase recycling rates and reduce availability of landfill[30]. Others indicate the opposite, claiming regulation can create problems for innovative small- and medium-sized companies[31].

---

addition of any more resin. In order for the laminate to cure, it is necessary to use a combination of pressure and heat. http://www.fibreglast.com/product/about-prepregs/Learning_Center

[28] CompositesWorld (2016) Composites recycling becomes a necessity

[29] Reinforced Plastics (2011) Composites can be recycled

[30] Composites UK (2016) Composites recycling – where are we now?

[31] Reinforced Plastics (2011) Composites can be recycled

8. FUTURE PERSPECTIVES

The wind power industry is an important user of FRP composite materials. The end of service life of the first wind industrial scale turbine installations is approaching. Similarly, repowering and decommissioning activities have begun and represent both challenges and opportunities for the European wind power sector. Most turbine components are already recyclable, which represents an advantage for the sustainability of the product and industry. Nevertheless, recycling FRP composite turbine blades remains a challenge due to a number of technical, market based and legislative reasons:

- Recycling FRP composites is technically possible but not cost effective (low cost of virgin materials, low value of recyclate);
- Technological maturity and scale of recycling methods;
- Differences in waste/recycling legislation between regions and how waste is defined;
- Differences in blade volumes (feedstock), their geographical distribution, their design (sizes, material compositions);
- Economical and sustainable logistics between the power plant site, sectioning site and recycling facilities;
- Scientific understanding of the environmental aspects associated with the different recycling methods (life cycle perspective, different impact categories).

Looking forward, a concerted effort between the wind power industry, composites industry, waste handling industry, research community and European authorities including Member States is desired. Intensified collaboration is welcomed between industry, academia and government on this subject through additional research and pilot projects that address the following:

- Cost-effective recycling processes as an essential step towards sustainable manufacturing and a circular economy (WindEurope background paper on the environmental impact of wind – a contribution to the discussion of circular economy);
- Technological advances in the recycling processes so the mechanical properties of the fibres can be recovered and the need for significant inputs can be minimized e.g. energy;
- Legislative measures and market mechanisms to stimulate the development of recycling processes, secondary markets and producer responsibility;
- A critical reconceptualization of the term "end of life" for turbine blades. It is an elastic term and we must consider if we view blades as waste or as assets at their end of service life (see the European Commission's End-of-waste criteria).

APPENDIX A. ADDITIONAL RESOURCES

PUBLICATION	SOURCE
Beauson, J., Brøndsted, P. (2016) Wind turbine blades: an end of life perspective. In Ostachowicz, W. McGugan, M., Schröder-Hinrichs, J., Luczak, M. (2016) MARE-WINT. New Materials and Reliability in Offshore Wind Turbine Technology, 421-432. Springer	Link
Beauson, J., Madsen, B., Toncelli, C., Brøndsted, P., Bech, J. (2016) Recycling of shredded composites from wind turbine blades in new thermoset polymer composites. *Composites Part A: Applied Science & Manufacturing*, 90, 390-399	Link
Cherrington, R., Goodship, V., Meredith, J., Wood, B., Coles, S., Vuillaume, A., Feito-Boirac, A., Spee, F., Kirwan, K. (2012) Producer responsibility: Defining the incentive for recycling composite wind turbine blades in Europe. *Energy Policy*, 47, 13-21	Link
Composites UK (unknown) End of life options	Link
Composites UK (2016) Composites recycling – where are we now?	Link
Correia, J., Almeida, N., Figueira, J. (2011) Recycling of FRP composites: reusing fine GFRP waste in concrete mixtures, *Journal of Cleaner Production*, 19:15, 1745-1753	Link
EuCIA (European Composites Industry Association) - Publications	Link
EuCIA (2011) Composites recycling made it easy	Link
EuCIA (2011) Glass fibre reinforced thermosets: recyclable and compliant with the EU legislation	Link
EuCIA (2013) Carbon footprint reduction through composites recycling	Link
GenVind Innovation Consortium - Resources	Link
Knowledge Transfer Network (2010) Composite recycling	Link
National Composites Network (2006) Best practice guide: end of life options for composite waste	Link
Oliveux, G., Dandy, L., Leeke, G. (2015) Current status of recycling of fibre reinforced polymers: review of technologies, reuse and resulting properties. *Progress in Materials Science*, 72, 61-99	Link
Pickering, S. (2006) Recycling technologies for thermoset composite materials—current status. *Composites Part A: Applied Science and Manufacturing*, 37(8), 1203-1215	Link
Superuse Studios (unknown) Blade Made	Link
Ribeiro, M., Fiúza, A., Ferreira, A., Dinis, M., Meira Castro, A., Meixedo, J., Alvim, M., (2016) Recycling Approach towards Sustainability Advance of Composite Materials' Industry. *Recycling*, 1, 178-193	Link
Windpower Engineering & Development (2016) Reaching retirement: recycling aging turbine blades	Link
Yazdanbakhsh, A., Bank, L., (2014) A Critical Review of Research on Reuse of Mechanically Recycled FRP Production and End-of-Life Waste for Construction. *Polymers*, 6, 1810-1826	Link

APPENDIX B. LIST OF COMPOSITE WASTE COMPANIES IN EUROPE

The purpose of this list is to provide an overview of the various organizations handling composite waste. If there are additions, please notify us at Sustainability-Platform@windeurope.org.

COMPANIES HANDLING COMPOSITE WASTE		
Carbon conversions (formerly MIT-RCF)	US	www.carbonconversions.com
CFK Valley Stade Recycling	DE	www.cfk-recycling.com
Damacq Recycling International	NL	www.demacq.nl
ELG Carbon Fibre	UK	www.elgcf.com
Karborek	IT	www.karborekrcf.it
Neocomp (formerly Zajons)	DE	www.neocomp.eu/de/Unternehmen
Neowa	DE	www.neowa.eu
TRC (R3FIBER)	ES	www.trcsl.com