Technology Collaboration Programme
by iea

June 2023

IEA Wind TCP Task 45

Deliverable 2.1 PUBLIC

A review of the current state of blade design and novel materials research for improved recyclability of wind turbine blades

iea wind

IEA Wind Task 45 Wind Turbine Blade Recycling
Deliverable 2.1

A review of the current state of blade design and novel materials research for improved recyclability of wind turbine blades

June 2023

Contributors

Name	Organisation	Expertise / Interest
Steffen Czichon	Fraunhofer IWES	Blade design and materials
Niels Ludwig	Fraunhofer IWES	Blade design and materials
Philippe Spring	TPI Composites	Blade design and materials
Marco J. Echeverria	Fraunhofer IWES	Blade design and materials

TABLE OF CONTENTS

List of Figures

List of Tables

A review of the current state of blade design and novel materials research for improved recyclability of wind turbine blades

Steffen Czichon[1]*, Niels Ludwig[1], Philippe Spring[2], Marco J. Echeverria[1]

[1] Fraunhofer-Institut für Windenergiesysteme, Fraunhofer, Bremerhaven, Germany

[2] TPI Composites, Berlin, Germany

*Corresponding author: steffen.czichon@iwes.fraunhofer.de

Abstract. This report is part of IEA wind Task 45: recycling of wind turbine blades. The purpose is to present a review of novel materials and blade design for improved blade recyclability and identify possible associated recycling processes and barriers that may arise.

Introduction

Wind turbines are considered a feasible and environmentally friendly technology to generate energy. Wind Turbines typically recoup the released CO2 emissions during production after only a couple of months. However, the manufacturing and end-of-life processes are energy intensive and associated with harmful environmental practices [1–3]. Both aspects (beginning- and end-of-life) have become emerging topics in the last decades owing to the steep rise in the installments of wind farms, as well as the lifespan of the once novel wind turbines coming to an end (typically ~ 20 years) [4–6]. Wind turbine blades' lifespan incites investigation into the apparatus and each component to find more easily recyclable, environmentally friendly, and efficient materials to generate the required energy consumption [7,8].

Wind turbines with a blade span upwards of 100 m can now be fabricated to produce the required energy [9]. While the increase in blade size renders more energy owing to an ampler span, it also makes the blades heavier, thus making the material selection a vital subject to meet the new mechanical requirements [7]. Wind rotor blades consist of various elements such as coatings, fiber composites, adhesives, lightning protection systems, and metal joints in multiple locations, making it a very intricate and complex apparatus to manufacture and recycle appropriately [10–13]. When a wind turbine is decommissioned, most materials and components including the rotor blades enter the waste stream. For each decommissioned MW of installed wind energy capacity we expect around 10 tons of composite material to become composite material waste[14–17], resulting in 2.5 million tons of composite materials around the world as of 2020 [10,16,18], and around 0.3 million tons in Europe alone by 2050 [15] (Figure 1). It is hard to recycle these amounts of composite material waste with the existing technologies and business models. [19–21].

Developing optimal techniques to recycle, reuse, and extend the lifespan of wind blades is of great importance in addressing waste management issues. For instance, improving protective coatings on the leading edge has significantly extended the lifespan with minimal changes to the blade structure [22–24]. Current recycling techniques of composite materials make it difficult to do in an industrial case, underpinned by the few techniques available and the resulting material with worsened mechanical properties after the post-processing [25]. For example, grinding the blades into small pieces makes it easy to recover energy in cement kilns [26] and enables the use of the ground blade to recover the glass fiber-reinforced polymers (GFRP) via pyrolysis. While pyrolysis enables the separation of the fibers and matrix into ash and oils, respectively, owing to the elevated temperatures inherent to the process, it renders a reduced strength fiber [14] compared to the virgin counterparts [15,26–29]. High temperatures are necessary due to the resin matrix typically being made of thermoset polymers that cannot be easily depolymerized, unlike thermoplastic counterparts [3,14]. Selecting recoverable matrices could offer a 28 % reduction in CO_2 emissions and a 90% recovery of the matrix and fibers [26,30].

This paper elucidates the current technologies in materials selection to create novel blades that can be fabricated from repurposed blades or easily recycled after decommissioning. This work focuses on reviewing the materials with proven recycling capabilities and new materials still under research or development. This review work is structured into four sections: Section 1 describes the current knowledge and challenges in rec. Section 2 describes the typical anatomy of the blade, materials, and manufacturing processes used to fabricate them. Section 3 reviews the novel technologies to enhance recyclability from the design stage. Finally, section 4 provides a list of recommendations and possible future work.

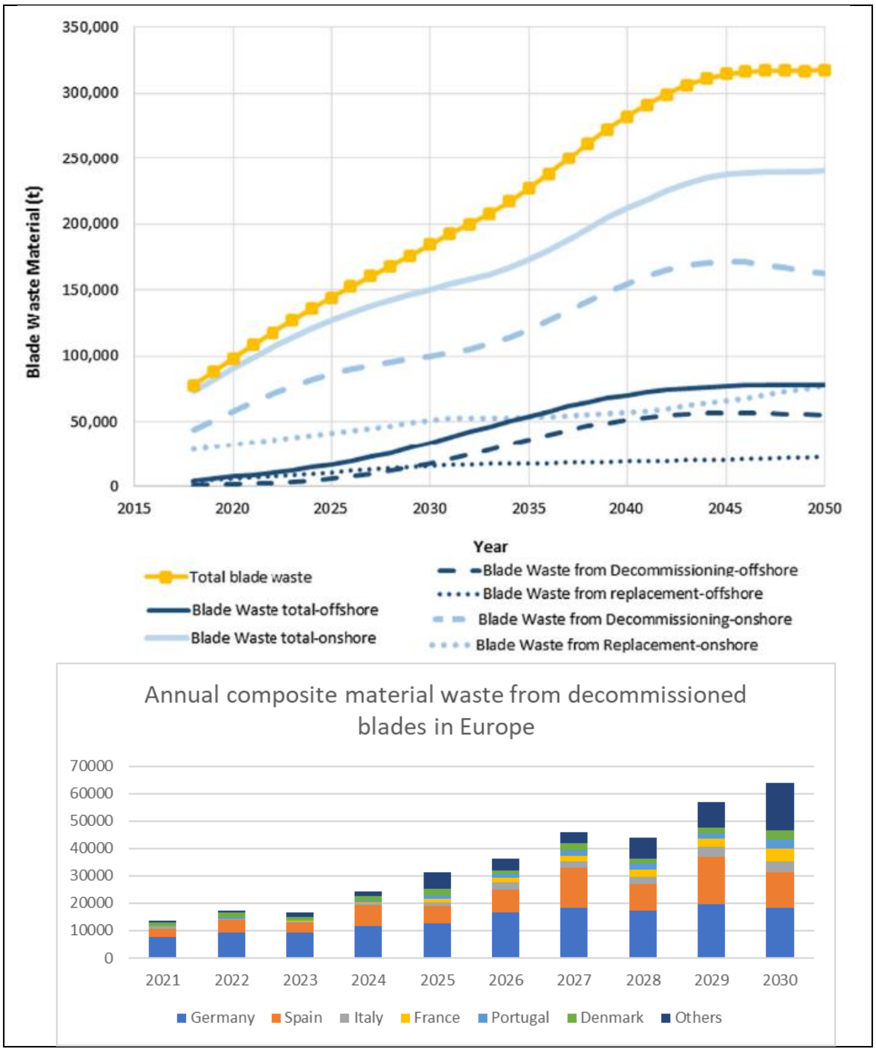

Figure 1. Blade waste material forecast (in tons) from wind turbines in Europe until 2050, retrieved from [15].