Maturity of fibre-to-fibre recycling in Europe

Assessment of recycling companies in Europe

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European textile industry, recycling, recycled fibres, clothes, TRL, business model

Preface

This report is part of a series of reports in the project *Sustainable clothing futures*. The project is funded by Formas and includes four partners: IVL Swedish Environmental Research Institute, Profu, Lund University and the Swedish School of Textiles. This report has been written by IVL Swedish Environmental Research Institute and is the third deliverable in the work package *Production and recycling*. Previous deliverables in this project from IVL include a mapping of actors in sorting and recycling of textiles in Europe (Dahlbom et al. 2023) and a consequential life cycle assessment on large-scale textile recycling in Europe (Sandin et al. 2023).

The assessment in this study was conducted in the autumn of 2024. The authors have not received any financial contribution from the companies included in this study.

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Abstract

This study aims to assess the maturity of a selection of existing European fibre-to-fibre recycling companies and to explore the future of post-consumer textile recycling. At present, only 1% of textiles fibres on the global market originate from recycled pre- or post-consumer textiles. Increasing textile recycling aligns with the EU strategy for sustainable and circular textiles and is necessary for creating a more sustainable textile industry. This study assessed six textile recycling companies across Europe, evaluating their level of technology readiness level (TRL), business readiness level (BRL), and customer readiness level (CRL) based on the KTH Innovation Readiness Level framework. The results indicate that mechanical recycling companies are generally more mature than chemical ones across the three parameters, with technology being the most mature and customer readiness the least. Scaling fibre-to-fibre recycling requires not just a high technical readiness level, but also a sustainable business models and strong value chain integration. A collaborative effort between large and small companies is essential to build a more sustainable textile industry that reduces virgin fibre dependence and promotes resource efficiency. Additionally, regulatory support is essential for recycling companies to scale production and compete effectively with virgin fibres.

Keywords: European textile industry, textile recycling, clothes, TRL, business model

Introduction

Today, 12.6 million tons of textile waste is generated within the European Union (EU) each year, of which 5.2 million tons are clothing and footwear. Only 22% of the discarded textiles are collected separately for reuse or recycling, the remaining 78% is generally incinerated or landfilled (European Commission, 2023). In 2023, recycled fibres accounted for 7.7% of the global fibre production. Of this, 7% originated from PET (polyethylene terephthalate) bottles, while less than 1% came from pre- and post-consumer textiles. The most common fibre types produced in 2023 were synthetic fibres[1] (67%) followed by plant fibres[2] (25%), manmade cellulosic fibres[3] (6%) and animal fibres[4] (1%) (Textile Exchange, 2024).

In 2022, the European Commission adopted the *EU Strategy for Sustainable and Circular Textiles* (EU Textile strategy) to foster resource efficiency and circularity in the textile sector. A central focus of this strategy is revising the Waste Framework Directive, introducing updated rules for managing textile waste, aiming to assure that collected textiles are primarily sorted for reuse and secondary for recycling, if not suitable for reuse (European Commission, 2022). From 2025 EU Member States will be required to implement separate textile collection systems as part of the updated Waste Framework Directive. This initiative aligns with the waste hierarchy principle, aiming to enhance textile waste management and support the transition to a circular economy in the European textile industry (European Commission, 2023).

McKinsey & Company (2022) estimated that 70% of the textile waste, reuse not included, in Europe can technically be fibre-to-fibre recycled by 2030. In order to reach the 70% recycled textiles, techniques must be improved as many textiles consist of blended fibre types (McKinsey & Company, 2022). Dahlbom et al. (2023) mapped the capacity for fibre-to-fibre recycling in Europe to 1.3 million tons by 2025. In the mapping, the number and capacity of mechanical recycling actors were greater than for chemical recycling actors; 25 actors with a total capacity of 1 million tons compared to 10 actors with a total capacity of 250 000 tons (Dahlbom, et al., 2023).

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[1] Polyester, polyamide, polypropylene, acrylics and elastane.
[2] Cotton, hemp, flax and other fibres.
[3] Viscose, acetate, lyocell, modal and cupro.
[4] Wool, silk and other fibres.

Although several technologies exist for recycling textiles based on mechanical, thermomechanical, thermochemical, chemical, or biochemical processes, a significant challenge lies in effectively processing highly heterogeneous textile waste (Loo, et al., 2023). This challenge stems from the fact that many textiles produced today are blends of two or more fibre types, each with distinct characteristics, requiring varying conditions for recycling, whether mechanically or chemically (Textile Exchange, 2024). Additionally, textiles often contain multiple rigid components such as buttons and zippers, as well as coating, prints and impurities (processing chemicals, dyes and finishes) that need to be removed before the recycling procedure (Garcia Candido, 2021). Furter, narrow prerequisites for the technologies and low supply of input material that meets the prerequisites also challenge the recycling of post-consumer textiles (Dahlbom, et al., 2023).

At present, there are no requirements for brands to incorporate recycled textile into clothing or textile products they put on the market. However, one vision in of EU Textile Strategy is that clothes and textile products placed on the EU market should, to a great extent, be made of recycled textile fibres. The strategy covers multiple actions, including setting design standards for clothes and textile products to be durable, repairable, and recyclable. The strategy covers the whole lifecycle of textile products and aim to reverse overproduction and consumption (European Parliament, 2023). Fibre-to-fibre recycling of textiles is an example of circularity in the textile sector where the EU will promote research and development of innovative technologies (European Commission, 2023). Sandin et al. (2023) concluded that there is a 92% probability that large-scale textile-to-textile recycling, in the EU, reduces climate impact. Further, the authors estimated that the average climate impact reduction per year is 1.2 million tons CO_2-eqivualents (Sandin Albertsson, et al., 2023).

Aim and research objectives

The aim of this study is to evaluate the maturity of existing fibre-to-fibre recycling companies in Europe and to explore what a future for recycling of post-consumer textiles might entail. This includes assessing fibre-to-fibre recycling companies recycling post-consumer textiles used in new clothing and textiles applications. To achieve these goals, the study has two research objectives:

1. Identify an assessment model that includes parameters to assess fibre-to-fibre recycling companies' progress in entering the textile recycling market.

2. Assess the fibre-to-fibre recycling companies using the identified assessment model and visualise the results in radar charts.

Scope

This study focuses on fibre-to-fibre recycling companies that utilise post-consumer textiles in their recycling processes, with their main operations based in Europe. Assessing the companies' impact on the nearby environment (i.e., air, water, soil) is outside of the scope, as well as their potential impacts outside of Europe. Social factors like job creation and working conditions are also outside of the scope of the study.

Theory

In this chapter, literature about the traditional linear value chain and recycling of textiles it presented. Furthermore, challenges hindering, and enablers driving the transition to recycle textiles are presented.

The linear textile value chain

The production of clothing or textile applications is complex, as it involves multiple stages to refine raw materials into a finished garment that can be used by the end consumer. This sequence is referred to as a linear value chain and is illustrated in Figure 1, and further explained below (Rahaman, et al., 2024).

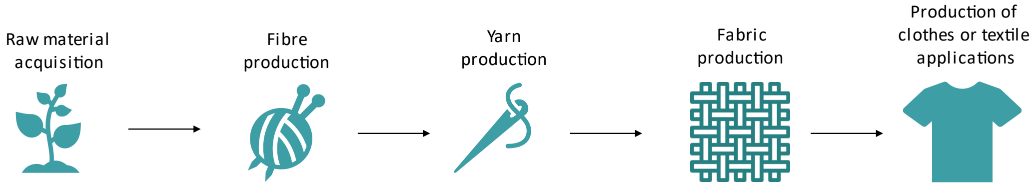

Figure 1. Simplified illustration of the linear textile value chain: from raw material extraction, followed by the production of fibre, yarn, and fabric, to manufacturing clothing or textile applications. (Illustration by the authors.)

The garment production process starts with sourcing raw materials, which can be either natural or synthetic. Depending on whether natural or synthetic raw materials are used, different cultivation and manufacturing techniques are required. Cotton and wool are examples of natural materials. Cotton is processed after harvesting to separate the fibres from the seeds, while wool is sourced from sheep or other animals and undergoes several processing steps before being converted into usable fibres (Rahaman, et al., 2024). Synthetic fibres, on the other hand, are derived from petrochemicals. In this case, raw oil is extracted, refined, and polymerised to create fibres like polyester (Abrishami, et al., 2024).

Fibre production involves processing these raw materials into fibres. For natural fibres, this process includes carding, spinning and twisting the fibres together to create a continuous thread (Lord, 2000). For synthetic fibres like polyester, the polymer is melted and extruded through a spinneret to form fibres, which are then cooled and drawn to enhance properties such as strength and elasticity (Chinan, 2008).

Yarn production involves further processing the spun fibres. This can include blending different fibres (e.g., cotton and polyester) to achieve specific properties, twisting the yarn to affect its strength, elasticity and texture, and dyeing the yarn, although dyeing can also occur later in the process (Lord, 2000).

The next step, described by Rahaman et al. (2024) is fabric production, where the yarn is used to produce fabric through weaving, knitting, or non-woven techniques. Once the fabric is produced, it undergoes finishing processes such as dyeing, printing, mechanical finishing and chemical finishing. The ready fabric is then used to produce clothes or textile applications (see Figure 1), which involves multiple steps like cutting, sewing and assembly. Throughout these stages, processes integration of components like buttons and zippers further add to the complexity of the production (Rahaman, et al., 2024).

Textile recycling

Once a textile has reached the end of its useful life and has potentially been reused, it should be recycled (Abrishami, et al., 2024). When recycled, the fibres re-enter the traditional textile value chain, creating a reversed, or circular, value chain (Hultberg, 2024; Garcia Candido, 2021). Abrishami et al. (2024) and Tripathi et al. (2024) describes that there are several types of recycling categories—upcycling, downcycling, open-loop recycling and fibre-to fibre recycling. Upcycling involves repurposing textiles into higher-quality or more valuable products, thereby enhancing the value of waste materials. Downcycling refers to breaking down textiles into products of lower value than the original product. Open-loop recycling repurposes textiles into entirely different product types, such as utilising post-consumer textiles to produce carpets or insulation or plastic bottles to polyester clothing. While open-loop recycling extends the life cycle of the materials, the resulting products are generally of lower economic and functional value compared to the original textiles. Fibre-to-fibre recycling entails breaking down textiles back into new fibres, which can then be re-spun into yarn and woven into new fabrics. This approach aims to maintain the quality and value of the original textile materials, enabling them to be used in the production of new textiles (Abrishami, et al., 2024; Tripathi, et al., 2024).

Further, Abrishami et al. (2024) and Tripathi et al. (2024) highlight that fibre-to-fibre recycling, in particular, preserves the value of textiles and provides significant environmental advantages by reducing the need for new, virgin fibres and efficently use resources. This approach also helps lower energy usage and cut carbon dioxide emissions, relative to the production of new materials. Additionally, recycling of textiles is a more sustainable practice compared to incineration or landfilling, which can have harmful environmental impacts (Abrishami, et al., 2024; Tripathi, et al., 2024).

Garcia Candido (2021) has divided the recycling process in five steps: firstly, the textiles are collected and secondly, sorted. In the sorting process, textiles are categorised by factors such as garment type, colour, material and potential for reuse. Reusable textiles will be further sorted into more detailed categories and sold in shops or to other actors. The non-reusable textile can also be further sorted, often in colours and fibre types. After the sorting, textiles for recycling are disassembled (for example, buttons and zippers are removed), shredded or dissolved. The fourth step in the fibre-to-fibre recycling procedure which is where the shredded or dissolved fibres are made into new textile fibres. The fifth and last step in the textile recycling process involves integrating the recycled fibres into the traditional value chain, creating a reverse value chain (see Figure 2) (Garcia Candido, 2021).

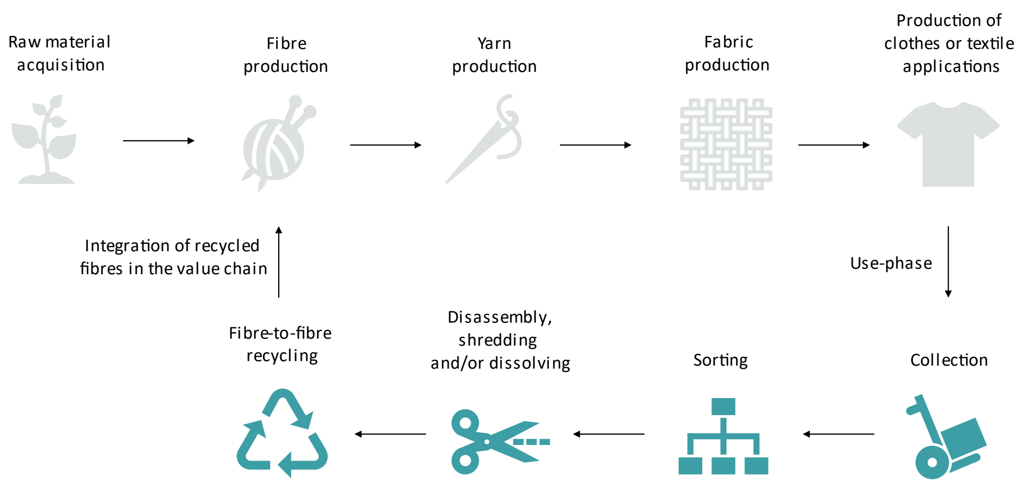

Figure 2. Illustration of a reversed textile value chain (in colour below): collection of textiles, sorting, disassembly, shredding or dissolving, recycling and finally integration into the textile value chain (in grey above). (Illustration by the authors.)

Input material for textile recycling

Textile waste that is used as input material in the recycling process typically falls into three categories: pre-consumer, post-consumer and industrial waste according to Abrishami et al. (2024). The ease of recycling depends on the complexity of the waste, such as the material blend and the level of contamination. Pre-consumer textiles include by-products and production scrap generated from manufacturing processes of natural, synthetic, or blended fibres into yarns, fabrics, and finished products such as garments, footwear, interior textiles, or technical textiles. Pre-consumer is generally easier to recycle than post-consumer textiles since it is more homogeneous and contains fewer unknown contaminants. Further, unsold stock and returns from both offline and online sales are often classified as pre-consumer waste. Post-consumer textiles include textiles or garments that have been used and discarded due to wear, tear, being outgrown, or going out of style. These worn-out textiles and garments are generally more difficult to recycle since they often consist of more than one type of fibre and are more heterogonous. Thirdly, industrial activities produce industrial textile waste, such as carpets, hospital waste and conveyer belts. The industrial waste is often considered to be dirty and is less likely to be recycled due to challenges with collection and the complexity of the chemical composition (Abrishami, et al., 2024).

Fibre-to-fibre recycling techniques

To recycle textiles into new fibre that can be used in clothes or textile applications (fibre-to-fibre recycling), different techniques can be used, with mechanical and chemical being the most common. Mechanical recycling involves breaking down materials through processes such as unravelling (with or without purification), cutting, shredding and grinding the textiles. Whereas chemical recycling involves processing textiles back into their original polymer or monomer forms (Duhoux, et al., 2021). Other recycling techniques are for example biological and thermal recycling. These recycling techniques can be applied either separately or in combination, depending on the requirements for the input textile waste and desired output specifications for the recycled fibres (Abrishami, et al., 2024; Duhoux, et al., 2021; Tripathi, et al., 2024). For example, mechanical recycling can serve as a pre-processing step to convert textile materials into fluff or fibres, which can then be further processed using other methods, such as chemical recycling (Tripathi, et al., 2024).

Mechanical recycling

Mechanical recycling involves cutting or shredding textiles into smaller pieces or fibres, which can then be carded if necessary and processed into new yarns. It is considered the most straightforward and efficient method of textile recycling. Mechanical recycling can also be followed by a sequence of thermal process steps, known as thermo-mechanical recycling (Abrishami, et al., 2024).

Most textile materials can be mechanically recycled; however, the shredding process reduces the fibre length, producing shorter fibres of lower quality and strength compared to virgin fibres (Abrishami, et al., 2024). As a result, these recycled fibres are often blended with virgin fibres to enhance their quality in a garment or textile application (Charnley, et al., 2024).

Wool is common to recycle mechanically as recycled wool yarns can be transformed into high-value apparel products using traditional methods. Wool textiles composed mainly of long, carefully treated fibres, are well-suited for mechanical recycling, which converts them back into fibres. The process of wool recycling is similar to that of mechanical cotton recycling (Damayanti, et al., 2021).

The thermo-mechanical process is often used in open-loop recycling of plastic bottles to recycle polyester or nylon fibres. It involves shredding the material, followed by a sequence of thermal processes such as heating, agitating, and filtering, to remove impurities and produce high-quality recycled materials. This method is quicker, cheaper, and more energy-efficient than chemical recycling, requiring no solvents and causing less quality degradation than traditional mechanical recycling. However, contaminants in the input material may impact the quality of the recycled fibres (Abrishami, et al., 2024). Nylon waste, including fishing nets and carpets, are commonly used in thermo-mechanical recycling as the recycled fibres will have appropriate strength and length after recycling (Damayanti, et al., 2021).

Almost all fibre types can be processed through the cutting or shredding techniques used in mechanical recycling (Abrishami, et al., 2024). Currently mechanical recycling is the most widely used fibre-to-fibre recycling method due to its simplicity and low cost (Andini, et al., 2024). However, according to Andini et. al (2024), mechanical recycling cannot process blended fibres, additives, or colorants. Similarly, Damayanti et al. (2021) highlight that the mechanical recycling of post-consumer textiles is constrained by the diverse and complex blend of fibres in a single garment, making blended textiles difficult to recycle efficiently. Mechanical shredding of textiles with a blend of fibre types causes more damage to natural fibres, than synthetic fibres, which makes polyester-cotton blends less suitable for mechanical recycling as the cotton fibres will be more damaged than the polyester fibres. As a result, chemical recycling offers a better alternative for processing blended fibres, like polyester and cotton (Damayanti, et al., 2021).

Chemical recycling

Chemical recycling involves separating materials by adding chemicals to the textiles to break down complex textile polymers into smaller molecules, like purified polymers, oligomers, or monomers. These monomers and oligomers can then be renewed through re-polymerisation. Hazardous solvents are often used in the dissolution process, where the polymer is preserved, and the textiles are regenerated. Additionally, hazardous chemicals like bleaching agents are used to remove dye form the textile waste. Recently, ionic liquid solvents have been used to recycle dyed post-consumer textiles, giving it a new life while minimising the environmental impact (Damayanti, et al., 2021). Chemical recycling is generally more expensive than mechanical recycling and the production of virgin fibres as it involves separation of components like blended fibres and dyes (Abrishami, et al., 2024).

One example of chemical recycling is the development of methods for textile waste containing blended textiles of polyester and cotton materials. These methods involve subjecting the blended textiles to a solvent to dissolve either cellulose or polyester. As a result, the cellulose from the cotton is extracted in powder form, while the remaining polymer can be recycled by steps such as filtration, drying or converted into derivative compound (Abrishami, et al., 2024; Heikkilä, et al., 2025).

Another chemical recycling method is the conversion of plant materials containing cellulose, typically derived from wood pulp but also from cellulose textile waste, such as worn-out cotton textiles. The resulting regenerated fibres, known as man-made cellulosic fibres, are commonly used in fabrics like viscose, lyocell, and modal. In this process, wood pulp or cellulosic rich textiles are treated following a sequence of steps to form dissolving pulp. The pulp can be extruded as filaments or fibres and knitted or woven into new fabric (Abrishami, et al., 2024). However, due to diminished physical properties, the yield of synthesised polymer chains is lower, compared to the wood pulp process. As a result, regenerated fibres often need to be blended with virgin fibres to achieve a high-quality end product (Damayanti, et al., 2021).

Other recycling techniques

Biological recycling utilises biodegradable fibres that decompose naturally or synthetically as enzymes break down their chemical bonds. Cotton fabrics are prone to degradation by fungi and bacteria due to their high cellulose content, which makes cotton fibres suitable for biological recycling (Tripathi, et al., 2024). Other recycling techniques are for example thermal recycling, which encompasses both thermo-mechanical and thermo-chemical methods, through a process that uses heat to recover either polymers or low molecular weight building blocks (Duhoux, et al., 2021).

The textile recycling market

During the latter part of the twentieth century, innovations in technology and infrastructure created favourable conditions for a fast-paced production and delivery system. This linear approach was adopted by the fashion and retail industries, leading to the rise of the fast fashion business model that has since dominated the textile market. This model, in turn, has influenced customer behaviour, fostering a throwaway culture where garments are used for increasingly shorter periods before being discarded (Hultberg, 2024). On the contrary, circular fashion represents a significant shift toward a more sustainable future for the fashion industry. As consumer awareness of the environmental and social impacts of fast fashion grows, the demand for sustainable alternatives to conventional practices becomes increasingly vital (Jimenez-Fernandez, et al., 2023).

One promising solution to achieve circularity in the textile industry, according to Charnley et al. (2024), is fibre-to-fibre recycling, which has gained attention in the literature as a crucial business case. Several textile recycling companies have successfully scaled their operations and gained market share. A study from 2024 highlights the achievements of start-up companies focused on scaling fibre-to-fibre recycling. Most of these companies, such as Renewcell and Södra in Sweden, Lenzing in Austria, and Infinited Fiber in Finland, specialise in chemical recycling. They primarily utilise cellulosic input materials, like wood or cotton-rich used textiles, to produce dissolving pulp (Charnley, et al., 2024). This pulp is either be wet spun into new fibre filaments or sold to fibre producers to create new fibres, depending on the specific technology they employ (CIRCULOSE, n.d.; Infinited Fiber Company, n.d.; Lenzing Group, n.d.; Södra, n.d.). Additionally, there are companies categorised as mechanical and chemical recyclers, focusing mainly on cotton textiles to produce fibres and yarns (Charnley, et al., 2024). One example of a recycling company that focus on chemically recycled polyester in Syre, which was founded in 2023 and aim to have multiple productions plants in full operation by 2032 with a capacity of 3 million tons recycled polyester per years (Syre, 2024).

Key challenges

Despite several emerging recycling techniques and start-up companies working to scale fibre-to-fibre recycling, the industry faces several challenges and dilemmas in transforming and maturing the market. Although fibre-to-fibre recycling is crucial for a circular textile industry, it currently accounts for less than 1% of global fibre production (Charnley, et al., 2024; Textile Exchange, 2024). Charnley et al. (2024) explain that this is due to a lack of clarity on the enabling conditions needed to significantly scale the process throughout the value chain. Additionally, the market for textile recycling remains a weak business case, struggling to move beyond proof-of-concept to widespread implementation and development of the required infrastructure (Charnley, et al., 2024).

Charney et al. (2024) identify several barriers that the textile recycling market must address to achieve scalability. One challenge is achieving economic viability in the collection and sorting of input materials, as the process of sorting post-consumer textiles remains expensive and labour-intensive (Charnley, et al., 2024). Stindt et al. (2016) further explain how the transition from a linear value chain to a reversed one affects the dynamic when it comes to collection of input material. In reverse markets, the roles of suppliers and consumers are inverted, making it difficult to secure input materials since consumers, typically not seen as suppliers, must now fulfil this role. Another key difference in reverse markets is that the flow of goods is supply-driven rather than demand-driven. For textiles, the quality of collected textiles can vary widely, influenced by factors such as initial design, usage patterns, and the availability of collection points or take-back systems (Stindt, et al., 2016). While the quality of the collected textiles can vary, the most significant challenges arise from the prevalence of blended fibre types, which complicates recycling; different fibre types must be separated to be effectively recycled (Textile Exchange, 2024; McKinsey & Company, 2022). Additionally, some obsolete products may never re-enter the recycling process due to export or improper disposal (Stindt, et al., 2016).

Another challenge presented by Charnley et al. (2024) is the cost of recycled fibres; brands aiming to incorporate a higher percentage of recycled textile fibres into their products face elevated prices. This is partly because the cost of virgin fibres does not reflect the environmental and social externalities associated with their production. Additionally, meeting customer expectations for recycled fibres that are both durable and competitively priced compared to virgin fibres is difficult. While data indicates that consumers increasingly prefer sustainable products, their purchasing behaviour does not fully align with these values. Consumers are not yet willing to pay a premium for products designed according to circular principles (Charnley, et al., 2024).

Example: The Case of Renewcell

Corvellec & F. Stowell (2024) gives an example of the current state of the textile recycling market, highlighting Renewcell as an example. In the spring of 2024, the company faced bankruptcy despite making significant progress in technical readiness. Renewcell had established a big production plant in a decommissioned pulp and paper factory in northern Sweden to recycle textile waste—such as worn-out jeans and production scraps consisting of cotton—into Circulose®, a fibre made entirely from textile waste, eliminating the need for virgin cotton, oil, or wood. However, unfavourable enabling conditions led to financial difficulties, raising questions about the viability of the business model – such as whether large-scale production of recycled fibres should be located closer to textile production hubs in Southeast Asia rather than in Northern Europe, and whether these challenges are partly due to end-users' reluctance to pay more for circular products (Corvellec & F. Stowell, 2024). An article by Brooke Roberts-Islam in Forbes (2024) also highlights that Renewcell, located in Sweden, is situated far from the regions where most clothing is produced and where the raw materials are sourced, which is primarily in Asia. According to Roberts-Islam, new recycling technologies are best evaluated and integrated by experts in countries like India and Bangladesh, who play a key role in the textile value chain (Roberts-Islam, 2024). In June 2024, Renewcell was acquired by the investment company Altor and renamed to Circulose. According to Altor, the company will continue producing Circulose® fibres and establish partnerships with key actors in the textile value chain (Renewcell, 2024).

Regulatory enablers for scaling fibre-to-fibre recycling

To scale fibre-to-fibre recycling and make it an attractive business case, in addition to the need for infrastructure for collection and sorting textiles, it is essential to aggregate volumes of textiles with similar fibre compositions and prepare low-value textiles for recycling in accordance with specifications that meet recycling requirements (Charnley, et al., 2024). Moreover, scaling fibre-to-fibre recycling depends on external factors and requires a supportive regulatory environment to enable market entry. Without appropriate market or regulatory signals, the time it takes for new recycling technology to reach the market and make an impact can be much longer than initially anticipated. Even fully develop recycling technologies may struggle to enter the market without sufficient regulatory support (Kobos, et al., 2018).

The increased use of recycled textile fibres in clothing and textile applications similarly depends on favourable regulatory conditions and, as Charnley et al. (2024) highlight, economic support to justify circularity and help the market mature. This support can include funding through Extended Producer Responsibility (EPR) schemes, as well as incentives for companies to invest in recycling technologies and infrastructure (Charnley, et al., 2024).

To strengthen the market, the European Commission is introducing several measures to enable a circular economy for textiles as part of the Textile Strategy. The strategy addresses regulatory considerations across the entire lifecycle of textile products. The strategy is particularly significant for the textile recycling industry, as it establishes a framework that fosters favourable conditions for recycling companies to scale their operations. By shaping policies that promote sustainable practices, the strategy plays an important role in advancing the circular economy in the textile sector, ensuring that regulatory support aligns with the industry's needs for growth and sustainability (European Parliament, 2023).

Starting on January 1st, 2025, textiles will be collected separately—a step likely to increase the volume of collected textiles but additional legislation is needed to incentivise textile recycling. To further support the development of separate collection, sorting, reuse, and recycling processes, the Commission has proposed an EPR scheme for textiles, assigning waste management responsibilities to producers. This scheme will help Member States meet the separate collection requirements, with contributions from producers funding investments in separate collection, sorting, reuse, and recycling infrastructure. This approach is also expected to motivate producers to design products that are reusable and recyclable at the end of their lifecycle, as they will bear the associated waste management costs (European Commission, 2023).

EPRs has proven effective in enhancing waste management across sectors such as packaging, batteries, and electronic equipment (European Commission, 2023). However, as of the completion of this report, negotiations are not yet completed and no decision has been made to implement an EPR scheme for textiles in the Parliament (European Commission, 2022). In the meantime, Member States will need to ensure that textiles are separately collected from the 1st of January 2025.

Another enabler is the Ecodesign for Sustainable Products Regulation (ESPR, Regulation (EU) 2024/1781), a framework legislation implemented by the EU in July 2024. Delegated acts for specific product groups will be developed in the coming years to set specific requirements to promote product circularity, energy efficiency, and environmental sustainability. Textiles, particularly garments and footwear, are among the prioritised product groups for which delegated acts with specific requirements will be introduced. The ESPR will introduce regulations aimed at enhancing product durability, repairability, and recyclability, including a specific ban on the destruction of unsold textiles and footwear (European Union, 2024).

Methodology

The work behind this study can be divided into two subparts: firstly, identify an assessment model and secondly, use the model to assess the fibre-to-fibre recycling companies, including reaching out to the assessed companies.

Assessment model

In this study, the *KTH Innovation Readiness Level™* framework has been used. The framework was identified via desktop studies and consultations with senior experts. Three parameters from the KTH Innovation Readiness Level™ were chosen for the assessment: Technology Readiness Level (TRL), Business Model Readiness Level (BRL) and Customer Readiness Level (CRL).

The desktop study included a literature search online with the following words, used together in different combinations: *textile recycling, recycled fibres, recycled textiles, evaluation, assessment, circular economy, business model, market strategy, technical readiness level.* As a complement to the desktop study, senior experts in the field of business development, textile technology, sustainable consumption and waste and resource flows were consulted. This consultation occurred throughout the study, to validate the assessment model and selection of parameters for the assessment.

Adapted assessment model for fibre-to-fibre recycling companies

The KTH Innovation Readiness Level™ is a framework used for assessing and guiding the development of a company from early idea to a market ready innovation (primarily with a focus on start-ups). It can be used as an internal tool for companies to assess the maturity of the products or services they are developing. Ideally, this framework is applied when there is full insight into a company's technologies, business model, and customer base. However, in this study, such comprehensive insight was not publicly available. Instead, information was sourced from public resources to understand and assess the companies TRL, BRL and CRL. The recycling companies included in this study range from smaller scale-up companies to spin-offs from research or established enterprises. Some of these companies have been operating for a long time and may hold substantial market shares, and it was of significant importance to keep in mind during the assessments that the companies are at different stages of development.

To clarify how these three parameters (TRL, BRL and CRL) apply specifically to the textile recycling market, an additional textile description is provided by the authors of this report (see “Adapted textile description” in Table 1). In the section *Justification of assessment model* more information about the textile description for each parameter is provided.

Table 1. Overview of the three parameters used for the assessment, including how it is adapted to fibre-to-fibre recycling companies (KTH Innovation, 2024 a; Strata, 2022).

	Scale	Description	Adapted textile description (authors interpretation)
TRL	**1-9**	Develop and test the technology, product, service, or concept.	Develop and test the technology to recycle post-consumer textiles and the feasibility of the recycled material in clothes or textile applications.
BRL	**1-9**	Establish that the concept can be financially, environmentally, and socially viable and feasible.	Establish that recycling of post-consumer textiles can be financially, environmentally and socially viable and feasible.
CRL	**1-9**	Confirm customer need and interest.	Confirm customers and end-users need, interest and possibilities to buy clothes or textile applications made of recycled post-consumer textiles.

Assessing BRL and CRL in the textile recycling context is challenging due to rapidly changing market dynamics and the complexity of the textile value chain, which can involve various actors before post-consumer textiles are recycled into new clothes and textile applications. The specific recycling technology a fibre-to-fibre company use, impacts the type of end-product and hence, if their downstream customers is a fibre, yarn of fabric producer. For example, a mechanical recycling company might process post-consumer textiles into recycled fibres, which are then sold to fibre or yarn producer. In contrast, a chemical recycling company could break down post-consumer textiles into dissolving pulp. This pulp can either be dried and sold to a fibre producer or further wet-spun into filaments and processed to fibres and sold to a yarn producer. As a result, the downstream customers of fibre-to-fibre recycling companies vary widely depending on the type of product, ultimately affecting how clothing or textile applications reach the end-user. As a result, some adjustments were made in the assessment model used in this study.

In the context of this study, customers are defined as the actors downstream in the textile recycling value chain. These could include fibre, yarn and fabric producers as well as garment manufacturers, and brand owners who transform the recycled textile into clothing or textile applications. Customers set the quality requirements for these fibres, as they are responsible for ensuring the recycled textile meet the necessary standards for clothing or textile applications. End-users, on the other hand, refer to the individuals or companies who purchase and use the final products, such as clothes or textile applications made from recycled textile. End-users create the demand for clothes and textile applications containing recycled textile, as they are the ones who directly benefit from the use of these products.

This study makes a clear distinction between customers and end-users. For BRL, agreements with downstream customers are assessed weather public information is available regarding these collaborations. For CRL, the recycling companies' is assessed from the end-user perspective. This is done by reviewing the market for clothes and textiles applications containing recycled textile produced by these companies. The distinction between customers and end-users is visually represented in Figure 3.

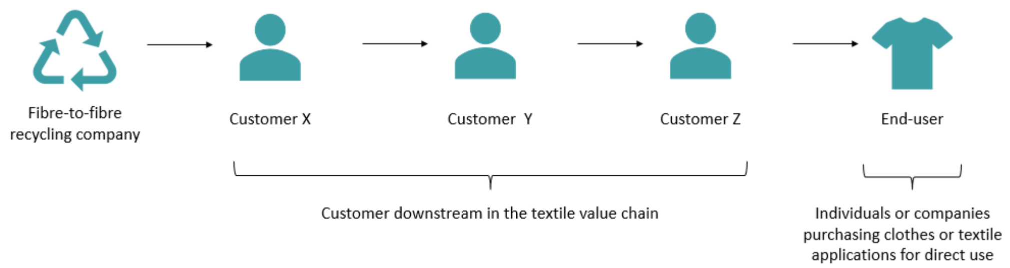

Figure 3. Simplified illustration of a textile recycling company's' downstream customers.

Assessment of companies

In the assessment, six recycling companies, both mechanical and chemical, in Europe using post-consumer textiles are included. The assessment was performed based on information from the companies' own websites, press releases, news articles, patents, reports and/or scientific articles. A selection of companies for the assessment was made based on 1) that the company utilise post-consumer textiles as input material in their recycling process and 2) that there was a variety of post-consumer textiles used (different fibre types).

For some of the companies, it was not possible to find sufficient publicly available information. A result of this is that some of the assessments might not reflect the actual maturity of a specific parameter for a company. In the cases where information was lacking, it has been made clear in the assessment. However, as mentioned in the next section, all companies have been given the opportunity to provide feedback on the findings and make us aware of any public information that may change our scoring.

For each company, their TRL, BRL and CRL was ranked between one and nine, along with a motivation. The companies were assessed one by one, by both authors. A verification of the assessments was done by looking at one parameter at a time (this time all companies at once). This made the assessment impartial and equitable, and made sure that the same parameters were assessed in the same way for the different companies. Additionally, all assessments were revised by a senior textile expert at IVL, whom also was involved in the validation and selection of parameters for the assessment, to revise the assessments. Throughout the work, great care was taken to guarantee that the assessments were carried out in a fully objective and equitable manner.

Feedback from companies

After the assessment was conducted, information was compiled in separate text documents and sent out to each company, including the aim of the project and information about the assessment model. The companies only received the assessments of their company, and not the other companies. The goal with sending the assessments to the companies was to collect additional information that was not available online. By having a prepared document with information about the company, it was easy for them to read and correct any mistakes. The companies were asked for any missing information that could be valuable for the assessment. However, changes in the assessments were only done if information that proved that the level of a certain parameter should be higher or lower was provided by the company. The companies were given 25 days to respond, with one reminder after 12 days. Additionally, phone calls were made to the companies that did not respond to the e-mail. Out of the six companies, five responded and three provided feedback on the assessment. In two cases the initial assessment was changed due to additional information that was given by the companies. It is important to note that none of the companies have paid for the assessment to be made.

Identification of an assessment model

This chapter presents the KTH Innovation Readiness Level™ framework and a justification of each of the chosen parameters for the assessments.

Measuring innovation and technology is a complex yet essential task, particularly when evaluating startups, innovation projects, and the maturity of technologies. One widely used tool for assessing the maturity of a technology, from the conceptual stage to proven operations in real-world settings, is the *Technology Readiness Level* (TRL) (Strata, 2022). Originally developed by NASA in the 1970s to evaluate the maturity of space exploration technologies, TRL has since been adopted across various sectors to assess technologies beyond space development. For example, the European Innovation Council accelerator, a funding program under Horizon Europe, uses TRL to support startups and small and medium-sized enterprises (European Innovation Council, 2023). However, relying solely on TRL does not fully capture the complexities of bringing a product to market. The TRL scale does not address crucial aspects such as whether customers are willing to buy and use the product or service (ALICE, 2022).

KTH Innovation Readiness Level™ Framework

The KTH Innovation Readiness Level™ has been developed with NASAs Technology Readiness Level as a basis and guides the development of an early idea into a market-ready innovation (KTH Royal Institute of Technology, 2021). This model is structured around six key parameters including the TRL, which guides idea development and is useful for teams, coaches, or managers to measure progress and status of a technology in a company. The model can help a company structure their innovation development process, visualise and measure the status and progress of ideas, guide in decision-making, communicate more efficiently with stakeholders and manage ideas in different stages in an effective way.
The six key parameters included in KTH Innovation Readiness Level™ are presented in Figure 4 and their respective focus are listed below (KTH Innovation, 2024 a):

- **Technology Readiness Level (TRL)** – The parameter is used to measure the maturity of a technology, guiding its development from research results to implementation in new products or processes.

- **Business Model Readiness Level (BRL)** – Evaluates the viability and feasibility of a business from financial, environmental, and social perspectives. To achieve a sustainable business model, the revenue generated must equal or exceed the costs, AND the positive impacts on the environment and society must be greater than the negative impacts.
- **Customer Readiness Level (CRL)** – Focuses on understanding the needs of customers or end-users for a product or service and capturing market sales.
- **IPR Readiness Level (IPRL)** – Clarifies the legal and IP situation and secures relevant IP protection.
- **Team Readiness Level (TMRL)** – Ensure the right competencies in the company and align the team.
- **Funding Readiness Level (FRL)** – Secures the necessary funding to bring the innovation closer to the market.

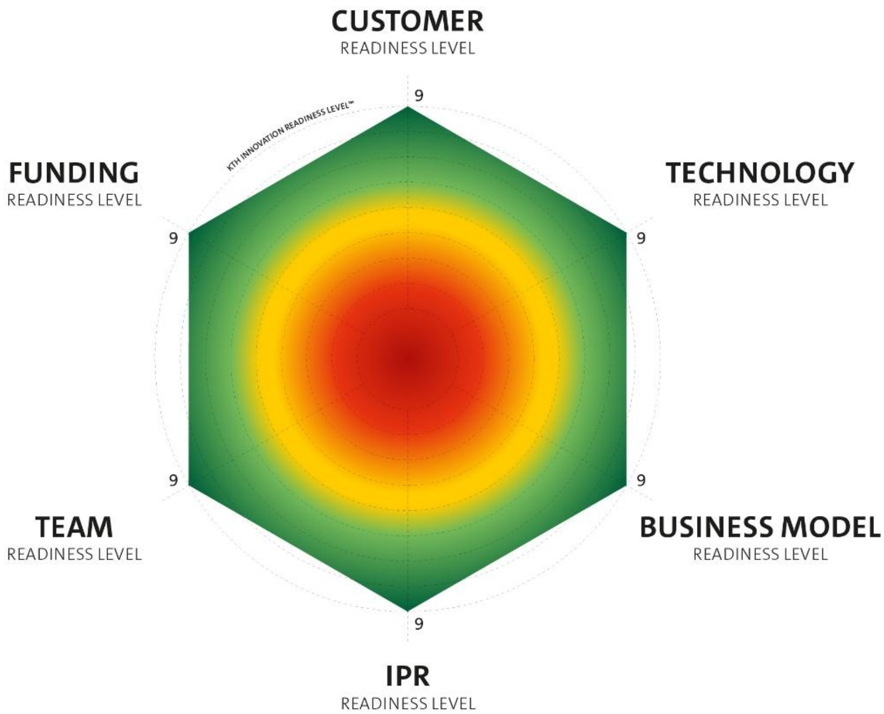

Figure 4. Visualisation, made by KTH Innovation, of the six parameters in the KTH Innovation Readiness Level™ Framework (KTH Innovation, 2025).

In the model, each dimension is equally important for an idea to thrive and scale in the market. The model outlines nine levels for each dimension, with level nine representing the highest maturity. Each level has specific definitions, milestones, and activities required to progress (KTH Innovation, 2024 b). KTH Innovation's model does not have a separate sustainability parameter. According to a Business Development Coach at KTH Innovation (2021), sustainability is integrated into BRL as a business model today must consider sustainability, along with diversity and equality, to build a successful and scalable business that remains competitive over time (KTH Royal Institute of Technology, 2021).

Justification of assessment model

The three parameters —TRL, BRL and CRL—from the KTH Innovation Readiness Level Framework are used to assess the recycling companies in this study. The reason only three of the six parameters are used in the assessment is that limited information about the textile recycling companies is available when it comes to IPR, team and funding. By evaluating a company's technique, business model and customer readiness level a comprehensive analysis of recycling companies can be achieved according to Ozcan et al. (2023), as these parameters focus on the most critical aspects of enabling a product or service to reach the market (Ozcan, et al., 2023).

Compared to the TRL, which measures the maturity of a technology, the BRL captures important aspects of how prepared a business is to bring the technology to the market. Emphasis is placed on value proposition, achieving economic feasibility, defining a sustainable business model as one where revenue exceeds costs while simultaneously making a positive contribution to the environment or society over time (KTH Innovation, 2024 b). According to Casado et al. (2020) combining TRL and BRL is useful for mapping and assessing a business’s progress to the market. By considering these two readiness levels, one can better understand the real-time competitive landscape, including competitors who may offer a similar product or service (Casado, et al., 2020).

CRL complements the model by focusing on the customer and end-users (KTH Innovation, 2024 c). While TRL highlights technological development stages, CRL assesses customer and end-users needs, interest, and willingness to pay, which are crucial for achieving scalable sales. Although a technology may progress through all TRL levels, its market acceptance depends on its perceived value, utility compared to other technologies, and insights from market participants' behaviour (Kobos, et al., 2018).

Technology Readiness Level (TRL)

The TRL scale ranges from one to nine and is divided into four phases. The first phase (levels one to three) is about developing an initial idea about a technology offering. The initial phase includes conducting tests in laboratory environment, further research and development of the technology and start defining quality requirements for the product or service (KTH Innovation, 2024 c). In the context of textile recycling market, a company achieving level three has demonstrated in a laboratory setting that post-consumer textiles can be recycled and are feasible for use in clothes or textile applications, and work with research and development of the technology.

The second phase (levels four to five) includes prototype development, where the technology moved from laboratory environment to relevant environment, with first results show positive results. Additional quality requirements have been identified (KTH Innovation, 2024 c). To achieve level five in the textile context a company must show that recycling of post-consumer textiles can work in a relevant environment by validation. Also, they need to refine the technology to meet the quality requirements for the recycled textile to be used in clothes or textile applications.

The third phase (levels six to seven) includes validation of the technology and focuses on delivering a prototype that closely resembles the final product and has been shown to work in an operational environment (KTH Innovation, 2024 c). For example, a recycling company at level seven should demonstrate that recycling of textiles works in an operational environment and meets all quality requirements to be used in clothes or textile applications, which also should be confirmed by customers.

The fourth and final phase (levels eight to nine) concerns the start of production, which involves ensuring that the technology is scalable and proven to work in actual operations by multiple customers over time, with ongoing efforts for improvements and optimisations of the technology (KTH Innovation, 2024 c). To achieve level nine in the textile context, the company has a complete technology that is proven to work overtime and is scalable.

In Table 2, the descriptions of the TRLs according to KTH (2024 a) are presented, along with an adapted description when the TRLs are applied to the textile sector, which is provided by the authors of this report.

Table 2. Description of TRL, including how it is adapted to fibre-to-fibre recycling companies (KTH Innovation, 2024 a; Strata, 2022).

Phase	TRL	Description	Adapted textile description (authors interpretations)
Idea	**1**	Interesting research results or initial technology idea identified.	Initial results of a technique that recycle post-consumer textiles are identified.
	2	Technology concept and/or application formulated.	The technique recycles post-consumer textiles that may be feasible to use in new clothes or textile applications, but no proof or detailed analysis that it will work exist.
	3	Proof-of-concept of critical functions and/or characteristics in laboratory.	Tests are done in a laboratory environment, showing initial results that post-consumer textiles can be recycled. There is a first idea of quality requirements of the recycled textile for the use in clothing or textile applications.
Prototype	**4**	Technology validation in laboratory.	Test results in a laboratory environment have been done, results show evidence that post-consumer textiles can be recycled.
	5	Technology validation in relevant environment.	Test results in a relevant environment have been done, showing that recycling of textiles will work (i.e., validation). Feedback has been gathered from customers to validate the quality of the recycled textile and define quality requirements.
Validation	**6**	Technology prototype demonstration in relevant environment.	A protype of the recycling technique has been proved in a relevant environment. The recycled textile meets some of the quality requirements to be used in clothes or textile applications.
	7	Technology prototype demonstration in operational environment.	A protype of the recycling technique has been demonstrated and proven to work in operational environment. All quality requirements are identified for the recycled textile to be used in clothes or textile applications.
Production	**8**	Technology complete* and demonstrated in actual operations.	The recycling technique is complete, has been demonstrated and proven to work in actual operations by customer. The recycled textile meets all requirements and specifications to be used in clothes or textile applications.
	9	Technology complete* and proven in actual operations over time.	The recycling technique is complete and proven in actual operations over time and is scalable. The company works with continuous improvements, optimisation of technology and production is ongoing.

**Complete: Contains everything necessary for both customer and end-user needs (KTH Innovation, 2024 c).*

Business Model Readiness Level (BRL)

The BRL scale ranges from one to nine and is divided into three phases. In the initial phase (levels one to three), conceptualisation occurs. Here, the product or service is defined, and a clear strategy for generating value for customers and/or end-users is established, including the business model, target market, and competition (KTH Innovation, 2024 c). For example, a company in the textile recycling market at level three has a described the business model and has defined and estimated the market for recycled textile and identified their competitors.

The second phase (levels four to five) involves business testing and engaging with stakeholders or early adopters to evaluate whether the company's business proposal meet customer and/or end-user needs (KTH Innovation, 2024 c). A textile recycling company at level five can demonstrate that its business model has been tested, with feedback from potential customers and/or end-users validating both the model and the costs. Additionally, the company provides information on measures to enhance positive and reduce negative environmental and social impacts, such as disclosing emissions, having third party-reviewed life cycle assessments (LCAs), or offering accessible sustainability reports.

The third and final phase (levels six to nine) focuses on business deployment i.e., acquiring, tracking, and scaling sales to ensure the long-term viability of the product or service. By this stage, the business is considered trustworthy by clients, and revenue starts to become predictable (KTH Innovation, 2024 c). For instance, a company at level nine has successfully recycled post-consumer textiles, meeting profit, scalability, and impact expectations. The company has credible systems and metrics demonstrating long-term profitability and sustainability through historical economic, environmental, and social performance data. This includes disclosing emissions, having third party reviewed LCAs, and providing accessible sustainability reports that are traceable over time and highlight improvements.

In Table 3, the descriptions of the BRLs according to KTH (2024 a) are presented, along with an adapted description when the BRLs are applied to the textile sector, which is provided by the authors of this report.

Table 3. Description of BRL, including how it is adapted to fibre-to-fibre recycling companies (KTH Innovation, 2024 a; Strata, 2022).

Phase	BRL	Description	Adapted textile description (authors interpretations)
Conceptualisation	**1**	No or unclear hypothesis of possible business idea, market potential, and competition.	No or unclear hypothesis of possible business model for recycling post-consumer textiles, market potential, value proposition and competition.
	2	First hypothesis of possible business concept (in any format) and identified overall market potential and competition.	First hypothesis of possible business model for recycled textile, the information is based on assumptions, typically from secondary sources.
	3	Description of sustainable business model* and target market(s), including competition.	Business model described and in place as well as description of factors causing positive and negative contribution to environment and society. The market and competitive landscape for recycled textile is defined and estimated.
Business testing	**4**	First calculations indicating economically viable business model. First assessment indicating environmental and social sustainability.	Initial financial plan outlining primary cost and revenue streams for the business model (based on assumptions and estimates). First assessment of the potential positive and negative environmental and social impacts of implementing the proposed business model.
	5	Key assumptions in sustainable business model* tested on the market.	The business model has been tested, with feedback from potential customers and/or end-users validating both revenue (revenue model, pricing) and costs (production, supply chain). Key measures to enhance positive and reduce negative environmental and social impacts have also been identified.

Phase	BRL	Description	Adapted textile description (authors interpretations)
Business deployment	6	Full sustainable business model* tested on customers, partners, suppliers (e.g., by test sales), calculations show economic viability.	A complete sustainable business model (cost and revenue side) for recycling post-consumer textiles, covering costs, revenues, and measures to enhance positive environmental and social impacts, is tested through realistic business scenarios (test sales, pilot etc.). Financial projections based on this testing show the model's economic viability.
	7	Viability of sustainable business model* (pricing, revenue model, etc.) validated by initial commercial sales.	Viability of sustainable business model for recycled textile validated by proof of initial sales. Agreement in place with key suppliers and partners aligned with expectations on the business model.
	8	Sales and metrics show that sustainable business model* is viable.	The recycling company is generating revenue with sales channels and supply chain fully operational. The business has run from 1-3 years indicating that the business model is sustainable, meaning that it meets expectation on profit, scalability as well as environmental and social impact.
	9	Sustainable business model* proven to meet internal and external expectations on profit, scalability and impact over time.	Recycling of post-consumer textiles has consistently met profit, scalability, and impact expectations. Credible systems and metrics show long-term profitability and sustainability through historical economic, environmental, and social performance data.

**Sustainable business model = Revenue ≥ Cost (over time) AND Positive contribution to the environment and society > Negative contribution to the environment and society (over time) (KTH Innovation, 2024 c).*

Customer Readiness Level (CRL)

CRLs can be categorised into three phases that a company progresses through: need, solution and sales confirmed. The first phase (levels one to four) focuses on validating customer and/or end-users needs for the product or service. During these initial levels, market research is conducted to gain knowledge about the market and potential customers and/or end-users. Feedback from customers and/or end-users helps to refine the understanding of problems the innovation needs to solve (KTH Innovation, 2024 c). In the context of the textile recycling market, a company at level four has demonstrated a need for their recycled textile by producing a first piece of clothing or textile application. Additionally, the recycled textile exhibits clear positioning against competitors´ alternatives, based on feedback (e.g., why their recycled textile is better than competitors).

The second phase (levels five to seven) focuses on confirming the solution. Customers and/or end-users' express interest in the product or service and confirm that it addresses their problems and needs, achieving an initial problem-solution fit. The product or service is tested to confirm its value and benefits, customer agreements are established, and a small number of end-users begin using early versions of the product (KTH Innovation, 2024 c). In the context of the textile recycling market, a company at level seven demonstrates initial sales of recycled textile, assessed by the presence of garments or textile applications available for purchase by end-users.

In the third and final phase (levels eight to nine), sales are confirmed, and widespread product deployment is achieved (KTH Innovation, 2024 c). A recycling company that demonstrates that sales of their recycled textiles are growing has achieved level nine. In the context of a local, intentionally small-scale operation (niche), both production output and sales need to remain steady and foreseeable.

As mentioned in the *Methodology* chapter, for the textile description of CRL, this assessment will focus on the end-user's perspective, as information about the recycling companies' downstream customers is limited. In Table 4, the descriptions of the CRLs according to KTH (2024 a) are presented, along with a textile description when the CRLs are applied to the textile sector, which is provided by the authors of this report.

Table 4. Description of CRL, including how it is adapted to fibre-to-fibre recycling companies (KTH Innovation, 2024 a; Strata, 2022).

Phase	CRL	Description	Adapted textile description (authors interpretations)
Need confirmed	**1**	Hypothesis of possible needs in the market.	Hypothesis that clothes or textile applications containing recycled post-consumer textiles could satisfy a need in the market.
	2	Identified specific needs in the market.	Brief market research is performed. Possible customers and end-users and their needs are identified.
	3	First market feedback established.	First feedback received from market research demonstrating that clothes or textile applications containing recycled textile satisfy a need in the market. A more developed understanding of possible customers and end-user segments.
	4	Confirmed problem/need from several customers or users.	The need for recycled textile is confirmed from customers downstream in the textile value chain. A first clothing piece or textile application has been produced. Customer and end-user segments in place as well as clear positioning against alternative fibres is defined.
Solution confirmed	**5**	Established interest and relations with customers.	The need for recycled textile is confirmed from multiple customers downstream in the textile value chain (i.e., initial problem solution fit). Relations with customers are established and which to focus on first are defined.
	6	Benefits confirmed by first customer testing.	Several pieces of clothing or textile applications containing recycled post-consumer textiles have been produced and showcased, confirming customer value and benefits based on feedback. Initial plan for sales of the recycled textile. Possible partners are identified to reach the customer and end-user segments.
	7	Customers in extended testing or first test sales. Small number of active users.	First sales, such as limited edition, of clothes or textile applications containing recycled post-consumer textiles have been made available for purchase by end-users. Small number of active customers and end-users. Further discussions with partners.
Sales confirmed	**8**	First commercial sales and implemented sales process. Substantial number of active users.	There is a substantial number of customers buying the recycled textile, at near market price. Clothes or textile applications containing recycled textile are available for purchase by end-users. Sales acquisition process implemented.
	9	Widespread sales that scale. Large number of active users with substantial growth.	The number of customers buying the recycled textile is steadily increasing. Widespread supply for end-users to purchase clothes of textile applications containing the recycled textile. Efforts for customer and/or partner acquisition are done to build demand. In case of local, deliberately small-scale operation, sales are consistent and predictable.

Assessment of fibre-to-fibre recycling companies

In this chapter, a description and assessment of the six selected fibre-to-fibre recycling companies are presented, see the overview in Table 5, followed by a compilation of all assessments.

Table 5. Summary of the six assessed, their location, technique and type of input material they utilise.

Company name	Location	Technique	Type of post-consumer textiles utilised
Aquafil	Slovenia	Chemical	Nylon
Comistra	Italy	Mechanical	Wool
CuRe Technology	The Netherlands	Chemical	Polyester
Ioncell Oy	Finland	Chemical	Cellulose
Recover™	Spain, Bangladesh and Pakistan	Mechanical	Cotton
Worn Again	UK and Switzerland	Chemical	Polyester and cotton

Aquafil

Aquafil is an Italian company founded in 1965 which manufactures yarns for carpets, synthetic fibres and polymers for clothes and textile applications. In 2011, Aquafil started production in Ljubljana, Slovenia of ECONYL®, which is a chemically regenerated nylon made from pre- and post-consumer waste (Aquafil, 2022 a). Years of research led up to ECONYL® Regeneration System (hereafter referred to as "ECONYL"), a technology that enables replacement of petroleum-derived nylon (caprolactam) with ECONYL caprolactam by regeneration of nylon waste. The recycling technique uses nylon waste as input material and process it to ECONYL via depolymerisation. In 2023, ECONYL was used by 1 700 brands in different products (Aquafil, 2024 a), Prada is one example (Prada, 2024).

The input material used to produce ECONYL comes from pre-and post-consumer waste such as old carpets destined for landfills and fishing nets from the aquaculture industry and the oceans. One foundation that Aquafil collaborates with is the *Healthy Seas Foundation*, a foundation that partners with small businesses and non-profit organisations to collect so-called "ghost nets" from the sea. The suitable nets made of nylon 6 (also called PA6) are cleaned and sorted before being regenerated (together with other waste) in the Aquafil plant in Slovenia (ECONYL, n.d.). In 2023, Aquafil had a collection capacity of 16 000 tons of post-consumer waste and by 2025, their goal is to reach a capacity of 35 000 tons. The collected carpets are treated in the United States, before reaching the plant in Slovenia. In Slovenia, the nylon is then regenerated into ECONYL raw material, which is used to produce ECONYL polymers and yarns (Aquafil, 2024 a). Since 2013, the ECONYL polymers (2.4 and 2.7 viscosity, i.e., the recycled nylon) have been covered by an Environmental Product Declaration (EPD) assessing environmental impact of 1 kg of recycled nylon 6 granules. Amongst other environmental categories assessed, global warming potential is assessed to 0.95 kg CO_2-equivalents (EPD International AB, 2020).

The continuous process for treating nylon waste involves first introducing the waste into a reactor, where it is washed, purified and depolymerised. Next, the resulting monomers are treated in a decolourising reactor to remove any colour (Desso, 2011; Deutsche Bank, 2021; Karasiak & Karasiak, 2012; The Blue Circular Economy, 2022). One advantage of this chemical process is its ability to remove foreign substances, ensuring a final product of 100% recycled nylon in its virgin form without the need for the steps involved in mechanical recycling such as separation which is needed to achieve similar quality (Global Ghost Gear Initiative, 2021).

Aquafil conducts research and development projects together with the University of Padua in Italy to regenerate and separate nylon from other materials, such as fibreglass. The research developed a patented technique to separate fibreglass from polymers, for recycling of nylon 6 by using the ECONYL process (Aquafil, 2024 b). According to Agnéus et al. (2021), Aquafil has been focused since 2016 on how to recycle blended materials containing nylon along with other components (Agnéus, et al., 2021), however, no information regarding the progress was found at the time of this study.

The growth in the Aquafil group’s revenue is driven by sales of ECONYL branded products, which now makes up an increasingly significant portion of the total value generated. The company’s goal for 2025 is that 60% of the turnover will be from ECONYL branded products (Aquafil, 2024 a).

According to the sustainability report for 2023, ECONYL regenerated nylon can be recycled an infinite number of times, has the same qualities as traditional nylon and during production, generates up to 90% less CO_2 emissions than conventional nylon (Aquafil, 2024 a). Additionally, for every ton of ECONYL raw material, seven barrels of crude oil is saved according to Aquafil (Aquafil, 2022 b). Since 2015, some suppliers to ECONYL have been subjected to ECONYLs *Qualified Guidelines for Partners*, set out both quantitative and qualitative criteria for the use of raw materials and energy resources, alongside standards for environmental management throughout the production process. Compliance is verified through audits, with certificates valid for two years and is currently voluntary, but in the future, it may be mandatory for all companies within the ECONYL value chain (Aquafil, 2024 a).

Assessment of Aquafil

The overall evaluation for Aquafil is shown in Figure 5. Aquafil achieves nine for TRL, nine for BRL and nine for CRL. For each readiness level, a motivation is provided below.

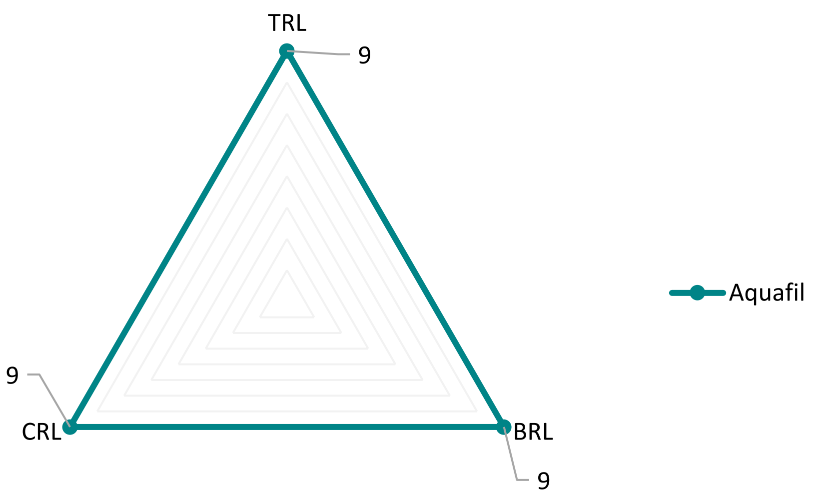

Figure 5. Radar chart with the assessment of TRL, BRL and CRL for Aquafil.

TRL

Aquafil's chemical recycling process to produce ECONYL is well-established, with the technology now commercially viable and successfully integrated into multiple global supply chains. The technology is in the production phase and Aquafil are today producing recycled nylon fibres at an industrial scale, which is used by over 1 700 brands (Aquafil, 2024 a). This demonstrates that the technology is fully developed and proven in real-world operations. Since the recycled nylon are used in products by multiple brands, it is assumed that the quality requirements of the recycled nylon are met to be used in clothes or textile applications, and that Aquafil work with continuous improvements. This positions Aquafil's technical maturity level to nine in this assessment, displaying a complete and proven recycling technique over time.

BRL

Aquafil's commercial success with ECONYL over the past decade, including established production facilities and partnerships with leading brand, indicates that Aquafil's business model is in the deployment phase. Their goal of 60% turnover from ECONYL branded products implies that the company has a clear strategy to increase its share of sustainable products and that ECONYL nylon is a crucial part of the company's future revenue streams and growth plans. Aquafil presents the environmental benefits of their recycled nylon, and their quality criteria for partners indicating progress in their sustainability work. Additionally, an EPD has been in place since 2013, providing information about sustainability aspects of the nylon fibres. Together, Aquafil achieves a business model maturity level of nine in this assessment, demonstrating a business model that consistently meets both internal and external expectations for profit, scalability, and long-term impact.

CRL

Aquafil has demonstrated a strong need from customers and are collaborating with high-profile brands. Their product is commercially available across various industries and textile brands, and its environmental benefits is quantified. Given the widespread adoption of ECONYL nylon and its integration into numerous product lines, Aquafil achieved a customer maturity level nine in this assessment, reflecting validated customer needs and extensive market acceptance.

Comistra

The Italian producer of mechanically regenerated wool, Comistra, is located in the Textile District of Prato (Comistra, n.d. a), and has been operating since 1920 (Comistra, n.d. b). The name Comistra (short for *Consorzio Obbligatorio Misto Indumenti Stracci e Affini*) is an acronym which originates from the fact that rags were brought to Prato from across the Western world, marking the start of their process. Sorting these used rags is essential for creating a recycled product in a single colour (Cikis Studio, 2022 a). Currently, they have a complete cycle of lanes to transform wool from used textiles into new wool yarns and fabrics (Comistra, n.d. a; Comistra, n.d. b). The regenerated wool fibres and fabrics are blended with virgin wool and synthetic fibres. Comistra showcases nine different yarns on their website. Two of these yarns are made of 100% regenerated fibres, in which regenerated wool is blended with other recycled fibre types such as nylon, other wool, or other fibres. They also offer four different lines of fabrics suitable for clothing or blankets. However, clear information about the percentage of regenerated wool in the fabrics is not available on their webpage (Comistra, n.d. c). According to an interview with the CEO in 2022, only 6% of the wool produced worldwide is actually recycled, despite wool being a recyclable material (Cikis Studio, 2022 a).

Comistra's process begins by sorting and separating collected wool textiles based on colour, fineness, and material composition. Then, they clean the textiles by removing buttons, zippers, and labels. Next, the cleaned wool textiles undergo several steps: water pulling, tumbling, sample carding machine treatment, yarn testing, spinning, winding, warping, and finally, weaving the recycled wool into new clothes and textiles (Comistra, n.d. a). Comistra has received the Global Recycled Standard, a third-party certification that verifies recycled material content, traceability, chemical restrictions, and compliance with environmental and social criteria throughout the process (Comistra, n.d. d).

The quality of regenerated wool and the ability to recycle wool multiple times depend on the design of the original wool textile and the length of the wool fibres. Comistra currently uses two methods to spin fibres and produce yarns, based on fibre length. The open-end spinning method, preferred by many major brands, is cost-effective and works well with short fibres. In contrast, the self-acting system, commonly used in the Prato region, requires longer fibres to operate effectively (Cikis Studio, 2022 a).

Comistra collaborates with universities and institutes within the fashion sector. For example, they partnered with students from Instituto Modartech, who designed a clothing collection that was showcased on the catwalk in 2023. Using the company's regenerated fabrics, the students created 16 outfits that represent the various stages of their production process, such as selecting raw materials (rags), sorting by colour, fineness, and composition, cleaning, transforming rags into high-quality fibres, and the study of colour and weaving (Comistra, n.d. e).

Comistra has conducted an LCA (not done by a third party) on regenerated wool produced through the mechanical shredding of post-consumer textiles (knitwear).

The LCA also included one of their yarns and one fabric, without clear specifications of regenerated wool content (Comistra, n.d. f). However, no comparison between the regenerated wool and virgin wool is done, which makes it difficult to draw any conclusions. According to an article on Comistra's website, regenerated wool has a lower environmental impact, compared to virgin wool, for two main reasons: firstly, no colouring is needed for the regenerated wool, saving water and reducing CO_2 emissions from dyeing, and secondly, it also avoids the intensive land use and animal farming associated with traditional wool production (Comistra, n.d. g).

Assessment of Comistra

The overall evaluation for Comistra is shown in Figure 6. Comistra achieves eight for TRL, eight for BRL and eight for CRL. For each readiness level, a motivation is provided below.

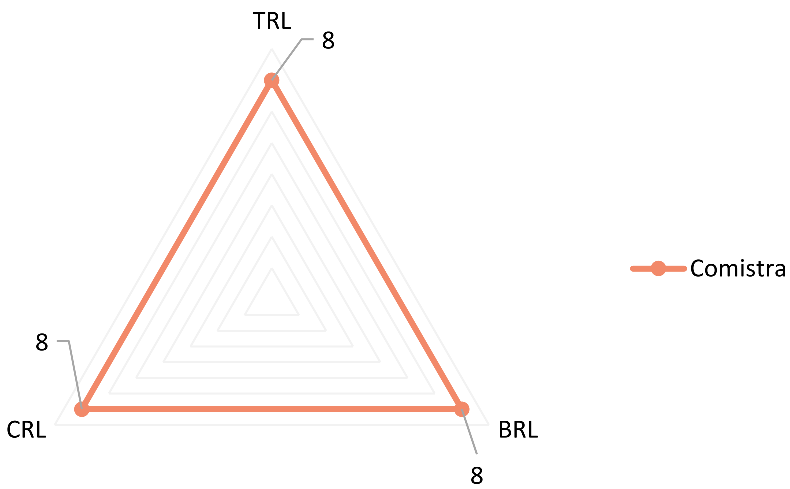

Figure 6. Radar chart with the assessment of TRL, BRL and CRL for Comistra.

TRL

Comistra have proved that their process of regenerating wool is complete and works in actual operations over time, for as long as over four generations (Comistra, n.d. b). Their technology is in the production phase and Comistra are today producing regenerated wool fibres and yarns. Comistra has collaborated with stakeholders within the fashion sector, implying that feedback has been gathered from customers, however no information about their plans for scalability or continuous improvements were found. However, Comistra seem to be a company with focus on the local level, Prato, which may imply that they have no aim or need to scale further. Altogether, Comistra achieves a technical maturity level of eight in this assessment. To achieve level nine, Comistra needs to show that they work with continuous improvements, optimisation of technology and that production is ongoing.

BRL

Limited information exists about Comistra's business model, making it difficult to fully assess their cost structure, revenue streams and scalability. However, there is a significant gap in the recycled wool market (only 6% of global wool is recycled (Cikis Studio, 2022 a), which indicates growth opportunities for Comistra. Comistra has conducted an LCA, although no comparison between regenerated and virgin wool was made. Their long-standing market presence and consistent sales suggest that they are in the business deployment phase and at a higher BRL. Therefore, Comistra achieves business model maturity readiness level eight in this assessment. Reaching level nine would require evidence of long-term profitability, scalability and environmental and social performance data.

CRL

Comistra has showcased one clothing collection in collaboration with Modartech (Comistra, n.d. e), but lacks information on where their products can be purchased by end-customers or details about downstream partnerships. Despite this, Comistra's 100-year history implies success in navigating various stages of customer readiness, including need confirmation, solution validation and confirmed sales. Their local, small-scale focus and long-term market presence is an indication of having achieved a high level and therefore, they achieve a customer maturity level of eight in this assessment. To achieve level nine, they need to confirm that clothes or textile applications containing regenerated wool are available for purchased by end-users, and that their sales are consistent and predictable.

CuRe Technology

CuRe Technology is a polyester recycling company, founded in 2018, that uses various types of input materials. These range from transparent plastic packaging that is mechanically recycled to transparent PET granulate, to colourful plastic packaging and used textiles, which are chemically recycled to remove contaminants like colour, achieve purification and restore molecular weight (Circular Textile Days, 2022; CuRe Technology, n.d. a; Fashion for Good, 2024).

Their goal is to process all types of polyester by purifying it and processing it into high-quality, 100% recycled PET, which can replace PET made from fossil sources. CuRe Technology formed a consortium in 2018 with several strategic partners, including NHL Stenden University of Applied Sciences, to develop their technology and make it scalable. Drawing on their lab-scale experiences, they have since 2018 been running laboratory trials, and in 2020 they launched a pilot plant in Emmen, in the northeast of the Netherlands. This plant focuses on the first phase of recycling techniques, depolymerisation and purification, with a capacity of 20 kg per hour in a continuous process. In 2021, the pilot plant expanded to include the second phase of the recycling techniques, repolymerisation (Circular Textile Days, 2022; CuRe Technology, n.d. b; Fashion for Good, 2024). According to CCO Josse Kunst (2024) the pilot plant serves as the facility where they conduct experiments with various input materials, demonstrating the capability to recycle all polyester-containing products. In terms of input material, CuRe Technology has established multiple collaborations with partner companies, receiving direct textile inputs from sources such as a mattress manufacturer and sportswear brands.

CuRe Technology states that once the chemical recycling technology is validated and tested, the knowledge gained will be used to build a demonstration plant for depolymerisation and repolymerisation with a capacity to recycle 25 000 tons per year (Circular Textile Days, 2022). The demonstration plant will be up and running in 2026, utilising packaging waste as a start, and eventually post-consumer textiles according to Kunst (2024). Building on this, a large-scale expansion is planned, with further collaboration with industry partners to achieve closed-loop recycling at scale for various types of polyester products, including post-consumer textiles (Circular Textile Days, 2022; CuRe Technology, n.d. a).

In a patent published in 2022, CuRe Technology´s method to enable recycling of polyester and a system for applying the method, is further explained. It includes a process for recycling polyester, regardless of the molecular weight in the waste material, using a technique called alcoholysis. This technique breaks down polyester into smaller components through a two-stage process. In the first stage, polyester is fed into an extruder that operates at a temperature above the melting point of polyester. During this stage, a specific amount of alcohol is added to facilitate the breakdown of the polyester into a fluid mixture that contains partly depolymerised polyester. In the second stage, this fluid mixture is transferred to a continuously stirred tank reactor. In the reactor, it is maintained at a high temperature while a second amount of alcohol is added. The mixture remains in the reactor for a set period, allowing it to fully depolymerise into oligomeric esters, which are smaller, usable components (Brons, et al., 2022).

In 2024, CuRe Technology´s second patent was published "A method to recycle a stream of polyester waste material and a system for applying the method," which differs slightly from the first. The latest patent emphasises a recycling process using a two-stage depolymerisation method to produce oligomers, whereas the first patent focuses on an integrated process for both depolymerisation and repolymerisation (Schmidt, et al., 2024).

In 2022, CuRe Technology joined the T-REX Project (T-REX, 2022; T-REX, n.d.), which aims to create a circular system for recycling post-consumer textiles. This project seeks to develop a harmonised EU blueprint for closed-loop sorting and recycling of household textiles. Over three years until 2025, the project aims to collect and sort textiles while demonstrating the full recycling process for polyester, polyamide 6, and cellulosic materials, ultimately turning them into new garments (CuRe Technology, 2022). According to Kunst (2024), within the T-REX project, CuRe Technology received post-consumer polyester from Spain and France. In the first round, they specified a maximum contaminant level of 5% in the post-consumer polyester textiles. However, testing revealed contamination levels as high as 20%, which exceeded what the recycling process can handle. They are also working with Fashion For Good, a platform for sustainable fashion innovation, currently on a project producing t-shirts. Yarns have been spun, and the t-shirts will be completed in the end of 2024. According to Kunst (2024), thanks to the T-REX project and collaboration with Fashion for Good, they have tested post-consumer recycled fibres in garments, working closely with multiple stakeholders. They are now in the process of validating their technology at the garment level (Kunst, 2024).

Currently, CuRe Technology is partnering with Adidas and is investigating how the composition of Adidas clothes and garments aligns with CuRe Technology’s recycling requirements. The goal is to adapt design and material choices in new clothing collections to enable recycling when the garments reach the end of their life cycle (Circular Textile Days, 2022). According to Kunst (2024), recurrent testing in close collaboration with Adidas has been done to improve the quality of the fibres for use in clothing. Additionally, they have their business model in place and believe that their recycled polyester will be profitable, which according to Kunst (2024) was a requirement when planning and building the demonstration plant.

CuRe Technology have performed an LCA on 1 ton of their recycled polyester fibre from post-consumer textiles (recycled in their pilot plant), which shows that it has 85% lower carbon footprint than 1 ton of virgin polyester (both scenarios used a European energy mix). Once the demonstration plant is up and running, a new LCA has to be performed (Kunst, 2024)

Assessment of CuRe Technology

The overall evaluation for CuRe Technology is shown in Figure 7. CuRe Technology achieves six for TRL, six for BRL and three for CRL. For each readiness level, a motivation is provided below.

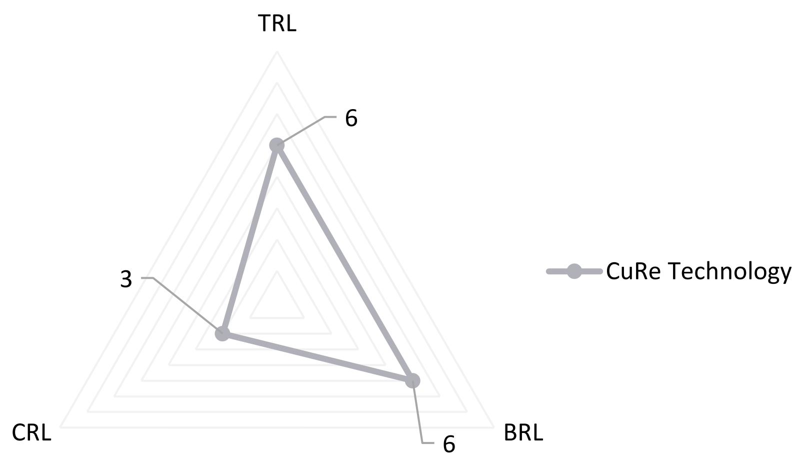

Figure 7. Radar chart with the assessment of TRL, BRL and CRL for CuRe Technology.

TRL

CuRe Technology has since 2018 made progress in developing its polyester recycling process. The company has moved from an initial idea and validated the technology in a laboratory, to the prototype phase, and are currently operating a pilot plant capable of processing 20 kg of material per hour (Circular Textile Days, 2022; CuRe Technology, n.d. a). The demonstration plant will launch in 2026, but not utilise post-consumer textiles at first, which limits the assessment. As a result, CuRe Technology's technical maturity level is six in this assessment. To achieve level seven, they need to prove that recycling of post-consumer textiles will work in the demonstration plant (operational environment) and that the recycled PET meet all quality requirements, for use in clothing or textiles applications, is necessary.

BRL

CuRe Technology has a business model in place and are convinced of profitability (Kunst, 2024). They have formed partnerships with industry leaders, including a close collaboration with Adidas, indicating that they are in the business deployment phase. They are participating in two projects with the aim to enable a circular system for recycling of post-consumer textiles (CuRe Technology, 2022; Textile Today, 2021). Additionally, they have conducted an LCA on their recycled polyester, showing its environmental benefits, compared to virgin polyester. Therefore, CuRe Technology ´s business model maturity level is set to six in this assessment. To reach level seven, the company need to show viability of their business model, by for example validating it through initial sales of their recycled PET from post-consumer textiles.

CRL

Up until now, CuRe Technology has actively collaborated with partners to align garment designs with recycling requirements (Circular Textile Days, 2022). Their innovative potential has been recognised, and they have a partnership in place with sportswear company Adidas, which indicates that the need for their recycled PET is confirmed by customers. However, the first piece of clothing from their recycled polyester is still under development as part of an EU-funded project at the time of this study (October 2024), and garment design is to be validated during the end of 2024. As a result, CuRe achieve a customer maturity level three in this assessment. To reach level four, garment design must be validated, relationships with customers need to be established and their first piece of clothing showcased.

Ioncell

Ioncell Oy (hereafter Ioncell) began as a research project stemming from a collaboration between Aalto University and the University of Helsinki (Aalto University, 2018; Remington, 2022; Michud, et al., 2015). Over nearly a decade, starting with technology and product development in 2013, research has led to the creation of the Ioncell process, a chemical recycling process. This process enables the dissolution of cellulose, which is then extruded into fibres using dry-jet wet spinning (Ioncell, n.d. a). According to the company's roadmap for commercialisation, a pilot plant was commissioned during 2021 to 2022, which would enable continuous manufacturing with an expected output of up to 10 kilograms a day (Aalto University, 2022; Ioncell, n.d. b). The start-up company, Ioncell Oy, was established in 2022. The next step in commercialising the Ioncell process is to achieve proof of concept for continuous production at the pilot plant (Ioncell, n.d. b; Rönkkö, 2024). At the time of writing (autumn 2024), they are seeking funding for progress with the pilot plant, as well as for scaling up and further commercialisation activities. The company holds a number of peer-reviewed scientific articles and patents (Ioncell, n.d. a). According to CEO Antti Rönkkö (2024), they have a long-term goal (20-40 years) to achieve a 5-10% market share of all textile fibres produced globally. Ioncell fibres can be used in the same applications as lyocell fibres, as the characteristics are very close to each other. Further, they aim to replace virgin fibres in different textile products like viscose, cotton, polyester, and not only lyocell (Rönkkö, 2024).

The Ioncell process utilises pulp as input material derived from wood or other cellulosic materials such as used textiles or old newspapers, which are dissolved using an ionic liquid as solvent, specifically [mTBDH][OAc] 7-methyl-1,5,7-triazabicyclo[4.4.0]dec-5-enium acetate, without co-solvents or stabilisers (Rönkkö, 2024). The only chemicals applied are the non-toxic ionic liquid and water, which are re-circulated in the process in a closed loop system. In the dissolved state, the cellulose can be extruded through a spinneret to create new Ioncell fibres. According to Michud et al. (2015) and Hussain (2023), Ioncell fibres possess several advantageous properties. They are strong, even when wet, and have a silk-like feel. The fibres are said to reflect colour very well, making them suitable for both clothing and technical applications (Michud, et al., 2015; Hussain, 2023). Additionally, Ioncell fibres are described as a viable alternative to high-impact raw materials like cotton and polyester. They are stronger than viscose and surpass the tenacity of commercial lyocell fibres. Moreover, Ioncell fibres have a lower environmental footprint than viscose and could be an environmentally friendly alternative to the water-intensive cotton production process (Aalto University, 2018; Hussain, 2023). Further, the technology could be used to separate cellulose and polyester from polycotton textiles (Hussain, 2023). According to Ioncell (2024), once the Ioncell process is commercialised, the company plan to use pulp made from cellulosic textile waste as raw material, purchased from external partners. Additionally, modal and hemp have been successfully used as raw material to produce Ioncell fibres (Rönkkö, 2024).

Ioncell has published several scientific articles. In one article from 2016, cotton textiles sourced from hospital bed sheets were recycled using the Ioncell process. Although the input material was pure cotton, challenges arose from finishing chemicals like lubricants and softeners, causing non-homogeneity and variations in molar mass. Pre-treatment was needed to adjust the cellulose's degree of polymerisation, and the cotton was blended with birch pulp to ensure the spun fibres had adequate physical properties (Asaadi, et al., 2016).

An article from 2019 demonstrates the potential of recycling white post-consumer cotton and polyester textiles and using it as input material for fibre spinning (Haslinger, et al., 2019). The textiles were first shredded and blended to a mixture of 50% cotton and 50% polyester and then pre-treated by VTT Technical Research Centre of Finland to remove contaminants, such as synthetic fibres and metals. Additional pre-treatments were necessary for the cellulose fraction to ensure a sufficient degree of polymerisation and an appropriate molar mass distribution. The spun cellulose fibres were found to have properties similar to lyocell, with linear densities ranging from 0.75 to 2.95 dtex, breaking tenacities of 27–48 cN/tex, and elongations of 7–9%. To achieve commercialisation, Haslinger et al. (2019) specify that developing efficient and reliable techniques for sorting and identifying materials in heterogeneous post-consumer textiles is essential (Haslinger, et al., 2019).

In a doctoral dissertation from 2021 on using the Ioncell process to produce textile fibres from birch, Elsayed (2021) outlines important criteria for commercialising the Ioncell process. These criteria include selecting a solvent with strong cellulose dissolution capabilities, ensuring a stable spinning process, achieving good mechanical properties in the regenerated fibres, and, most importantly, quantitatively recovering the solvent from the coagulation bath without compromising its solvation power (Elsayed, 2021).

Ioncell collaborates with textile recyclers, brands, and retailers to source used textiles and production scrap (Hussain, 2023). According to Rönkkö (2024), Ioncell operates within the value chain of cellulosic chemical recycling, which is significantly different from mechanical recycling. This value chain includes activities as collection, sorting, and pulping—where the pulping step acts as a pre-treatment process that removes impurities. After this, Ioncell purchases the pulp and process it into Ioncell fibres, which can then be integrated into the traditional lyocell value chain. The final product i.e., the recycled Ioncell fibres, can take different pathways and bought by customers downstream in the textile value chain before reaching the end-customer (Rönkkö, 2024). Ioncell displays several demonstration products, most of them made from birch pulp, but one knitted garment made of recycled cotton is showcased as a result from a project called "Trash-2-Cash" (Ioncell, n.d. c). However, no information was found about the origin of the cotton.

Assessment of Ioncell

The overall evaluation for Ioncell is shown in Figure 8. Ioncell achieves four for TRL, four for BRL and four for CRL. For each readiness level, a motivation is provided below.

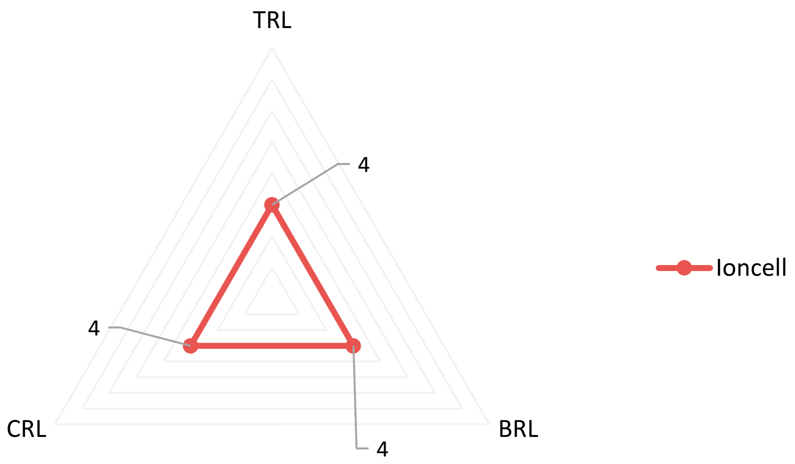

Figure 8. Radar chart with the assessment of TRL, BRL and CRL for Ioncell.

TRL

Ioncell has made progress in developing the Ioncell process, which utilises pulp derived from wood or other cellulosic materials to produce fibres. The process has advanced from an initial concept to the prototype phase, where tests have been conducted in a laboratory environment. In 2021, a continuous pilot plant was launched at Aalto University that processes wood-based materials and textiles into fibres, aiming for a closed-loop operation with 100% solvent recovery (Aalto University, 2021). This indicates progress toward technology validation in a relevant environment. According to Ioncell (n.d. b) and Rönkkö (2024), Ioncell's next step is to provide proof of concept for the continuous production process at the pilot plant. As a result, Ioncell's technical maturity level is assessed to four. To achieve level five, Ioncell needs to demonstrate proof of concept for the continuous production process at the pilot plant.

BRL

The Ioncell process is similar to the commercial lyocell process, which makes Ioncell fibres suitable for use in the traditional lyocell value chain, a market that is growing according to Rönkkö (2024). Further, Rönkkö (2024) means that an initial indication of primary costs, revenue streams and financial model can be outlined by comparing it to the lyocell process. Ioncell have done a first assessment of the environmental impact from their process, and they use less chemicals than in the traditional lyocell process (Rönkkö, 2024), indicating that Ioncell are in the business testing phase. Additionally, Ioncell are improving their process to achieve a closed-loop system, indicating a goal of resource efficiency. Ioncell’s business model maturity level is assessed to four in this assessment. To reach level five, Ioncell would need to test their business model and gather feedback from potential customers.

CRL

Ioncell has presented a garment made from recycled cotton and collaborated with Marimekko (Ioncell, n.d. c), emphasising a need for their recycled fibres from downstream customers. The Ioncell fibres are comparable with commercial lyocell fibres, indicating a clear positioning against competitors. However, there is no evidence that clothing or textile applications containing Ioncell fibres, made from post-consumer textiles, are currently available for purchase by consumers. Discussions with potential customers are ongoing according to Rönkkö (2024), proving that customer relationships are under development and that there is an interest for Ioncell’s recycled fibres. Therefore, Ioncell achieves a customer maturity level of four in this assessment. To achieve level five, Ioncell needs to confirm the need for their recycled fibres from more customers as well as establish relationships with customers.

Recover

Recover™ (hereafter Recover) is a Spanish company with more than 75 years of experience of using fibres in yarn spinning and textiles. They are a global producer of low-impact, high-quality mechanically recycled cotton fibre and cotton fibre blends (Recover, 2024 a). Recover employed around 300 people in 2023 and has production hubs in Spain, Bangladesh and Pakistan. The company utilises textiles, both pre- and post-consumer, as its primary raw material, delivering two different product lines: Rcotton and RcolorBlend, described below (Recover, 2024 b).

- Rcotton consists of 100% recycled fibres and include three products:
  - Rpure: 100% unblended recycled cotton fibres.
  - Rmix: more than 90% unblended recycled cotton fibres from cotton-blended textiles, contains up to 10% of other fibres.
  - Rdenim: more than 80% recycled cotton fibre from pre- and post-consumer denim, with up to 20% other fibres.
- RcolorBlend: Combines at least 50% recycled cotton fibres with recycled polyester or organic cotton, dyed to create new blends.
  - Rblue: 52% recycled cotton blended with 48% recycled PET.
  - Rearth: 50% recycled cotton blended with 50% organic cotton.

In their sustainability report for 2022, Recover stated that they primarily use pre-consumer textiles, which is sorted by colour and composition by suppliers. Approximately 1% of the recycled cotton production at the Spanish hub came from post-consumer textiles, and in Bangladesh resources purchased came mainly from pre-consumer textiles. The company strives to scale up production of fibre-to-fibre recycling (Recover, 2023), but in the report for 2023 they state that they face challenges in sourcing large quantities of suitable post-consumer textiles for their processes (Recover, 2024 b). In 2023, the company did an environmental, social and governance assessment on all their textile suppliers in Bangladesh, where a majority of the textiles are sourced from. In the assessment, areas for improvement were identified and during 2024 these improvements will be implemented by the suppliers (Recover, 2024 b). In 2022, Recover launched a production hub in Dhaka, Bangladesh. The facility's location is stated to be strategic to reduce transportation within the supply chain by being close to both the supply of textiles and the demand for recycled fibres (Recover, 2023).

Recover buys pre- and post-consumer textiles that is already sorted by colour and material composition (Cikis Studio, 2022 b). The recycling process begins with large pieces of textiles being cut into smaller pieces. Non-textile components, such as buttons and zippers, are then removed. The small textile pieces are treated with an anti-static spray, using minimal water, to prepare them for the next step. These pieces are then shredded in an automated machine using a proprietary formula unique to Recover. Finally, the fibres are baled and sold to customers (Recover, 2024 c).

The fibres produced by Recover have diverse applications, in apparel, accessories and home textiles. Recover have partnered with leading global brands and retailers. For example, the European retailer C&A have made a collection with Recover (Recover, 2024 b). Currently, the majority of recycled cotton from Recover, which is used in C&A clothes, is sourced from post-industrial cotton, such as cutting scraps from suppliers (C&A, n.d.). Additionally, Recover also have a long-term partnership with Primark (Recover, 2023).

Recover has made an LCA on Rpure and Rblue, two products that both are made in Spain and compared it to conventional alternatives. The results show, amongst other, that 1 kg of Rpure saves 2 116 litres of water and cuts down global warming potential by 1.73 kg CO_2-equivalents. Rblue saves 1 195 litres of water and lowers global warming potential by 6.38 kg CO_2-equivalents, For the products made in Bangladesh and Pakistan, LCAs are planned to be performed during 2024. Recover also track and report their emissions in scope 1, 2 and 3 (Recover, 2024 b).

Recover places emphasis on research and development, collaborating with spinning and weaving companies to create yarns and fabrics that meet industry qualities. In 2022, the company approved a total of 269 yarn qualities and 49 fabric qualities, reflecting their commitment to innovation and quality (Recover, 2023). They also perform research and development projects on how to increase the percentage of their recycled fibres in the final products (Recover, 2024 b).

Assessment of Recover

The overall evaluation for Recover is shown in Figure 9. Recover achieves seven for TRL, seven for BRL and three for CRL. For each readiness level, a motivation is provided below.

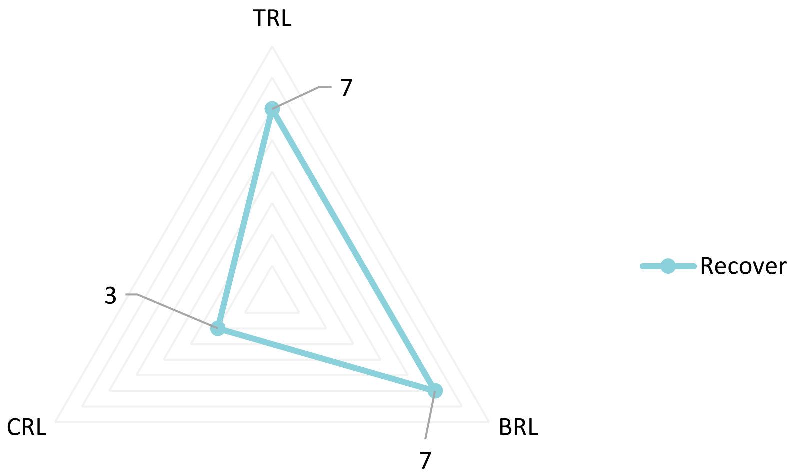

Figure 9. Radar chart with the assessment of TRL, BRL and CRL for Recover.

TRL

Recover's mechanical recycling technology is demonstrated in an operational environment across three facilities, though only the facility in Spain currently processes post-consumer textiles. This indicates that the technology remains in the validation phase. Recover aims to scale up its fibre-to-fibre recycling technology (Recover, 2023) but faces challenges in sourcing large quantities of suitable post-consumer textiles. These sourcing challenges suggest that Recover has identified specific quality requirements for recycled fibres to be used in clothing or textile applications, which narrows the range of acceptable input material. Consequently, Recover achieves a technical maturity level of seven in this assessment. To reach level eight, the technique must be fully developed and operationally validated. For instance, by demonstrating an increased percentage of post-consumer textiles in their recycling process.

BRL

Recover has scaled its operations with new facilities and clearly demonstrates the environmental impact with LCAs on two of its products, in addition, more LCAs are planned during 2024 (Recover, 2024 b). Through collaborations and multi-year contracts with various brands and customers, they have developed two product lines. This indicates a business model supported by sales evidence, showing they are in the business deployment phase. While no specific revenue information was found, their two product lines indicate that their sales are assumed to be consistent and predictable, although the amount of their revenue generated from recycling post-consumer textiles is uncertain. Therefore, Recover´s business model maturity level to seven in this assessment. To reach level eight, they would need to provide more evidence on their revenue streams and profit for recycling of post-consumer textiles.

CRL

To date, Recover has collaborated with several brands, suggesting that they have defined their customer and end-user segments. Their recycled fibres are featured in various clothing collections, indicating confirmed demand from customers, even though the input material is predominantly pre-consumer. Based on this, Recover achieves a customer maturity level of three in this assessment. To reach level four, Recover must demonstrate that recycled fibres derived from post-consumer textiles are viable for use in clothing and textile applications, for instance, by showcasing a garment or textile application and clearly positioning their recycled fibres against alternative options.

Worn Again

Worn Again, a UK-based company, specialises in chemically recycling textiles. Founded in 2005, the company initially focused on upcycling textiles. In 2012, Worn Again advanced its efforts by beginning laboratory tests on textile dissolution. In 2019 Worn Again opened a pilot plant with the aim to validate their technology, by increasing the capacity by a hundred times, compared to lab scale. Worn Again secured funding in 2022 for building a demonstration plant in Winterthur, Switzerland, which would increase the capacity a thousand times – and reach a capacity of 1 000 tons textile per years, compared to the pilot scale (Worn Again, n.d. a). The location of the demonstration plant is in an industrial park of textile machinery and near one of their technical partners, Sulzer Chemtech (Worn Again, n.d. b). The demonstration plant was planned to start up during 2024 (Worn Again, n.d. a), but no updated information about its progress could be found. According to an interview with CEO Cyndi Rhoades, Worn Again plans to have 40 operating plants by 2028 with a total capacity of 50 000 tons per year (Business Life, 2019).

In the recycling process, Worn Again can utilise both polyester (including PET bottles and packaging) and cotton from post-consumer sources (Worn Again, n.d. a; Worn Again, 2018). Their technology also enables the separation of polyester and cotton when they are blended in a textile material (Worn Again, n.d. a). The input textile material can contain up to 10% other materials like dyes, wool, elastane, nylon etc. (YnFx, 2021). Before the textiles arrive at Worn Again, it has been sorted by fibre type and zippers and buttons have been removed (Worn Again, n.d. a). The recycling process includes cleaning, separating, and decontaminating the fibres in the textiles. This is done with special chemicals to decontaminate the fibres from dyes and finishes, to separate the polyester and cotton textiles. The chemicals used in the separation process are captured and regenerated in a closed-loop system (Worn Again, n.d. a). According to an interview with Worn Again from 2020, their final product should be cost competitive and have a quality comparable with virgin material. Additionally, the recycling process should have a lower negative environmental impact, compared to conventional production (Waste360, 2020), however no information about the process' environmental impact has been found.

Worn Again, sells two different types of products: PET resin in pellets form and cellulosic pulp. The PET is chemically identical and has the same molecular weight as virgin PET. According to an interview with the company from 2020, the cellulosic pulp can be reintegrated into the viscose supply chain and used interchangeably with wood pulp (in production of viscose and lyocell for example) (Waste360, 2020).

Worn Again's patent (Australia Patent No. AU2020265790B9, 2020) outlines details of separating polyester and cotton to retrieve PET resin and cellulosic pulp. The inventors found that it is crucial to extract the polyester first, as the solvent used to dissolve cellulose can damage or degrade polyester if left in the mixture.
By extracting polyester first, its integrity is maintained, ensuring an efficient recycling process (Hauru, et al., 2020). The solvent for extracting the polyester is made up of compounds categorised under a set of chemical formulas, referred to as Formula I to VI. Each formula defines different structures, incorporating elements such as hydrogen, various hydrocarbon groups, oxygen, and sulphur. This flexibility allows the solvent's properties to be customised, optimising the polyester extraction process (Walker, 2013). After extraction of the polyester, the cellulose is first wetted with a solvent and then exposed to another solvent. This mixture is then kept at a specific temperature for a time-period, followed by another set time period, in order to fully dissolve the cellulose. Finally, the dissolved cellulose is separated from the solvents and can be recovered by adding an anti-solvent to precipitate the cellulose. According to the patent owned by Worn Again, this

process is considered superior to previous methods due to its cost-effectiveness, and that it uses non-hazardous solvents (Hauru, et al., 2020).

Worn Again have a recently started project called "Towards a NetZero Plastics Industry" together with Institut für Werkstofftechnik und Kunststoffverarbeitung and Sulzer. The project is funded by the Swiss Innovation Agency and will run from 2024 to 2028 with the goal to create a platform for Swiss companies to collaborate within the sustainable plastics industry. Worn Again's role in the project is to convert used textiles into a higher-grade PET, however the PET will be processed by Sulzer into advance foams and not textile fibres (Worn Again, 2023). Worn Again has initiated the network called "Swiss Textile Recycling Ecosystem" with the aim to gather key industry players in the textile value chain. The network includes textile manufacturers, textile collectors and sorters, retailers, brand owners and technology providers. Worn Again will receive different types of textiles from the partners with the aim to use in the demonstration plant (Worn Again, 2022).

Worn Again have received investments from H&M early on in the development of the technology, and also from Sulzer and Oerlikon joining a couple of years later (Worn Again, n.d. a). According to the interview with Rhoades, the customers of Worn Again are fibre spinners that manufactures polyester and viscose, and it is important that actors in the circular value chain collaborate, hence why their investors are involved (Business Life, 2019).

There is no data available on whether the PET resin or cellulosic pulp derived from Worn Again's recycling process have been used in clothing or textile applications, or if any tests or feedback mechanisms involving end customers and markets have been conducted. Additionally, no information has been found regarding environmental assessments that measure the benefits of the recycled material or the recycling process itself.

Assessment of Worn Again

The overall evaluation for Worn Again is shown in Figure 10. Worn Again achieves five for TRL, three for BRL and three for CRL. For each readiness level, a motivation is provided below.

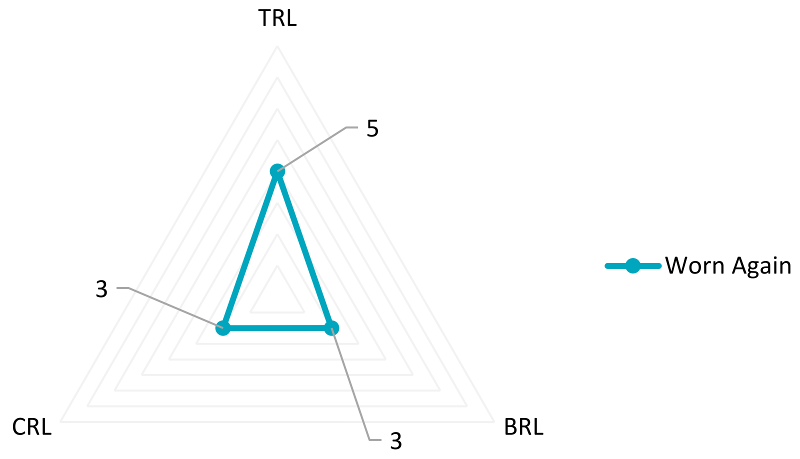

Figure 10. Radar chart with the assessment of TRL, BRL and CRL for Worn Again.

TRL

Worn Again has demonstrated that post-consumer textiles made from polyester and cotton can be recycled in their process (Walker, 2013; Hauru, et al., 2020), with a pilot plant established in 2019, indicating they are in the prototype phase. Additionally, a demonstration plant is planned for 2024, strategically located for close collaboration with customers (Worn Again, n.d. b). However, no information about developments or produced amounts in the demonstration plant was found, limiting Worn Again's technical maturity level to five in this assessment.
To achieve level six, Worn Again must provide updated information on the viability of its demonstration plant, as well as confirm that the quality of the recycled PET resin or cellulosic pulp is suitable for use in clothing or textile applications.

BRL

Worn again plans for scaling and growth, moving from the conceptualisation phase to the business testing phase implies that that the business model for recycling textiles is described, and in place. However, no information on primary costs, revenue streams, environmental or social impact was found. Worn Again is participating in a project and a network aimed at collaboration in textile research, development, and manufacturing (Worn Again, 2022; Worn Again, 2023). Additionally, they have three investors, all of whom are active in the textile value chain (Worn Again, n.d. a). As a result, Worn Again's business model maturity level is three in this assessment. To reach level four, they would need to provide details on financial planning and conduct an initial environmental and social impact assessment.

CRL

Worn Again has attracted interest from investors such as H&M, indicating a need for their recycled PET resin or cellulosic pulp from customers. However, there is no evidence that an actual piece of clothing or textile application containing their recycled PET resin or cellulosic pulp is currently available on the market and can be bought by end-customers. As a result, Worn Again achieves a customer maturity level three in this assessment. To reach level four, Worn Again must confirm the need for their recycled material from customers and identify their customer and end-user segments, demonstrate a clothing piece or textile application, and position their recycled PET resin or cellulosic pulp against its alternatives.

Compilation of assessed recycling companies

A compilation of all assessments is shown in Figure 11. Overall, technology seems to be the most progressed level out of the three, for all companies, with a mean value of 6.5. Close behind is the business model, with a mean value of 6.2, followed by customer readiness maturity level, with a mean value of 5.0. No company was assessed to be in the lowest levels (one or two) of any of the parameters. TRL and BRL varied for the companies, more so than CRL, where the companies clustered more in the mid-lower levels (three and four) or in the higher levels (eight and nine). The mechanical recycling companies (Comistra and Recover) had mean values of 7.5 for TRL and BRL and 5.5 for CRL. As for the chemical recycling companies (Aquafil, CuRe Technology, Ioncell and Worn Again), the mean values were 6 for TRL, 5.5 for BRL and 4.8 for CRL.

The three companies which achieved the lowest TRL (CuRe Technology, Ioncell and Worn Again) are all working with a chemical recycling technique. However, Aquafil also work with a chemical recycling technique, but achieved the highest TRL. Regarding BRL, Aquafil was the only company that provided information about revenue from their recycled nylon. The companies which achieved BRL six or higher BRL (Aquafil, Comistra, CuRe Technology and Recover) all provided information about partnerships and environmental assessments on their products. Only two companies (Aquafil and Comistra) had gained a CRL on the higher end of the scale. These two companies were the only ones that presented products containing their recycled material, which could be bought either by customers or end-users. For the other four companies, no textile products, made from post-consumer waste, were available for purchase by end-users.

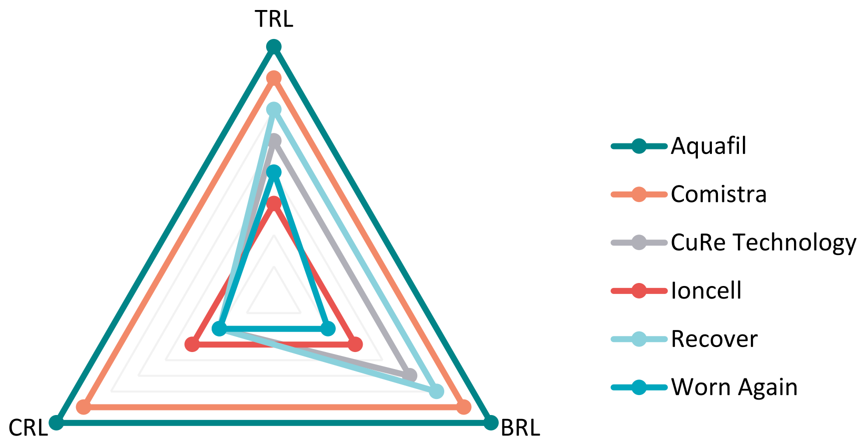

Figure 11. Radar chart with the assessment of TRL, BRL and CRL for all assessed companies.

Discussion

This study had two research objectives: firstly, to identify an assessment model that can be used to evaluate fibre-to-fibre recycling companies progress in entering the textile recycling market. Secondly, to use the model to assess the recycling companies. In this discussion, limitations with the assessments are presented, followed by a discussion about what is needed to scale fibre-to-fibre recycling in Europe.

Limitations with the assessment model

This assessment model enables an evaluation of fibre-to-fibre recyclers in Europe; however, there may be other models available for assessing a company's progress in entering the textile recycling market, that also can be used. By assessing the recycling company's TRL, BRL, and CRL, this assessment also captures other important aspects than only achieving a high technical maturity level. BRL incorporates the significance of attaining economic feasibility while also accounting for the environmental and social dimension, and CRL captures customer and end-user needs, including the importance of thoroughly understanding aspects such as their willingness to pay for recycled textile and competitive landscape.

For BRL, the study's insight into key economic factors such as pricing, margins, supply chain establishment and production costs, and available investment capital is limited. For CRL, this study lacks complete information about the companies' downstream customers and brands, which they may collaborate with to incorporate their recycled textile into clothes or textile applications. As a result, the demand for the recycled textile in textile or clothing applications is evaluated based on whether the recycling company presents products that can be identified and purchased through internet searches. This is, of course, an interpretation that may result in certain products being overlooked.

Maturity of the assessed fibre-to-fibre recycling companies

Higher maturity assessments may depend on many factors. However, as supported by the literature, mechanical recycling is a relatively well-established technique, partly due to its simplicity and low cost (Andini, et al., 2024). Nevertheless, since it cannot separate blended materials, this method has significant limitations. Due to these limitations, chemical recycling may emerge as a valuable alternative as this method has the possibility to separate blended textiles. However, when it comes to limitations, this type of techniques is generally more expensive (Abrishami, et al., 2024).

Two companies, Aquafil and Comistra stand out in this assessment, with high levels for all three parameters. Aquafil specialises in chemical recycling, producing regenerated nylon under the ECONYL brand, which has gained a strong global presence over the past decade. In contrast, Comistra, with over a century in the industry, focuses on mechanical recycling of wool, appears to concentrate primarily on a regional market. Their respective success highlights how both chemical and mechanical recycling methods can take market positions despite their advantages and limitations. Both companies, regardless of world-wide or regional, have progressed and found their place in the market. These examples show that not only large companies with ambitions to target thousands of customers can be successful and make an impact.

Aquafil, Comistra and Recover all have other products than just the recycled textile, which could have facilitated the diversification of the company's products and their progress in recycling textiles as well. This could be viewed as a key strength of their strategies and market approaches. By comparison, CuRe Technology, Ioncell and Worn Again have focused solely on recycling textiles, having begun by developing their technologies within a laboratory setting — a strategy that, in this regulatory environment, may be a weakness.

Large versus small-scale recycling companies

A question is whether only large, established companies possess the resources and confidence to venture into the market of recycling post-consumer textiles. Larger companies often have greater financial stability, established supply chains, and access to advanced technologies that facilitate the integration of recycled textile. One example of this is Aquafil, which achieved the highest readiness level for all parameters in this assessment. Aquafil has established a global market presence with its ECONYL brand for over a decade.

A larger company may have a more substantial impact on transforming the linear textile value chain, into a more circular one, by introducing recycled textile into clothing and textile applications. This in turn may reduce the need for virgin resources and increase the amount of post-consumer textiles that are utilised and processed into recycled textile. However, this does not mean that smaller companies or startups cannot establish themselves in the market. As shown in the assessment of Comistra, with over a century in the industry, primarily focuses on a regional market, achieved level eighth for all three parameters.

Even more, small-scale companies operating on a more local level can also play a crucial role. These companies often act as innovation hubs, experimenting with unique materials, sustainable practices, and localised supply chains that larger companies might be slower to adopt. Although they may lack the finances and market reach of larger corporations, their agility and focus on sustainability may allow them to make quick decisions in close collaboration with their customers. The challenge for smaller companies often lies in overcoming initial barriers to entry, such as securing a reliable input material, and building brand recognition. However, with increasing consumer demand for sustainable products, there are plenty of opportunities for smaller companies to find their place in the market.

Scaling of fibre-to-fibre recycling

In order to scale fibre-to-fibre recycling, the literature identifies several challenges (Charnley, et al., 2024; Stindt, et al., 2016; Textile Exchange, 2024; McKinsey & Company, 2022). Many of these challenges arise from a lack of clarity regarding the enabling conditions necessary to scale the process effectively across the value chain, as well as how to achieve economic viability in collection and sorting of post-consumer textiles (Charnley, et al., 2024). While processes for collection and sorting are not the primary focus of this study, they are significant for enabling fibre-to-fibre recycling and meeting the requirements for input material. Another enabler is how the regulatory landscape will impact and create favourable conditions for handling post-consumer textiles according to the waste hierarchy, ensuring that when textiles are unsuitable for reuse, are recycled to support the transitioning into a circular textile ecosystem. All the recycling companies in this study operate within the European market, thus are subject to the same regulatory landscape. While this study does not assess regulatory differences, it is important to acknowledge that the regulatory environment plays a critical role in this transitioning.

An example of a challenge within the recycling industry, and might hinder scaling, is to source sufficient volumes of suitable post-consumer textiles. This issue may be attributed to the higher quality requirements for input materials to produce recycled textile that meet standards for specific applications. Another challenge in scaling fibre-to-fibre recycling is the large number of blended textiles in clothing (Charnley, et al., 2024). These materials cannot be recycled using traditional mechanical methods because mechanical recycling cannot separate blended fibres. In this study, companies used different approaches to their input materials, often focusing on single types like nylon, polyester, or cotton. This focus on uniform materials limits the variety of post-consumer textiles that can be recycled. In this study, Worn Again is the only company aiming to separate polyester and cotton, and therefore prefers a blend of these material as input material. While this approach allows for a broader range of input material, it is essential to develop technology capable of separating the fibres without causing damage, ensuring both recycled cotton and polyester fibres can be used in clothes or textiles applications. This type of chemical recycling has the potential to significantly advance textile recycling by enabling the recovery of multiple fibre types from blended textiles, which are common in clothing today. By separating cotton and polyester at the molecular level, chemical recycling could transform the recycling of blended textiles that are typically unsuitable for mechanical recycling. The choice of recycling method—mechanical, chemical, or a combination of both—has its respective prospects and limitations. A balanced approach may be necessary to overcome current challenges and leverage the strengths of each method.

Regulatory measures and the textile strategy

An important aspect of scaling a technology into a market ready product or service is the favourable conditions created by legislation, often referred to as the *Regulatory Readiness Level*. As stated by Kobos et al. (2018), in the absence of appropriate market conditions or regulatory landscape, a technology´s development can stretch far beyond initial expectations.

In the context of the textile recycling market, conditions in the EU have in recent years been perceived as favourable. The introduction of the EU Textile Strategy and the regulation for separate collection of textiles seem to set the stage for a more structured and supportive regulatory environment. Additionally, discussions around a harmonised EPR system for textiles could create financial incentives and foster a more advantageous regulatory landscape. However, these discussions have not yet resulted in concrete outcomes, which also affects the favourable conditions for development in this sector. This regulatory gap is significant: without clear, actionable guidelines, companies may struggle to attract investment, navigate compliance, or confidently plan for long-term growth. The question remains: to what extent can textile recycling scale without more robust and specific regulatory support?

Can recycled textile truly make fast fashion sustainable?

Larger companies may have the resources and market reach to implement recycled post-consumer textiles at scale, but this can lead to rebound effects throughout the value chain and with end-users. For example, as larger recycling companies enable brands to incorporate more recycled textile into products, there is a risk that overall production and thus, consumption, could increase, with consumers perceiving these products as more sustainable and therefore purchasing more frequently. This could ultimately undermine the environmental benefits of using recycled materials by leading to higher resource use and waste generation overall.

The role of recycling companies supplying recycled textile to fast-fashion brands raises critical questions about the true sustainability of such partnerships. While recycling companies can provide an environmentally preferable raw material, supplying to fast-fashion brands may inadvertently support a high-turnover business model that encourages overconsumption and short life cycles of clothing. However, quality clothing, or clothing made from recycled textile, often comes at a higher price point, making it less accessible to consumers with limited budgets who may rely on affordable fast-fashion options. This reality highlights a key tension between sustainable materials and affordability. Recycling companies like Aquafil and Recover, can make recycled post-consumer textiles in clothes and textile applications more widely accessible, potentially raising consumer awareness and normalising the use of recycled textile. Both small and large-scale companies have their strengths, weaknesses and opportunities in the textile recycling market, and it is not obvious that one is better than another.

Conclusions

In this assessment, which encompasses both mechanical and chemical recycling companies, differences were observed in maturity levels, as well as in the techniques and input material requirements. Mechanical recycling companies generally demonstrated higher average levels across all three parameters compared to chemical recycling companies.

In this project, it has become clear that entering and establishing a position in the textile recycling market is challenging and involves more than just achieving technical maturity. It is important that the recycled textile is of sufficient quality, which can be used in clothes and textile applications. But it is equally important to develop a sustainable business model, including understanding the company's environmental and social impact. Additionally, it is essential to understand the value chain, by having partnerships and relations with downstream customers, to enable the integration of recycled post-consumer textiles into the textile value chain and reach out to end-customers with clothes or textile applications containing recycled textile.

A crucial factor for scaling recycling of post-consumer textiles, which might facilitate for the companies, is the regulatory landscape. To support companies entering the recycling market, the EU's textile strategy and upcoming regulations play a key role in creating favourable conditions as well as creating competitive economic landscape (between virgin and recycled fibres).

In a sustainable clothing future, the need for virgin fibres would decrease as the demand for recycled textile fibres grows, with a larger share of the fibres on the market originating from post-consumer textiles. This shift towards a circular economy would reduce dependence on virgin materials and facilitate greater resource efficiency. Achieving this vision requires collaboration between large and small-scale companies: larger companies can provide the scale necessary to influence global markets, while smaller companies can drive innovation and sustainable practices. By working together, the industry can shift towards a more circular textile industry. Not only regarding recycling post-consumer textiles that can be used in clothes and textile application, but also moving away from overproduction and overconsumption by testing new business models. It involves creating a textile value chain where existing textiles are used for as long as it is possible, and only when they are non-usable, they can be utilised for fibre-to-fibre recycling.

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This report has been reviewed and approved in accordance with IVL's audit and approval management system.