



Self-introduction

Please introduce yourself and where you work. What are you hoping to learn through this workshop?

Write what you think here:

.....

.....

.....

.....

.....

.....

.....

.....

.....

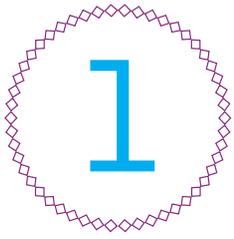
.....

OBJECTIVES

The objectives for this workshop are to enable you to:

1. Identify the main aspects of making sustainable material choices and adopting circular design;
2. Understand the core principles of “Design for Circularity,” emphasizing design for recyclability and longevity, along with the strategies that support these approaches.
3. Explain how circular design impacts sourcing decisions, product design, and the requirements for sorting processes.
4. Assess and analyze industry best practices in implementing strategies focused on recyclability and longevity-driven design.

SESSION



Designing for Circularity in the Textile and Clothing Industry



Answer the question

When we talk about “**designing for circularity**” in the textile and apparel industry, what do you think it means? What kinds of activities come to your mind?

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Making Sustainable Material Choices, Designing for Recyclability and Strategies for Garment Longevity

In this video, we will discuss circular design approaches to enhancing the recyclability and longevity of your textile and apparel.

By better understanding what you can do to make sure that your products can last a long time and can be recycled effectively at the end of their useful lives, you will be able to make better design decisions and choose more sustainable materials.

The topics we will touch upon include:

1. How to make sustainable material choices?
2. How to design for recyclability; and
3. Applying circular design strategies for garment longevity

Let's get started!

1. Choosing sustainable fibres and materials

There are many tools you can use to decide on the fibre and materials you use. Some are proprietary, while others are publicly available free of charge.

Among the freely available tools, Textile Exchange's Preferred Fibre & Material Matrix (PFMM) provides a comprehensive evaluation backed by a robust and transparent methodology. It can be used to make sustainable material choices and sourcing decisions by assessing the trade-offs of different sustainability certifications, initiatives, and branded materials.

You can access the PFMM tool here (scan the QR code):



Let's take a brief look at how it works.

How to use the PFMM tool

The PFMM tool enables **assessments across 5 fibre or raw material categories**: cotton, synthetics, manmade cellulosic fibres (MMCFs), flax, and wool. Each of these is further subdivided into a total of **60 preferred raw material categories**, some of which are associated with sustainability standards, and others which are not.

Each of these raw material categories is assessed across **8 core impact areas**: Climate, Water, Chemistry, Land Use, Biodiversity, Resource Use and Waste, Human Rights, and Initiative Integrity,

using a total of 80 indicators. PFMM assesses 68 categories over these 8 impact areas to produce an overall score for each.

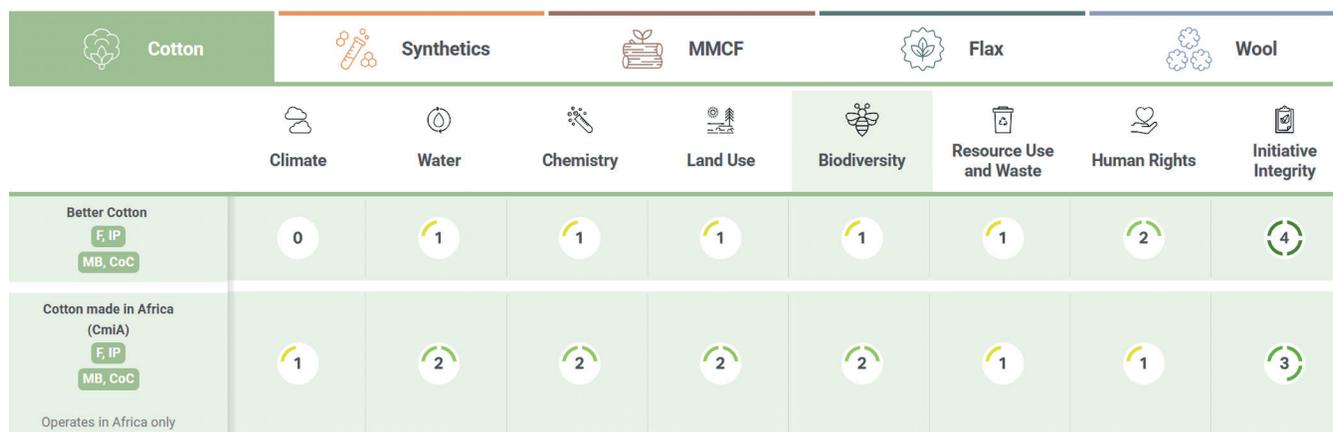


Figure 1.1. PFMM tool snapshot. (Source: Textile Exchange)

The PFMM tool's scores

The PFMM uses a scale of 0 to 4, with level 0 usually representing “status quo” production systems and Level 4 representing “transformational” performance. The impact area scores are determined by a weighting of 50% for the 6 quantitative indicators and 50% for the 74 qualitative indicators, where applicable.

To view a score, select a material of your choice, such as “cotton.” Then, select an impact area, such as “climate”. This will show you the score of each of the preferred raw material categories in percentage terms for each of the indicators, a brief description of its performance, and the overall “roll-up” score for the impact area.

Changing the materials you are using to move towards circularity

OK, so you’ve used the PFMM tool to look at different raw material categories and chosen one based on its circularity criteria. You will still need to implement a change within your business to move from whatever you are using currently to your new material.

Here, it is useful to see how others are doing, and how major international brands are managing their own material transition to more “preferred” materials for circularity. To do this, we recommend using Textile Exchange’s Material Change Index (MCI), which is available here (scan the QR code):



It is a comprehensive tool available free of charge that provides insights on the textile sector’s progress towards sourcing more sustainable materials by tracking and assessing leading brands.

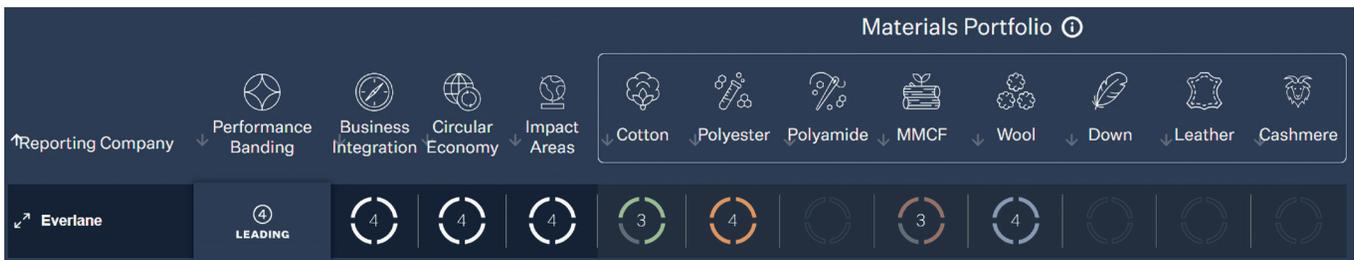


Figure 1.2. Material Change Index (MCI) tool snapshot. (Source: Textile Exchange)

How to use the Material Change Index

The Material Change Index provides performance-based score “bands” across four elements:

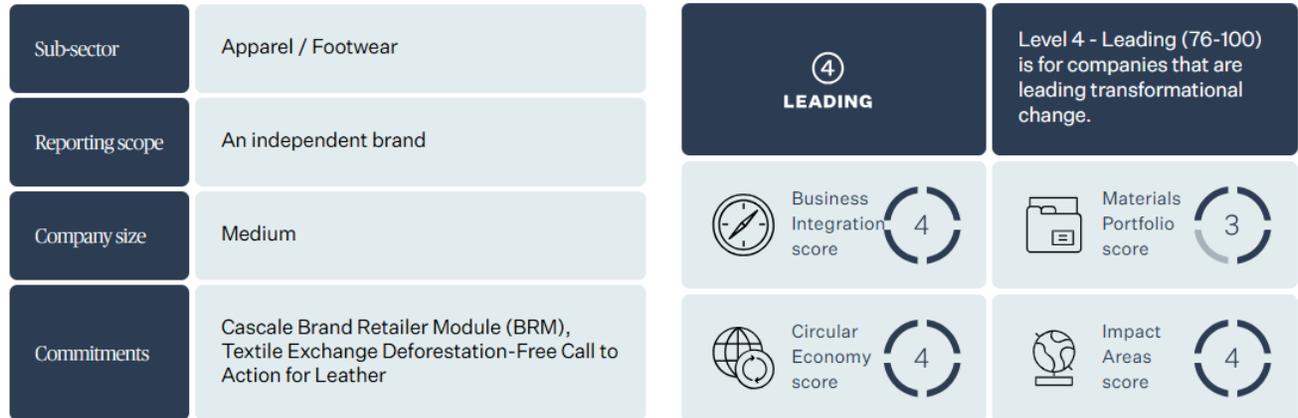
- **Business Integration**, which reflects on the brand’s raw material sourcing strategy and how it is integrated into its core business;
- **Circular Economy**, which reflects on the brand’s progress towards circularity;
- **Impact areas**, which reflects the brand’s prioritization of climate in its raw materials management and sourcing; and
- **Material Portfolio**, which refers to the range of raw materials that a brand sources and uses in its product.

The MCI creates a progress card for each brand using a weighted system, where the **four aspects are assigned weights of 20%, 10%, 10%, and 60%**, respectively. This progress card evaluates the brand both at an aggregated level and for each of the four aspects, using a scale from 1 to 4. For the **Material Portfolio** aspect, the scale can also provide scores for each of the 14 raw materials, if the data is available. The scoring scale is defined as follows:

- **Scale 1 (Score 1–25): Developing**
Companies are in the early stages of building the foundation for their sustainability programs.
- **Scale 2 (Score 26–50): Establishing**
Companies are enhancing their accountability and strengthening their programs.
- **Scale 3 (Score 51–75): Scaling**
Companies are integrating sustainable materials programs into mainstream operations.
- **Scale 4 (Score 76–100): Leading**
Companies are driving transformational change and setting industry benchmarks.

EVERLANE

Everlane's mission is to empower people to live their best lives with the least impact on the planet. Everlane is working to do their part by building an ethical supply chain that creates high-quality, low-impact, long-lasting products. They carefully consider their raw material sources and work with their production partners to reduce waste, water, and carbon emissions. Their timeless basics are designed to making fashion more responsible, and weaving a more sustainable future. [Visit website](#)



Priority Materials Portfolio ⓘ



Figure 1.3. Performance-based score "bands" using MCI tool. (Source: Textile Exchange)

2. Conditions and principles to design for recyclability

For apparel and textile recycling to be feasible, several factors must come together. These include:

- **Sufficient gross volumes** of sorted fractions for recycling;
- **High yield** of the targeted fibre content for the intended recycling process;
- **Low costs** to sort and process fractions.

You will notice that none of these factors are related to design directly. And yet, adopting principles of conditional design can significantly influence them. For example, using separation technologies and incorporating both **mono-materiality** and **modularity** in your designs can greatly help to optimize your products' potential for recycling.

You may remember you learned about these concepts during Module 3 of the online part of this workshop.

The “Design for Recyclability” Classification System

The “Design for Recyclability” Classification System is used to increase the efficiency of materials processing during recycling. The different classifications possible under this system are:

BEST – A1: Mono-Materiality

- All material components, including trimmings, sewing threads, and labels, are made from the same basic material (e.g., cotton or polyester).
- This is the ideal scenario for recyclability.

A2: Semi-Modular with Automatic Separation

- Non-mono components are present but can be automatically separated during the recycling process (e.g., metal zippers or buttons removed after cutting but before shredding).

B: Semi-Modular with Manual Separation

- Non-mono components require manual separation (e.g., labels, pockets, and buttons removed by cutting or detaching).

WORST – C: Non-Mono Composition

- Materials that are not easily separable or recyclable (e.g., polyester-cellulose blends or materials treated with chemicals, dyes, or paints that are challenging to separate cost-effectively).

Bills of Materials (BOM) aimed at recyclability

Let’s quickly look at how a bill of materials works by examining a company called Houdini Sportswear. You may remember that we already looked at their C9 Jacket with Padded Midlayer during the online part of this workshop.

The jacket is constructed entirely from polyester, incorporating a blend of **Teijin Eco Circle materials** (recycled polyester) and virgin polyester. To enhance recyclability, the sewing threads and lining fabrics are also made from polyester, ensuring that all components are compatible for recycling. Additionally, the insulation fabric is **Bluesign® certified**, signifying adherence to high environmental and safety standards in its production.



Figure 1.4. Houdini C9 Houdi. (Source: Freeride)

Here, we see the simplified **Bill of Materials (BOM)** for this garment, including the “design for recycling” information. As we can see, the garment achieves the highest classification of “A1”, due to its mono-materiality. Most of its components, such as fabric, threads, and lining, are made from polyester.

This is great – A1 is the highest classification possible in the system! However, things could still improve. In an **ideal scenario**, for example, the jacket could also have included zippers made from polyester to maintain full mono-materiality. Another critical consideration is that synthetic materials, such as polyester, can release **microplastics**, which pose a hazard to marine life.

In this case, transitioning the BOM toward enhanced recyclability would involve **no additional cost**, making it a practical and sustainable design choice.

Item	Information	Cost		Pricetag	Classification (With current recycling technologies)	Highest possible classification
		Material	Labour			
Insulation fabric	Polartec® Alpha Insulation, 100% polyester, Bluesign® certifierat, Vikt: 100 g/m2	80 SEK /m2	47 min, 94 SEK. Total Production cost ca 400 SEK	2000 SEK	A1	A1
Shell fabric	Teijin C9 ripstop, 100% recycled polyester, Diffusion Stretch 100% recycled 65g/m2	40 SEK /m2				
Sewing thread	Polyester	50 SEK/kg				
Lining fabric	Polyester	30 SEK/ m2				
Zipper	Metal co	100 SEK				

Figure 1.5. Simplified Bill of Material (BOM) for C9 Houdi. (Source: Feasibility of Conditional Design)

Let’s look at another product, the “Houdini Wooler Hoody” wool jacket.

The garment is made of wool with pocket linings made of polyester. It has high circular properties.



Figure 1.6. Houdini Wooler Hoody wool jacket. (Source: CarlOfCarl)

Here, we can see a simplified representation of the BOM for this garment. As you can see, it achieves a classification of A2. One key materials choice consideration here is that, while the jacket’s wool fabric has high biodegradability, processes such as the dyeing and finishing of the garment are likely to limit these positive effects.

That said, there are ways for the garment to increase its classification. One of these would be to use innovative technologies such as Resortecs®, which would potentially enable it to improve its ranking to A1. Of course, doing so has cost implications!

Item	Information	Cost		Pricetag	Classification (With current recycling technologies)	Highest possible classification
		Material	Labour			
Shell fabric	100% mulesing free merino wool, Wooler GridMerino 17,5 microns, Biodegradable	200 SEK /kg	27 min, 60 SEK. Total Production cost ca 400 SEK	2000 SEK	B	A2 Wear2 technology is used in assembly*
Lining fabric	Polyester	30 SEK/kg				
Swing thread	Polyester	50 SEK/kg				
Zipper	Polyester & Steel	100 SEK				

Figure 1.7. Simplified Bill of Material (BOM) for Wooler Hoody. (Source: Feasibility of Conditional Design)

Information needed to ensure “Design for Recyclability” in your own BOM

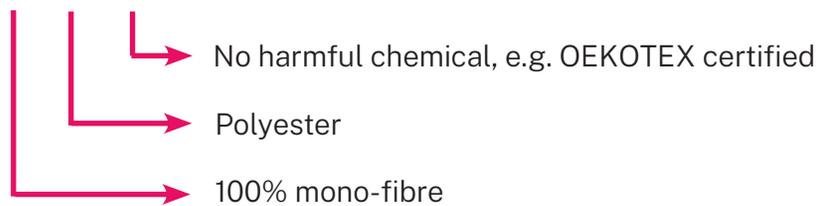
As we have seen, BOMs can be used to assess the level of “Design for Recyclability” of garments. To do so effectively, however, you will need to:

- Make sure that you have accurate fibre and component compositions to help recyclers with meeting feedstock specifications.
- Provide accurate product and component weights to make it possible to calculate precise fibre percentages.
- Develop accurate “care” labels to ensure that your fibre content is accurate and that all the materials and components are listed correctly.

Implications on automatic sorting schematics

Traceability is essential to ensure design for recyclability, as it allows for visibility into the entire product lifecycle. One powerful tool in achieving this is the “Digital Product Passport” (DPP) which plays a critical role in tracking products from creation to disposal.

For example A1a



With this in mind, the “Design for Recyclability” classification system that we have just seen can be used as part of a DPP or other product ID to enhance traceability and recyclability.

As you can see on the screen, the same DPP or product ID can also be used for sorting.

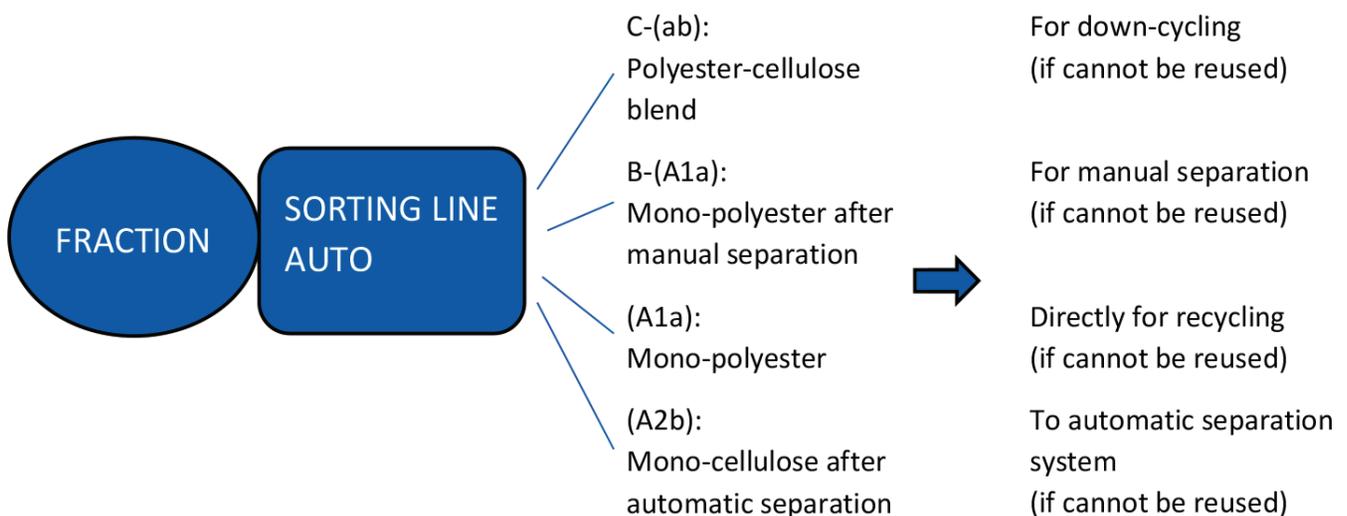


Figure 1.8. Automatic sorting schematics. (Source: Feasibility of Conditional Design)

3 Design for longevity

Now, let's look at some design for longevity principles.

Design for longevity focuses on creating apparel that maintains its aesthetic appeal over time and transcends seasonal trends. Longevity-focused circular design strategies aim to enhance physical and emotional durability, promote care and repair, and introduce features such as multi-functionality, modularity, adjustability, and timelessness. These strategies are not exhaustive but represent key approaches to designing long-lasting garments.

The two most prominent strategies to design for longevity are:

- 1. Modular design:** In this strategy, garments are designed to be detachable or modular, making them biodegradable or disposable. For the wearer, this reduces the need for frequent washing and offers designers the flexibility to transform the garment's properties during its lifecycle.
- 2. Incremental design:** Here, garments are designed to evolve with age, becoming more engaging or functional over time. This approach creates value by allowing garments to purposefully change and adapt through use.

Bill of Materials (BOM) for longevity

To understand how longevity-led design strategies impact material choices, let's look at practical examples.

The image you are seeing on your screen shows a capsule collection by **Lindex**, designed by Anna Lidström, and which exemplifies modular design. This collection features 18 scarves that can be combined into five different types of garments. The entire collection is made of **mono-material** (100% polyester, including stitching), ensuring recyclability at the fibre level. The modular approach also offers flexibility in design, fit, and construction, supporting both longevity and sustainability.



Figure 1.9. Lindex capsule collection - modular design approach. (Source: Feasibility of Conditional Design)

The Klättermusen **Mithril Pants** are another example of a modular design approach aimed at enhancing both longevity and functionality. These pants feature attachable and detachable pockets and gear loops, allowing users to customize them according to specific needs.

The garment is constructed from a blend of **polyester**, **polyamide**, and **aramid fibres**, which significantly limits its circular properties due to the difficulty of recycling mixed-material products. However, the standout feature of this pant is its **modularity**. The design allows users to customize its functionality by attaching or detaching pockets, enabling the addition or removal of specific features as needed.



Figure 1.10. Klättermusen Mithril Pants – modular design approach. (Source: Feasibility of Conditional Design)

On the screen, we can see a simplified Bill of Materials for this garment, showing its excellent design for longevity. That said, it only achieves the lowest classification of “C” according to the “Design for Recyclability” Classification System. This is due to its mixed-materials composition and its limited circular properties, which make recycling challenging.

Despite not scoring high on the **design for recyclability** scale, the garment showcases **longevity-led design** through its modular and functional construction. While recyclability is not its strength, its modularity supports sustainability by extending the product’s lifespan and reducing the need for frequent replacements.

Item	Information	Cost		Pricetag	Classification (With current recycling technologies)	Highest possible classification
		Material	Labour			
Shell fabric	Windstretch 180g/m2- 70% Polyamid, 20% Polyester, 10% Elastan Bluesign approved, Reinforcement 100% Kevlar, Shoe cleaning area, 100% Polyester	80 kr/m2	90 min cost 180 SEK. Total production cost 460 SEK	2300 SEK	C	C, as this is an example on modularity, the ambition is not to have as high classification as possible but to showcase modularity.
Sewing thread	Polyester	50 SEK/kg				
Zipper	Polyester & Metal	30 SEK/kg				

Figure 1.11. Simplified Bill of Material (BOM) for Klättermusen Mithril Pants. (Source: Feasibility of Conditional Design)

CONCLUSION

In this video, we explored **circular design** and sustainable material choices during the textile design and development phase. We highlighted how companies can navigate factors influencing **preferred fibre and material selection** to promote circularity.

We focused on two key principles:

1. **Design for recyclability**
2. **Design for longevity**

Through case studies, we demonstrated how these principles impact **sourcing criteria**, such as the **bill of materials (BOM)** and **sorting processes**, and provided a **change plan** to support their implementation.



Knowledge check

Answer the following questions in the spaces provided below.

1) What kind of data do you need to look at when assessing the sustainability of fibres and/or raw materials?

.....

.....

.....

.....

2) Rank the following options from 1 (best) to 3 (worst) based on their suitability for design for recyclability:

- **A.** The garment is made of 100% polyester fabric, trims, and threads, but the buttons and accessories are non-polyester and require manual removal before recycling.
- **B.** The garment is a blend of polyester, cotton, and elastane.
- **C.** The garment is made entirely of polyester, including trimmings, sewing threads, and labels, with metallic zippers attached using dissolvable thread.

3) In your own words, explain the following circular design principles: modularity, mono-materiality, multi-functionality, adjustability.

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

4) What are the benefits of using Material Change Indices, such as the Textile Exchange's MCI, when making circular design and sourcing decisions?

.....

.....

.....

.....

.....

5) Is the following statement true or false? Why, or why not?

Design for recyclability and design for longevity principles can conflict with each other.

True False

.....

.....

6) Traceability is key to ensure design for recyclability. How?

.....

.....

.....

.....

.....

.....

.....



Exercise - scenario

Take a few minutes to read the case study showcasing the circular product transformation journey of fashion brand Circ Apparel.

Circ Apparel

Circ Apparel, an activewear brand launched in 2019, initially focused on durable outdoor jackets for sports activities. Their products, made with polyester and polyamide blends, became known for their long-lasting performance. The winter jackets featured an inner wool lining, with all trims and accessories stitched using polyester threads.

In 2021, Circ Apparel shifted towards circularity by introducing biodegradable polyester (PLA) and recycled polyamide in their winter jacket collection. The biodegradable PLA, enhanced with organic compounds, maintains fabric performance while allowing microbial degradation under anaerobic conditions. The recycled polyamide was sourced from Econyl's reclaimed fishing nets.

Garment construction was also adapted for circularity. Polyester sewing threads were replaced with Resortec® dissolvable thread for stitching zippers and buttons, while the wool lining and modular retrofits were attached using Velcro. These modular features enhanced multi-functionality, allowing users to adapt the jacket for various sports activities.

Answer the following questions:

1) What circular design principles did Circ Apparel apply during its circular design transformation?

.....

.....

.....

.....

2) What were some concrete ways in which Circ Apparel implemented these circular design principles?

.....

.....

.....

3) What other circular design strategies could Circ Apparel have considered?

.....

.....

.....

.....

WRAP-UP AND Q&A

So, what have we learned?

- Circular apparel design begins with **selecting more sustainable fibres and materials** and **making informed sourcing decisions**.
- Companies must consider various **environmental and social lifecycle impacts** when choosing the right fibres or raw materials and **transitioning toward circularity**.
- Key principles of design for recyclability include **mono-materiality** and **modularity**, as well as incorporating **separation schematics** during the design phase.
- Design for recyclability supports the creation of **circular bills of materials (BOM)** and facilitates automatic or semi-automatic sorting at a product's end-of-life stage.
- The two most effective strategies for design for longevity are modular design and incremental design.

Do you have any final questions?

.....

.....

List of additional readings (optional)

- RE:Textile, 2019 *Feasibility of Conditional Design*
- WRAP, 2023 *Circular Design Toolkit for Fashion and Textiles*



End of session 1

Thank you for your participation.

SESSION

2

Maximizing the Efficiency of Reverse Logistics for Used and Waste Textiles

INTRODUCTION

Welcome! The objectives of this session are to:

1. Identify the main elements of mapping and analysing post-consumer and post-industrial streams of used textile and waste.
2. Outline key strategies and critical success factors for effective collection and sorting in reverse logistics.
3. Enhance your understanding of sorting for recycling by examining relevant analytics and methodologies. Assess the various innovations and new technologies driving advances in reverse logistics.



Answer the question

The used textile waste management value chain involves the **collection, sorting** and processing of post-consumer and post-industrial textiles to enable their reuse, recycling or disposal.

Based on what you know about this value chain, where do you see inefficiencies? What are some things that could be done to **enhance the efficiency and sustainability** of the used textile waste management value chain?

well as the impact they have both within a country, and on receiving countries. In terms of international trade, mapping textile flows can also provide insights on the global used textile supply chain and help better assess the socio-economic and environmental footprints of the textile industry as a whole.

Incoming flows provide data on the makeup of textiles collected in the country of focus, as well as variations across collection sources.

Outgoing flows help clarify the type of end use and provide data on material composition, which helps with recycling.

Used textiles are generally classified into two main product codes:

- HS (Harmonized System) code 6309 – worn textiles and clothing; and
- HS 6310 – sorted and unsorted used rags and textile scraps.

HS 6309 is given to textiles fit for reuse, while 6310 is given to textiles unfit for reuse, and which may or may not have already been processed or recycled.

There is no code for the export of textile waste. As a rule of thumb, the vast majority of textile waste is exported under code 6310.

Data on used textiles exports and imports is available in the United Nations' Comtrade database. When looking at flows within a single country, national databases are generally used.

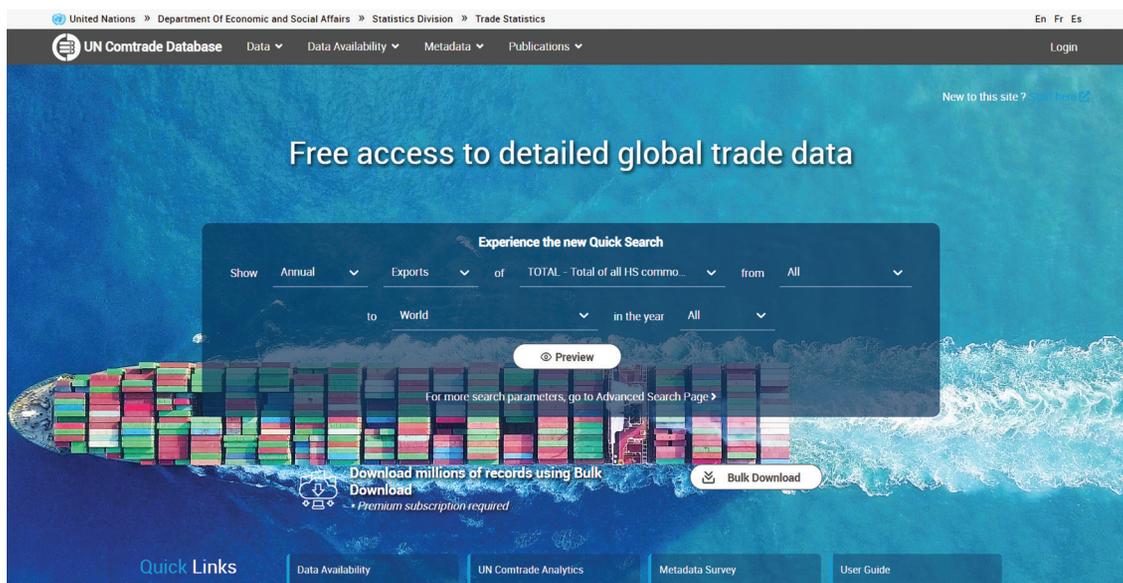


Figure 2.1. United Nations' Comtrade database. (Source: <https://comtradeplus.un.org/>)

Mapping textile waste

Mapping textile waste is similar, though not the same, as mapping used textile flows. Unlike for used textiles fit for reuse, there is no single database that can be used to map textile waste. As such, data must be gathered through enterprise surveys and the use of flow models that track the availability, production and import of textiles from raw materials to finished clothing.

When it comes to mapping post-industrial textile waste, a **parameter waste-to-material ratio** is often used to calculate the volume of fibres processed and the amount of waste generated at each stage of the supply chain. The whole waste mapping process is thus a less precise and more decentralized exercise than the mapping of used textiles.

Key steps of textile waste mapping

Step 1: Calculate the trade balance to estimate the physical volume of textile imports and exports in the country. This provides an overview of the waste generated at each stage of the value chain.

Step 2: Classify the textile waste by process stage, fibre type, and colour. If needed, map the waste's geographic distribution to identify concentrations. This helps determine which regions produce specific waste types, which helps planning and logistics.

Step 3: Use waste mapping data to develop business scenarios for the textile recycling value chain. Analyse trends such as required sorting, shredding, and recycling capacities, or production volumes for recycled fibres. Estimate the geographic distribution of production capacity, current sorting/recycling rates, and processing line capacities.

Step 4: Perform a SWOT analysis and benchmark against other countries. Conduct financial analyses to determine the necessary capital expenditures (CAPEX) for recycling infrastructure and operational expenses (OPEX) related to transport, labour, energy, and raw materials.

If you want to get started, World of Waste, accessible [here](#), is a platform offering freely accessible waste data from several countries.

Systems and strategies to collect and sort used textiles and waste

The systems and strategies used to collect and sort **post-consumer** used textiles are quite different from those used for **post-industrial** used textile materials. Let's start by looking at post-consumer collection and sorting.

Collecting post-consumer used textiles

Post-consumer used textiles can be collected in various ways, including door-to-door visits, public collection points, mobile units, public building drop-offs, clothing shops, and reuse centres. While no collection system is necessarily better than the others, all of them require balancing **initial investment, return volume, operating costs, control, and customer satisfaction**, all while accounting for **local specificities**.

What's more, the collection value chain includes large numbers of stakeholders, including charities, commercial collectors, municipalities, waste companies, brokers, aggregators, shredders, traders and clothing brands/retailers. At the most basic level, collectors retrieve waste from factories and sell it to aggregators, who sort it further to meet the needs of shredders and recyclers.

Success factors for individual collectors

As an individual collector, the most elemental factor for your success is good governance, especially in regions with established textile EPR schemes. Municipalities are crucial here, as they typically regulate who can collect used textiles on public land, and may also collect used textiles directly. Beyond this, however, there are a few things you can do to maximize your chances of success:

- Increase your collection rates through branded containers and dry, supervised collection environments.
- Place “bring banks” away from waste containers to prevent contamination, and encourage donations in sealed bags.
- Maintain clear communication with the local population to promote proper disposal practices. To build trust, be transparent about where their donations will go and remain both visible and accessible to address their questions or concerns.
- Locate collection points in safe, convenient, and easily accessible areas.
- Use modern technology, such as sensors, to monitor container fill rates and optimize collection efficiency.

Sorting post-consumer textiles

Usually, the sorting process starts with automated unloading at the sorting site, followed by manual sorting, and ends with automated packing and baling.

Manual sorting is generally divided into two stages: **pre-sorting**, and **fine sorting**.

In **pre-sorting**, items are separated into “rewearable,” “non-rewearable,” and “incineration” categories. Key performance indicators include:

- Average capacity per operation table (kilos/day)
- Number of sorting tables required
- Number of sorters required

In **semi-automatic fine sorting**, items are graded by gender categories, material type, product type, and seasonality. Each item is individually inspected for quality and business-to-business (B2B) demands.

In **larger manual sorting sites**, more granularity is added by dividing the sorting process into three stages.

In the **first sorting**, shoes and non-clothing items are removed, and wet items are sent for in-house drying. Items are fed via conveyor belts into chutes for the second sorting. Shoes are paired manually in a separate section.

In the **second sorting**, textiles are evaluated, and broken items are repurposed into industrial wipers, sorted by colour.

In the **third and final sorting**, items undergo detailed manual sorting as described earlier. Emerging

technologies could improve the efficiency and speed of this stage, which will be discussed later in this video.

After sorting

After sorting, items are packed, labelled, barcoded, and recorded before being exported or sent to second-hand shops. Packing is done in plastic bags or compressed bales, with EU market bales typically weighing 10 kilos, and overseas bales weighing 25 or 55 kilos. Once filled, bales are labelled with a barcode, scanned into the stock system, and marked with the item code, weight, and sometimes the customer's name. Transportation is commonly handled in 40-foot containers.

Currently, the market value and valorization potential for non-rewearable and low-value reusable items remain low. Although industrial wipers and rags have a sizeable, established market, their value is minimal.

For the EU context, the Sorting for Europe (2022) study estimates per kilo prices as follows:

Type of sorted fraction	Market price per kilo
Second-hand EU market	3.5-13 Euros (Average: 4-5 Euros)
Second-hand international markets	0.2-3.5 Euros (Average: 1-1.2 Euros)
Low value reuse (6%)	0.77 Euros
Wipers (10%)	0.13-0.45 Euros
Downcycling (14%)	0.08 Euros
Fibre-to-fibre recycling (2%)	0.02-0.14 Euros

Figure 2.2: Estimated per kilo prices of different used textile sorted fractions. (Source: Sorting for Europe, 2022)

Importing post-consumer used textiles

Post-consumer used textiles imported into the Global South are typically managed by agents or importers who negotiate agreements with suppliers to define prices, quantities and shipping terms. They also usually manage transportation, customs clearance, documentation, and all other import procedures.

Upon arrival, bales are sorted in warehouses by category, demographic target, season, and style. Understanding market needs and stock requirements is crucial to set appropriate pricing and maximize value here.

The collection and sorting process for post-industrial used textiles

The collection and sorting of post-industrial used textiles is very different from post-consumer used textiles. It involves various systems, each with distinct processes and costs. Let's look at them in turn.

- Multi-waste collection and segregation:** In this system, waste is collected in bulk or bags from textile factories, transported to warehouses, and sold as segregated, mixed, or

shredded waste at varying prices.

- **Waste returned to supplier:** This system is used in cut-make-trim (CMT) production, in cases where a supplier requests to have their textile waste returned to them. In this system, the collector simply separates and bales the waste before returning it with a traceability sheet.
- **Industrial zone waste management:** While industrial zones do manage their waste, they tend not to separate their textiles. The collector thus has the added responsibility of separating and sorting textile waste.

Targeted vs. bulk collection

In “**bulk**” systems that do not sort their waste, such as industrial zones, collecting and sorting used textiles requires significant initial investment in sorting equipment. However, operational costs tend to be lower, since companies typically pay for waste removal services.

More targeted systems, such as multi-waste collection, require large warehouses and advanced sorting technology to separate materials by type and colour.

Fully targeted collection, which focuses on specific fractions like cotton waste, involves lower initial costs, since sorting occurs at collection points using dedicated bins and personnel. However, operational costs are higher due to limited economies of scale.

Innovations in collection and sorting for reuse and recycling

In recent years, new technologies have been integrated to optimize the collection and sorting of textiles, both for reuse and recycling. Let’s take a brief look at some of them.

Smart collection bins: Smart, sensor-enabled collection bins can track fill rates. They can also be connected to QR codes and mobile apps for real-time reporting, making it possible to optimize collection activities.

Two-stream collection system: Pioneered in Denmark, this system involves separating used textiles into “reuse” and “recycling” streams at collection points, thus making sorting possible in situ.

Conveyor belts: These systems streamline sorting by directing textiles into appropriate containers. They help track operator efficiency, sorted volumes, and bale production, all while reducing costs and the space required.

Speech sorting systems: This innovative tool supports manual sorting by equipping sorters with microphones to verbally categorize items. Items are placed on a nearby conveyor, and the system uses the voice input to transport them along a larger conveyor belt, ejecting them into the correct bin. Such systems can accommodate an unlimited number of categories, restricted only by the sorter’s recognition capabilities. Voice software can also be customized for different languages and dialects, making it highly adaptable.

Sorting for recycling

The sorting of non-rewearable textiles is crucial, as their share of total textile collection is expected

to rise significantly in the coming years. However, sorting this fraction currently presents a negative business case in many developed regions of the world, including Europe.

One way to increase the business feasibility of sorting for recycling is to perform a **sorting analysis**. This involves identifying the distribution of textiles by product category, fibre type, and blend composition to improve the efficiency of sorting and, thus, improve the business case for it.

Key steps in sorting analysis

Step 1. The first step in any sorting analysis is selecting the fraction to be examined. For example, the table here shows the different scope of two recent studies: Sorting for Europe (2022) and Re_Fashion 2023

	Refashion	SFC Europe
Mid to high value reused textiles	X	X
Low value reused textiles	X	✓
Recycled textiles	✓	✓
Energy-recovered textiles	✓	X
Ultimate waste textiles	✓	X

Figure 2.3. Sorting analysis comparison. (Source: Re_Fashion 2023)

Step 2: Then, a pick analysis is carried out to confirm the composition of the fraction selected. Hand-held scanners using NIR (Near-Infrared) technology are used here. If the scanner cannot determine the fibre composition, the information is manually entered based on the item's label.

Step 3: A further analysis is conducted to determine the exact material composition and volume. It also identifies key characteristics, such as mono- versus multi-layer items, colour, common product categories, the presence of disruptors, and age group classification. These factors are crucial in assessing the suitability of textiles as feedstock for recycling processes.

Step 4: The data is then extrapolated to estimate the volumes of each fibre type, using collection volumes from existing databases. This enables projections of future business potential, including the share of recyclable feedstock by fibre type and colour. It also identifies the infrastructure needed and the business models required for sorters to commercialize these fractions as feedstock for fibre-to-fibre recycling.

Innovations and technologies enabling sorting for recycling

Implementing automatic sorting mechanisms is critical to achieve the high-volume, high-purity feedstock needed for fibre-to-fibre recycling. One of the most effective technologies that can be used here is near-infrared (NIR) spectrometry. NIR works by emitting electromagnetic waves that

are absorbed by textile fibres, creating a unique spectrum for each fibre type. This spectrum is then matched against a predefined database to determine the material composition of the textile, thus automating textile recognition in the sorting process.

Since its analysis focuses only on the surface of the material, NIR is particularly effective for sorting large volumes of mixed post-consumer textiles. Spectrometers used in NIR sorting are relatively affordable, costing between €15,000 and €25,000, compared to other optical sorting machines, which are 10 to 12 times more expensive.

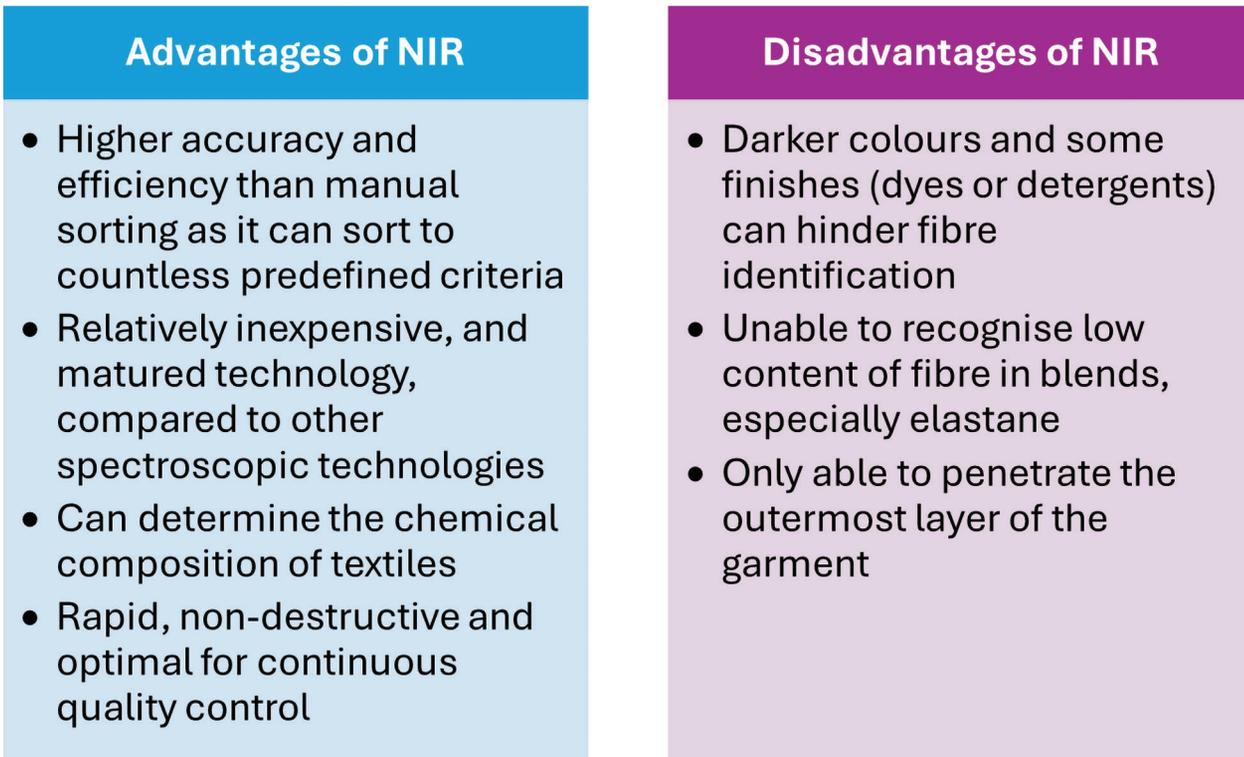


Figure 2.4. NIR – advantages and disadvantages

What's more, various companies such as TOMRA, Valvan, and Spectral Engines combine optical scanners with NIR to enable automatic sorting on the basis of not just fibre composition, but also colour. High-level sensors and cameras can also be combined to enable more categorical recognition, such as in terms of structure, wear and tear, size, weight, mould, the presence of hazardous chemicals, multi-layer material composition, brand, and more.

The Danish company NewRetex has gone one step further by building a fully automated system that combines NIR with advanced sensors to sort textiles into 31 fractions, which are then picked and handled by robots based on material composition and colour.

Other emerging technologies are also being piloted. These include chemical analysis methods such as dissolution, microscopy, differential scanning calorimetry, gas chromatography, and laser-based systems, all of which provide greater precision in identifying and separating materials

Finally, online digital platforms are also playing a significant role in advancing sorting for recycling. These platforms facilitate information sharing on waste volumes and offer end-to-end transactional marketplace solutions. We will look at them in greater detail in Session 4.

Conclusion

In this video, we explored the reverse logistics of handling and valorizing used textiles and waste, with a focus on mapping waste flows, collection, and sorting processes. We highlighted the role of innovative technologies in sorting for recycling and shared recommendations for optimizing collection systems and improving sorting efficiency. We hope you have found this video both interesting and useful.



Knowledge check

Answer the following questions in the spaces provided below.

1) In your own words, describe textile waste mapping. **What** does mapping textile waste involve, **what** does it aim to do, and why is it **important**?

.....

.....

.....

.....

.....

.....

.....

.....

.....

2) What is the significance of sorting analysis in the context of textile recycling?

.....

.....

.....

.....

.....

3) Match the following technologies/innovations to where they are applied along the used textiles supply chain:

NIR technology

Collection

Voice or speech recognition system

Sorting for recycling

Fill rate detection sensors

Material handling

Robot feeding

Fine sorting

4) What are some important strategies and success factors to design efficient collection and sorting systems in reverse logistics? How can they address challenges such as contamination and resource recovery?

.....

.....

.....

.....

.....

.....

.....

.....

.....

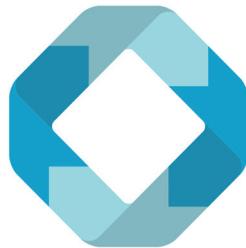
.....

.....



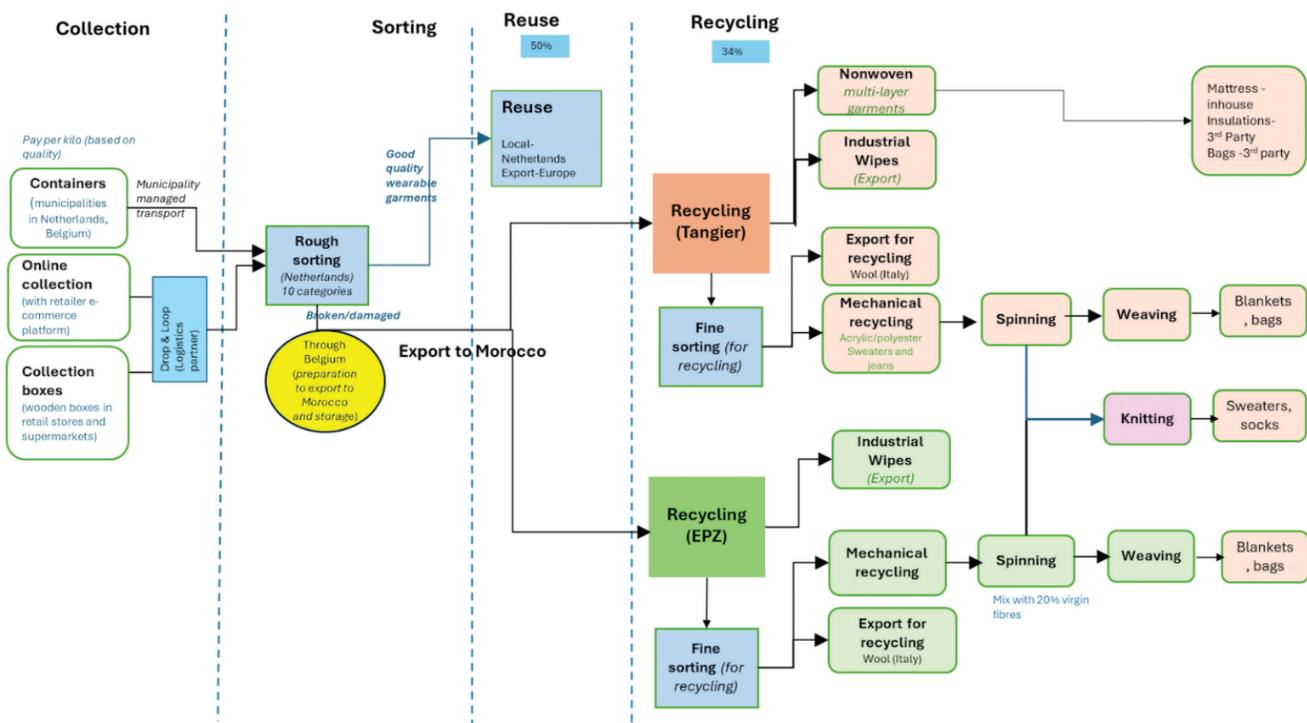
Exercise - scenario

Take a few minutes to read the case study on Dutch textile processor Wolkat's used textiles supply chain.



Wolkat

Wolkat is a vertically-integrated used textiles processor headquartered in the Netherlands, working with collection, sorting and recycling, including textile production. Its supply network structure is shown here:



Wolkat collects post-consumer used textiles through three primary methods:

- **Container-based collection:** In partnership with municipalities in the Netherlands and Belgium, Wolkat places containers where donors can drop off textiles. Donors receive discount coupons based on the quantity returned, calculated per kilogram.
- **Retail collection boxes:** Collection boxes are located in retail stores and supermarkets, where consumers dropping off textiles receive discounts on future purchases.

- **Online collection:** Wolkat collaborates with retailers' e-commerce platforms to facilitate recommerce solutions. Consumers send discarded textiles back to the retailer, often using pre-provided bags.

While municipalities manage transportation for container-based collections, the retail and online streams are part of Wolkat's **Drop and Loop** program, managed by a logistics partner.

Sorting process:

Initial sorting takes place at a centralised facility in the Netherlands, where items are classified into 10 categories:

- Reusable clothing
- Paired shoes
- Unpaired shoes
- White wipes
- Coloured wipes
- Non-wearable jeans
- Non-wearable knitted garments
- Non-wearable other items
- Blankets
- Waste

Approximately 50% of sorted items are good-quality rewearable garments. Premium garments are sold in Europe, while Grades A and B are sold to global markets, with major destinations including Cameroon, Senegal, Ivory Coast, and Pakistan. About 34% of non-rewearable textiles suitable for recycling are sent to Wolkat's Moroccan facilities via a warehouse in Belgium.

Recycling process:

At the Moroccan facilities, textiles undergo fine sorting by quality, colour, and composition before recycling. Wolkat's mechanical recycling facility handles polyester and acrylic feedstocks, such as sweaters and jeans, which are spun, woven, and turned into new products. Wool is exported to Italy for further processing, while spinning and weaving facilities are operated in-house.

Multi-layered garments are processed for non-woven manufacturing using airlay and thermo-bonding technologies. Cotton-rich textiles are converted into industrial wipes, handled within Wolkat's subsidiaries.

Collaboration and research:

Wolkat works with major brands like Nike and IKEA to produce capsule collections made from recycled materials. The company also collaborates with local textile universities to improve the properties of recycled fibres, driving innovation in sustainable textile production.

Wolkat also engages in research activities with local textile universities to improve recycled fiber properties.



Exercise - scenario 2

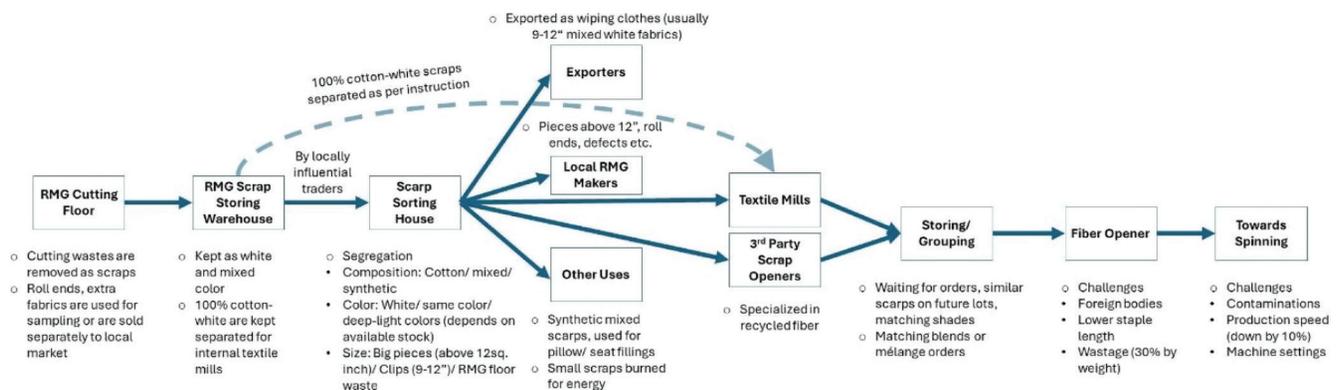
Take a few minutes to read the case study on **Bangladesh's ready-made garment (RMG) waste**. You can find this in your workbook.

The ready-made garment (RMG) industry in Bangladesh contributes over 11% of the country's GDP and 83% of exports. However, an estimated 20-25% of raw materials are wasted in various forms, including yarn, fabric roll ends, cut pieces, and rejected garments. Most waste originates from the cutting stage and ends up in "jhoot" sorting markets, while excess or defective fabrics and garments are sold in stock-lot markets.

Jhoot sorting facilities handle small or unusable waste like torn yarns, fabric scraps, and cut panels, whereas stock-lot markets deal with reusable materials such as excess yarn, fabrics, minor defective garments, and shaded fabric rolls. Bangladesh's textile waste trade operates informally, involving multiple middlemen, inefficient segregation, and high contamination levels. Local regulations prohibit selling these materials domestically since they are processed under a duty-free bonded-warehouse license for export. As a result, much of the waste is exported to India, where it is downcycled into lower-value products. In 2019, over 250,000 tonnes of cotton waste were sold to the recycling market for \$100 million.

Despite its informal nature, the *jhoot* supply chain is economically and socially significant, involving 20,000-22,000 traders, employing 500,000-600,000 workers (mostly women), and supporting around 1 million people indirectly.

Jhoot value chain



Jhoot from cutting floors is initially stored in factories before being sold in bulk to sorting houses. At this stage, waste is typically sorted only by colour (white or non-white). Some factories set aside high-quality waste (e.g., cotton-rich, light-coloured) for their own textile mills. Others participate in global platforms like Reverse Resources, allowing direct waste transfers from cutting floors to recyclers, such as yarn manufacturers.

The *jhoot* business follows three main steps: influential local collectors gather waste from factories, sell it to sorting hubs, where it is manually sorted by colour and composition, and then resold for reuse or recycling.

Market potential of *jhoot* waste

Due to informal handling and a lack of traceability, tracking pre-consumer waste disposal is challenging. In 2022, BGMEA reported that only 5% of this waste was recycled locally, while 60% was exported, primarily to India. However, reporting inconsistencies exist. Despite limited data, Bangladesh’s mechanical cotton fibre recycling capacity is estimated at 220,000-240,000 tons per year. If properly processed and reintegrated into garment production, this could reduce raw material imports by 15%, saving approximately \$500 million.

Recognizing this potential, initiatives like the Textile Sustainability Platform and UNIDO’s SWITCH2CE program are working to support Bangladeshi producers by improving capacity, data collection, ecosystem development, and access to finance for circular models.

Answer the following questions:

1) What are the most significant challenges to Bangladesh’s RMG waste industry?

.....

.....

.....

.....

.....

.....

2) How could Bangladesh’s RMG waste industry transform from an informal to a more formal structure?

.....

.....

.....

.....

.....

.....

3) How could the regional waste trading of post-industrial waste, such as between Bangladesh and India in terms of *jhoot* trade, be better valorized?

.....

.....

.....

.....

WRAP-UP AND Q&A

So, what have we learned?

- **Effective reverse logistics:** Reverse logistics is critical for circular valorisation of used textiles and waste, ensuring efficient collection and sorting processes.
- **Mapping used textiles and waste flows** includes:
 - » Conducting post-consumer material flow analysis to understand the volume, value, and disposition routes of used textiles.
 - » Mapping export-import flows to assess the impact of used textiles on receiving countries.
 - » Performing waste mapping to estimate volumes and characteristics, supporting better recycling strategies, traceability, and future projections.
- **Strategic collection processes:** Optimizing collection systems requires attention to local specificities and active stakeholder engagement. Establish convenient, accessible drop-off points for consumers and implement incentive programs to encourage donations and in-situ sorting. Effective governance and coordination among stakeholders are essential.
- **Sorting for reuse and recycling:** A coordinated approach combining human expertise with technological innovation is key. Tools such as sensors, NIR spectrometry, and online platforms can significantly improve sorting efficiency and effectiveness for recycling.

Do you have any final questions?

.....

.....

.....

.....

List of additional readings (optional)

- Fashion for Good, 2022, *Sorting For Circularity Europe*
- Fashion for Good, 2022, *Wealth in Waste: India's Potential to Bring Textile Waste Back Into The Supply Chain*
- Re_Fashion, 2023, *Characterisation study of the incoming and outgoing streams from sorting facilities*
- Switchmed, 2021, *Textile waste mapping in Morocco and Tunisia*
- Switchmed, 2022, *Textile waste mapping in Egypt*
- IFC, 2022, *Sourcing of post-industrial cotton textile waste in the Tangier area, Morocco*



End of session 1

Thank you for your participation.



End of Day 1
Coffee and Tea

SESSION



The Textile Recycling Value Chain: Technologies, Processes and Market Potential

INTRODUCTION

Welcome! The objectives of this session are to:

1. Identify the key textile recycling pathways (methods), focusing on the steps of their processes and the technologies used in them, and explore ways to enhance their efficiency.
2. Explain how critical process and quality parameters influence the output and usability of recycled fibres.
3. Evaluate strategies to maximize the value of textile recycling by analyzing process costs and market potential for recycled fibres across various applications.
4. Assess the technological readiness of different recycling methods for scaling up to industrial production.



Answer the question

In your opinion, what are the key elements required to make textile recycling successful?

Try to think about elements along the entire value chain.

.....

.....

.....

.....

The primary methods used to produce recycled fibers are **mechanical** and **chemical recycling**. Mechanical recycling is currently the more important of the two. Today, most recycled fibers in the market consist of mechanically recycled cotton from post-industrial textile waste, although post-consumer textile recycling is also expanding rapidly. For its part, chemical recycling is still in its infancy, although it is expected to scale up within the next 5 to 10 years.

There are other textile recycling methods in existence, such as thermo-mechanical, thermo-chemical, and enzymatic approaches, among others. However, they are still at the pilot stage, or not yet used to produce fibre outputs. Thermal recycling is the exception here, since it is already used commercially to produce rPET (for PES-fibres) and PA-pellets, which are sold to fibre spinners. Most of these, however, do not come from textiles, but rather from thermally-recycled plastic bottles.

Given their centrality to today's textile recycling process, in this video, we will focus on mechanical and textile recycling.

Mechanical recycling

Mechanical recycling uses physical forces to recycle fabric or fibres, either as a standalone process or as a pre-step for thermo-mechanical, chemical, or biochemical recycling.

It can be divided into two main stages:

- **Pretreatment:** Here, textiles are sorted by colour and/or material. They may be cleaned if necessary, and all their “hard parts,” such as labels, coatings, prints, etc. are removed either manually, or using methods such as magnetic or gravimetric separation.
- **Mechanical action:** Here, textiles are cut into specific sized pieces, and pre-opened if they have a high fabric density. After this, they are torn or opened to release individual fibres, which are then pressed into bales for transport. If necessary, additional “fine opening” can be carried out on any last unopened fibres.

Note: Chemical treatment is a part of the pre-treatment process, depending on the level of contamination in used textiles (e.g., unwashed clothing, dirty carpets, or soiled workwear). If contamination is significant, the pre-treatment stage may also include sanitation through industrial cleaning or washing. These processes are similar to those used in textile maintenance, such as for workwear, and may involve detergents, ozone, or liquid CO₂ to remove contaminants like sweat and sand. Additional resources, including water, chemicals, and heat, may be required.

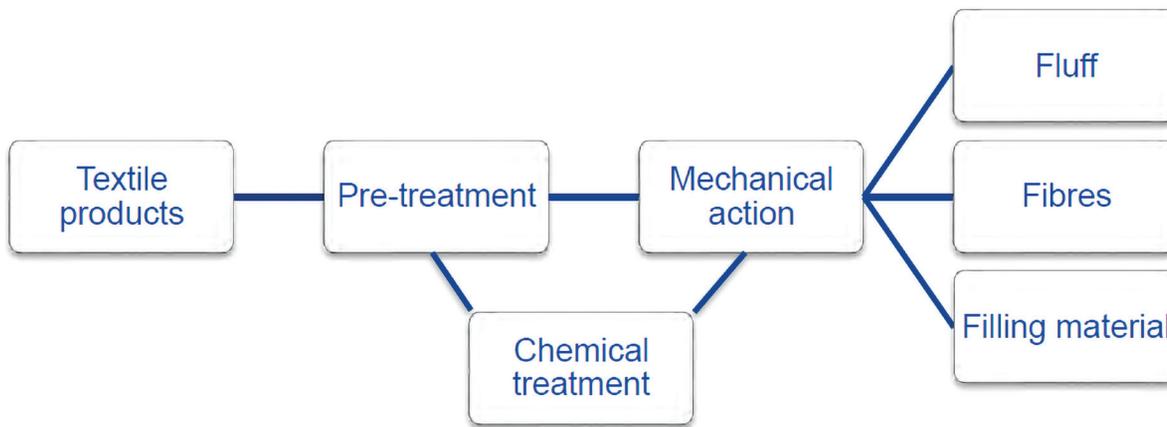


Figure 3.1. Generic steps for mechanical recycling. (Source: Duhoux et al., 2021)

Key quality parameters

In mechanical recycling, several **process-level parameters** are crucial for achieving high-quality outputs. To start, inputs need to be sorted in as granular a manner as practicable. This will make it possible to select the most appropriate machinery depending on fibre type and structure, such as loosely knitted versus tightly woven fabrics.

There is also a **balance** that needs to be struck between the **size of fibres** and the **ease of fabric opening**. Pre-opening woven fabrics takes time, but makes it possible to achieve a higher percentage of long fibres. Similarly, cutting the input fabric into larger pieces will also yield longer fibres, but will make each individual piece more difficult to open.

Finally, some novel chemical treatments are beginning to be available to remove fibre contamination. This field may be worth keeping an eye on, as changes are rapidly occurring in this space.

Quality, however, cannot just be achieved through process-level measures. The **input materials** also play a significant role. Uniform, untreated, and uncontaminated fibres improve quality. Good post-consumer fabric yields at least 20% respinnable fibres, with 25–55% considered excellent. In all cases, the elastane content should remain below 10%. It is also helpful if the garments used as inputs were designed for circularity, as this will make their separation into their different components easier.

Process costs and the recycled fibre market

When it comes to **cotton**, process costs for mechanical recycling vary from **500 to 3,000 per tonne of output**. The cost largely depends on the percentage of **respinnable fibre**, which typically ranges from 5 to 20%. So-called “**fluff**,” which is primarily used in non-woven production, constitutes **75 to 90%** of the output. Any remainder is made up of short fibres and dust, which are used for filling materials and insulation in the construction and automotive industries. Roughly **5% of output is typically “contaminated”** and remains unusable. Today, efforts are underway to find markets for more high-value applications of the outputs from cotton mechanical recycling. For example, cotton dust can be composted for organic farming as a substitute for chemical fertilizers, or used as a reinforced

composite in building materials.

In terms of polyester, polycotton or polyamide, process costs in Europe range from **150 to 600 per tonne of output**, again depending on the **respinnable fibre percentage** (typically **25 to 55%**). The output distribution also includes **40 to 70% of “fluff”**; short fibres and dust for filling and insulation; and **5% of contamination**. With global market prices of €700–€1,500 for polyester and €2,000–€4,500 for polyamide, the process is economically viable today.

Chemical recycling

Chemical recycling involves breaking down textile materials through chemical dissolution or reactions to recover polymers and monomers. In **monomer recycling**, polymers are decomposed into their base monomers, which are then used to create new polymeric fibres. In **polymer recycling**, meanwhile, fibres are processed to extract polymers, which are then re-spun into new fibres.

Generic fiber type	Polymer (P)	Monomers (M)
PET/Polyester	Poly(ethylene terephthalate)	Ethylene glycol + terephthalic acid
Cotton/Viscose	Cellulose	β -1,4-D(+)-glucopyranose
Linen	Cellulose	Cellobiose
Acrylic	Polyacrylonitrile	Acrylonitrile
Nylon	Polyamide	Caprolactam
Wool	Alpha Keratin (α -keratin)	α -keratin is a polypeptide chain, typically high in alanine, leucine, arginine, and cysteine, that forms a right-handed α -helix.
Silk	Fibroin	Mainly alanine and glycine made up of amino acid.

Various chemical recycling technologies are available, differing based on the fiber type, solvents, chemicals, and catalysts used. You can get a brief overview of each of them here. This table is also in your workbook.

Chemical recycling technologies	Description	Fibers					
		Cotton	MMCF ¹	Poly-cotton	Poly-ester	Poly-amide	Other fibers
Chemical-polymer	Pulping	Uses sulphate, sulphite, and sulphur-free to produce cellulosic pulp	■				
	Solvent-based	Uses solvent-based dissolution and filtration to extract polymers			■		
	Hydrothermal	Uses water containing one or more green acids to extract polymers (under pressure and high temperatures)			■		
Chemical-monomer	Methanolysis	Uses methanol to depolymerize (under pressure and at 200°C)				■	
	Glycolysis	Uses ethylene glycol to depolymerize (under pressure and at 200°C)				■	
	Hydrolysis	Hydrolyzes through water treatment and acid or caustic soda treatment				■	
	Enzymatic	Uses enzymes to depolymerize			■		

Figure 3.2. Various chemical recycling technologies. (Source: Mckinsey a& Company, 2022)

That said, the three major chemical recycling technologies currently in use are:

- Polymer recycling of cotton via pulping;
- Monomer recycling of PA6 or PET via (partial) degradation into oligomers or monomers; and
- Recovery of both cellulose and PET from polycotton blends

Let’s look at each of them in turn.

Polymer recycling of cotton via pulping

Polymer recycling of cotton via pulping involves three main stages: **pretreatment**, **dissolution**, and **solution spinning**.

- **Pretreatment:** The process begins with sorting cotton materials based on colour and/or composition. Hard parts, labels, and contaminants are removed using magnetic or gravimetric separation, followed by shredding or grinding to prepare the material for

chemical processing.

- **Dissolution:** The shredded material is suspended in a chemical solution to form a dissolving pulp. Optional steps, such as decolorization or bleaching, may be applied to remove dyes or additives. Contaminants like polyester or elastane are also optionally separated during this phase, ensuring a cleaner pulp.
- **Solution Spinning:** The dissolving pulp is processed into a viscous solution and extruded through spinnerets to form continuous fibres. These fibres are solidified through coagulation, producing regenerated cellulose suitable for creating new textiles.

This process has achieved a high level of technological readiness, particularly when using pure or cotton-rich textiles as the input material.

Monomer recycling of PA6 or PET

Monomer recycling of PA6 or PET involves three primary stages: **pretreatment**, **chemical depolymerization**, and **post-treatment and polymerization**.

- **Pretreatment:** The process begins with manually or mechanically cleaning and sorting the materials based on colour and composition. Non-recyclable or non-PET/PA6 components, such as hard parts or labels, are removed using techniques such as magnetic or gravimetric separation. Following this, the material is shredded or ground to reduce its size, and may undergo additional steps such as washing, granulation, or pelletizing to prepare it for the next stage.
- **Chemical Depolymerization:** At this stage, the material is dissolved using various technologies and specific reaction conditions. This process breaks down the polymer chains into their monomeric or smaller molecular units, which are essential for the subsequent re-polymerization process.
- **Post-Treatment and Polymerization:** The dissolved material undergoes purification, which may involve removing insoluble substances through microfiltration or eliminating colorants with activated carbon. Further separation steps, such as the distillation of caprolactam or solvent removal through evaporation, are conducted. Crystallization of intermediates like BHET or PTA may take place, and the material is dried to prepare it for reuse in manufacturing processes.

This comprehensive recycling approach effectively transforms polymers into high-quality monomers for repurposing in new products.

Recycling of polycotton blends

Three main approaches are used for recycling polycotton blends:

- **Solvent-Based Dissolution:** This method separates different materials by dissolving components in specific solvents. It involves removing contaminants such as dyes, followed by purification and polymer restoration.
- **Hydrothermal Recycling:** This process partially degrades cotton, PET, or both using subcritical water (100°C–374°C) and green acids. Cotton decomposes, and polyester fibres

are separated via filtration, melting, or extrusion and pelletization. Alternatively, PET may be depolymerized into TPA and dried for reuse.

- **Enzymatic or Biochemical Recycling:** This approach uses fungi and enzymes to degrade cotton in the blend. Fungi grow on textile waste, secreting enzymes that are later recovered. The textile waste is hydrolyzed in a bioreactor, separating PET by filtration. The cotton hydrolysate is purified with activated carbon to produce a glucose-rich syrup.

After standard pre-treatment, similar to other recycling pathways, separation and recovery processes are performed.

Key quality parameters

Similarly to mechanical cycling, one of the **process-level parameters** key to quality in chemical recycling is the granular sorting of the inputs into mono-streams and the removal of any non-textile parts, before the materials are shredded or ground into fibrous form. As the solution is dissolved, it is necessary to regularly adjust its viscosity and reactivity, including by increasing its molecular weight to achieve virgin-quality polymers. This process often involves adding chain extenders or stabilizers, especially for PET and PA6 pellets. Favourable reaction conditions — such as high temperatures, high pressures, shorter lead times, and the use of catalysts — must be optimized to enhance efficiency and reduce energy consumption.

The quality of the **input material** is equally important in chemical recycling. Ideally, the input should consist of a single or compatible polymer types, with feedstock requiring more than 99% pure polyester or polyamide. High purity and precise blend ratios are essential for maintaining quality, along with blending recycled materials with virgin materials to optimize processes and scale production. As in mechanical recycling, material composition-based separation technologies at the design or end-of-life stages are critical to achieving high-quality results.

Process costs for different chemical recycling streams

The chemical recycling process cost for different feedstock streams in Europe is shown [here](#).

What can we conclude from this? First, **chemical cotton recycling** is only feasible when process losses during pulping are low (<10%) and process efficiency and productivity are high. To achieve this, wet or semi-dried recycled cellulose pulp is often blended with more than 40–50% wood pulp by weight before respinning.

Second, **polycotton recycling** is still a relatively new process, with insufficient data available to fully evaluate its commercial-scale market feasibility.

Third, **enzymatic recycling** is the most expensive method, particularly when compared to the market price of virgin PET flakes. However, the import price of glucose, a key component in enzymatic recycling, helps the process reach break-even and improve its economic outlook.

Finally, while **Lifecycle Costing (LCC) data for recycled PET (rPET) and recycled PA6 (rPA6)** is limited, these processes are well-established and economically viable. The process yields are typically high, exceeding 90% for polyester streams and 70% for polyamide streams, further supporting their feasibility.

Cotton stream	Polycotton stream	Polyester stream	Polyamide stream
Via cellulose pulping process: <ul style="list-style-type: none"> ~900 EUR per tonne of recycled cellulose Reference baseline: Market value of wood pulp = 750-1200 EUR per tonne 	Via dissolution process: <ul style="list-style-type: none"> Replaces use of virgin wood pulp and virgin production of PET monomers (No LCC data is available) Reference baseline: Market value of (purified) TA = 450-700 EUR per tonne; (mono)EG = 500-800 EUR per tonne; DMT = 800-1050 EUR per tonne (in 2018/19) Via enzymatic process: <ul style="list-style-type: none"> Estimated process cost = 1950 EUR per tonne of recycled PET fibres Market value of PET flakes (900-1100 EUR per tonne (2019/20 data)) Reference baseline: Replaces import of glucose syrup (Market value of glucose syrup = 320-1700 EUR per tonne (av. 1000 EUR)) (Results in break-even) 	Via solvolysis process: <ul style="list-style-type: none"> Replaces use of virgin PET (No LCC data is available) rPET production cost (No LCC data available) Reference baseline: Market value of (purified) TA = 450-700 EUR per tonne; (mono)EG = 500-800 EUR per tonne; DMT = 800-1050 EUR per tonne (in 2018/19) (Price showing downward trend) 	Via solvolysis process: <ul style="list-style-type: none"> Replaces use of virgin PA6 (No LCC data is available) rPA6 production cost (No LCC data available) Reference baseline: Market value of PA6 polymers = 950-1100 EUR per tonne (2024)

Figure 3.3. Process costs for different chemical recycling streams using LCC data. (Source: Duhoux et al., 2021)

Another way to analyze process costs is by dividing them into **Operating Expenditure (OPEX)** and **Capital Expenditure (CAPEX)**. The table on the screen summarizes the estimated costs of different recycling methods in the EU. While this provides a good basis for comparing process costs, it is important to note that the process costs for mechanical recycling are significantly lower in regions such as Asia and Africa. However, these geographies face challenges, such as the limited availability of post-consumer feedstock. Additionally, other recycling technologies in these regions are less developed, making direct cost comparisons difficult.

Recycling pathways	Opex (excl. feedstock cost)	Capex (15% capex charge)	Total cost (with 15% capex charge)	Potential price per output ton
Mechanical recycling (Open-loop/downcycling)	250-500	200-400 (30-60)	280-560	Low
Traditional closed-loop	450-800	300-600 (45-90)	500-900	Medium Very high
"Soft" closed loop	2700-3500	2200-2400 (330-360)	3000-3900	High
Chemical-polymer (pulping)	1000-1900	3800-4700 (570-700)	1570-2600	High
Chemical-polymer (Solvent-based)	750-1300	1350-1500 (200-230)	950-1500	High
Chemical-monomer (Methanolysis)	825-1750	2450-3700 (370-560)	1200-2300	High
Chemical-monomer (Glycolysis)	825-1700	2150-3400 (320-510)	1150-2200	High
Thermo-mechanical	400-850	650-800 (100-120)	500-950	High

Figure 3.4. Process costs for different chemical recycling streams using OPEX and CAPEX method. (Source: McKinsey & Company)

Textile recyclers' different stages of technology readiness

The demand for textile recycling is growing rapidly, with established players and new entrants increasingly shaping the landscape. Broadly speaking, we can group textile recyclers into 3 stages of technological readiness:

- **Pilot stage:** Recycling solutions are tested at the laboratory scale and can produce and test outputs on a very small scale.
- **Operational stage:** Recycling processes can handle larger amounts of textile waste but are

limited to a small commercial scale, typically serving selected customers.

- **Commercial stage:** Fully functional systems process large volumes of waste, producing raw materials, fibres, yarns, fabrics, or finished products for wide-scale distribution.

Production and applications of recycled fibres

Recycled textile products can be manufactured in one of two ways: by using **spun yarns**, or through **nonwoven processes**.

Recycled spun yarns

To achieve high-quality spun yarns, it is necessary to have high-quality recycled fibres, and perform the appropriate machine modifications and adjustments at nearly every stage of the spinning process. Swiss textile machinery company Rieter has developed a classification system to grade mechanically recycled fibres by evaluating their **short fibre content**, the **mean fibre length**, and the **average length of the longest 5% of fibres**. This system helps estimate the fibres' processability and the resulting yarn quality.

Classification	Short-Fiber Content	Mean Fiber Length	5% Fiber Length
Very good	45%	17 mm	31 mm
Good	55%	14 mm	29 mm
Medium	60%	13 mm	28 mm
Poor	78%	10 mm	22 mm
Cotton as a reference	24%	21 mm	34 mm

Figure 3.5. Rieter classification system to grade mechanically recycled fibres. (Source: Rieter, 2020)

For long fibres (up to 70–75% of virgin cotton fibre length), classified as 'medium' grade or higher, **ring spinning** is the preferred method. Ring-spun recycled yarns offer the highest tenacity due to improved fibre integration. Compact spinning further enhances yarn strength, making them suitable for woven apparel applications with finer counts and softer textures. The carding process can improve ring spinning potential, and adding combing allows up to 50% recycled fibre content while maintaining ring spinning viability.

A typical ring spinning system might include a **blender, card, comber, drawframe, roving with cleaning devices, and a ring frame with compacting devices, followed by winding**. Similar processes, with modifications, can assess the spinnability of chemically recycled fibres.

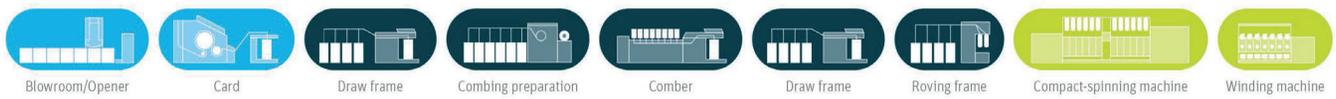


Figure 3.6. Rieter ring spinning system for recycled fibres. (Source: Rieter, 2020)

Rotor spinning

For short fibers, **rotor spinning** is the most common process, particularly for knitting applications with counts up to Ne 40. Rotor spinning benefits from shortened processes and specialized modules on carding machines, significantly improving yarn quality. With the right setup, rotor spinning achieves the lowest unevenness compared to other methods, ensuring better performance and consistency. Various rotor spinning system setups can further optimize the process and output quality.

Rieter investigated the economic viability of spinning with mechanically recycled fibres and found that up to **75% of recycled content for rotor spinning**, and up to **60% for ring spinning** are commercially valuable.

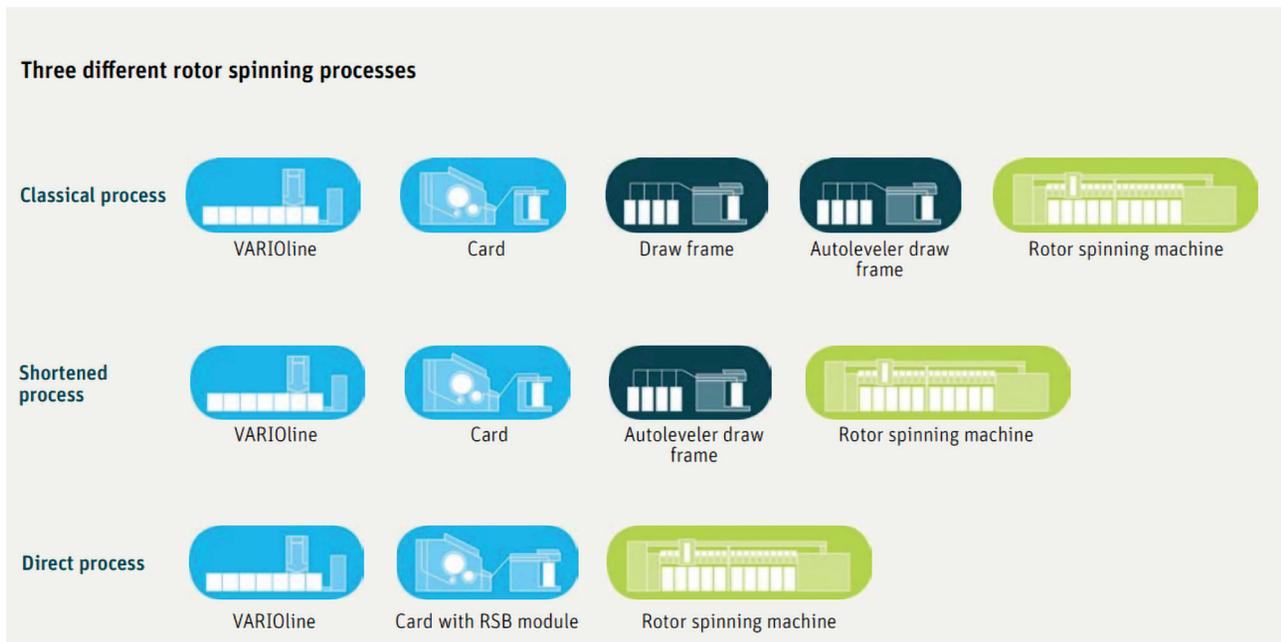


Figure 3.7. Rieter's different rotor spinning system for recycled fibres. (Source: Rieter, 2020)

Nonwoven technology for recycled fibres

Transforming recycled textile fibres into technical nonwoven felts is vital to create new products. Advanced nonwoven production lines, such as **airlay thermobonding**, **needlepunch**, **spunlace**, and **Wetlace CP**, are specifically designed to process recycled fibres efficiently.

Different nonwoven technologies have unique advantages for recycling fibres into valuable products. These materials are widely used as thermal and acoustic insulation for buildings, furniture, and automotive applications. They are also repurposed as carpet underlays, furniture paddings, automotive waddings, and hardboard for various industries.

Technology	Set-up	Recycled fiber used	Application
AIRLAY	Complete production lines with Needle punching, thermobonding and/or other bonding processes	Upto 100% recycled fibers can be used	Building, construction, automotive, mattresses and more.
NEEDLEPUNCH	Complete production lines with needle punch bonding	Upto 100% recycled fibers can be used	Building, construction, automotive, carpets and more
SPUNLACE	Complete production lines with hydro-entanglement bonding	Upto 65% recycled fibers can be used	Household wipes
WETLACE CP (CARDED-PULP)	Complete production lines with drylaid and wetlaid forming and hydro-entanglement bonding. Recycled fibers can be used within the carded/drylaid layer.	Upto 25% recycled fibers can be used	Technical wipes

Figure 3.8. Nonwoven technology for recycled fibres. (Source: Andritz)

Conclusion

In this video, we highlighted the textile recycling value chain, focusing on mechanical and chemical recycling processes, including steps, market aspects, and technological readiness. We also reviewed some key process and quality parameters to enhance the efficiency of textile recycling. By employing multi-criteria decision-making, companies can improve the economic feasibility of textile recycling by optimizing processing costs, leveraging market potential, and integrating recycled fibres into product value chains.



Knowledge check

Answer the following questions in the spaces provided below.

1) What factors influence the cost of mechanical recycling, and how do these costs compare for cotton versus polyester recycling?

.....

.....

.....

.....

2) What role does fibre quality (fibre length) play in the success of both mechanical and chemical recycling, and what input material characteristics are ideal?

.....

.....

.....

.....

3) What factors contribute to the cost differences between mechanical and chemical recycling?

.....

.....

.....

4) In the context of chemical textile recycling, explain the difference between monomer recycling and polymer recycling.

.....

.....

.....

.....

Are the following statements true or false?

5) Rotor spinning produces the most even yarn when properly set up, while ring spinning creates yarn with the greatest strength (tenacity).

True False

6) Open-loop mechanical recycling is currently the costliest textile recycling option.

True False

7) Chemical recycling technologies are associated with higher value fibre outputs.

True False

8) Chemical recycling technologies are associated with high efficiencies of scale.

True False



Coffee Break

30 min



Exercise - scenario

Take a few minutes to read this case study on Spain-based mechanical recycler **Recover™**.



Recover™ has been recycling textile waste into cotton yarns since 1947. In 2020, it established a specialized recycling unit in Valencia dedicated to producing mechanically recycled cotton fibers and cotton fiber blends.

Feedstock and Production Process

Recover™ sources its feedstock from post-industrial, pre-consumer, and post-consumer cotton waste, as well as cotton-rich blends. The recycling process involves:

- Cutting sorted textile waste into smaller pieces.
- Treating the material with an anti-static spray (using less water).
- Shredding and blending the fibres to create:
 - » **RCotton**: 100% recycled cotton.
 - » **RColorBlend**: Cotton blended with 30-70% recycled polyester.
 - » **REarth**: A 50/50 mix of recycled and organic cotton. These fibers are then sold to yarn spinners in varying compositions, including **RPure** (100% Recover™ recycled cotton), **RMix** (>90%), and **RDenim** (>80%).

Global expansion and sustainability goals

Recover™ produces fabrics for the fashion and interior design industries, with recycling facilities in Pakistan and Bangladesh. It plans to open plants in India, Vietnam, Turkey, Brazil, and Mexico to process textile waste closer to both supply and demand, reducing its carbon footprint.

The company has partnered with Sysav's Siptex automated sorting plant to ensure a steady supply of post-consumer waste. Other collaborators include Textile Exchange, ReHubs, Sustainable Apparel

Coalition, Circular Fashion Partnerships, and Denim Deal. By 2025, Recover™ aims for 40% of its feedstock to come from post-consumer sources and to process 350,000 metric tons annually by 2026.

Environmental Leadership

Aligned with Science-Based Targets, Recover™ calculates the environmental footprint of its recycled fibres. Its data is verified by the *Higg Materials Sustainability Index (MSI)*, enabling industry stakeholders to measure environmental impact. Adherence to certifications like GRS and Higg Index standards ensures credibility and sustainability.

Based on what you have read, what are some key strategies used by Recover™ to succeed in the textile recycling industry?

.....

.....

.....

.....

.....

.....

.....

.....



Exercise - scenario 2

Take a few minutes to read this case study on Finland-based chemical recycler **Infinite Fiber Company**.



Founded in 2016, Infinited Fiber Company specializes in textile-to-textile recycling using feedstock with over 88% cellulosic content, such as cotton from post-consumer waste. Additionally, decomposed cardboard and agricultural waste can serve as cellulose sources.

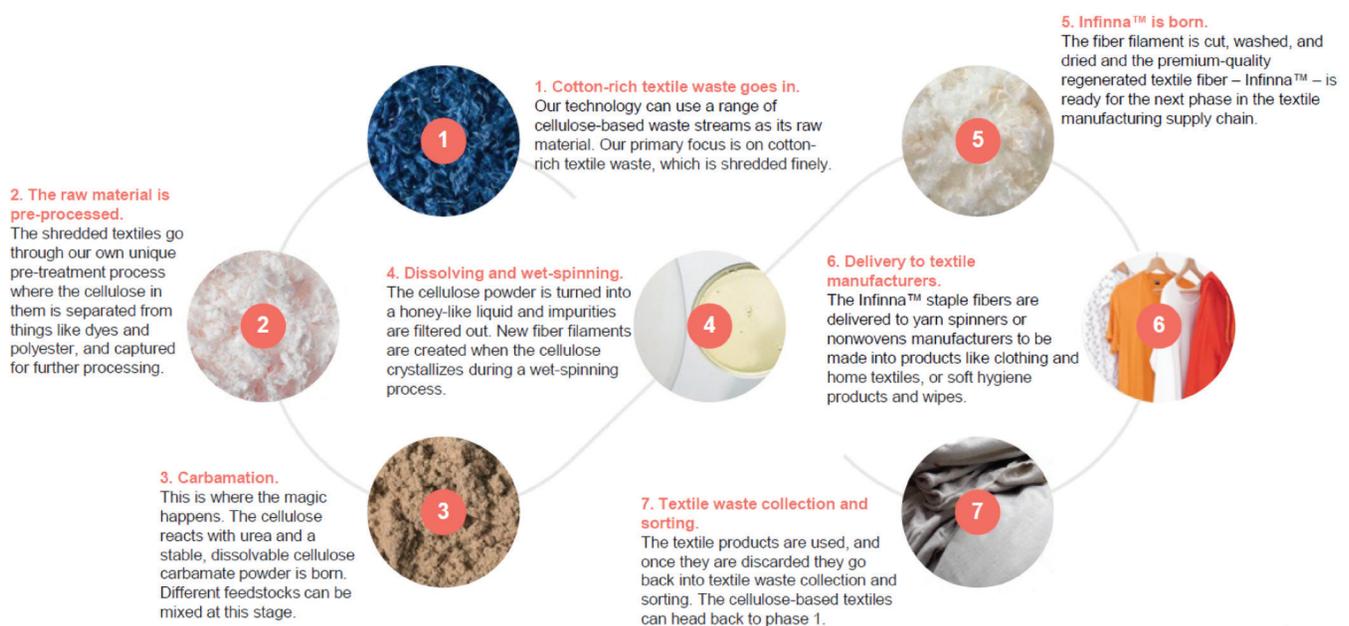
Recycling Process

The process begins with:

- 1. Shredding and Pretreatment:** Removal of hard components, dyes, polyester, and elastane.
- 2. Carbamation:** In this stage, cellulose reacts with urea to produce dissolvable cellulose carbamate powder.
- 3. Dissolution and Wet-Spinning:** Dissolution prepares liquid cellulose, allowing for further impurity removal. As the cellulose crystallizes, it transforms into Regenerated Infinna™ textile fiber.

The fibers are then cut into filaments, washed, and dried, ready to enter the next stage of the textile manufacturing supply chain.

See the process steps here:



End-Use Applications and Fibre Outputs

Infinna™ fibres are versatile and used in circular knits, denim, woven fabrics, and nonwovens. The fibres can produce yarns with counts ranging from **Ne7 to Ne40** in 100% Infinna, and up to **Ne50** when blended. Various spinning methods, such as ring, compact ring, open-end, and air-jet spinning, are compatible with these fibres.

Thanks to their cotton-like feel, Infinna™ fibres are particularly suited for clothing applications. Major brands, including Bestseller, Ganni, Patagonia, and Tommy Hilfiger, have secured supplies through off-take agreements, ensuring access to the fibres for years to come.

Production and Expansion Plans

Currently, Infinited Fiber Company operates two pilot facilities in Finland. The company aims to scale production by opening a commercial-scale factory in 2026, with an annual capacity of **30,000 metric tons**. Additionally, it plans to implement a technology licensing business model to expand its reach and impact globally.

Answer the questions:

1) How does Infinited Fiber compare to irrigated cotton?

2) How is Infinited Fiber addressing scalability and cost challenges?

WRAP-UP AND Q&A

So, what have we learned?

- Understanding the textile recycling value chain requires understanding the different recycling methods available and the steps of their processes. **Mechanical and chemical recycling are the primary methods** for textile-to-textile recycling.
- **Recycling process steps:** Mechanical recycling involves sorting, sanitation, cutting, tearing, and pressing. Chemical recycling includes dissolution and polymer or monomer recovery.
- **Key considerations:**
 - » Processing costs and market potential: Mechanical recycling costs vary widely, with respinnable fibres being the most valuable output. Chemical recycling, though costlier, yields higher-quality fibres.

- » Technology readiness: Mechanical recycling is well-established, while chemical recycling is expected to scale up significantly in 5–10 years.
- **Critical parameters:** Mechanical recycling depends on sorting accuracy, machinery optimization, and fibre quality. Chemical recycling requires granular sorting and removal of non-textile components to achieve high material purity.
- **Market potential:** Economic viability increases with high-value applications for recycled fibres. Quality fibers and machine adjustments are essential for spinning yarns, while nonwoven technologies produce technical felts and insulation materials from recycled fibres.

Do you have any final questions?

.....

.....

.....

List of additional readings (optional)

- European Commission, 2021, Duhoux et al., *Study on the technical, regulatory, economic and environmental effectiveness of textile fibres recycling*
- Mckinsey & Company, 2022, *Scaling textile recycling in Europe—turning waste into value*
- Rieter, 2020, *The Increasing Importance of Recycling in the Staple-Fiber Spinning Process*
- Rieter, 2020, *The Ideal Rotor Spinning Process for a High Short-Fiber Content*



End of session 3

Thank you for your participation.

SESSION

4

Valorizing Textile Business Models

INTRODUCTION

Welcome! The objectives of this session are to:

1. Explore the various business models operating within the textile recycling value chain.
2. Identify the key strategic resources and supply chain capabilities necessary for scaling the textile recycling value chain effectively.
3. Gain deeper insights into developing recycling business roadmaps and national monitoring frameworks. Additionally, understand the pivotal role of data traceability and feasibility analysis in these processes.



Answer the question

The textile recycling value chain embeds various actors with different types of business models.

Based on what you know about this value chain, what do you think **hinders scaling**?

What are some things that could be done to **enhance scalability** of the textile recycling value chain?

recyclers, intermediaries, and service providers such as marketplaces and digital platforms. All of them use different business models.

Textile recyclers

Textile recyclers are primarily for-profit entities that acquire non-rewearable textiles and recycle them using various technologies and processes, such as mechanical or chemical recycling. These recyclers differ in terms of:

- The **recycling technology** they use
- The **type of feedstock** they handle, categorized by material (such as cotton, polyester, etc.) or source (such as post-industrial or post-consumer waste)
- The **output** they produce, such as specific types of recycled fibres.

Their business models vary depending on the source of feedstock they use.

- **Post-consumer waste** is typically managed by “born recyclers”, which are organizations exclusively focused on recycling.
- **Post-industrial waste** is processed by both traditional recyclers and textile manufacturers, with many large manufacturers recycling their own production waste.
- Organizations that specialize in collecting, sorting, and reselling textiles, are increasingly also processing **non-rewearable waste** through recycling operations.
- Finally, **Innovative technology developers**, which specialize in chemical or enzymatic recycling, often use license-based models. In these, they license their technologies to other actors, such as textile producers. This approach facilitates technology scaling and positions recycling plants closer to feedstock sources.

Used and waste textile intermediaries

Intermediaries connect feedstock sources with recyclers, acting as middlemen in the textile recycling value chain. Examples include waste traders, brokers, and sorters who aggregate and prepare feedstock for recycling.

Aggregators and sorters collect non-rewearable textiles from collection points and sort them by colour, size, and recyclers’ needs. **Pre-processors** sometimes remove non-textile components and perform garneting, in which elements such as production off-cuts and used clothing are shredded using high-speed spiked cylinders.

Service providers

Service providers play an essential role in enabling textile recycling, even though they do not directly process waste streams. They offer solutions, such as marketplaces and digital platforms, that facilitate

and streamline recycling activities, particularly in the trading and management of textile waste.

Information-based digital platforms

These platforms enhance visibility and connectivity within the textile recycling value chain by **mapping the volume and location of textile waste**, and **matching the supply and demand for waste streams**.

For example, **Refashion's Recycle platform** specializes in digital waste mapping and matchmaking, focusing on post-consumer household textile waste. It provides insights into feedstock availability, recycling solutions, and key stakeholder profiles across Europe.

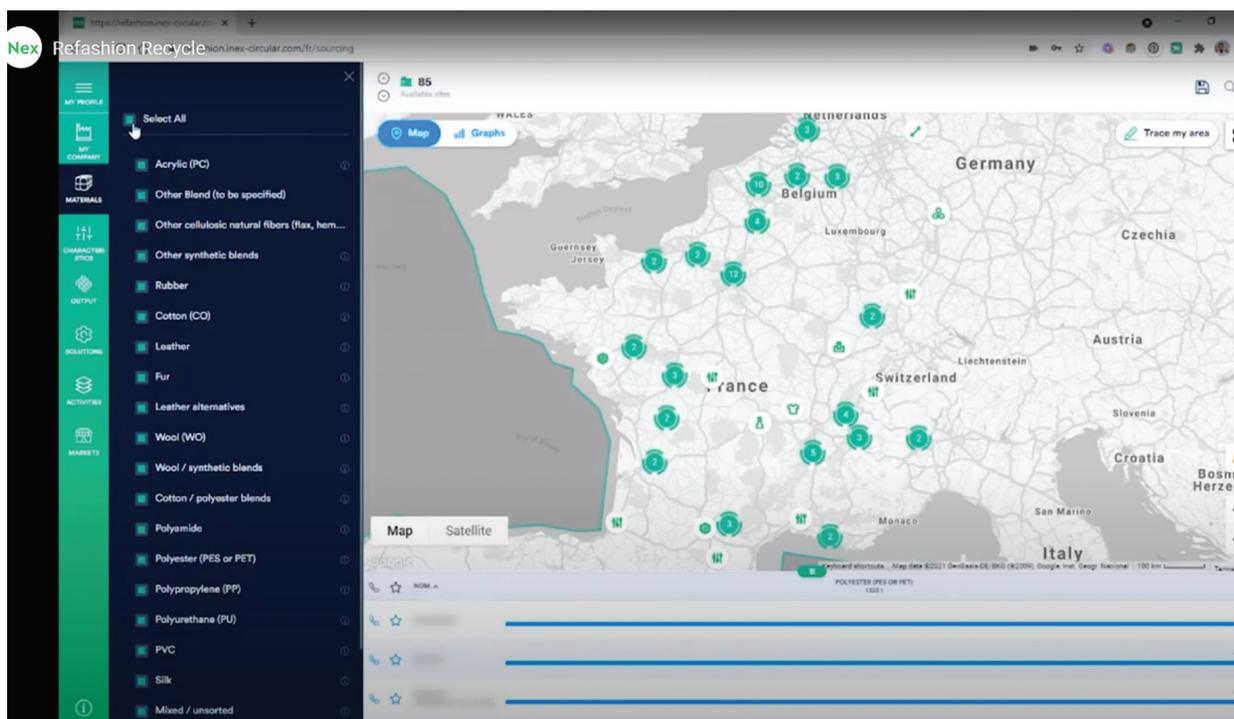


Figure 4.1. Example of information-based digital platform for textile recycling. (Source: Refashion)

Transaction-based digital platforms

These platforms serve as comprehensive marketplaces connecting sorting partners with recyclers, enabling business-to-business (B2B) transactions through essential tools and data.

A good example of such a platform is **Reverse Resources**, a SaaS platform. It offers:

- **Open-access matchmaking** across collectors, sorters, manufacturers, and service providers.
- **Tools for stakeholders** to jointly offer textiles categorized by type and composition.
- **Verification systems** to track where and how waste is recycled.
- **Real-time data and market insights** to scale fibre circulation.

Extended Producer Responsibility (EPR) funding can support these platforms, improving feedstock

affordability and accessibility for recyclers. Channelling EPR resources through such platforms fosters efficient and widespread recycling practices.

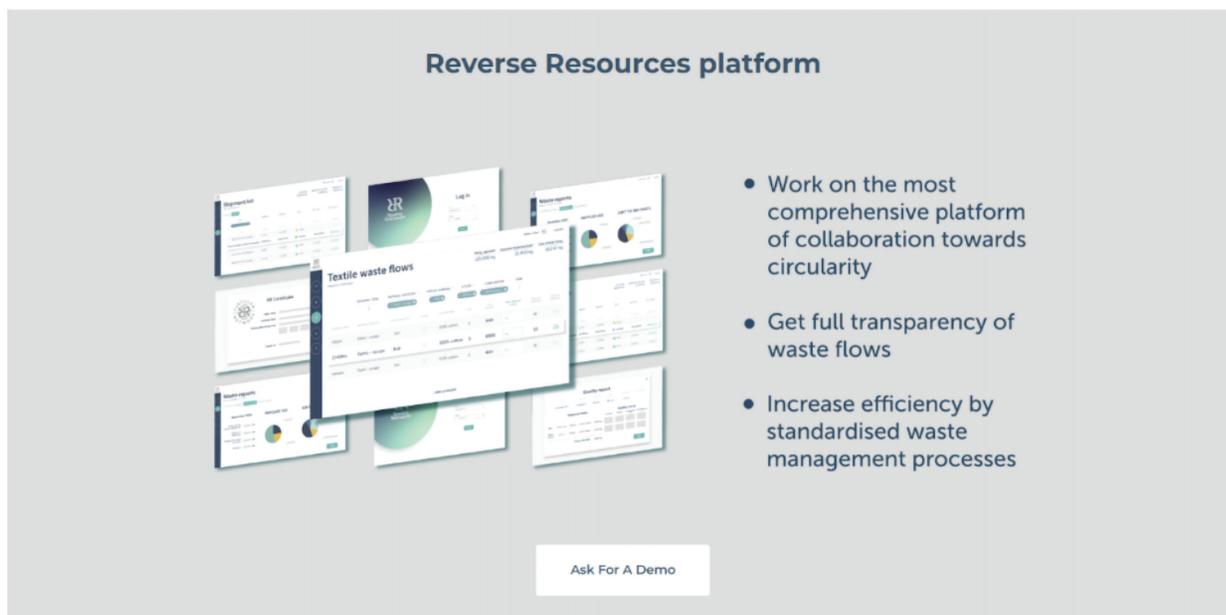


Figure 4.2. Example of transaction-based digital platform for textile recycling. (Source: Reverse Resources)

Strategic resource and capabilities to scale the textile recycling value chain

As you can see in the screen, there are 11 strategic resources and capabilities that are vital to scaling the textile recycling value chain.

Collaborative collection

This involves increasing the efficiency and volume of textile waste collection by building partnerships across various regions. This creates economies of scale, making the collection process more cost-effective. It also includes participating in industry-led pilot projects that test governance models for collective waste management. Additionally, collaborative efforts focus on improving the separation of textile waste streams through customer awareness campaigns and capacity-building initiatives for collection systems.

Transportation management

Transportation management ensures that textile waste is transported cost-efficiently. This involves minimizing the distance between collection points and warehouses or sorting facilities by collaborating with regional partners and planning optimized logistics routes. By leveraging efficient transportation networks, including achieving full truckloads and proper baling, the process minimizes waste and reduces transportation costs.

Designing logistics infrastructure

Designing logistics infrastructure entails creating efficient systems for storing and sorting textile waste. This includes localizing these operations to reduce transportation costs and deciding between centralized or decentralized operations to streamline feedstock sourcing. Building infrastructure with the right ownership models and working with international partners to expand capacity helps improve economies of scale.

Creating transparency

Creating transparency involves implementing systems that provide visibility and traceability throughout the textile recycling value chain. This includes conducting regular audits, collecting data systematically, and performing collection and sorting analyses. Transparency also means measuring the environmental and social impacts of operations and tracking progress toward resource reduction and decarbonization goals.

Supply of sorting feedstock

Securing a reliable supply of feedstock for sorting involves partnering with a variety of collectors to maintain a steady inflow of materials. It also includes ensuring stable regional supply chains, which help guarantee predictable volumes and consistent quality for sorting and recycling.

Improving sorting operations

Improving sorting operations focuses on making sorting more efficient and effective. This includes training employees through upskilling and reskilling programs to develop expertise in recycling-oriented sorting. Additionally, the integration of automatic sorting technologies alongside manual processes optimizes costs. Advocating for sorting practices during collection ensures better waste separation early in the process.

Organizing pre-sorting activities

Pre-sorting activities involve preparing textile waste for automated sorting systems. This includes managing costs associated with pre-sorting and collaborating on projects that enhance pre-sorting methods. Organizing these activities can also create business opportunities, such as offering sorting services to support automated processes.

Enabling feedstock supply for recycling

This process aligns the supply of sorted textiles with the demand for recycled fibres. It includes dynamic sorting practices to meet market requirements and collaborating with recyclers to ensure sufficient volumes and diverse materials. This alignment supports the continuous operation of recycling facilities.

Organizing preparation activities

Preparation activities involve tasks like trimming textiles to make them suitable for recycling. These processes are conducted alongside recycling operations and require careful management to control associated costs effectively.

Geographical localization

Geographical localization focuses on positioning recycling facilities close to waste generation sites to reduce supply chain and logistics costs. It involves optimizing inbound and outbound logistics and strategically licensing technology to users in these regions for long-term operational efficiency.

Matchmaking recycling and linear production

This involves connecting recycling processes with traditional textile production to close the loop in the value chain. Strategic collaboration with fibre producers and brands through offtake agreements ensures a steady demand for recycled materials. Additionally, providing transparency into recycled material production and insights on recycling-friendly design supports brands and suppliers in integrating sustainable practices.

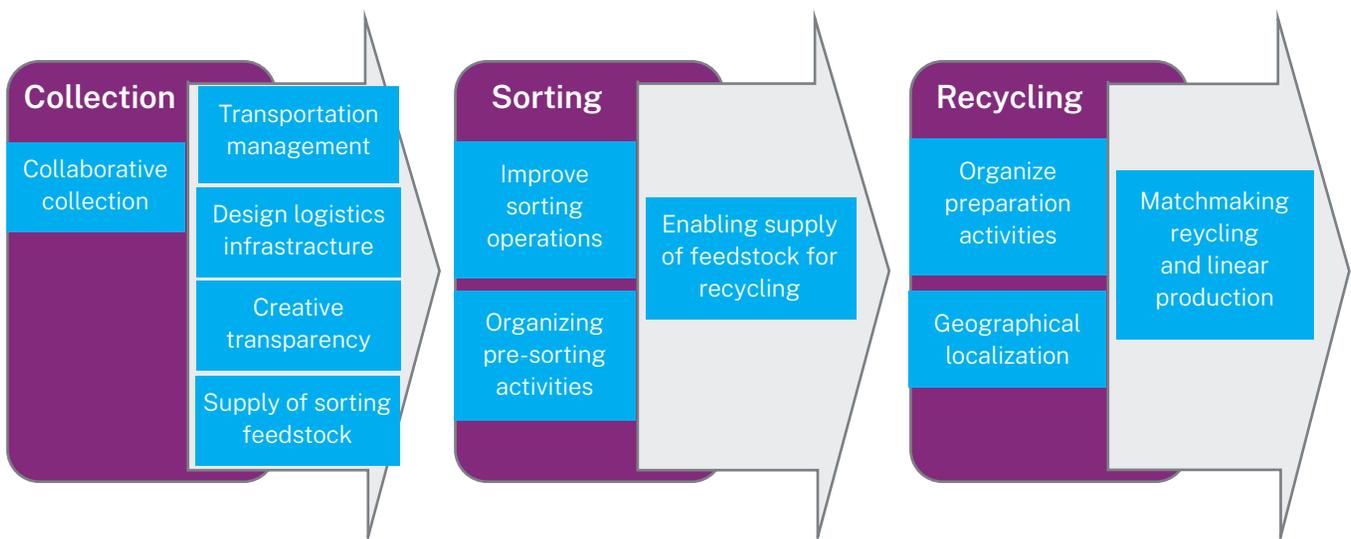


Figure 4.3. Strategic resource and capabilities to scale the textile recycling value chain. (Source: Sandberg and Pal, 2024)

Recycling business roadmaps and scalability assessments

At the individual organization level, building a roadmap for textile recycling involves creating both a stakeholder-level project plan, and a national monitoring framework.

Let's start by looking at the steps required to set up a stakeholder-level project plan:

Step 1: Plan setup

Clearly identify the opportunity or problem you want to solve, and the objectives you want to achieve. Typical project plan objectives can be written as you see on your screen:

- Increased efforts in **collecting, processing, and recycling** spent textiles to create new

products.

- **Collaboration on data collection and reporting** to identify where infrastructure and investment are needed to accelerate textile recycling.
- **Development of new business models and partnerships** that connect existing and emerging stakeholders.
- **Enhanced collaboration** between textile-to-textile stakeholders, including collectors, recyclers, and pre-processors, to improve efficiency and outcomes.

These objectives, whether implemented collectively or individually, will shape the project plan, guide the governance structure, and determine the key stakeholders to involve.

Step 2: Create a governing structure

Identify the most effective governance structure, whether for a new entity or as part of an existing organization, and set up a steering committee to provide oversight for the following activities:

- Determine how decisions are made, and who does what
- Develop the business plan
- Execute financing models and fundraising schemes
- Recruit new participants and support membership interests

Establish working groups to offer expertise and operational guidance on topics aligned with project goals. These groups may address areas such as staffing, partner requirements, sorting specifications, and business case development.

Step 3: Engage stakeholders

Create a stakeholder map to identify key questions for scouting suitable stakeholders. Define their roles, responsibilities, challenges, and corresponding action plans

Step 4: Build a budget & establish funding

Developing a financial strategy for textile recycling involves two critical steps: identifying cost components and securing funding.

When determining cost components, consider the following expenses:

- **Operational expenses** (staffing, IT, legal, office space, equipment, apps, etc.)
- **Capital expenses** (technology development, traceability systems, etc.)
- **Marketing and business development**
- **Research and trialing**
- **Trial program expenses** (raw materials, freight, testing, etc.)
- **Miscellaneous expenses** (travel, supplies, etc.)

Various funding schemes can be considered, including private investments from angel investors, venture capitalists, or green business loans. Grants from private entities, corporations, or governments are often suitable for technologies at lower readiness levels. Shareholder investments from brands and retailers are another option, with funding approaches differing by region. EPR subsidies can also provide effective transition funding.

Step 5: Pilot the value chain and business model

This step focuses on identifying supply chain partners and their operations, including process parameters like feedstock availability, volumes, capacities, and skill requirements. It is crucial to account for potential bottlenecks, such as limited capacity, high costs, or skillset shortages. Additionally, market demands from brands and retailers must be evaluated to align the product with their offerings. You can see the key variables to map on the screen. Take some time to read them more fully in your workbook later.

	PRODUCT-LEVEL	PROCESS-LEVEL	SUPPLY CHAIN-LEVEL
Collaborative collection	<ul style="list-style-type: none"> • Reuseable fraction% 	<ul style="list-style-type: none"> • Collection costs • Collection volume and Collection rate 	<ul style="list-style-type: none"> • Collection modes and governance model • Number of collectors and collection sites
Supply of sorting feedstock	<ul style="list-style-type: none"> • Prices based on market condition • % of total collected textile sorted 	<ul style="list-style-type: none"> • Overall capacity in storing/warehousing • Material handling costs 	
Organize pre-sorting activities	<ul style="list-style-type: none"> • Number of sorting fractions & volumes • Techn. enabled productivity 	<ul style="list-style-type: none"> • Sorting yield and conversion rate/efficiency 	<ul style="list-style-type: none"> • Number of pre-sorters & sorters • Sorting mode, and resp. governance model
Improve sorting operations			
Enabling supply of feedstock for recycling	<ul style="list-style-type: none"> • Colour, Material and Composition • Fabric density and other chemical/thermal/mechanical characters • Chemical and dye contents, other purities • Prices 	<ul style="list-style-type: none"> • Sorted volume and sorted material quality • Overall capacity in storing/warehousing 	
Organize preparation activities		<ul style="list-style-type: none"> • Preparation stages and costs • Feedstock variety and variability 	
Matchmaking recycling and market requirements	<ul style="list-style-type: none"> • Recycled product demand 	<ul style="list-style-type: none"> • Recycling yield and conversion rate • Quality of output suited to requirement • Optimized recycling process flow 	<ul style="list-style-type: none"> • Demand volume and MoQ • Recycling mode, and resp. governance model
Geographical scoping	<ul style="list-style-type: none"> • Location of all actors and distances between each node • Textile waste export/import taxation 		
Creating traceability and information mgmt system	<ul style="list-style-type: none"> • All data in a chain of custody • Standards, eg. GRS, ... 		
Design value chain and logistics infrastructure	<ul style="list-style-type: none"> • Available infrastructure and material flow • Overall capacity in storing/warehousing 		<ul style="list-style-type: none"> • Logistics cost efficiency
Transportation management	<ul style="list-style-type: none"> • Truck load, volume & frequency (Space eff) 	<ul style="list-style-type: none"> • Truck load, volume & frequency (Space eff) • Transportation costs, Footprints 	<ul style="list-style-type: none"> • Distances between each node • Textile waste export/import taxes

Figure 4.4. Data requirement mapping in the textile recycling value chain.

Step 6: Trials for scaling

To transition a pilot program into full-scale manufacturing, effective planning for minimum order quantity (MOQ) is essential. The key requirements include:

- Aligning process batch sizes with expected production outputs.
- Balancing demand and supply to meet end-market needs.
- Enhancing feedstock and process quality through standardization and optimization.
- Developing sustainability reporting metrics to measure performance and assess scalability.
- Implementing a formal tracking system using a suitable Chain of Custody (CoC) model to maintain supply chain integrity.

Setting up a national monitoring framework

Setting up a national monitoring framework is vital for tracking progress toward specific targets and goals. This framework integrates stakeholder-led projects, ensuring alignment between national and stakeholder approaches to evaluate the overall transition effectively.

In addition to setting long-term priorities, the framework serves as a critical tool for strategy development and planning among economic actors. It offers forward-looking guidance to shape future actions while providing backward-looking feedback to assess performance and refine strategies.

Steps to setting up a national monitoring framework

Step 1: Set up objectives and priorities

- Key objectives should be established across priority areas, including policy reform, information systems, capacity building, market-based incentives for investment, and training and awareness campaigns. Some examples of key objectives might include:
- Expand recycling capacity and modernize recycling equipment to increase quality and profitability
- Increase waste segregation and collection rates.
- Increase the use of recycled fibres in the value chains.

Step 2: Develop an action plan

For each priority objective, develop a detailed action plan including:

- **Status-quo mapping** to evaluate the current situation.
- **Identification of gaps** that need to be addressed.
- **Definition of key performance indicators (KPIs)** to measure progress.
- **Engagement of key stakeholders** responsible for implementation

For example, when establishing a national information system and digital platforms for textile waste valorization, transparency, and traceability, consider the following:

- **Current Status:** What is the current state of textile waste quantification and characterization?
- **Existing Initiatives:** What incentivization schemes and training programs are already available?
- **Legal Frameworks:** What regulations are currently in place or anticipated?
- **KPIs:** What are the measurable goals, such as the number of participating companies, tons of waste registered and traced, etc.?
- **Key Stakeholders:** Who are the main players, such as ministries, businesses, and business-support organizations?

Step 3: Create an information dashboard

A carefully chosen set of KPIs should be established to monitor progress. These may include qualitative metrics, such as operational performance, as well as experimental indicators, like revenue generation, which may require further refinement as the program evolves.

Step 4: Deploy implementation plan

The roadmap schedule is divided into phases according to the priority of each intervention within the framework. Timelines must be clearly defined for every action plan, setting expectations for short-, medium-, and long-term outcomes.

The two key enablers for successfully implementing a road mapping action plan are:

- **Robust data, traceability, and reporting mechanisms** to ensure transparency, monitor progress, and provide actionable insights.
- **Capital investment plans and feasibility assessment models** to secure funding and evaluate the practicality and sustainability of proposed actions.

Data traceability and reporting mechanisms

Different Chain of Custody (CoC) models can ensure formal tracking in textile waste value chain by following a generic methodology. Here's how the process works:

At the simplest level, CoC is divided into three key stages: **Segregation, Tracking, and Waste Collection and Handling**.

1. Segregation

The first step involves identifying and categorizing textile waste based on its properties:

- **Identify** the textile waste by attributes such as fibre type (e.g., cotton, polyester) and colour.
- **Segregate** the waste into distinct groups according to these attributes for better handling and processing.
- **Label** the segregated materials with specific details about the fibre type and colour to ensure accurate identification throughout the chain.

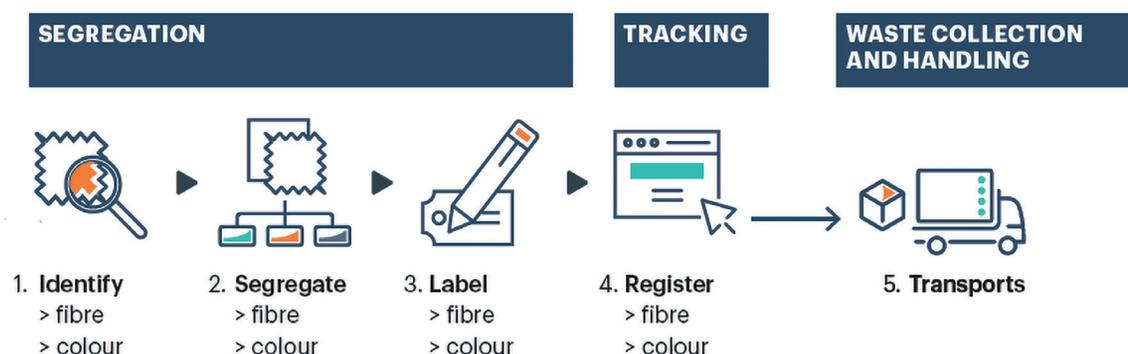


Figure 4.5. Chain of Custody (CoC) requirement in the textile recycling value chain. (Source: BluMine)

2. Tracking

Once the waste is segregated and labelled, it is formally tracked by registering its details:

- **Register** the fibre and colour data into a tracking system or database. This ensures that the material's journey through the value chain can be monitored, providing transparency and accountability.

3. Waste Collection and Handling

The final stage focuses on managing and transporting the registered textile waste:

- The registered materials are transported to designated collection, sorting, or recycling facilities, maintaining traceability throughout the supply chain.

Note: Traceability is compromised when intermediaries aggregate waste. Implementing segregation practices directly at the factory level increases the quality and value of waste, all while decreasing the recycler's costs.

Capital investment plans and feasibility assessment model

A textile recycling financial model can be evaluated using a basic leeway model, which determines the allowable process costs after collection and initial sorting. This model considers fractions and yields at various stages, comparing them to current market prices of virgin dissolving pulp and polyester chips.

Capital and operating expenses in the textile recycling value chain depend on several factors:

- **Design for recycling** to enable easy disassembly and separation.
- **Volume, yield, and costs** associated with the initial collection and sorting.
- **Fractions** generated during the second sorting stage.
- **Yield in cutting and separation** of components.
- **Process costs and yield** along with the value of residual materials during recycling.
- **Overall process costs** across the value chain.



Figure 4.6. Basic leeway model for evaluating textile recycling financial feasibility. (Source: Feasibility of Conditional Design)

Conclusion

In this video, we examined various textile recycling business models, including those for recyclers, intermediaries, and digital platforms. We outlined key strategic capabilities critical to the value chain, such as collaborative collection, efficient logistics, and traceability. Additionally, we explored the development of business roadmaps and national monitoring frameworks, emphasizing planning, stakeholder engagement, and scaling. Finally, we discussed how to assess the financial feasibility of action plans. We hope this video has been both informative and valuable.



Knowledge check

Answer the following questions in the spaces provided below.

1) As we have seen in the video, building a stakeholder-level project plan and business roadmap consists of several steps. In your own words, explain each of these steps and what they involve.

1. Plan setup
2. Create a governing structure
3. Engage stakeholders
4. Build a budget and establish funding
5. Pilot the value chain and business model
6. Trials for scaling

2) Why is setting up a national monitoring framework important to scale textile recycling operations in a country?

3) What role does traceability play in enhancing the competitiveness of textile recycling value chain?

4) Match the following businesses to their activities:

Waste traders and brokers	Removes non-textile accessories and perform initial shredding.
Sorters for recycling	Connect feedstock sources to recyclers.
Marketplaces and digital platforms	Aggregate and prepare feedstock for recycling.
Pre-processors	Facilitate textile-waste trading and provide visibility and matchmaking services.

5) In your own words, explain what factors influence the feasibility of a textile recycling business model.

.....

.....

.....

.....

.....

.....

textile recycling centre of Panipat alone exported over 33,000 shipments of recycled products worth \$1.4 billion to buyers like H&M, Primark, and Walmart.

Panipat's value chain and recycled product outputs

Panipat processes both post-consumer and post-industrial textile waste for mechanical recycling. The post-consumer textile recycling chain in India consists of (i) sorting, (ii) spinning, and (iii) product manufacturing through weaving and other techniques. Most post-consumer textile waste comes from Kandla SEZ, where companies import, sort, and store used textiles. While much is re-exported, a portion is mutilated and transported to Panipat for recycling. There, materials are re-sorted by fiber and color, hard parts removed, and textiles shredded for mechanical recycling before re-entering the yarn-making process.

Panipat also handles post-industrial textile waste, primarily factory cuttings from Delhi/NCR and, increasingly, cross-border inflows from Bangladesh. Scrap dealers collect and sort these cuttings by size, color, and fabric type, then sell them to Panipat-based contractors or directly to recycling units.

Panipat's sorting and spinning factories primarily produce recycled yarn, with over 50 spinning mills, as well as weaving and non-woven manufacturing units. Common end products include blankets, carpets, and household textiles, while coarser yarn is used for throws, rugs, doormats, and shawls. These products are exported to Europe, the US, Canada, Australia, Japan, and sold locally. The recycled yarn is also shipped worldwide, including to Kenya and Colombia for weaving. Additionally, leftover garments are processed into industrial wipers for various industries, and high-quality textiles are baled for export to textile hubs like Prato, Italy.

India's textile infrastructure and supply chain

India's large-scale infrastructure for sorting, processing, and recycling textiles has gained global attention. Investments by Fashion for Good, Reverse Resources, and major textile players (e.g., Arvind, Welspun, Birla Cellulose) are driving progress, alongside international partners like PVH, Adidas, and Levi's. With increasing domestic textile waste and growing purchasing power, India is poised to become a global leader in textile recycling, fostering novel value chains and business models for intercontinental collaboration.

To expand India's textile recycling ecosystem, it is vital to address key success factors and challenges. Recycling remains a niche segment, facing issues of volume, cost, quality, and supply chain consistency. Four critical factors for ecosystem development include feedstock availability, collection and sorting infrastructure, recycling technology, and market demand. While India has the foundation for competitiveness, strategic collaborations are crucial to:

- Establish inclusive, cross-border value chains and systemic solutions.
- Align supply and demand to valorize global recycling chains.
- Drive innovation through public-private partnerships and regulatory support.

Four dimensions to scale the textile recycling ecosystem are:

- **Value chain optimization:** Advance technologies, build multi-technology platforms, and implement certifications and standards to improve brand credibility and supply chain design.

- **Strategic alignment:** Enhance market intelligence, improve supply chain orientation, and balance standardization with creative innovation.
- **Lifecycle thinking:** Foster systemic perspectives and triple-bottom-line sustainability to address recycling gaps, ensuring net-zero outcomes.
- **Multi-stakeholder partnerships:** Promote circular financing and incentivization to formalize the ecosystem, enabling shared learning and knowledge-based solutions.

India's ecosystem has vast potential, but scaling requires orchestrated efforts to ensure sustainability, innovation, and economic growth.

Read the full white paper, *Pal et al. (2024), Positioning Indian textile recycling ecosystem globally: Setting the strategic intervention areas for future road mapping*



Answer the following questions:

1) Based on your understanding from this ecosystem case study, what do you think are the key points for the Indian textile recycling ecosystem to consider for successful road mapping in the future?

.....

.....

.....

.....

2) How could partnerships enhance sustainability in the Indian textile recycling ecosystem?

.....

.....

.....

.....

So, what have we learned?

- **Diverse business models:** The textile recycling value chain encompasses various business models, including recyclers, intermediaries, and service providers, each contributing distinct roles and expertise.
- **Strategic resources and capabilities:** Effective systems for collection, transportation, sorting, and ensuring transparency are critical for scaling operations within the textile recycling value chain.
- **Collaborative roadmapping:** A stakeholder-driven approach with well-defined goals, governance structures, and ongoing feedback mechanisms is essential for creating effective business roadmaps.
- **National monitoring framework:** Developing a national framework is crucial for tracking progress, ensuring compliance, and refining strategies through consistent feedback.
- **Traceability and digital platforms:** Adopting traceability systems and leveraging digital platforms improve transparency, enhance market access, and strengthen supply chain integrity.

Do you have any final questions?

List of additional readings (optional)

- Sandberg and Pal, 2024, *Exploring supply chain capabilities in textile-to-textile recycling–A European interview study*
- *Accelerating Circularity Reports*
- Switchmed, 2024, *National Roadmap for minimizing and valorizing pre-consumption textile waste in Egypt*
- Switchmed, 2024, *National Roadmap for minimizing and valorizing pre-consumption textile waste in Tunisia*
- *Positioning Indian textile recycling ecosystem globally: Setting the strategic intervention areas for future road mapping*
- Arisa, *Textile recycling unravelled*



End of session 4

Thank you for your participation.



Post-workshop

Coffee and Tea

