NATIONAL COMPOSITES CENTRE

Delivering a sustainable future for composites in wind

SusWIND annual review
April 2022

Executive Summary

In 2021 the National Composites Centre (NCC) launched SusWIND to accelerate the development of technology, processes and materials that address the recyclability and future development of composite wind turbine blades.

We are growing a community of stakeholders in the composites industry and energy sector to create end-of-life value from past and current generations of turbine blades and embed circularity at the heart of future generations of turbines. To make that happen, the programme is tackling the main challenges of legacy and future blades, as shown in Figure 1.

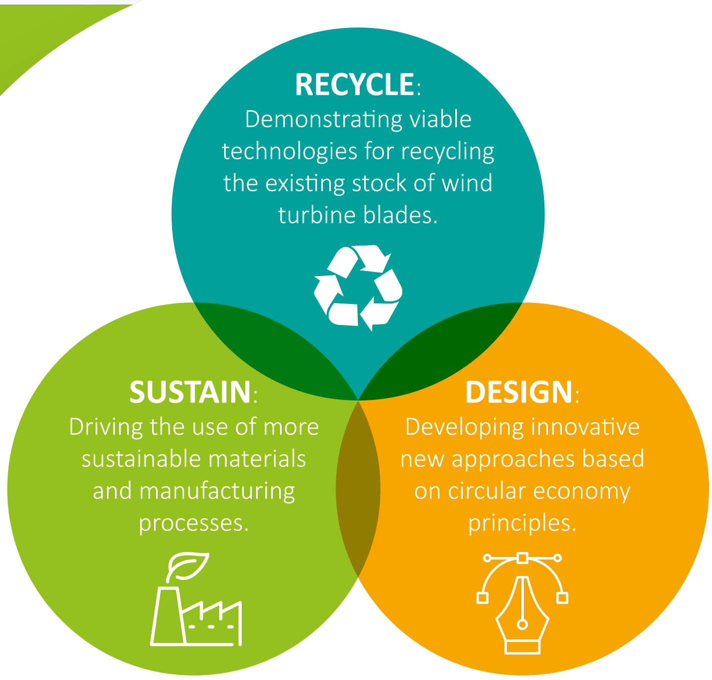


Figure 1 The SusWIND approach; three interdependent areas of focus to solve the challenges of current and future wind turbine blades.

Since the programme inception there have been a number of key achievements:

- To achieve our goals, we need industry support and collaboration and we were pleased to welcome 10 partners during the first 6 months of the programme.
- We have a full decommissioning profile of all UK blades, forecasting composite waste streams for the next 30 years and enabling our partners to make key decisions at blade end-of-life.
- Mechanical recycling and cement kiln co-processing have been identified as the only viable industrial scale processing routes for glass fibre composite waste for the coming decade.
- We have defined the development requirements of promising low Technology Readiness Level (TRL) processing routes for end-of-life blade waste to deliver more benefit for the higher volumes of waste post-2032.
- Our cradle-to-grave lifecycle assessment has identified where targeted introduction of alternative materials in manufacturing can reduce the environmental impact of the blade.

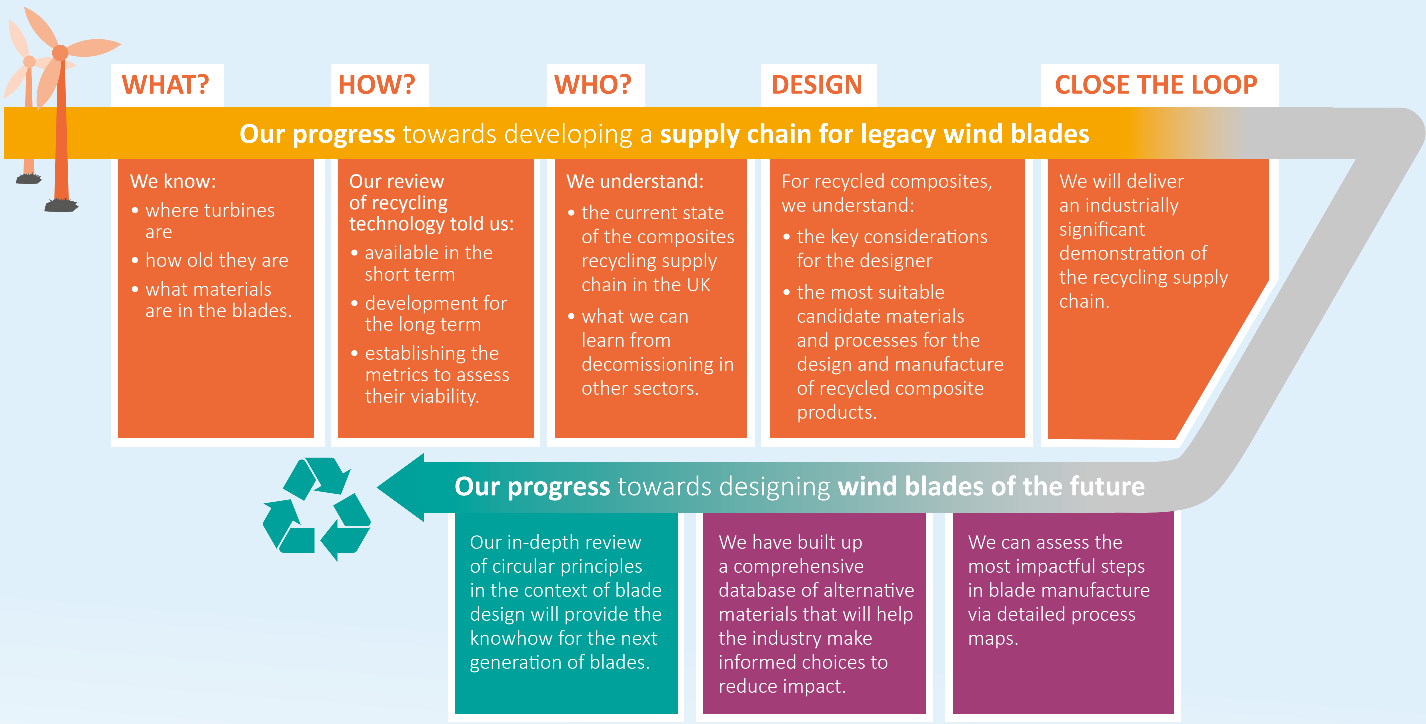


Figure 2 How SusWIND is delivering insight to the industry.

The initial phase of SusWIND, as shown in orange in Figure 2, has proven that there is no functioning supply chain for the recycling of wind turbine blades. Further, in the UK there are no commercially operational composite recycling facilities, however several of the most promising emergent technologies are progressing through lower TRL development domestically.

To ensure the composites industry has a viable UK recycling supply chain for the coming decade, SusWIND partners from throughout the value chain will deliver a coherent programme of demonstration, technical and business case development ("Close the Loop" in Figure 2).

insight for our partners, and the wider community, on how alternative materials can replace those traditionally used and reduce impact, both in manufacture and at end-of-life. By convening the industrial knowledge of SusWIND partners we will develop and demonstrate the potential for eliminating waste in production, preserving through-life value, and adopting circular design to solve end-of-life challenges.

After a successful start to the programme, SusWIND will bring together the supply chain for end-of-life composites and ensure that the future for wind is a sustainable one.

Our ambition is to end 2022 with a meaningful investment case for critical industrial capabilities in mechanical recycling and cement kiln co-processing of glass fibre reinforced composites in the UK.

Alongside seeding and demonstrating a domestic supply chain, we will ensure that all stakeholders are empowered to make data-driven end-of-life decisions using our accumulated knowledge to assess the economic, societal, and environmental impacts of turbine blade recycling.

SusWIND is committed to ensuring future turbine blades are an integral part of a functioning circular economy for wind and the wider composites industry. Drawing on deep cross-sector knowledge of composites we will provide

Where is the UK market now?

Composite structures present a problem at end of life. Along with rare Earth metals, they are the last remaining components of a wind turbine that are not considered recyclable.

Whilst there are technologies for reclaiming fibres and resin from composite parts, there is no commercial supply chain to handle the end-of-life blades or the outputs of reclamation (as depicted in Figure 3).

This presents a significant issue for all composite using sectors in the UK, meaning that cross-sector collaboration is vital to the success of an end-of-life composite structure supply chain.

The situation poses several important questions:

1. **What is the market for composites recycling in the UK?**
2. **Is a domestic supply chain the answer?**
3. **What are the environmental, economic, and societal impacts of the various end-of-life options?**
4. **Who are the key players and what are their capabilities?**
5. **Can legislation play a role?**
6. **Where is the demand for recycled composites?**

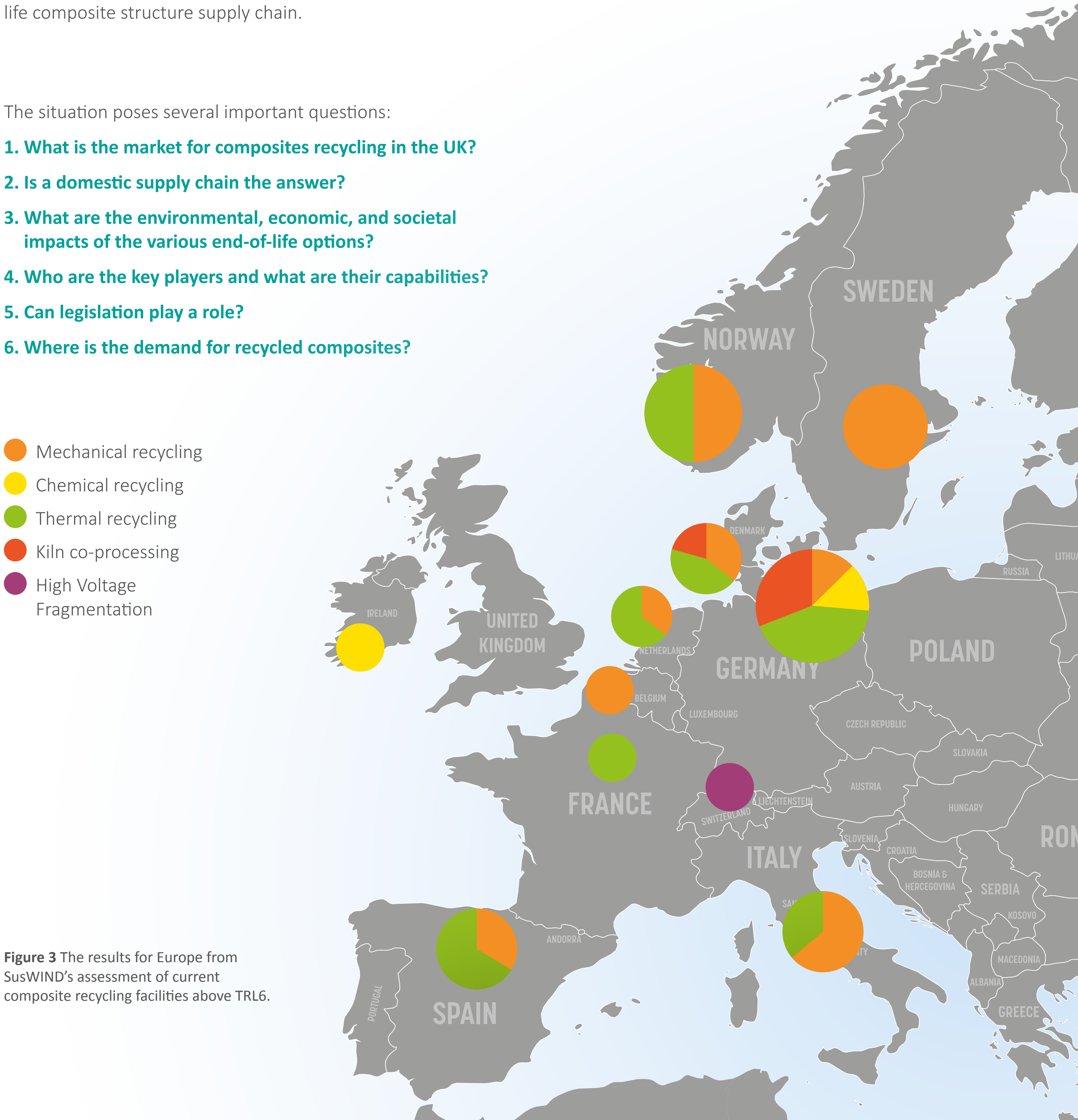


Figure 3 The results for Europe from SusWIND's assessment of current composite recycling facilities above TRL6.

To answer these questions and establish a supply chain for recycled composites, we are working with our partners from the wind and offshore energy industries, as well as organisations from aerospace, marine and construction.

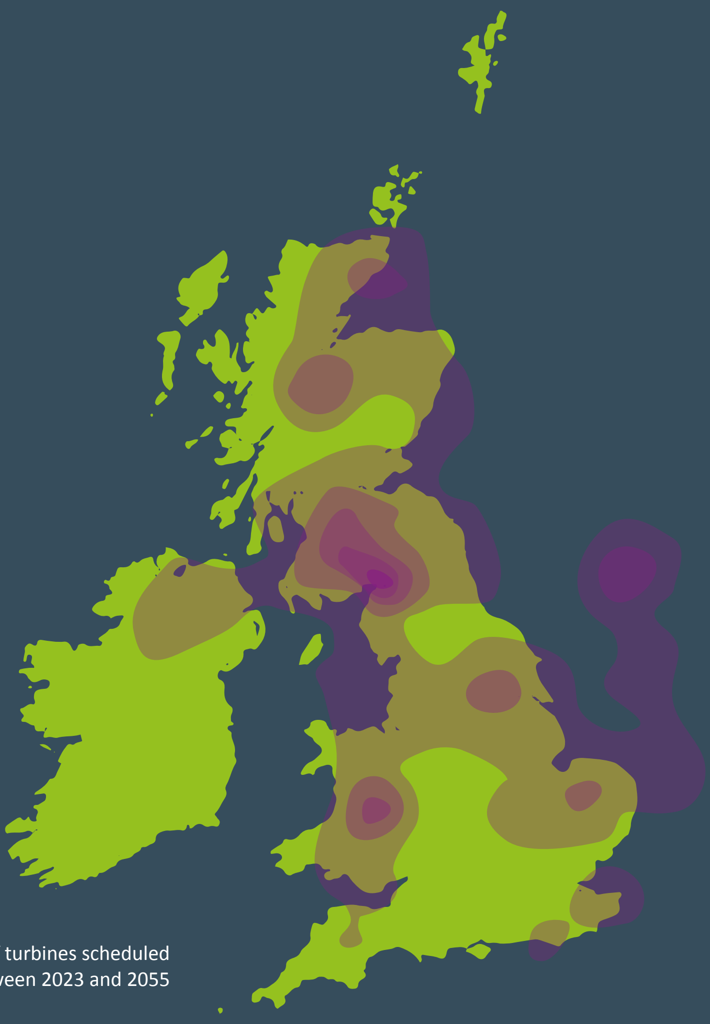
We have undertaken several activities that we see as vital to help start building a viable value chain:

- **Benchmarking** of the volumes, locations, and probable availability of composite waste derived from decommissioned onshore and offshore blades through to 2055.
- **Assessment of recycling technologies** with the aim to champion and then support the development of those we regard as the most promising for the reclamation of glass fibre reinforced composites from multiple sector sources.
- **Identifying and engaging** with the organisations that have the capabilities to process end-of-life blades in the short-term and support the development of technologies for the long-term.
- **Developing concepts** for designing with recycled fibre composites.

Delivering insight

Through collaborative workshops with our partners to capture industry knowhow, our work to date has already produced some significant results; improving the knowledge of the SusWIND consortium and giving us the tools to understand what is required to form the supply chain.

SusWIND has developed a wind turbine blade waste map which provides a clear picture of the location, age, and type of all UK wind turbines, including both onshore and offshore. This tool was designed by NCC and Offshore Renewable Energy Catapult (OREC) engineers and is underpinned by data from RenewableUK's Project Intelligence hub. The tool also provides estimates of decommissioning year for each farm. Combining these estimates with the locations and capabilities of other parts of the supply chain, such as recycling facilities, is positioning SusWIND to support the decisions of industry and liaise with government on the optimal processing routes for end-of-life blades. This holistic value chain view will help us ensure that this key domestic capability is well prepared for the volumes of composite waste to come.



Heat map showing the location of turbines scheduled to be decommissioned between 2023 and 2055

To help contextualise this composite waste, we have broken down the blade into its constituents and presented the masses of glass and carbon fibre, resin, core material, adhesive, paint, and root connection. As shown in Figure 4 we expect a significant increase in composite waste from 2030 onwards, with glass fibre waste alone expected to be in the region of 30,000 tonnes in 2044. This level of detail is vital for selecting the most appropriate processing route at end-of-life and is directly informing our work on the assessment of recycling technologies and required scale of the supply chain.

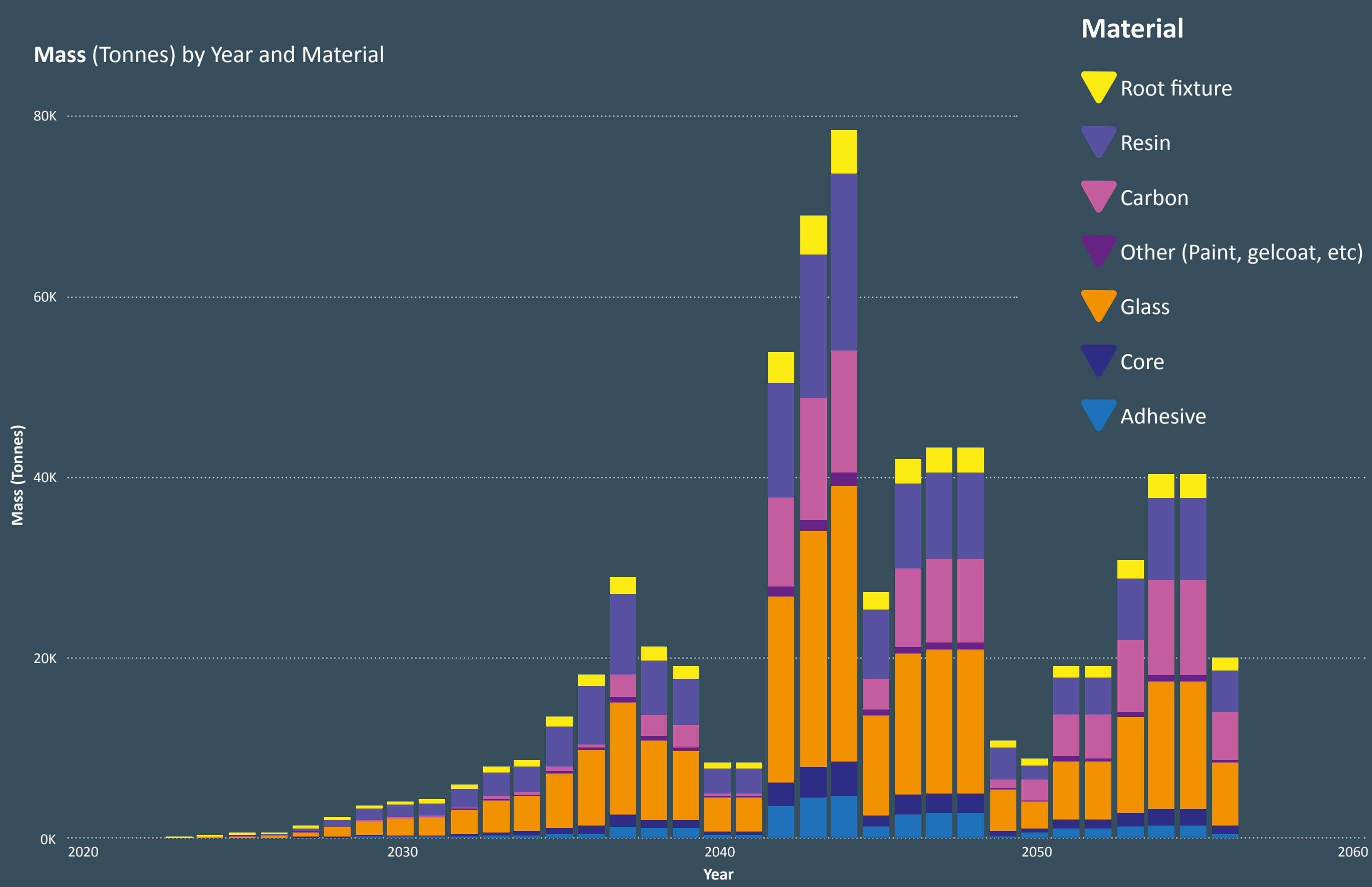


Figure 4 Offshore blade masses by material

SusWIND's work in assessing existing and emerging reclamation processes have been divided into short-term and long-term options.

Selection of the most feasible recycling route for end-of-life blades requires consideration of the process type (thermal, chemical, mechanical, electrical) and key parameters such as TRL, throughput, energy demand, global warming potential (GWP) and cost. It is important to understand the influence of the key process variables of each process and their effects on the quantity, quality, and cost of the recyclate.

Short-term availability (green side of Figure 5)

- Mechanical grinding and cement co-processing are commercially operational technologies and have been used successfully with composite waste. Neither are commercially available in the UK.
- Cement co-processing needs to be trialled in the UK and could represent an economically viable route.
- Mechanical grinding of the blades is viewed as a possible route to provide recycled feedstock for the production of engineered profiles and panels, displacing the use of wood and cement.
- Pyrolysis is seen as promising for carbon fibre reinforced composites but trials of Glass Fiber Reinforced Polymer (GFPR) have shown that the fibres are heavily damaged by the processing environment, resulting in a low quality recyclate of limited usefulness and therefore resale value potential.
- Our work suggests that these approaches should be viewed as being viable for the short-term (<10 years) and could be utilised while the technologies with the potential to produce higher value outputs are developed.

Long-term development (blue side of Figure 5)

- Technologies such as solvolysis, high voltage fragmentation and microwave assisted pyrolysis represent the future of composites recycling.
- SusWIND continues to engage with academia and industry to assess and establish the scale-up potential of these technologies, with consideration of the business case and environmental impact.
- Reprocessing of the reclaimed fibres is necessary to convert the recyclate into a marketable material. The technologies for doing so are available but the business case for using recycled fibres in place of or alongside virgin fibres needs to be established to enable a viable supply chain.
- Our initial findings indicate that, on their current trajectory, the development of these technologies will take 10+ years. However, this is too long to maximise the added value of the most promising technologies. SusWIND will support and champion their development to accelerate this timeframe and ensure that they are ready for the large increase in blade waste coming in the next decade.

Figure 5 TRL and regional locations of composite recycling technologies

To see increased usage of recycled materials, it is imperative to give design and manufacturing engineers confidence in their application.

In conjunction with the work to assess technologies and the supply chain for recycling, we have been developing design concepts for recycled fibre composites – which we are referring to as Design for Recycled. This will come together as a set of practical guidelines to provide engineers with the tools to use recycled fibre composites in the design of new components. Context will then be provided by a series of industrially relevant case studies.

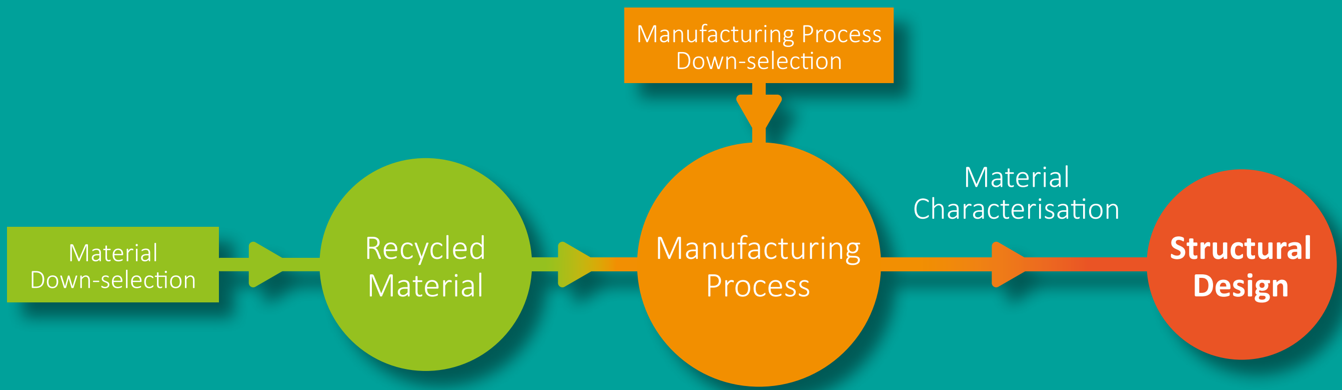
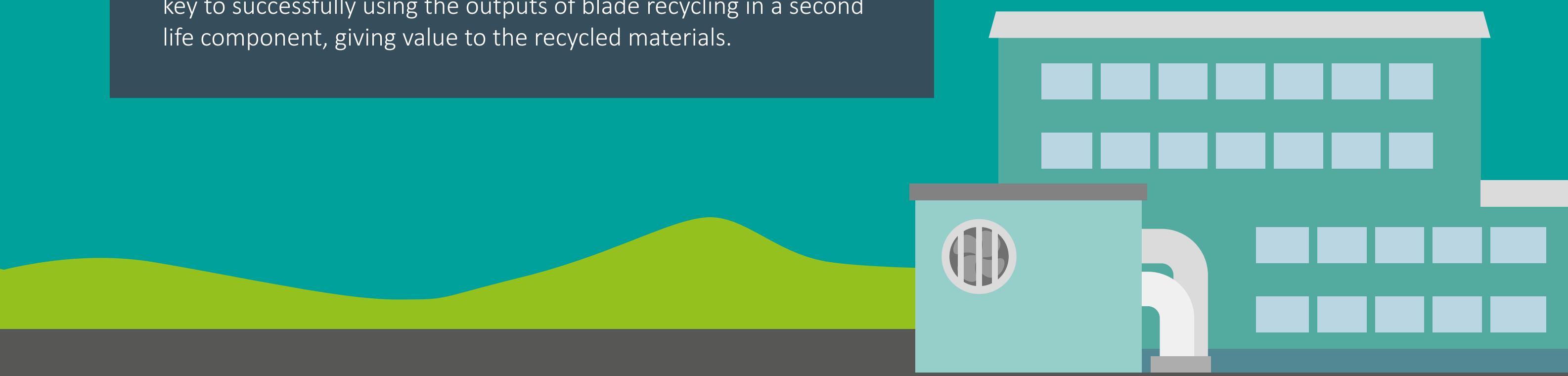


Figure 6 Illustrating the connection between material, manufacturing and design that underpins Design for Recycled.

Initial work to underpin the guidelines has considered commercially available recycled material formats and, as shown in Figure 6, begun to develop our Design for Recycled concept around the relationship between materials, manufacturing, and design, with a strong focus on material characterisation. Bringing together these aspects is the key to successfully using the outputs of blade recycling in a second life component, giving value to the recycled materials.



The future according to SusWIND

It is our aim to fundamentally change future blade architectures via the adoption of alternative materials and circularity in design to:

- **Eliminate waste in production.**
- **Preserve material value through-life.**
- **Remove the reclamation challenges at end-of-life.**

The best route to circular turbines is not yet clear, however the industry will need to be guided by a thorough understanding of the through-life environmental impact of current and alternative materials and manufacturing processes together with pragmatic and effective design for circularity approaches.

A critical first step has been to highlight the most impactful areas of blade manufacture using life cycle assessment. We have shown that materials make up 72% of the overall global warming potential (GWP) of the blade from cradle-to-grave, which supports the findings of other recently published studies. Of this contribution from the materials, over 80% comes from the spar cap and shells – clearly showing that these are the blade structures that should be targeted for reducing the environmental impact of blade manufacture.

In support of this activity, the SusWIND team at the NCC has carried out comprehensive research into alternative materials. To be considered a true alternative solution in a blade, these materials need to meet the design requirements and not lead to reduced Annual Energy Production (AEP). These operational impacts are being analysed using in-house blade design tools and LCA to provide our partners with a holistic view of the potential for new materials in wind turbine blades.

It is important to understand what circularity means for blades. Using the waste hierarchy can be a guide to consider different 'Design for R' concepts and Figure 7 shows how we have applied these to the blade lifecycle. Designing for Repair or Repurposing, for example, need to be thought about carefully. Repair strategies must be realistic, reducing risk to operatives and maintaining the reliability of the blade.

Design for Repurposing, though theoretically favourable, is also a difficult concept to apply to wind turbine blades. It requires the designer to know the probable second-life application after a 25+ year service life.

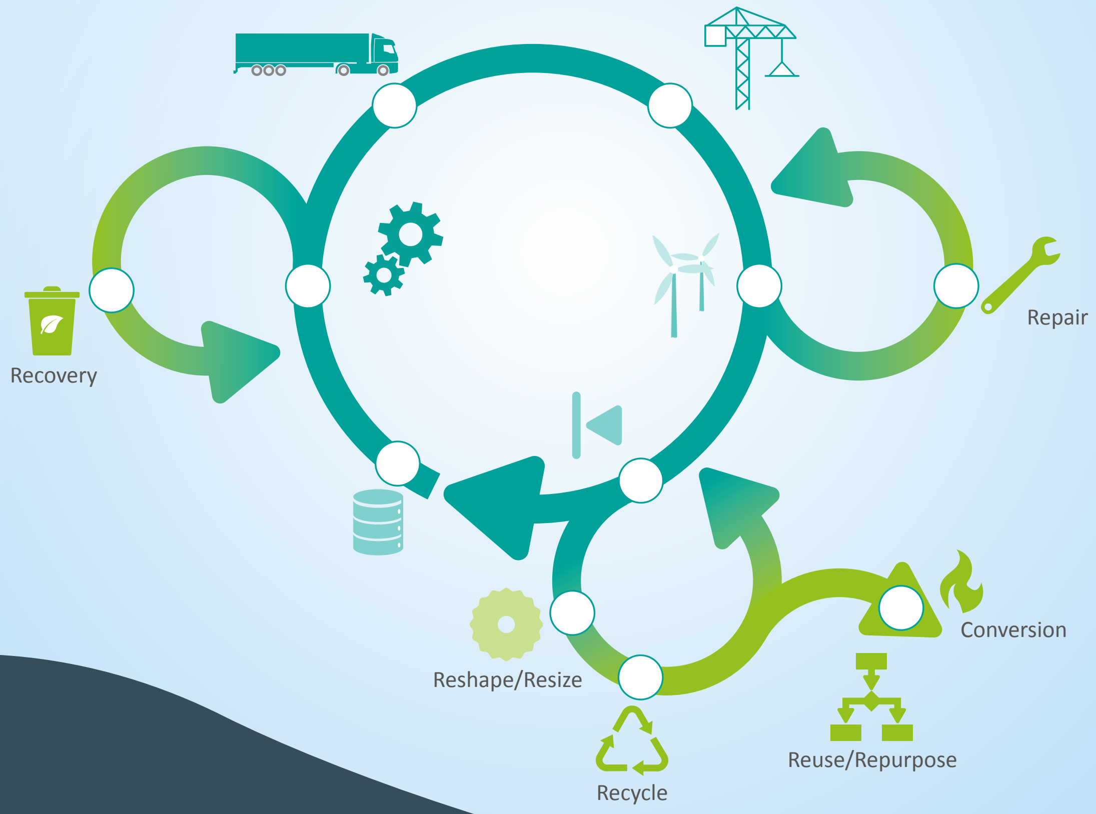


Figure 7 The future according to SusWIND

Within that future circular economy, materials must retain their value as they move from “recycle” back to “manufacture” in Figure 7. We have proposed a simple framework to explain what “retaining value” means in engineering terms in Figure 8.

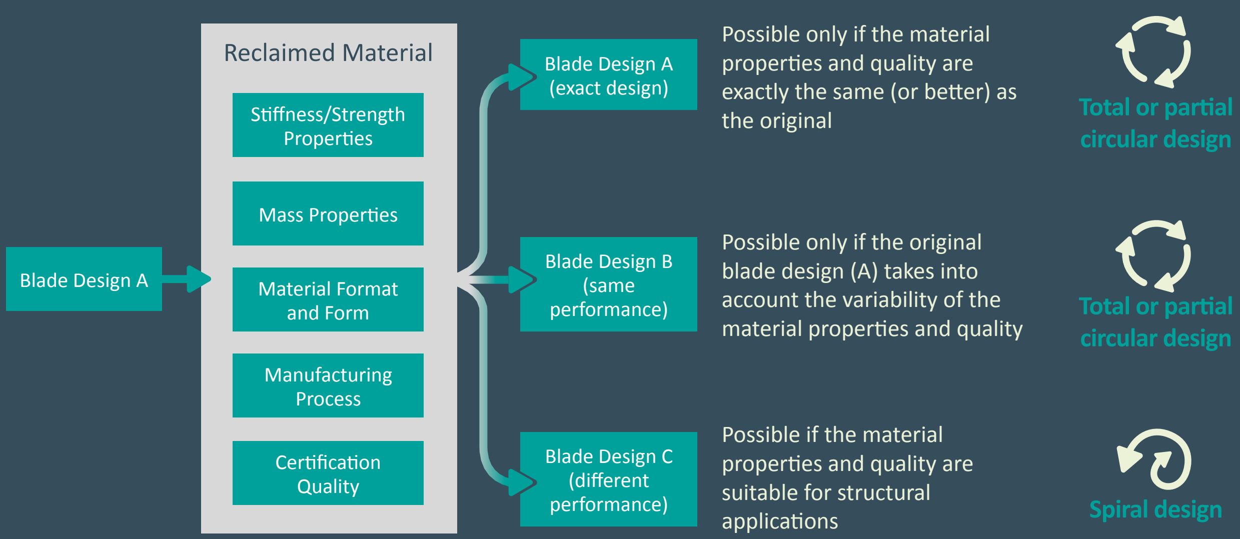


Figure 8 The considerations for Design for Recycling

SusWIND is developing strategies to objectively assess and improve the circularity of new designs. These strategies will be underpinned by clear design guidance on the changes needed to eliminate production waste to retain material value and remove challenges at end-of-life. Rethinking blade design will ultimately help the industry grow to meet the demands of net zero, and do it sustainably.

SusWIND Programme

Composite materials are a key enabler for the success of wind energy and the role that it will play in delivering a low carbon global economy. SusWIND is bringing together stakeholders across the composites industry and wind energy sector to look at every aspect of the wind turbine product lifecycle to achieve a sustainable future.

Our Partners and Supporters

Offshore Renewable Energy Catapult - Delivery partner

Vestas

SSE Renewables

EDF Renewables

Shell

Net Zero Technology Centre

The Crown Estate

RenewableUK

BVG Associates

Zero Waste Scotland

Contact us

Contact us to discuss the programme in more detail and how you can get involved in this exciting initiative. We look forward to working with you to drive the successful outcomes we need to deliver the sustainable future we are all committed to achieving.

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Sustainable Composites