White Paper: Business Impact of Glass Fiber Full Cycle Circular Economy & Digital Tools in Nordic Manufacturing Industries

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1. INTRODUCTION TO GLASS CIRCLE

The evidence of use of glass fibers can be traced back to ancient times. In Egypt, coarse fibers were drawn from heat-softened glass and made into vessels by winding it on a mandrel and fusing it together. However, glass fibers fine enough which one could weave were demonstrated first in 1893 by Edward Libbey. Commercial glass fibers were produced in the 1930s by the Owens-Illinois Glass Company in Newark, Ohio. They developed processes for both insulation-type (spun) and reinforcement-type (drawn) glass fibers. Nowadays, glass fiber reinforced plastics (GFRP) are high-volume commodity materials, and glass fiber consumption is by orders of magnitude greater than all other reinforcement fibers combined.

Glass fiber is typically made into fine strands by melting glass consisting of silica, alumina, calcium oxide, magnesium oxide, etc. "Glassmaking sand" is the source of silica. China clay (aluminosilicate) of low alkali content is often the source for alumina. Magnesia is introduced either with dolomite, an equimolar magnesium/calcium carbonate, or with burnt dolomite, the corresponding mixed oxide, which is less of a pollution problem. Calcium oxide comes from limestone. Boric oxide is introduced either with colemanite (calcium borate) or boric acid (hydrous boric oxide).

The glass is melted and then extruded through fine holes to create thin filaments. These filaments are combined into bundles which can then be woven into various types of fabrics. The bundles may consist of different number of single filaments, typically thousands of fibers are bundled together. Depending on number of fibers in the bundle (e.g., 6000, 12000, 24000, 48000) the bundle is given specification 6k, 12k, 24k or 48k. These bundles then can be assembled in various fabrics, unidirectional, woven (e.g. plain weave, twill, satin, etc.), multi-axial non-crimp, or randomly oriented fabrics.

In general, glass fibers are known for their high tensile strength, resistance to heat and corrosion, and non-conductive properties. This makes a demand for glass fibers in various industries, including construction, automotive, aerospace, marine, energy, and electronics. Not only high mechanical performance is of use in different load-carrying applications, but also multi-functionality use of these fibers is widely utilized.

Depending on the composition, various grades of glass fibers are produced: A-, C-, D-, E-, R- and S- glass fibers. These different grades may be used for different applications depending on requirements of service conditions. For example, S-glass possess high strength, modulus and durability under conditions of extreme temperature of corrosive environments; R-glass exhibits higher strength and temperature resistance; C-glass has superior chemical resistance. E-glass is the least expensive and most used fiber in applications where good mechanical performance and electrical resistance (insulation) are required.

Currently there are large amount of glass fiber composites which have reached end-of-life as well as a great volume of discarded glass fibers that need to be somehow recycled. Unfortunately recycling glass fibers and their products may be rather challenging. One should consider the following factors:

- In composites, glass fibers are embedded in a polymer matrix and the recovery of fibers (especially from thermoset polymers) is difficult and is energy-intensive and may require use of harmful chemicals.

- Due to the harsh conditions during the recycling process, glass fibers can suffer significant degradation of properties, which makes them unsuitable for high-performance applications.

- Since glass fibers are rather inexpensive, the cost of recycling glass fibers may exceed the cost of new fibers (since recycling is energy demanding process).

- Because recycled fibers may possess lower performance characteristics compared to new fibers, the demand for such materials is rather limited and it discourages the recycling efforts;

- The recycling of glass fibers may cause environmental and health concerns, since it may release fine glass dust, generate additional residual waste, and may produce more greenhouse gases.

Because of the abovementioned reasons, the recycling rates for glass fibers are rather low. As a result, most often, end-of-life glass fiber products are downcycled into low value materials or sent to landfills.

2. Types of glass fiber products & why it is hard to recycle

There are different types of glass fiber waste generated in the glass fiber industry. It has been estimated that around 10-20% of the material used or produced within the glass fiber industry is sent to the landfill. Within the glass fiber manufacturing process, there are several types of residues generated. Firstly, there is the shard type of residue. This type is usually generated when there are suboptimal manufacturing conditions (e.g., temperature). This type of residue cannot be directly used without additional manufacturing steps (e.g., melting or grinding). Then there are fibers and their bundles that do not pass the quality test and have oiling added to them, which are often long fibers in wet or dry conditions. Most often, the residues of GF are in piles and thus very difficult to use as a long-fiber material. The last type of residue is different cut-off of the glass fiber products – nets, fabrics, etc. These are the ends that are cut-off to obtain standardized sizes of these materials.

Unfortunately, most of the residues have different oiling chemicals on the fibers. When burned, these chemicals create a very acidic environment that is damaging the glass melting ovens and thus all of the residue cannot be used as a raw material for glass fiber manufacturing. One of the directions the consortium sees for future research is to study possible removal methods of these chemicals. In this way, all the fibers could be directly reused in the factory. In some cases, it is possible to reuse some of the residue to create other products. For example, fibers can be chopped down to create short fiber mats – however it has been noticed that this process cannot be repeated on the same mats more than few times. The cutting process shortens fibers, thus if applied several times, the fiber length is too short to form fiber mats. In addition, not all residues can be used for every product since different chemicals are used for different products.

Within the companies that use different glass fiber products that are assembled in fabrics, mats, or tapes, most of the residue comes from the cut-offs. Often the standardized size produced by the companies is too large to fit the manufactured product. These ends are often cut-off and thrown away. In many cases, these are very large parts. During the project, we found that some of the residue cut-off pieces can be up to 0.8x2m in size. Often these materials are of high quality and can be used directly without any additional manufacturing steps. For many applications, it would be enough to use very small pieces. Thus, within the project, we are trying to create a database where companies that have such residue can connect with the companies that could use this material. However, one of the main challenges we faced is the companies' uninterest to deal with small amounts. Thus, we see a potential for a company to collect this residue in larger quantities and resell them to other companies that do not require large size glass fibers. Another opportunity we see is for policy makers. Often, companies are not interested in finding solutions for this residue since it is cheaper to bury them in landfill. In countries where waste management is more taxed (e.g. Scandinavia), the companies are more open-minded to different solutions for glass fiber waste.

3. Introduction to business circularity in glass fiber and focus cases

The following section is defining what circularity in glass fiber business means for the project. To do this, several case studies were applied by utilizing master's students in the BTECH department at Aarhus Universityby working on qualitative and quantitative cases from relevant industries in Nordic/Baltic countries as part of Technological Business Model Innovation and Digital Front End Solutions courses. Three cases studies will be highlighted in this report and anonymized at appropriate level to avoid conflict of interest and GDPR.

Case Study 1 - Circular Economy Business Models Regarding Recycling of Glass Fiber Recycling and Reuse Company

The enterprise in this case study is suppling chopped fibers to Tier One suppliers and OEMs. The enterprise employs reverse logistics vital for the glass fiber circular economy in large scale. Reverse logistics (RL) is defined as "the process of planning, implementing and controlling backward flows of raw materials, in process inventory, packaging, and finished goods from a manufacturing, distribution, or use point to a point of recovery or point of proper disposal" and primarily concerns the recycling of materials and products (De Brito & Dekker, 2004, p. 3);(Fleischmann et al., 1997). However, some authors also include remanufacturing and refurbishing (K. Kim, Song, Kim, & Jeong, 2006);(Ravi, Shankara, & Tiwarib, 2005). Since RL deals with return management, including the return of products to manufacturers due to damage, profitability is an important part of the concept. Return management is closely related to customer retention, so to ensure a stable customer base, it is important to implement a good RL strategy. Online retailers in particular use this topic as a key driver for success (Daugherty, Myers, & Richey, 2002).

This case study took the linear economic model of “take-make-use-dispose" and aimed to replace it with a “borrow-use-replenish" model. By applying a circular economy model to a business, that business would be able to achieve social well-being and environmental protection. CE is distinguished from the linear economic model because it seeks to reduce the over-consumption of raw materials. The goal of the concept CE is to decrease waste to a minimum by reusing materials but also to keep the materials within the economy for as long as possible (Brears, 2018);(Larsson, 2018);(Geissdoefer, Savaget, Bocken, & Hultink, 2017). Other goals of CE is to use sustainable and renewable energy sources, reduce greenhouse gas emissions, and avoid the use of hazardous substances and non-renewable materials (Larsson, 2018);(Geissdoefer et al., 2017). The concept of CE also seeks to separate the economic growth from resource use and environmental impact (Brears, 2018);(Geissdoefer et al., 2017) and embraces more than waste prevention and waste reduction, as it also inspires social, organizational, and technological innovation both within and across value chains (van Eijk, 2015).

By incorporating the design of products and processes, as well as assessing the impact of the resources used, waste can be eliminated from all phases of the life cycle (Brears, 2018);(van Eijk, 2015). This means that CE is used as a driving force for innovation in both new and existing business models, which enables growth in existing markets but also generates opportunities to create new ones. There is an increasing pressure on organizations to develop sustainable business models, but also to take an active part in sustainability-oriented innovations (Bocken, Rana, & Short, 2015). These innovations must contain incremental changes to ensure the greatest and most valuable impact (Bocken et al., 2015);(Antikainen & Valkokari, 2016).

The aim of new circular and sustainable business models is not only to create economic value, but also solutions that create value for both the environment and society

(Antikainen & Valkokari, 2016). Although the increased attention on CE is still a vision (Larsson, 2018), CE creates an opportunity for creativity and innovation so the circular development can continue and the pilot-projects can grow within organizational structures, financing solutions, and business models (Larsson, 2018). In the future, circular supply chains must accommodate highly specialized companies who both can make products and services which can compete with those already provided by the global linear economy (Larsson, 2018). Therefore, innovation in many areas is a necessity to accelerate the transition to CE as well as society (Larsson, 2018). Circularity can be implemented at several different levels, including micro (single business or consumer), meso (eco-industrial parks and industrial symbiosis), and macro (city, regions or nations) (Ghisellini, Cialani, & Ulgiati, 2016);(Lieder & Rashid, 2016). A full transition to CE, however, requires the entire social system to follow and transform from linear to circular (Larsson, 2018);(van Eijk, 2015);(Ghisellini et al., 2016);(Lieder & Rashid, 2016).
To summarize the strengths of circular economy versus linear economy, the general competitive advantage of reverse material flow, including reduction of material costs and less resource dependence is very beneficial. Furthermore, the circularity contributes to the development of higher quality and more durable components. Due to the closed circuit, the economy is less exposed to fluctuations in material prices, which result in a more efficient use of resources. (Sariatli, 2017). Looking further into the weaknesses, which in this analysis consist of seven points, the circular economy still suffers from no specific guidelines and no internationally recognized standards. In general, there is a lack of legal regulation of the circular economy and its application. The circular economy also requires the company to deal with the entire product life cycle from raw material supply to disposal, which may require new investments. (Sariatli, 2017).

Case Study 2 - The study aims to discover how to enhance a company's current value proposition which has activities with residual glass fiber from manufacturing processes.

The aim of case study 2 analyzed a global leader in designing, manufacturing, and delivering composite components for the wind industry. The company's core products are different types of housing for wind industry equipment. Case Study 2's company has six different manufacturing and assembly facilities and employs over 1,000 employees worldwide. The production and assembly facilities are located in Denmark, Lithuania, Poland, USA, and China.

Glass fiber, known for its strength and low weight, is widely used in various industries. However, its recycling process is complex, resulting in most glass fiber waste in landfills. Glass fiber cannot be incinerated and can burn off a plastic matrix, but the glass fiber itself will be a melted lump or slurry and remain as ash. Waste incineration power plants do not want composite waste because of the glass that will clog and disturb the air flow in the incineration plant and create a lot of ash. The purpose of case study 2 is to develop a sustainable CE business model for a manufacturing company within the wind industry, where the high value of its glass fiber reinforced polymer (GFRP) waste is seen as a business opportunity. Through a comparison of available GFRP recycling processes, the solvolysis process enabling the reuse of both glass fiber and resin was found preferable.

It is suggested that the company acquires the new technology through cooperation (to minimize risk) with other players in the glass fiber industry and uses it to address the waste issues and enhance its value proposition on three factors. First, Case Study 2 Company can recycle GFRP end-of-life products, the recycled scrap GFRP can be seen as a contribution to society in the dimension of corporate social responsibility. Second, a service is offered to recycle customers' end-of-life products and waste, which can attract new customers. Third, the recycled materials can be sold to new customers in a new market. However, as a part of the validation plan, the solvolysis recycling process must first be validated and proven economically viable by researchers. Further, potential customers for the recycled materials must be identified and investors must be found before Case Study 2 Company invests in such a project.

Case study 3 - Investigate dry glass recycling in wind turbine blade manufacturing.

Glass fiber is a crucial element of modern GFRP composite parts and is widely utilized in a variety of engineering applications, including the wind and aerospace industries. Fiber glass has also found its use in construction, where it is incorporated into a concrete matrix as reinforcing fibers. Glass fiber usage is rising, which means there is a growing need to minimize its environmental impact and dispose of waste in a sustainable way. Information and essential components about glass fiber consumption, waste disposal, and life cycle assessment (LCA) are gathered for this study through interviews conducted at a Nordic wind turbine blade manufacturer. The purpose of this study is to identify the amount of glass fiber used in the production of blades and to offer a substitute method for dealing with glass fiber waste. This will serve as a model for other glass fiber users to follow to cut down on glass fiber waste and recycle already existing materials. The enterprise of case study 3 works on R&D circular actions focusing on the most technologically mature and cost-effective processes: mechanical shredding, cement co-processing, and pyrolysis. During the project, one of the key challenges mentioned by the interviewees on sustainability projects were challenges in obtaining relevant information from waste handlers. Transportation of glass waste is found to be a significant cost associated with glass recycling. This hinders the extent to which glass waste can be recycled. Therefore, it is vital that the businesses are situated near one another geographically as the transportation process may have a significant environmental impact (Kristensen, 2023). Further investigation can be employed to highlight whether circularity, sustainable design, or a combination of several sustainable initiatives, is the most optimal solution.
The case study 3 enterprise is manufacturing composite products, and it aims to serve as a model for other glass fiber consumers to seek inspiration for similar initiatives, ensuring reduced waste and increased glass fiber recycling. Collaboration between stakeholders, policymakers, and research institutions is crucial for success. Lessons learned can be applied beyond wind energy to industries like automotive manufacturing and infrastructure development, enhancing sustainability across sectors. Optimizing glass fiber usage and waste management not only addresses environmental concerns but also offers economic benefits. By reducing raw material consumption and minimizing disposal costs, companies can improve profitability while enhancing their corporate social responsibility. Innovations in glass fiber recycling present opportunities for new revenue streams and a circular economy. Transforming waste into valuable

resources contributes to a more sustainable future and taps into emerging markets for sustainable materials.

Case study 4 – Shorting of residual glass fiber in production lines

Podcomp is a composite manufacturing company and partner in GlassCircle project. The main product is modular bathrooms for use in factory-built apartments. The service life expectancy of the bathroom is ~100 years, thus end of life products are not the main concern for Podcomp. However, in everyday production, glass fiber and glass fiber composite sandwich panels of various dimensions are continuously generated. The largest number of composite cutoffs is from the doorblade; each bathroom has ceiling, floor, four walls and a door opening. The four walls and the door opening (doorblade) are cut out from a large sandwich panel ~10x2.5m and the doorblade was previously scrapped and sent to landfill. 2,300 bathrooms can be produced annually, thus large volumes of doorblades are generated. In similar ways, other glass fiber and composites sandwich cut-offs are generated. Every week, hundreds of kilos of cut-offs must be addressed, and this presents a significant challenge for a company that strives to be sustainable both economically and environmentally.

During the GlassCircle, project Podcomp has been quite active trying to find solutions for this production waste. Several ideas for development of products in-house were generated and some prototypes were built, including storage, shelves, benches, flowerpots, ladders, and bathroom basin are some examples. This changed the way Podcomp treats the doorblade scraps; instead of sending 5-10 doorblades of $2m^2$ and 26 kg each to a landfill every day, cut-offs are now sorted and stored. Thus, when any of the beforementioned products are ordered or when new ideas are generated, the material is available to enable a close loop in material handling, promoting the principles of circular economy.

Figure 1. Left image represents the old handling of glass fiber composite panel scraps. The right image represents current sorted stacks of doorblades ready for use and easily accessible for lifting inside when needed.

One of the prototypes, the bathroom basin, used glass fiber cut-offs. This product has not been further developed yet. Even though the prototype was nice, the tooling cost would be quite significant and the customers would have to be convinced to switch from porcelain to glass fiber composite which would require lots of testing and convincing.

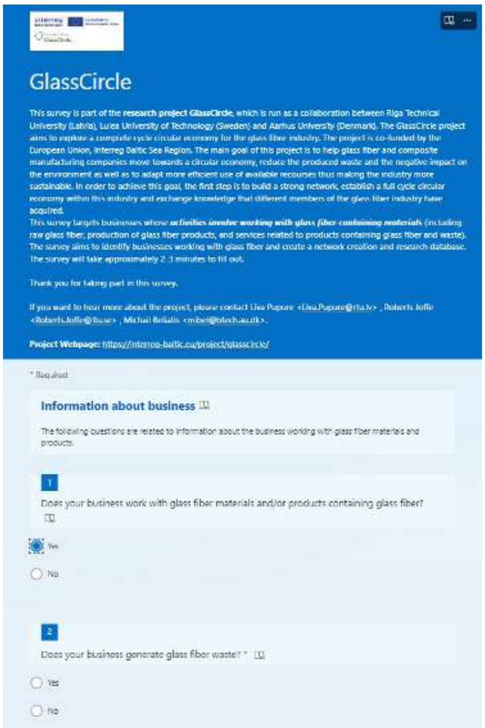
Figure 2. Two types of glass fiber cut-offs; to the left mainly non-woven fabric, often several meter long and 20-40 cm wide. To the right, mainly chopped strand mat of various dimensions and shapes.

The storage of Podcomp's glass fiber cut-offs has not been solved yet but it is a work in progress. Eventually, if the right idea is generated or the right companies are connected, the glass fiber cut-offs can become Podcomp's or somebody else's new product promoting circularity in business.

4. DESIGNING GLASS CIRCLE

Structural interviews

A digital survey has being developed as entry point to digital database tool for mapping the GlassFiber Circular Economy Ecosystem in Nordic/Baltic Countries and identify successful green business cases as light-houses of circular economy among different ecosystems together with bottlenecks in horizontal and vertical applications.



GlassCircle

This survey is part of the **research project GlassCircle**, which is run as a collaboration between Riga Technical University (Latvia), Lulea University of Technology (Sweden) and Aarhus University (Denmark). The GlassCircle project aims to explore a complete cycle circular economy for the glass fibre industry. The project is co-funded by the European Union, Interreg Baltic Sea Region. The main goal of this project is to help glass fiber and composite manufacturing companies move towards a circular economy, reduce the produced waste and the negative impact on the environment as well as to adapt more efficient use of available recourses thus making the industry more sustainable. In order to achieve this goal, the first step is to build a strong network, establish a full cycle circular economy within this industry and exchange knowledge that different members of the glass fiber industry have acquired.
This survey targets businesses whose ***activities involve working with glass fiber containing materials*** (including raw glass fiber, production of glass fiber products, and services related to products containing glass fiber and waste). The survey aims to identify businesses working with glass fiber and create a network creation and research database. The survey will take approximately 2-3 minutes to fill out.

Thank you for taking part in this survey.

If you want to hear more about the project, please contact Liva Pupure <Liva.Pupure@rtu.lv> , Roberts Joffe <Roberts.Joffe@ltu.se> , Michail Beliatis <mibel@btech.au.dk>.

Project Webpage: https://interreg-baltic.eu/project/glasscircle/

* Required

Information about business

The following questions are related to information about the business working with glass fiber materials and products.

1

Does your business work with glass fiber materials and/or products containing glass fiber?

- (•) Yes
- ( ) No

2

Does your business generate glass fiber waste? *

- ( ) Yes
- ( ) No

Figure 3 Digital form of survey and automatic entry to database

The entries from digital survey form are exported to PowerBi data analytics for further analysis and adding capabilities of category per circular economy sector as well as interactive search on a digital map. These enable every interested third party to search and find relevant stakeholders in the glass fiber ecosystem. The PowerBi interactive database is accessible at Interreg BSR website here:
https://interreg-baltic.eu/project/glasscircle/#output-0

Business value chain and ecosystem mapping all companies involved are accessible in the "Interactive Database"

The PowerBi interactive database maps key players for glass fiber within the glass fibers life cycle (manufacturers, users, re-users, recyclers, etc.) within the Baltic Sea region and creates a value circular network mapping to foster best practices & connections between glass fiber residue donors with possible receptors for boosting circular use of fiberglass.

The PowerBi interactive database as shown below is offered with instructions on how to download it and use it from Interreg BSR website.

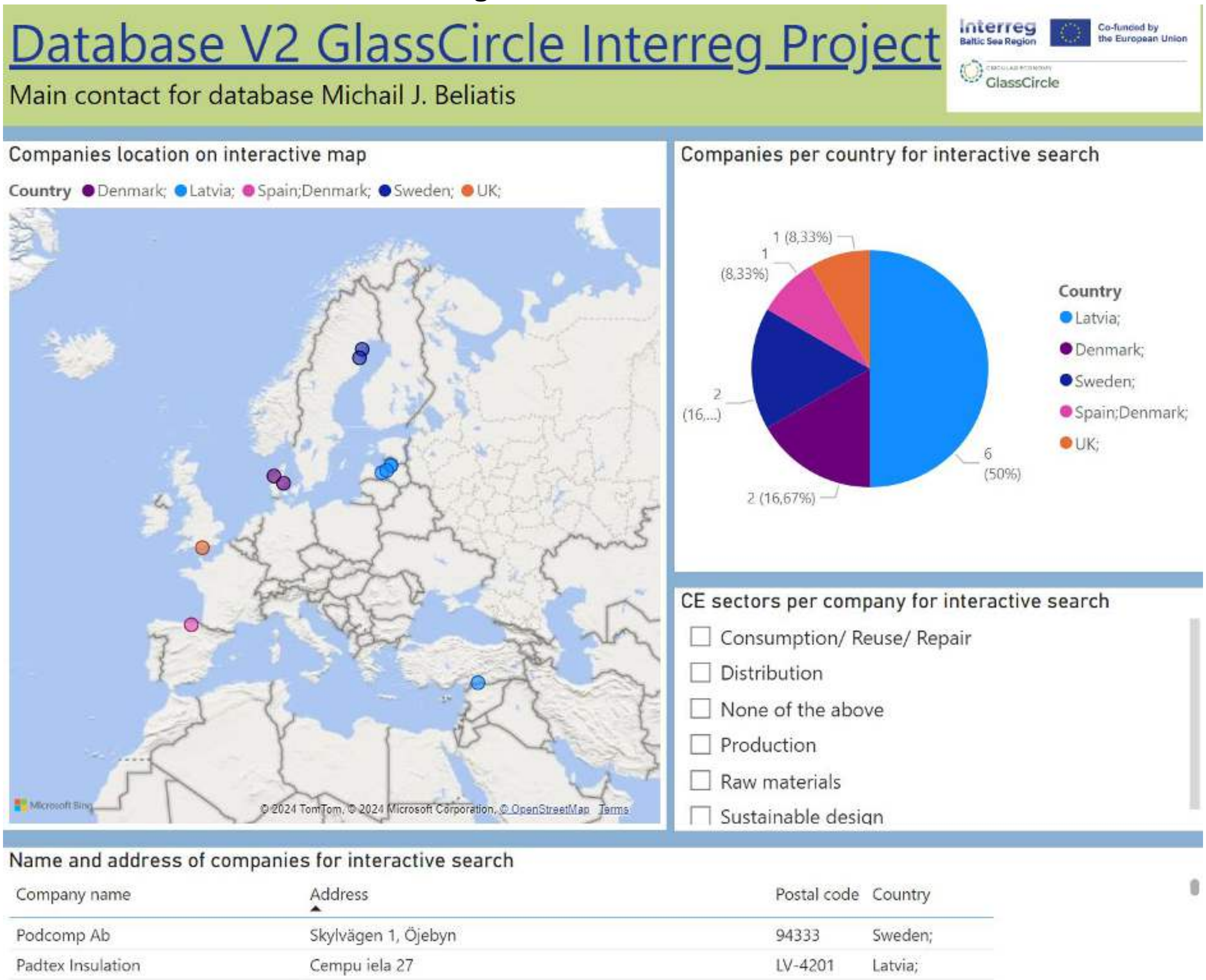


Figure 4 An overview of the interactive database

5. Project Timeline and Activities

The Glasscircle project spaned two years included several activities targeting different groups in society. A brief timeline with the activities and the outcomes are displayed below.

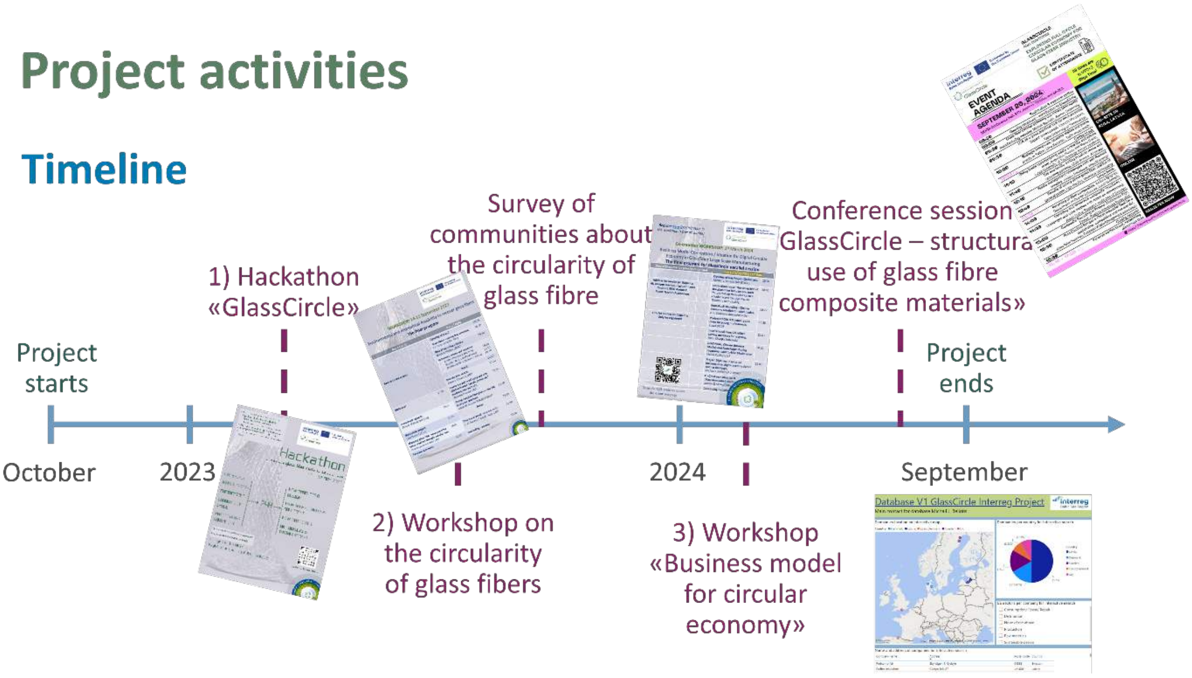


Figure 5 An overview of project timeline and the activities which took part

Activity 1 Hackathon activity

The aim of the GlassCircle hackathon event was to gain attention of students (young specialists) and tell the growing need to apply a circular economy approach in the production of advanced goods. Particularly, to avoid direct arrival to the landfill as an industrial waste of residue glass fiber material created by composite material or glass fiber production industry. Instead, use this material for some new applications. By the definition of a hackathon – there were a lot of materials, tools, prototyping equipment, laboratory space available and limited time (24 hours) given to the students to work on their ideas. The hackathon was organized as a hybrid event simultaneously happening at three places – Riga Technical University, Aarhus University, and Luleå University of Technology. Communication between all participants was organized by means of the Zoom application. Teams comprised of international and interdisciplinary members. Teams were supported and guided by mentors at three checkpoints. In total five international teams worked and presented their ideas. Team 2 from Sweden worked on the idea “Interior design or furniture elements with specific requirements” and was evaluated as the best-presented idea at the hackathon. Team 4 from Denmark worked on the idea “Housing for different IoT and Remote control toys” were evaluated as the second best, and the third best team evaluated was Team 3 from Latvia working on the idea “Glass fiber textile as formwork for concrete”.

Figure 6 Some of the winning teams/ ideas during first Hackathon

Activity 2 Environmental and economic feasibility to recover glass fibers

The aim of this workshop activity was to address issues of recycling and recovery of glass fibers (GF). It consisted of presentations from composite and LCA analysis experts showing success stories of recycling/recovery of glass fibers, followed by a discussion panel with representation from academia and relevant industries to engage industry academics together with everyone who is interested in circular economy for glass fiber production. During the workshop, participating companies had the possibility to describe their needs in terms of recycling/recovery of GF and have opportunity for networking with experts from academia. The workshop was hybrid, taking place at Aarhus University Herning as parallel activity to the local Maker Festival, allowing the project toreach more local companies. The activity supplemented with a mini hackathon for visiting students at Maker Festival a Aarhus University Herning.

Figure 7 some feedback form participants at workshop and the mini hackathon at maker festival in AU BTECH

Activity 3 Business Model Co-creation / Ideation for Digital Circular Economy in GlassFiber Large Scale Manufacturing

The aim of this workshop activity was to present and work on how to create new business models for recycling and recovery of glass fibers (GF). It consisted of inspirational presentations from industry and public sector experts showing success stories of ecosystems on recycling/reuse, new business from models from wind industry, and LCA of glass fibers followed by a co-creation activity and discussions with the participants. The workshop activity targeted everyone who is concerned about the increasing amount of waste from manufacturing glass fibers. However, local SME industries producing GF and composites benefited the most. The workshop was held in hybrid format online and on-site at Aarhus University Navitas. The workshop was organized as parallel session within Circular Economy for Enterprises event organized by Aarhus University to reach wider audience. The format of the workshop was made in such a way that it can be used as inspiration tool for companies who what to engage in circular economy activities. It started with inspirational presentations/discussions as knowledge lighthouse followed by co-creation of new business models for GF residue by-products from the point of sustainability and circular economy towards achieving net-zero. Below are the developed templates for the business co-creation workshop.

***Figure 8** The developed templates for the business co-creation workshop.*

During the workshop, participants had the possibility to describe and digitally share ideas for further discussion their needs in terms of new business for recycling/recovery of GF in the developed templates. The participants had the opportunity for further networking with experts in new business innovation modeling and circular economy for glass fiber composites.

Figure 9 Some of the feedback and business models from participants at co-creation workshop

6. Identified main challenges and lessons learned

During the project, several interviews with companies took place as well as surveys and workshops, and through these activities, several main challenges were identified.

-Optimized and cost-effective supply chain of glass fiber material for recycling/repurposing entities. The supply chain of "residual/scrap" glass fiber material needs to be optimized to enable continues operations. The fluctuating cost for logistics transportation can be a substantial bottleneck to closing the loop of value network for supplier/customer ecosystem to enable circular economy in GF.

Figure 10 The loop of value chain network for supplier/customer ecosystem to enable circular economy in GF

-Shorting of residual/scrap/waste glass fiber material at different stages in the full value chain (see figure below) to remove “contaminated” material to meet the secondary life customer requirements for their products. Such operations in the production stage can be resource challenging hindering CE business processes.

Figure 11 the full value chain of GF from raw material to product recycling. (Source of image: EIT RawMaterial accessed 09/04/2024)

Full elimination of waste is wanted, but if "waste" of some sort is created, it should be a value-produced resource (Lovins, 2008). This implies that companies need to implement collection and recovery procedures within the supply chain, which highlights the strong linkage to the research stream of reverse logistics (Geisendorf & Pietrulla, 2018). C2C also suggests using both renewable material and energy, which embraces the ideal diversity from natural systems. Digital tools such as AI, Machine Vision, and robotics together with a good strategy for handling the residual/scrap/waste glass fiber material within GF ecosystems can be very beneficial if the cost/benefit analysis can positively justify their use.

- Access to new cost-efficient recycling techniques at industrial level, such as solvolysis and dissolvable resins, to fully recover the raw GF material with minimal damage in the mechanical properties as well as to easy assessment tools for high level value map stream (VMS) and LCA, can be seen as challenges to further promote circular economy in real business context. Processes such as solvolysis are still in lab level and LCA is limited to consultancy experts who have the know-how and access to relatively expensive software tools.

7. Elements of policy – Vision forward

The benefits and opportunities of circular economy may seem obvious, but there are still some challenges. A circular economy involves, among other things, waste management, reusable resources, profitable organizations, and a more sustainable environment (Sariatli, 2017).

The DIRECTIVE 2008/98/EC of the European Parliament differs between reuse and prepare for reuse, where reuse is defined as reusing components for the same purpose as they were intended for. Prepare for reuse in contrast requires the material or product to be checked, cleaned, or repaired before it can be reused for the same purpose or another purpose (Gharfalkar, Court, Campbell, Zulfiqur, & Hillier, 2015).

There are several examples for the category prepare for reuse such as using end-of-life wind turbine blades as bicycle shelters, playgrounds, or pedestrian bridges (Lozanova, 2022).

Data collection using digital technologies like interactive visual databases, industrial dataspaces, and digital product passports can help to understand the geographic locations of companies generating glass fiber waste and can bring a paradigm shift to the way the industry operates. This data collection on site can also define transparency in industries and can attract new investment proposals, or companies can use such information for data driven business intelligence to expand their operation to have strategically placed recycling/reuse facilities.

Furthermore, a new setup with a solvolysis process on industrial level could be tested in areas where a high density of such waste generation exists to recycle/reuse waste and give Nordic/Baltic companies know-how and competitive advantage in the global business operations.

8. Quick guide for circular business transition (a playbook from Aarhus University, BTECH)

To help companies in the process of shifting focus from linear thinking to circular thinking, we suggest an empirical roadmap of five consequent steps as illustrated in the diagram below followed by iterations for achieving continues improvement and agility.

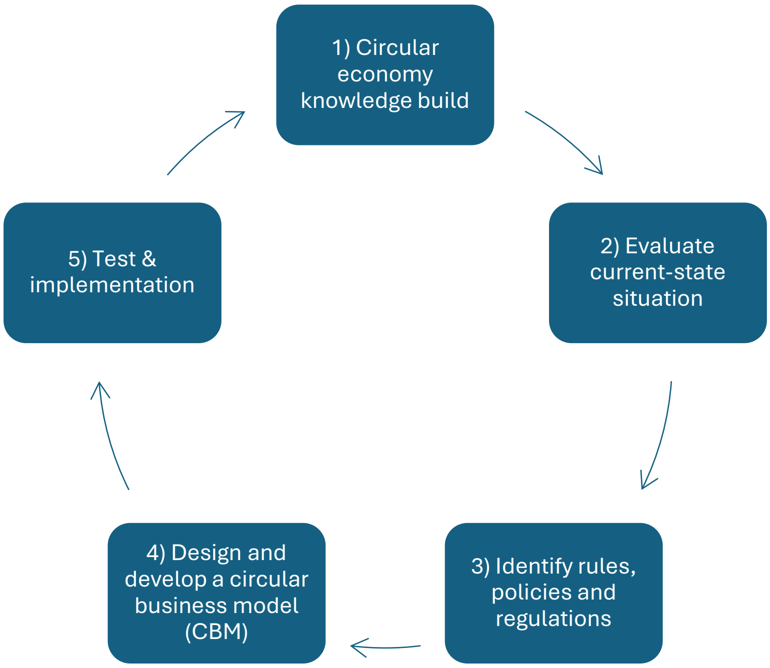


Figure 12 The proposed five steps roadmap for moving towards circular economy

Step 1 Circular economy knowledge build:

First step in the suggested roadmap comprises gathering information and be familiarized about circular economy and understanding the core principle. The core principle of circular economy can be summarized in the 3Rs - reduce, reuse, and recycle. These represent three different options when a company want to introduce circular economy. Reduce represents the endeavor of eco-efficiency in production and consumption. Reuse implies for better product design and business models for cyclical disassembly and reuse sequence. Recycle represents any recovery operation by which materials are reprocessed into products. Nine different CE concepts are presented in this paper, including: 1. Cradle to cradle, 2. Blue economy, 3. Regenerative design, 4. Closed supply chains, 5. Natural capitalism, 6. Industrial ecology, 7. Performance economy, 8. Biomimicry, 9. Reverse logistics Common to all of these concepts are the overall goal for closing the loop.

Step 2 Evaluate current-state situation:

The current-state analysis should be used to analyze the as-is situation. It is a management method to identify and evaluate a company's process and workflows. As-is processes help to determine how the company can improve the business task - in this case - how to move from linear to circular business models. This could be examining the existing functions for e.g., eco-efficiency, sustainability, and customer product development. The purpose of the examination is to identify each process's strengths, weaknesses, opportunities, and threats.

The current state analysis could focus on either the entire organization or one specific process. This could be how to handle waste in production for example.

The as-is analysis can be conducted in three steps including research, documentation and identification. –Research, the first step, is to develop an overview of the company's current activities, goods, and services. –Documentation, the second step, demands that after conducting the research, the process needs to be documented, which is the second step in the as-is analysis. A process map can be used to get a visual overview of the process. The third step, identification, consists of the process map, which can be used to identify gaps, obstacles, or flaws, meaning that the process map should be examined before moving to a future state diagram where circularity is included.

Step 3 Identify rules and policy regulations at national and European level:

The third step in the roadmap is to identify rules and regulations within the area of circular economy. In 2019, an ambitious plan named The European Green Deal was created to transform the EU's economy into a fair, sustainable, and prosperous one.

In 2022, the European Commission published the EU Circular Economy Action Plan as a part of the EU Green Deal. The action plan looks at reducing the consumption of resources, reducing waste, and increasing circularity in the EU economy. The action plan makes initiative through the entire life cycle of products and targets how products are designed, promotes circular economy processes, encourages sustainable consumption, and aims to ensure preventing waste and keep the resources used within the EU economy for as long as possible. The objectives of the action plan include to make sustainable products the norm in EU, empower consumers and public buyers, focus on sectors that use most resources, and where the potential for circularity is high and ensure less waste (European Commission, 2023).

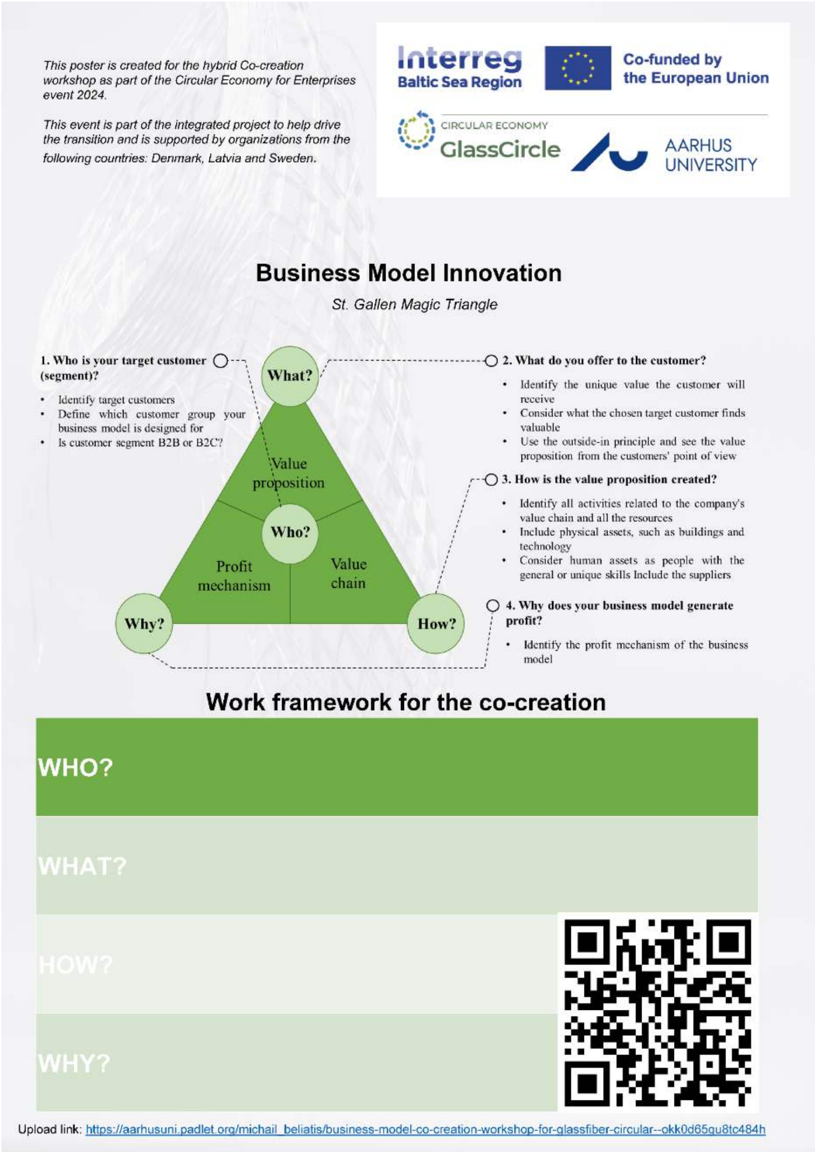
Step 4 Design and develop a circular business model (CBM):

Next step in the roadmap includes design and development of a new circular business model. Two main things need to be in focus when designing and developing the new business model, which is recycling technologies and which circular economy concept to use. Other things to keep in mind are risks associated with implementing circular economy and whether the culture is ready for this shift. Looking at the current dominant production models, the focus is still on taking, making, and disposing resources and goods, which threaten natural ecosystems. Eco-efficiency indicators can be used to identify how efficient the company makes use of the resources.

Circular economy is defined as a regenerative system, where resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. Long-lasting designs, maintenance, repair, reuse, re-manufacture, refurbish, and/or recycling help the company to achieve this. Circular economy itself may not be the goal, but rather a part of an ongoing process to reach a greater resource efficiency and effectiveness. Other useful tools to use for understanding a product life circle are Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (S-LCA), Industrial symbiosis, CE Culture in company and reverse logistics.

For the empirical part, it is suggested to start with a co-creation workshop with internal stakeholders to develop a suitable roadmap for a specific product based on the needs of company to move from linear to circular business model. The co-creation workshop could start with some presentation of inspiration CE cases and then move to mind mapping and discussions with internal stakeholders on:

a) Mapping the Value Chain Ecosystem to Identify Potential CE Opportunities (identify a customer or supplier who could use your GF residue/scrap)
b) Creating a Business Model with value proposition (what) aiming for mutual benefit filling the provided template (see below). There are many available business models our in proposed template is based on the St. Gallen magic triangle business model innovation because it is easy and quick to use.



Step 5 Test & implementation:

Last steps contain a test of whether the value delivered is the value that customers expect and will pay for. It is suggested that the new circular business model is tested in

two or three parts, depending on which focus the company has. The parts include (1) customer/- consumer satisfaction, (2) environmental impact, and (3) profitability ratio.
If the analyzed test results were found satisfying, then the implementation can begin.
If the tests are not satisfying, changes must be made in the new circular business model. When the test approves the new circular business model, the implementation can begin. The company thus must keep in mind that implementing a circular business model can involve challenges both at the employee, organizational, value chain and institutional level (Guldmann, Bocken, & Brezet, 2019).

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