The FiberEUse Demand-Driven, Cross-Sectorial, Circular Economy Approach

Marcello Colledani, Stefano Turri, and Marco Diani

Abstract Composite materials are widely used in several industrial sectors such as wind energy, aeronautics, automotive, construction, boating, sports equipment, furniture and design. The ongoing increase in composites market size will result in relevant waste flows with related environmental issues and value losses if sustainable solutions for their post-use recovery and reuse are not developed and upscaled. The H2020 FiberEUse project aimed at the large-scale demonstration of new circular economy value-chains based on the reuse of End-of-Life fiber reinforced composites. The project showed the opportunities enabled by the creation of robust circular value-chains based on the implementation of a demand-driven, cross-sectorial circular economy approach, in which a material recovered from a sector is reused within high-added value products in different sectors. A holistic approach based on the synergic use of different hardware and digital enabling technologies, compounded by non-technological innovations, have been implemented to develop eight demonstrators grouped in three use cases, fostering different strategies. In particular, Use Case 1 focused on the mechanical recycling of short glass fibers, Use Case 2 on the thermal recycling of long fibers, while Use Case 3 focused on the inspection, repair and remanufacturing of carbon fiber reinforced plastics products and parts.

Keywords Composite materials · FiberEUse project · Cross-sectorial approach · Demand-driven approach · Recycling technologies

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1 Introduction

Composites are relatively young and intrinsically durable materials, but composite-based components or products have a definite lifetime, normally shorter than 20–30 years. For example, wind turbines are predicted to have a lifecycle of 20–25 years, with related dismantling and recycling issues emerging after the use phase. Similarly, many of composite-made boats are still operating, but the average lifetime for recreational boats is around 10 years, and up to 30 years for sailboats [1]. Again, the average lifetime of composite components in car bodies does not exceed 10 years. As the demand for composites in these sectors is continuously growing it is evident that a correct waste management will become an important issue for industrial stakeholders operating in these business sectors. A systemic and systematical waste management strategy has to be defined, supporting the transition from a linear to circular economy. Indeed, the currently limited recycling of composites is seen as an industry challenge that bounds market growth in strategic sectors, such as e-mobility. For example, according to the EU ELV (End-of-life Vehicles) legislation [2], the 95% in weight of vehicles disposed after 2015 must be recyclable. The possibility to reach this strategic goal in the automotive sector, undergoing a profound transformation towards E-mobility, may be bounded if proper solutions for composite materials, very attractive for e-vehicles due to the lightweight properties compensating the additional weight of battery packs, are not found.

Innovative technological approaches and economical models have to be jointly developed considering not only the compliance with environmental regulations, but also the generation of profit. Current waste management practices in composites are dominated by landfilling which is still a relatively cheap option, however it is the least preferred by the legislation and doesn't comply with the European Waste Framework Directive [3]. It is recognized that landfilling will become unviable mainly due to the legislation-driven cost increases. Landfilling of composite waste is actually already forbidden in Germany and Austria, and other EU countries are expected to follow this approach.

The preferred strategy for EoL composite components is certainly passing through recycling and reuse. Mechanical, thermal and chemical recycling methods are well known at state of the art [4–6]. An alternative option is incineration with energy recovery and incorporation of fiber residues in ashes or cement.

Not only research institutions but also industries and sectorial associations, such as WindEurope, are sensitive to the problem of a correct management of EoL composite products and components. The official position of the European Composite Industry Association is to promote co-processing of glass fiber waste in the cement kiln route [7]. According to this view, Life Cycle Assessment studies showed that significant reduction of CO_2 emission of the clinker manufacturing process can be obtained (up to 16%). However, it has been also shown that no more than 10% of the fuel input to a cement kiln route could be substituted by Glass Fiber Reinforced Plastics (GFRP) waste [6]. Indeed, the presence of boron in E-glass fibers negatively impacts the performance of the cement. Even if co-processing of composite waste in the cement kiln route is compliant with the current EU legislation, technical added-value of fibers and polymer matrices are lost in this approach. Co-processing offers environmental benefits but low, if any, profitability.

Among stakeholder associations, the European Boating Association (EBA) presented a position paper on the problem of EoL boats, underlining that there is a compelling need for a specific legislation considering the concept of extended producer responsibility as the best route to take [8], and highlighting the difficult transition from linear to circular economy in the sector.

In particular, the material composition and the cross-linked nature of fiber-reinforced plastics, especially thermosets, make recyclability complex. The existing limitations for a transition to a sustainable circular economy approach for composite-made parts are discussed in the following.

- Lack of a systemic value-chain integration for re-use: Although research effort has been devoted to the development of isolated technologies and processes for recycling composites, the opportunity for a circular economy model for post-use fiber reinforced plastics parts in Europe is still unexploited, mainly because of the lack of a systematic approach for integrating different stakeholders in the value-chain in a stable, trustful, and efficient way.
- Low volume, unstable and unpredictable supply of post-use products for material and components for re-use: At industrial level, it is usually very complex to guarantee a constant, in terms of volume, and replicable supply of input post-use products if a single sector is considered. This can be overcome through the implementation of a *cross-sectorial approach*, exploiting the innovative idea of *demand-driven circular economy*, consisting in adapting the recycling and re-use strategy and processes in order to meet, in certified and traceable way, the requirements of high added-value products in other sectors.
- Poor consumers acceptance of products embedding recovered materials: A general belief that products embedding recycled materials present lower performance than products made of virgin materials still exists. Awareness raising and citizens involvement are essential to foster circular economy implementation.
- Lack of circular business models for boosting profitability: Even in the cases when recycling and re-use is technically feasible, it is usually very hard for companies to prove the profitability of the business through sustainable business cases. This is mainly due to the lack of service-oriented business models, targeted to boost virtuous circular economy practices by enabling a direct accessibility to post-use parts and a certain level of control on the reverse logistics flows, to properly bound costs.

Many of these barriers are the results of fragmentation, poor communication, limited knowledge on the market demand, lack of common vision and strategy both across vertical and horizontal value chains, as well as low revenue and a paucity of supporting legislation and incentives to encourage composites reuse.

The EU H2020 FiberEUse project (GA No. H2020-730,323-1, www.fibereuse.eu) was set-up with the target objective to overcome these limitations by developing and demonstrating industry-mature circular economy practices for composite-made products, inspired by the aforementioned principles of cross-sectorial and demand-driven circular economy. FiberEUse involves a consortium of 21 partners from 7 EU Countries (as shown in Fig. 1) representative of reference stakeholders of the targeted circular value-chain. The project aimed at integrating different innovation actions through a holistic approach, enhancing the profitability of composite recycling and reuse in new value-added products. The project developed and demonstrated an integrated technically and economically viable system for the valorization of composite recyclates through innovation in recycling, reprocessing and remanufacturing technologies, compounded by innovation at non-technological, value-chain integration oriented, level. Through these achievements, FiberEUse established a cross-sectorial, cross-industry, technological and innovation platform able to promote an efficient and cost-effective recycling and reuse of post-use glass and carbon fiber composites, at the same time bringing benefit to the environment, end-users, and the sector as a whole.

This book presents the results obtained during the project, emphasizing the achieved maturity level of the developed solutions in view of their future up-scale at wider industrial value-chain level within different composite-relevant sectors and regional areas at worldwide scale.

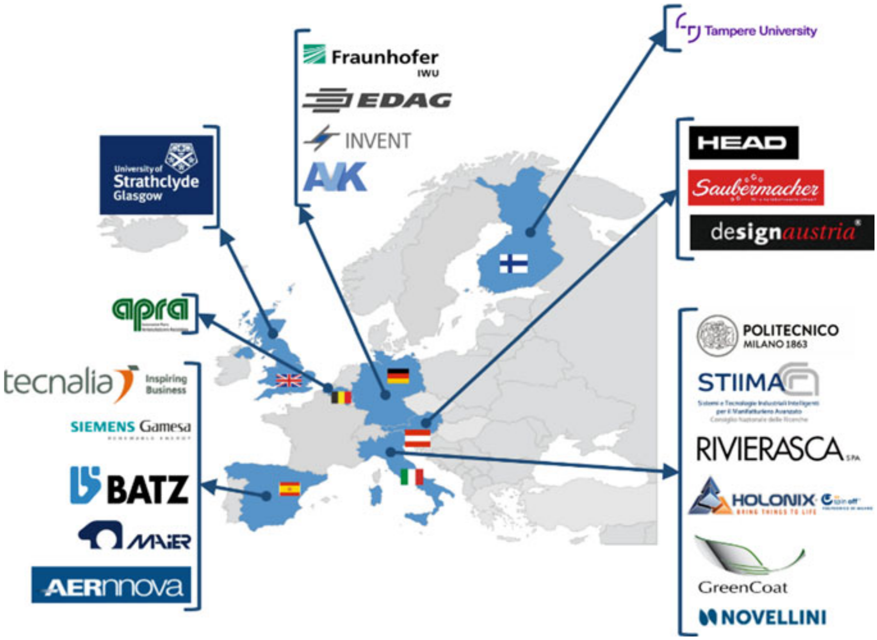

Fig. 1 The FiberEUse project consortium

2 The FiberEUse Demand-Driven, Cross-Sectorial Circular Economy Approach and Vision

The FiberEUse vision is based on the observation that circular value-chains for composite materials can be made economically viable for the involved stakeholders only if the value of the obtained output fractions is maintained high throughout multiple use-cycles, i.e. without significant value losses caused by excessive material property down-cycling. In line with this vision, the target objective of the FiberEUse circular strategies is to obtain output fractions featuring sufficient physical properties to match the input requirements and specifications imposed by the target output applications. This is made possible by a novel demand-driven, cross-sectorial circular economy approach. The rationale of this approach is explained in the next section.

2.1 The Concept of Cross-Sectorial Circular Economy Approach

The essence of the proposed cross-sectorial circular economy approach consists in the recycling, reprocessing and re-use of materials from products in sectors characterized by higher requirements and more demanding technical specifications in new products and applications featuring less demanding, more liberal, specifications. As a matter of fact, this approach exploits the technical degrees of freedom provided by the different input material specification sets characterizing different applications and sectors. The practical implication of this approach is explained in the following through concrete examples.

In Figs. 2 and 3 [9] the characteristics industry requirements and specifications for composite materials (both glass and carbon fiber based) in different sectors are shown, in terms of tensile strength and tensile module. As it can be noticed, for both composite materials, the specification areas characterizing different application scenarios are not overlapping. For example, for both CFRP and GFRP, the typical tensile strength required by the aeronautics sector is almost twice as large as that required by automotive applications. Similarly, considering GFRPs, the typical tensile strength required by wind energy applications is approximately 30% higher than that required by the boating industry. This means that, although recycling processes may contribute to a deterioration of the mechanical properties of materials extracted from post-use products, if these characteristics are properly controlled and managed then the output material fractions may still maintain sufficient residual properties for other applications, across two or more use-cycles.

This technical observation highlights the opportunity for establishing cross-sectorial value-chains for the implementation of new circular economy business cases, provided that innovation in the recycling, reprocessing and re-use process-chain can make it flexible and adaptable to varying target material properties

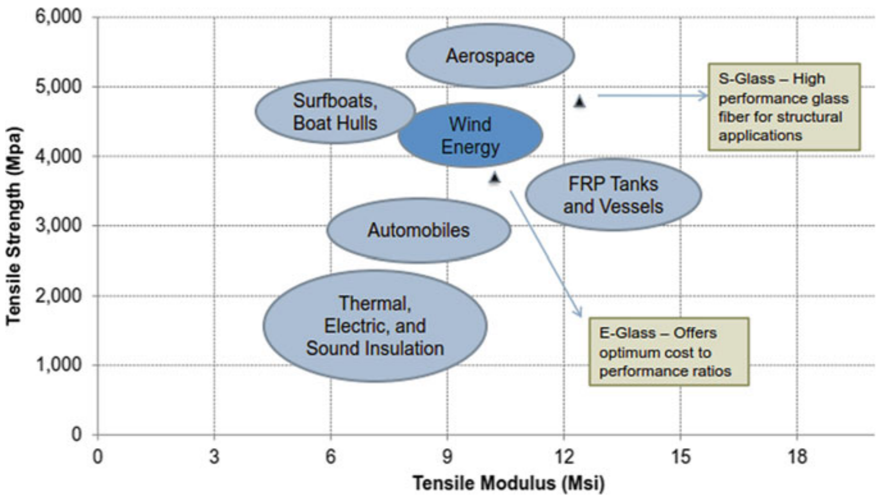

Fig. 2 Industry requirements for GFRP made parts in different sectors [9]

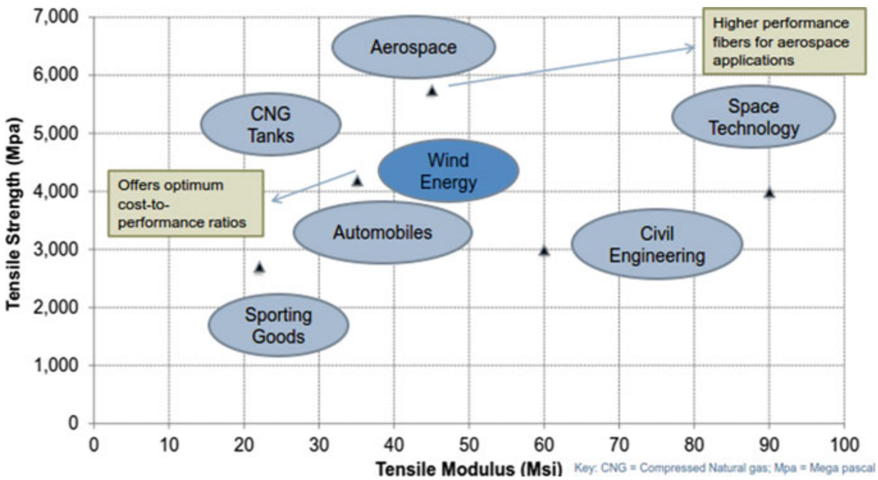

Fig. 3 Industry requirements for CFRP made parts in different sectors [9]

required by different applications. This is the essence of the demand-driven approach explained in detail in the next paragraph.

2.2 The Concept of Demand-Driven Circular Economy Approach

To enable this cross-sectorial approach, a recycling, reprocessing and re-use process-chain have to be implemented, that is able to provide to the output fractions containing fibers and resin the input characteristics needed by the sector in which they will be used as secondary raw materials, in partial or complete substitution or virgin raw materials. The FiberEUse demand-driven approach is formalized to support this vision.

Current fiber reinforced plastics industrial value-chains, for example in the wind energy and boat industries, are essentially linear as represented in Fig. 4, where the main product flow is captured by horizontal directed arrows, while the secondary resource flows contributing to the transformation in each value-chain phase are represented through vertical arrows crossing each transformation box. The only exception is the existence of few industrial players with capability to process composite materials limiting to production waste and not accepting post-use products in input. The main destination of these materials and components from composite post-use products today is the disposal in landfills, or the non-profitable incineration in cement kiln factories. For example, wind energy parks operators and producers are struggling finding a solution to their post use products as no industrial stakeholders accepts their post-use wind blades for recycling and re-use.

As reported in Chap. 1, the scientific literature has developed and demonstrated potentially applicable technical solutions for composite recycling. However, these solutions are grounding on the recent but traditional concept of circular economy. As a matter of fact, the current approach is essentially "push" in the sense that the goal is to maximize the quality and quantity of the materials recovered by recycling processes and, only later, to scout potential re-use applications based on the obtained material properties (Fig. 5). In this way, only few high added-value re-use applications in very specific sectors can be achieved, covering a minor fraction of the EoL composite potential.

In order to unlock high-value circular value-chains for fiber reinforced plastics, a new concept of demand-driven circular economy has to be adopted that will revolutionize the current circular economy oriented industrial practices in the composites field. The key FiberEUse concept of demand-driven circular economy solution is

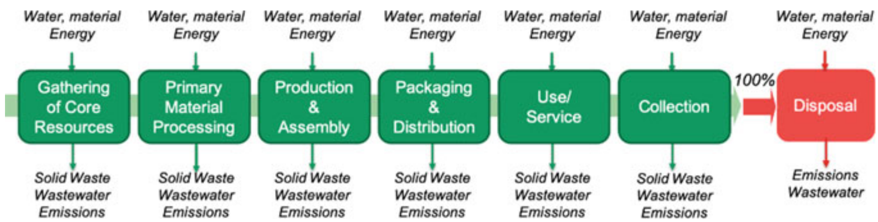

Fig. 4 Current linear value-chain for composite post-use products (100% landfilled)

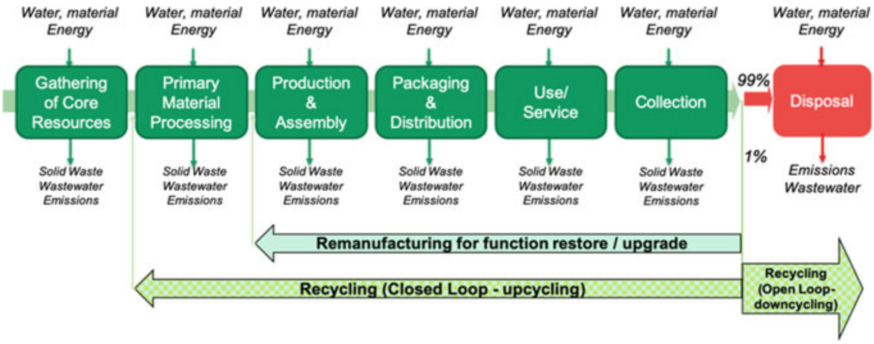

Fig. 5 "Push" traditional circular value-chains

represented in Fig. 6. The core idea is that the circular value-chain is transformed into a "pull" system, where the requirements and specifications on the materials and components to be re-used are transferred directly from the demand side in terms of characteristics and functionalities of the high added-value products reusing such materials and components, and, in turn, propagated upstream to recycling, reprocessing or remanufacturing, in case of component function recovery, stages. This approach will guarantee that the materials and components obtained through circular economy practices are actually re-usable into new products that are demanded by the market, thus bringing circular value-chains at the same level of maturity as linear value-chains and fostering the implementation of the aforementioned cross-sectorial approach. This will also support the creation of sufficiently high volume of waste streams across composite use sectors, crucial to build economies of scale and industrialization of recycling. This approach has been preliminarily exploited in the FiberEUse project for the development of the demonstrators. Considering its potential, the implementation of the demand-driven approach has to be considered as a future innovation priority in circular economy.

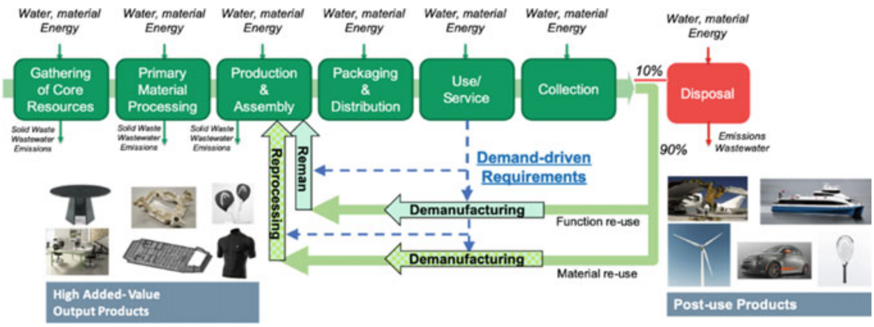

Fig. 6 "Pull" demand-driven circular value-chains

3 The FiberEUse Use Cases and Demonstrators

The project developed and demonstrated at a large scale a set of environmentally and simultaneously economically profitable solutions for the treatment and valorization of EoL composite waste deriving from different manufacturing sectors. A holistic approach based on the synergistic use of different enabling technologies has been implemented in the realization of three large scale use cases shown as yellow, blue and green lines in Fig. 7. Each of these large use case generated several other demo-cases (8 in total) to close the loop of composites lifecycle in different industrial sectors from a circular economy viewpoint.

More in detail, Use Case 1 (represented in Fig. 8) was dedicated to mechanical recycling of short GFRP from post-use products from wind energy, construction and sanitary sectors and their reuse in high added-value customized applications, including furniture (Demo-Case 1), design and creative products (Demo-Case 2) and sports equipment (Demo-Case 3) through additive remanufacturing, compounding, extrusion, molding and finishing. The process-chain involved in Use Case 1 is represented in Fig. 9.

Use Case 2 (represented in Fig. 10) aimed at thermal recycling of long fibers (glass and carbon) and re-use in high-tech, high-resistance applications. Input products was End-of-Life wind turbines and aerospace components and the reuse of obtained composites in automotive (Demo-Cases 4 and 5) and construction sector (Demo-Case 6) has been demonstrated by applying controlled pyrolysis and compounding, molding and extrusion. The process-chain involved in Use Case 2 is represented in Fig. 11.

Use Case 3 (represented in Fig. 12) focused on the inspection, repair and remanufacturing of End-of-Life CFRP products and parts in high-tech applications (in particular automotive). Several technologies have been implemented as non-destructive

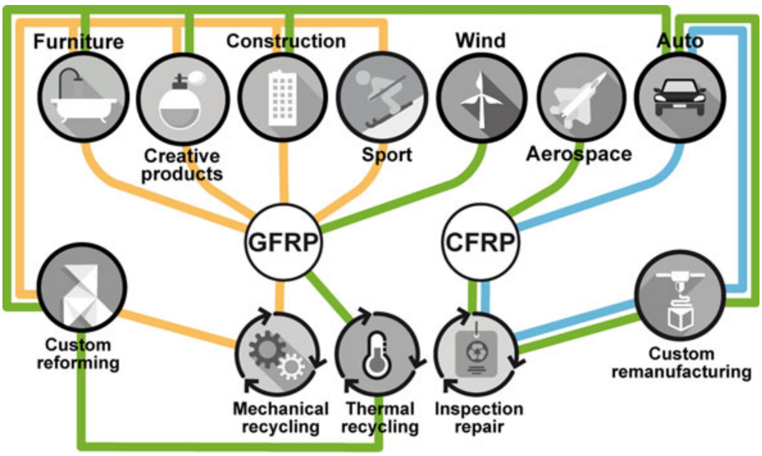

Fig. 7 Visualization of use cases of the FiberEUse project (credits to S. Ridolfi)

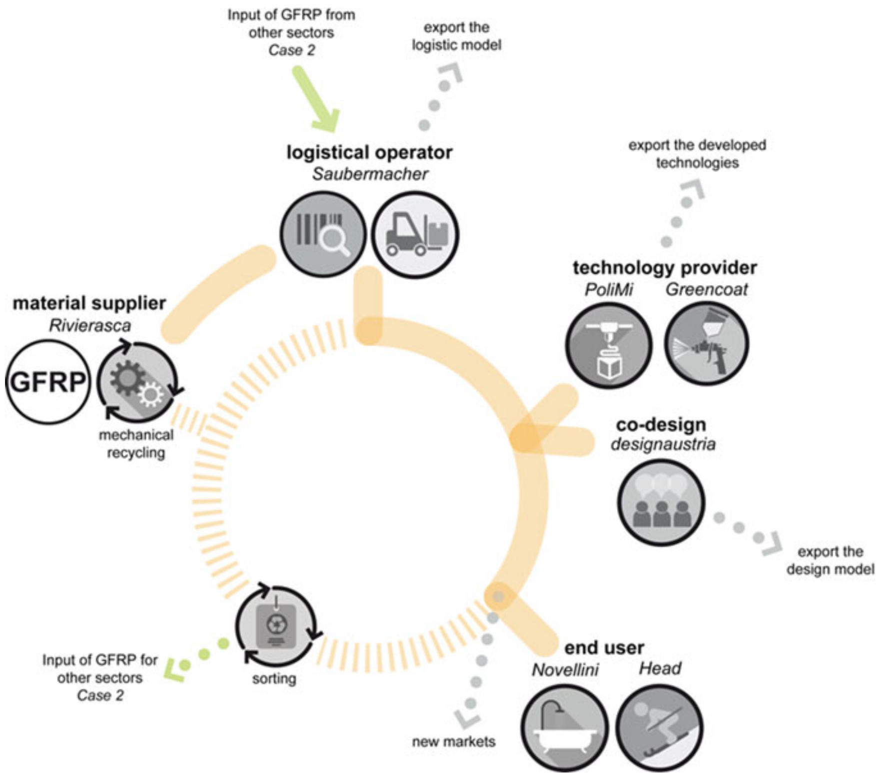

Fig. 8 Use Case 1 value-chain key stakeholders, dedicated to mechanical recycling of short GFRP (credits to S. Ridolfi)

inspection techniques, laser cutting and repair, and innovative design to allow a complete circular economy demonstration in the automotive sector (Demo-Cases 7 and 8). The process-chain involved in Use Case 2 is represented in Fig. 13.

The FiberEUse technological and non-technological pillars have supported the realization of each demo-case and will be amenable to industry upscale to support the generation of further demo-cases for opening the demand of pos-use composite fractions, thus leading to a wider impact in the future. This has been achieved by demonstrating a comprehensive, modular solution that combines: (a) optimized mechanical and thermal composite recycling, inspection, repair and reprocessing technologies; (b) specific value-chain integration actions aimed at improving the market of the recyclates and the profitability of the target reuse options through the demonstration of three large use cases. The FiberEUse technological and non-technological innovations are further detailed in the following sections.

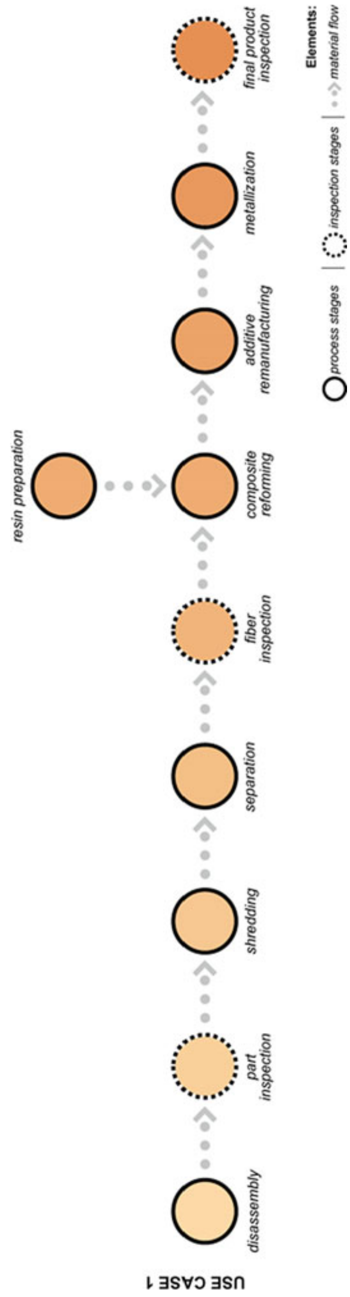

Fig. 9 Use Case 1 process-chain (credits to S. Ridolfi)

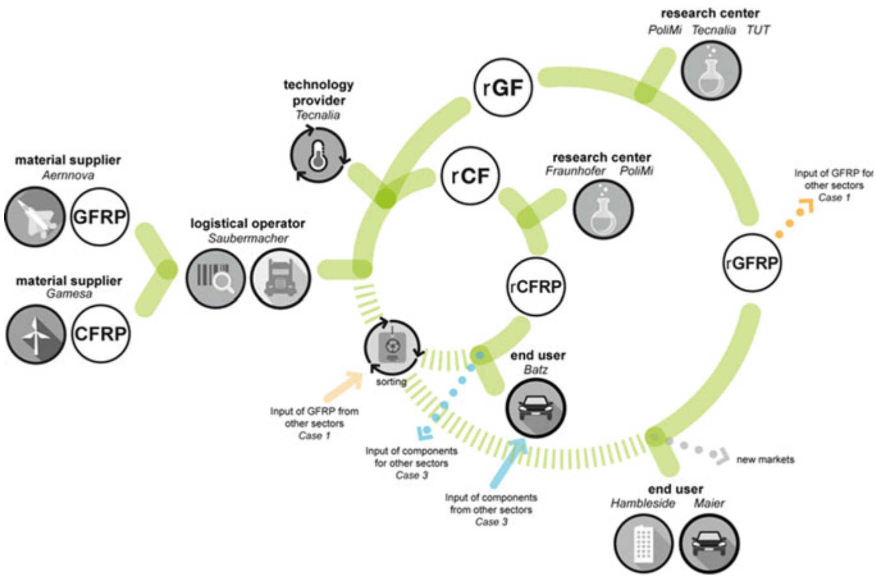

Fig. 10 Use Case 2 value-chain key stakeholders, dedicated to thermal recycling of long fibers (credits to S. Ridolfi)

4 The FiberEUse Technologies

The realization of the aforementioned eight FiberEUse demo-cases and the validation of the achieved performance has been supported by the development and validation of a set of technologies supporting the FiberEUse demand-driven, cross-sectorial circular economy vision. A brief discussion of each technical pillar follow.

Disassembly of large infrastructures. The first stage of the process chain to treat EoL products is disassembly. It is a fundamental step, in particular when dealing with composite-rich large infrastructures, as wind blades. It can influence both the quality of the following processes (as recycling) and the economic sustainability of the entire process. Different route can be followed, with tasks that can be performed both in situ or directly in the recycling plant, and several jobs have to be optimized (as cutting) to facilitate recycling. Chap. 3 of this book focuses on the optimization of the disassembly procedure of large infrastructures, presenting a model that is able to minimize the costs considering all the different aspects, from machining to logistics.

Low-cost and highly-controlled mechanical grinding of GFRP waste. As already presented before, mechanical recycling is one of the most used solutions to treat GFRP. This is due in particular for the low cost of these materials that requires non-expensive processes. On the other hand, non-optimized processes hinder the possibility to reuse this material in new high-added value products. To overcome this issue, the design of optimized suitable solutions, with high throughput and low costs, following a demand-driven approach, is fundamental. Chapter 4 of this book

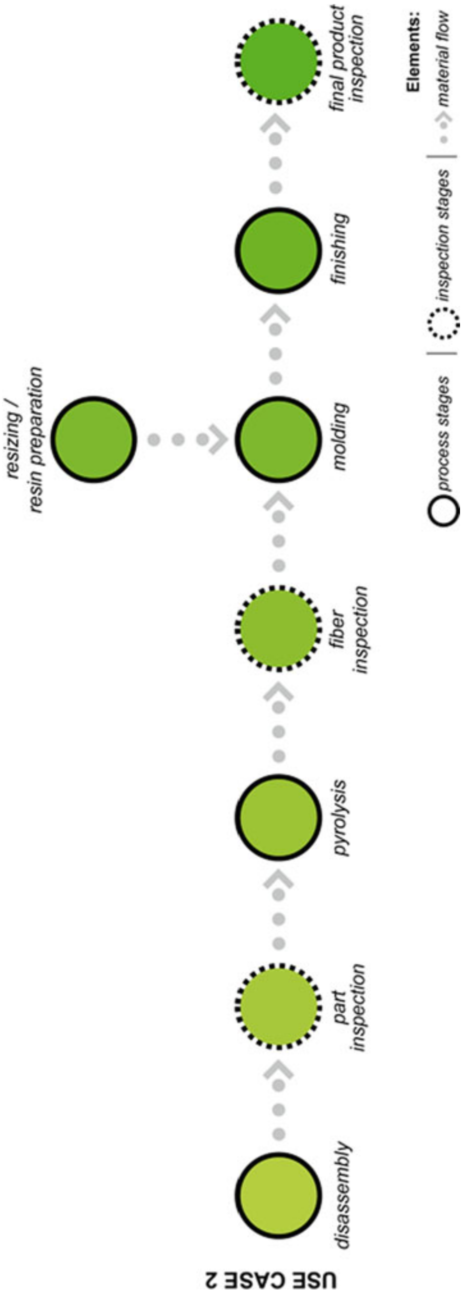

Fig. 11 Use Case 2 process-chain (credits to S. Ridolfi)

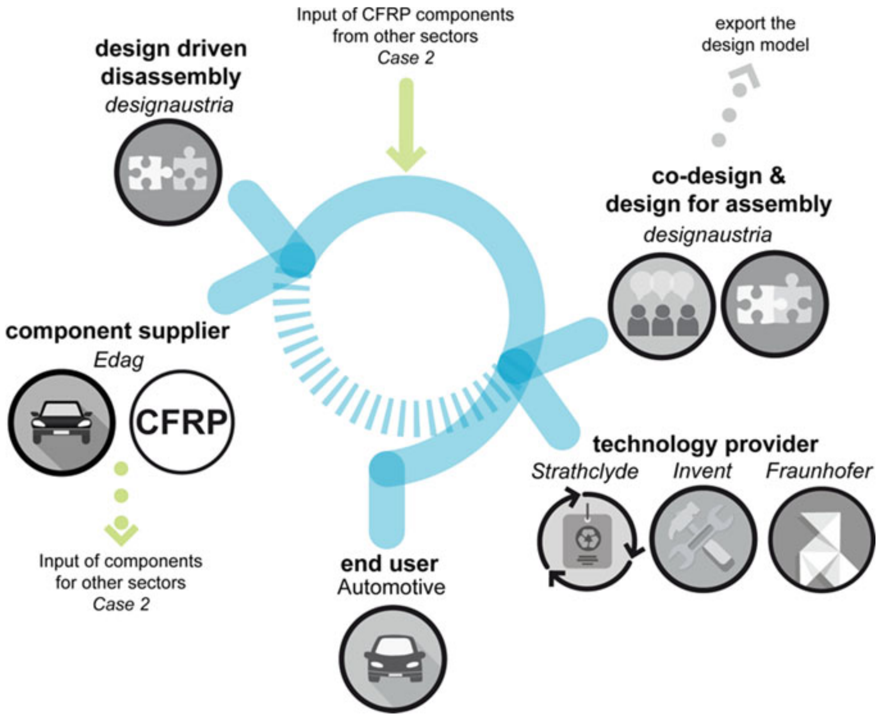

Fig. 12 Use Case 3 value-chain key stakeholders, dedicated to remanufacturing of End-of-Life CFRP products and parts (credits to S. Ridolfi)

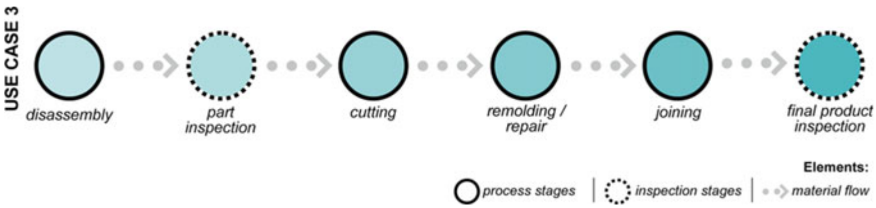

Fig. 13 Use Case 3 process-chain (credits to S. Ridolfi)

is dedicated to the presentation of the results obtained in smart mechanical recycling processes of composite materials with the related developed models.

Innovative pyrolysis process. Thermal recycling is the most suitable solution to treat composites to obtain long fibers. Traditional processes show good results in terms of fibers cleaning but suffer from two aspects. The first one is the possible degradation of the fibers that can affect their reuse in high-added value products. The second one is the cost, mainly due to the high energy consumption, limiting their application to CFRP (that have higher selling price). In addition, even if the fibers are recovered, the resin cannot be recycled to be reused in new applications.

Chapter 5 of this book will show the results obtained during FiberEUse project on thermal demanufacturing for long fibers recovery, presenting different approaches and an innovative thermal depolymerization process.

Reformulation. The resins currently used in manufacturing of composite materials are based on styrene. This is due mainly on the characteristics of this monomer, in particular the possibility to finely tune the final properties of the cured material through the reduction of the viscosity and improving the processability. This results in thermoset resins with high mechanical properties and good heat and chemical resistance. On the other hand, styrene shows low environmental sustainability, together with health and safety issues as it is hazardous, flammable and volatile. Chapter 6 of this book is dedicated to the work held during FiberEUse project on the development of new styrene-free liquid resins for composite reformulation.

Resizing and reprocessing. In the production of composite products, a fundamental role is played by the interface between the matrix and the reinforcement. If its quality is too low, this results in bad adhesion between the fibers and the matrix, and, as a consequence, in low mechanical properties. To create a good interface, a surface treatment is performed on the fibers, called sizing. During recycling processes (in particular thermal and chemical ones), the original sizing is removed. For this reason, a new surface treatment is needed, called resizing. Chapter 7 of this book presents the developed resizing processes and the results obtained substituting virgin fibers in compounding of automotive products.

Additive manufacturing with customized 3D-printing machinery and software. In the last years, additive manufacturing technologies, or 3D-printing, show a rapidly growth for a variety of reasons, in particular for the easiness in personalization of production with active involvement of end-users in the co-design of the final product and the possibility to realize complex geometries, unattainable through conventional manufacturing techniques. Many of those appealing features are typical of open, low cost 3D-printers which are fed by thermoplastic filaments like in the case of FDM machines. These printers must be modified in order to allow a correct composite reprocessing. In particular, both discontinuous fibers and grinded recyclates have to be correctly reprocessed, including thermosets composites. Chapter 8 is dedicated to the solutions developed during FiberEUse project on the additive remanufacturing of recycled composites.

Environmental friendly surface finishing for aesthetic and functional performance enhancement. Enhancing the performances of remanufactured or repaired goods through suitable surface treatments and coatings is a mandatory step to increase the perceived quality of the product. Surface enhancement can occur through the application of both organic and inorganic environmental friendly coatings. Composites suffer from poor erosion and temperature resistance, which partially limit their use in metal part replacement. Metallization can minimize wear or degradation. Surface properties can be improved by metallization through environmental friendly magnetron sputtering physical vapor deposition (PVD) and thermal spraying. Chapter 9 is dedicated to the presentation of the results obtained during FiberEUse project in composite finishing for reuse.

Development and automation of laser assisted cutting and repair technologies for CFRP component reuse. Currently, the repair of fiber reinforced structures is a difficult and time consuming process. In many cases the damaged part is ground manually in order to prepare the resulting cavity to be refilled with a patch of new plies. This repair preparation procedure requires experienced and highly qualified workers and it is not easy to generalize. Furthermore, the manual grinding process results in an accelerated tool wear and a costly replacement. Replacing the manual grinding process with an automated laser cutting process has the potential advantage to precisely cut the composite structure by locally focusing a small laser spot on the area to be removed. In addition, non-destructive techniques can be used to inspect parts and components before and after repair. Chapter 10 is dedicated to the work done in FiberEUse project on composite repair and remanufacturing, based on both traditional and innovative solutions.

Design guidelines. Design plays a fundamental role in circular economy. As an example, it can hinder the disassembly of some components. As a result, a destructive disassembly has to be performed, preventing the reuse of a part or component. This is relevant in particular in sectors as automotive, in which the End-of-Life parts still have a high added value. For this reason, it is important to design new products avoiding fixing systems as glue or rivets, in favour of solutions that can facilitate their second life. On the other hand, to increase customer acceptance of products manufactured with recycled material, a solution can be the involvement of final users since the design phase following a co-design approach. Chapters 11 and 12 of this book will concentrate on these two design opportunities, both for co-design of creative products embedding recycled fibers and on an innovative modular car design concept for reuse. In addition, Chapter 13 will give hints on product redesign through specific guidelines.

ICT solutions. Even if all the previous technologies will be implemented and adopted by different companies, one of the most critical issue can be the communication between them. Currently, there is not a robust value-chain to rely on to implement circular economy in composites sector. To overcome this issue, an ICT tool has to be developed to connect all the actors along the value-chain, from the wind blades producers to the final manufacturers embedding recycled material in their products. Chapter 14 presents the digital cloud-based platform developed during FiberEUse project for the value-chain integration.

5 The FiberEUse Non-technological Pillars

The FiberEUse cross-cutting innovation has been achieved through the scalable and replicable development of the aforementioned technologies, compounded by the following set of non-technological innovation actions.

Scouting new markets for recycled material. The research included the identification and documentation of the properties and market value of the GF and CF recyclates in an accessible user-friendly manner, as well as current legislative barriers and propositions on potential supporting legislative incentives to enable (i) enhanced decision making on EoL scenarios of recyclates (ii) symbiosis between sectors such as energy, building, automotive, and aircraft. A series of physical and virtual tools for a further stimulation of potential end-user have been developed, namely through the realization of a physical and virtual product and material library, and through the management of data in a user-friendly, cloud-based ICT platform.

New service-oriented business model development. New business models supporting the FiberEUse close-loop manufacturing vision have been designed, with the active involvement of end-users. The main building blocks have been identified for each target application (value proposition, revenue model, collection strategy, supply chain) and then hierarchically organized in a coherent business model.

Optimization of logistical infrastructures. Efforts have been dedicated to explore appropriate collection systems and infrastructures. Alternative scenarios for reverse logistics network design have been modelled and evaluated and optimized for each demo-case for both cost and environmental impact minimization objectives, to match their individual requirements.

Sustainable co-design with end-users. Sustainable co-design aimed at the realization of products with better usability, easier disassembly and user friendliness has been studied involving end-users and stakeholders associations. Co-design of remanufactured products involves the realization of an array of different product concepts, their prototyping and dissemination among end-users. The customer feedback collection, performed exploiting IT tools, allows a direct contact with end-users, and addresses an iterative process of product revision leading to a final wider social and market acceptance for goods derived from composite recyclates.

Dissemination, communication and training. A key barrier to overcoming the challenges resulting from fragmentation is dissemination, education and communication. Such communication offers truly disruptive potential. FiberEUse implemented robust tools to ensure effective education and training (training modules, white book, workshops) and dissemination and communication (working groups, website, social networks, workshops and seminars) across the value chain.

Vision, strategy and roadmap. Based on the outcome of the innovation system assessment and working closely with the key stakeholder platform, the FiberEUse consortium defined and agreed a common vision, strategy and roadmap for overcoming the identified cross cutting challenges, creating a framework to facilitate the take-up of the proposed solutions.

Legislation and incentives. The research efforts here included the identification of the range of legislation and instruments that would forward the composite recycling, remanufacturing and reuse industry. Examination of the current EU legislation and a consultation among the stakeholders identified the gaps, and guidelines for the alignment of regional legislations has been individuated, while a prioritization of needed actions have been outlined using robust methods.

Stakeholders engagement and eco-system building. By mobilizing key knowledge holders, facilitators, clusters, decision makers, providers, beneficiaries, etc. within a single platform, FiberEUse involved the necessary critical mass of capabilities, resources and competences to be able to support a real transition to its innovative circular value-chain.

6 Conclusions and Structure of This Book

Composite materials are widely used in several sectors, from wind energy to design. The market size of both GFRP and CFRP products, and the related amount of waste are constantly increasing. The recycling and reuse of these materials constitutes a relevant opportunity at economic, environmental and social level. FiberEUse worked in the implementation of a demand-driven, cross-sectorial approach, in which the material recycled from a sector will be re-used in another sector requiring less demanding characteristics, avoiding value losses. This approach will be the basis of the innovative concept of demand-driven circular economy, in which the End-of-Life product is treated through processes that are optimized based on specific requirements that depends on the properties of the final product embedding that recycled material, maximizing in this way the recovery of the residual value.

This book reports the results obtained during the entire FiberEUse project. Chapters 1 and 2 introduced the context, the motivations and the opportunities of implementing circular economy in composites, with a specific focus dedicated to the demand-driven cross-sectorial approach and its potentiality in GFRP and CFRP sector. Following this introduction, several topics of scientific and industrial relevance, able to allow a robust circular economy in composites, are described in depth.

The first macro group of chapters focuses on EoL products treatment as the disassembly of large composite-rich installations (Chap. 3), smart composite mechanical demanufacturing processes to obtain particles with specific dimensions that could be reused in new products (Chap. 4), and thermal demanufacturing processes for long fibers recovery (Chap. 5).

The second part is dedicated to the reuse of the recovered particles. Chapters present composite reformulation form granulates, with a focus on innovative resins (Chap. 6), fiber re-sizing, compounding and inspection (Chap. 7), additive manufacturing of recycled composites (Chap. 8), surface finishing for reuse (Chap. 9) and composite repair and remanufacturing (Chap. 10).

Third group of chapters underlines the role of design for de- and remanufacturing in composites sector. Innovative approaches as the co-design of creative products embedding recycled fibers are explored (Chap. 11) and a new modular car design concept for reuse is shown (Chap. 12), together with products re-design guidelines (Chap. 13).

Chapter 14 is dedicated to the cloud-based platform for value-chain integration developed in FiberEUse, to connect all the different stakeholders and to facilitate the exchange of materials among them.

The objective of the next group of chapters is to present the results obtained in the three use cases of FiberEUse. As already stated, the focus is on mechanical recycling of short fibers for Use Case 1 (Chap. 15), thermal recycling of long fibers for Use Case 2 (Chap. 16) and modular car parts disassembly and remanufacturing for Use Case 3 (Chap. 17).

Chapter 18 is dedicated to the presentation of the material library systems that will facilitate the adoption of the developed solutions through a tangible-intangible interaction approach.

Next chapters show the opportunities enabled by the implementation of circular economy solutions in composite sectors. New circular business models are presented (Chap. 19), together with their economic and risk assessment (Chap. 20).

Finally, the book ends with a specific focus on the analysis policy actions to be considered and implemented in the next years to favor the industrial implementation of the FiberEUse results (Chap. 21).

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