

IMASUS

Imageneering Sustainability

Design for Recyclability

IMASUS Training Module

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About

IMASUS (Imagineering Sustainability) is a pioneering initiative dedicated to transforming the fashion industry towards sustainability and addressing climate change challenges and led by the partnership of the Institute of Nanoscience and Materials of Aragon, Lottozero textile laboratories, Munkun creative strategy & learning studio and the European Creative Hubs Network.

Fashion, while influential, is one of the largest contributors to environmental degradation. IMASUS seeks to catalyze a shift in industry practices by promoting sustainable methods, such as using organic materials, recycling, and adopting circular design principles. Our goal is to inspire a widespread change in behaviors and practices, fostering a sustainable, ethical, and creative future for fashion.

The project integrates academic research, industry expertise, and practical learning experiences to equip fashion professionals with the necessary skills and tools for the sustainable fashion sector. Through workshops, digital tools, and collaborative approaches, we are building a community focused on innovation and real-world solutions for the fashion industry.



Part 1 – The Training Module

1. Introduction to Design for Recyclability

Design for recyclability addresses one of the central challenges of contemporary fashion: how to ensure that garments can meaningfully re-enter production systems at the end of their use phase. As textile waste continues to grow and virgin resource extraction remains dominant, recyclability has become a critical pillar of circular transition strategies. This section clarifies the concept of recyclability, distinguishes it from related practices such as upcycling, and outlines the systemic, environmental, and design implications that make it an urgent priority within sustainable fashion.

1.1 Learning Objectives

By the end of this module, learners should be able to:

- Define design for recyclability as a strategic approach in fashion design
- Distinguish between mechanical, chemical, and biological recycling systems
- Identify material and construction choices that enable or hinder recyclability
- Analyse how fibre blends, trims, coatings, and finishes impact end-of-life recovery
- Evaluate the limitations and trade-offs of recycling within circular systems
- Apply recyclability principles when developing a garment concept

1.2 Definition and Scope

Clothing recycling refers to breaking down used garments into raw materials that can be reprocessed into new products. This differs from upcycling, which transforms existing garments into new items without reducing them to fibre form (Recovo, n.d.).

It is important to distinguish between *recycled* and *recyclable* materials. Recycled garments are made from materials that have already been processed back into raw form and reused to create new textiles or products. Recyclability, by contrast, refers to the capacity of a product or material to be collected, disassembled, and reintroduced into the manufacturing cycle without significant loss of quality or functionality (Redress, n.d.).

Recyclability is largely determined at the design stage. Choices regarding material composition, construction methods, trims, and labeling influence whether a product can be effectively recovered. Barriers such as incompatible fibre blends, complex constructions, and inconsistent labeling continue to limit textile recovery. Moreover, being recyclable does not guarantee being recycled; actual recovery depends on available technology, infrastructure, market demand, and consumer participation.

Recycling in fashion operates at several levels (Baloyi et al., 2023):

Fibre recycling – mechanically breaking down fabrics into fibres (e.g., turning used cotton textiles into new cotton fibre), which can then be spun and reprocessed into textile products.

Polymer recycling – chemically depolymerising synthetic fibres such as PET or nylon back into monomers, which can then be respun into new materials.

Component recycling – reusing garment elements such as buttons, zippers, or trims in new products.

Closed-loop recycling keeps materials within the textile sector, whereas open-loop recycling redirects them into other industries (Ellen MacArthur Foundation, 2017).

Designing for recyclability therefore means creating garments from the outset with end-of-life recovery in mind. It involves deliberate decisions about materials, construction, labeling, and traceability to ensure that products can meaningfully re-enter production systems.

1.3 The Urgency of Recyclability in Fashion

The fashion industry is highly resource-intensive, generating waste and emissions at every stage—from raw material cultivation to end-of-life disposal. Each year, approximately 92 million tonnes of textile waste are produced globally, equivalent to a truckload of clothing landfilled or incinerated every second (Ellen MacArthur Foundation, 2023). Over 80% of textiles exit the system at disposal without any form of recovery.

Currently, less than 1% of textiles are recycled into new clothing, while more than 97% of fibre inputs come from virgin resources (Ellen MacArthur Foundation, 2017). These figures highlight the structural imbalance between production and recovery and underscore the need to redesign textiles with recovery in mind.

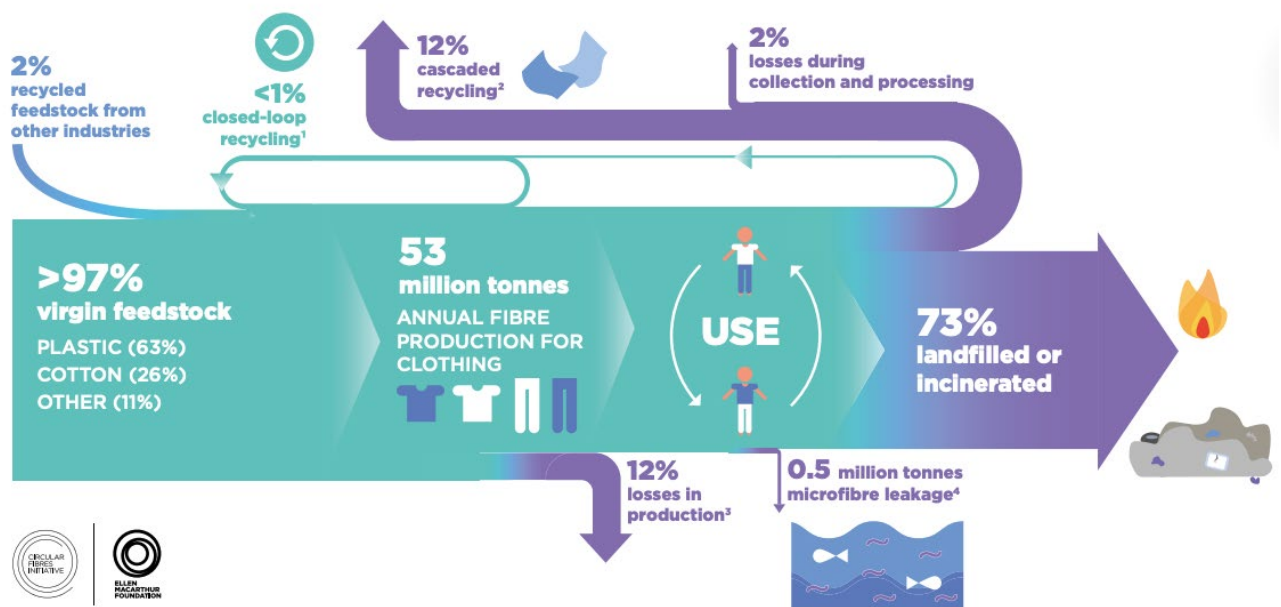


Figure 1. Global Material Flow for Clothing in 2015 (Ellen MaCarthur Foundation, 2017) retrieved from:

<https://content.ellenmacarthurfoundation.org/m/7f818b40f06e1afd/original/Summary-of-findings-A-New-Textiles-Economy.pdf>

Circular business models—repair, resale, rental, and remaking—could generate USD 700 billion by 2030 while significantly reducing waste and emissions. Regulatory frameworks are accelerating this transition. The EU Strategy for Sustainable and Circular Textiles (2022) mandates that textile products sold in the EU must be durable, repairable, and recyclable by 2030. Extended Producer Responsibility (EPR) policies require producers to finance and manage end-of-life collection and recycling systems.

Although textile-to-textile recycling is considered a critical pathway to impact reduction, it remains in its early stages. Most recycled textiles currently available are derived from recycled PET bottles rather than fibre-to-fibre systems (Sandin, 2025). Scaling fibre-to-fibre recycling is therefore identified as a priority within the EU strategy.

These developments signal a systemic shift—from linear production and planned obsolescence toward material stewardship and circular responsibility.

1.4 Designers as Change Agents

Designers play a pivotal role in shaping circular systems. The European Commission (2020) estimates that up to 80% of a product’s environmental impact is determined during the design phase, when decisions about materials, construction, and end-of-life pathways are established.

Designing for circularity requires *end-of-next-life thinking*: anticipating how materials will be recovered, reprocessed, and recirculated after the use phase (Ellen MacArthur Foundation, 2023). This approach is grounded in:

Systems thinking – understanding garments as part of interconnected networks of fibre producers, manufacturers, recyclers, retailers, and users.

Material literacy – recognising how fibre properties, blends, finishes, and construction techniques influence recyclability.

Collaboration – aligning design decisions with technological capabilities and post-use infrastructure.

The Butterfly Diagram developed by the Ellen MacArthur Foundation illustrates a hierarchy of circular strategies. Inner loops—maintenance, repair, and reuse—retain the highest material value, while recycling represents a later recovery stage.

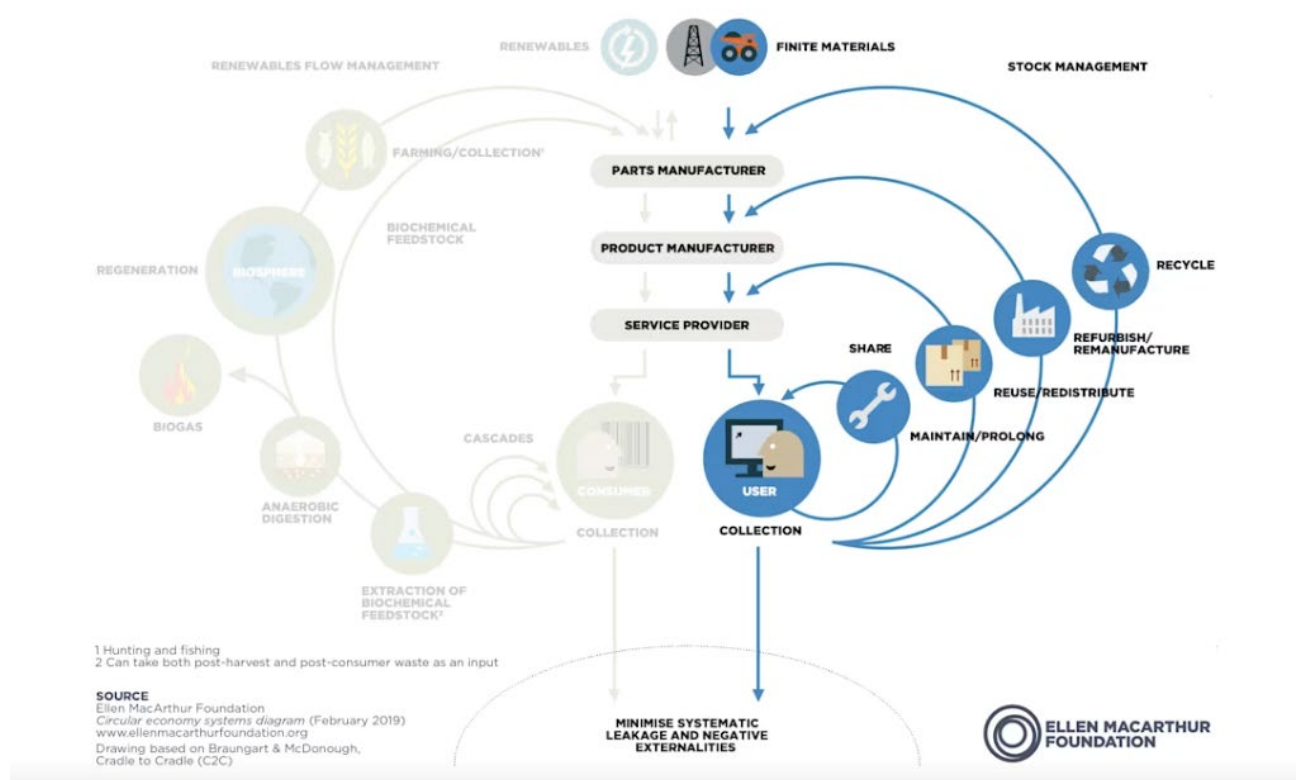


Figure 2. The technical cycle of the butterfly diagram, from Ellen MacArthur Foundation Circular economy systems diagram (February 2019) retrieved from: <https://www.ellenmacarthurfoundation.org/articles/the-technical-cycle-of-the-butterfly-diagram>

For fashion design, this means prioritising durability and reparability while ensuring recyclability is embedded from the start. Under EPR systems, producers—and increasingly consumers—share responsibility for returning garments into circulation.

Clear communication through labeling, storytelling, and Digital Product Passports (DPPs) helps users understand how to maintain materials within the system.

In this context, design becomes both a technical and ethical practice, guiding the transition from linear consumption toward regenerative models.

1.5 Lifecycle thinking and design for disassembly

Designing for recyclability requires lifecycle thinking: considering how garments move through phases of use, care, repair, and eventual recovery (Ellen MacArthur Foundation, 2017; Ellen MacArthur Foundation, 2023).

A key strategy is **design for disassembly**, which ensures that materials can be separated into clean streams for recycling. This requires simplifying material combinations and avoiding constructions that prevent separation (Redress, n.d.; Mindful Fashion New Zealand, n.d.).

Two principles guide this process:

Material efficiency – using resources effectively, minimising waste, and reducing incompatible material mixes (Ellen MacArthur Foundation, 2023).

Design as activism – embedding responsibility and transparency into design decisions to challenge the take-make-waste paradigm (Ellen MacArthur Foundation, 2017).

By planning for reuse, redistribution, remanufacturing, and repair, designers keep garments circulating within higher-value loops. Recycling should remain the final step, activated only when further use is no longer possible. Lifecycle thinking ensures materials are not lost to landfill but continue contributing value within circular systems.

2. Historical Context: Reuse and Recycling in Fashion

Textile recycling is often presented as a contemporary innovation, yet practices of material recovery have deep historical roots. Long before sustainability became a formalised concept, economic necessity and material scarcity drove systems of repair, reuse, and fibre regeneration.

2.1 Pre-Industrial Circular Practices

Before the Industrial Revolution, textiles were produced through slow and labour-intensive processes—spinning, weaving, and hand-sewing—which made garments valuable and rarely discarded. Clothing was routinely repaired, resized, and repurposed, often circulating across generations. In many households, children’s garments were cut down from adult clothing, and leftover fabric was reused for accessories or domestic items (Blum, 2018).

Early forms of textile recovery also existed. Across Europe, discarded rags and cloth remnants were collected and sold to industries such as papermaking or low-grade fibre production. This early rag trade reduced reliance on new raw materials and represents one of the first organised systems of material circulation.

2.2 The Rag and Mungo Industry

By the 18th and 19th centuries, textile reuse had developed into an established secondary economy. In Britain, rag collectors gathered unwanted household textiles and sold them to merchants, creating supply chains that supported industries such as mattress stuffing, papermaking, and early textile regeneration.

A particularly influential example emerged in Prato, Italy, where textile recycling shaped local identity for centuries. Prato became known for its carded wool (*cardato*) industry, which regenerated fibres from discarded wool garments and tailoring offcuts. A major turning point occurred in the mid-19th century when Giovanni Battista Mazzoni refined spinning and carding machinery, enabling efficient shredding and reprocessing of waste textiles.

This innovation laid the foundation for Prato’s contemporary textile ecosystem—an interconnected network of small and medium enterprises, each specialising in a stage of the recycling process. Today, the district recycles over 100,000 tons of post-consumer textiles and production scraps annually (Cardato Riciclato Pratese, 2023).

Meanwhile, in Yorkshire, Britain, the shoddy and mungo trades developed as early industrial fibre-recycling systems. Beginning around 1813, manufacturers shredded rags and blended the fibres with virgin wool to produce shoddy cloth—a cost-effective textile enabled by advances in mechanised spinning and carding during the Industrial Revolution. Together, these systems demonstrate how necessity, technical

knowledge, and mechanisation produced some of the earliest examples of textile-to-textile recycling.

2.3 Decline and Re-emergence

Industrialisation transformed textile production, dramatically lowering costs and increasing output. As garments became cheaper and easier to replace, traditional practices of repair and reuse declined.

During World War II, material shortages temporarily revived repair culture under campaigns such as *Make Do and Mend*. However, post-war economic growth and the rise of fast fashion in the late twentieth century accelerated overproduction and normalised disposable consumption. Globalised manufacturing, the expansion of synthetic fibres, and falling prices further distanced consumers from the material value of clothing.

In the 21st century, this trajectory has begun to shift. Environmental concerns, resource scarcity, and growing awareness of labour conditions have renewed interest in extended use and material recovery. Consumer research (Textile Exchange, 2023) indicates increasing demand for durable, repairable, and recyclable garments, while regulatory frameworks—most notably the EU Strategy for Sustainable and Circular Textiles and Extended Producer Responsibility (EPR) schemes—require brands to integrate recovery systems across the value chain (European Commission, 2022).

This renewed focus echoes earlier traditions of care and efficiency but is now supported by technological innovation and emerging recycling infrastructure. Historical systems such as Prato's *cardato* model illustrate how longstanding regional expertise can inform contemporary circular textile strategies.

From early rag-collecting networks to industrial shoddy mills and Prato's carded-wool district, textile reuse has deep historical roots. What distinguishes the present moment is the scale of global production and the technological capacity to recover fibres industrially. The next section examines the fibre properties, material constraints, and technological processes that underpin modern textile-to-textile recycling.

3. Materials and Fiber Science for Recyclability

Understanding recyclability requires moving from historical context into material science. The ability of a garment to re-enter production systems depends on fibre composition, chemical structure, construction, and compatibility with existing recycling technologies. This section examines how textile recycling processes function at material level, highlighting the technical constraints and design decisions that determine whether fibre-to-fibre recovery is possible.

3.1 Understanding Textile Recycling Processes

Textile recycling begins long before fibres are broken down. The collection and sorting phase is one of the most crucial—and most challenging—steps in the process. Successful recycling depends on the quantity, purity, and separability of recovered materials.

In Prato, Italy, skilled workers known as *cenciaioli* still sort garments by hand, optimize them by fibre type and colour to optimize mechanical recycling. This precision-based system contributes to Prato's reputation for high-quality regenerated wool.

Effective recycling requires more than collection. Designers influence recyclability by:

- Selecting mono-materials or compatible fibre blends that are easier to process,
- Using construction methods that allow disassembly,
- Providing accurate material documentation and disposal guidance (e.g., through labelling or Digital Product Passports).

Once garments are collected, they typically undergo mechanical or chemical recycling. According to Recovo (2023), the general textile recycling process involves six stages:

Collection – Retrieval of used garments through donation, take-back schemes, or recycling programs.

Sorting – Organising by fibre type, colour, and quality.

Shredding – Mechanically reducing textiles to fibre form.

Cleaning – Removing dyes, finishes, and contaminants.

Processing – Respinning or forming new yarns and fabrics.

Manufacturing – Creating new textile products.

As illustrated in Figure 3, value retention varies across recycling pathways, echoing the hierarchy presented in the Butterfly Diagram (Figure 2). Inner loops preserve more material value, while outer loops involve greater structural transformation.

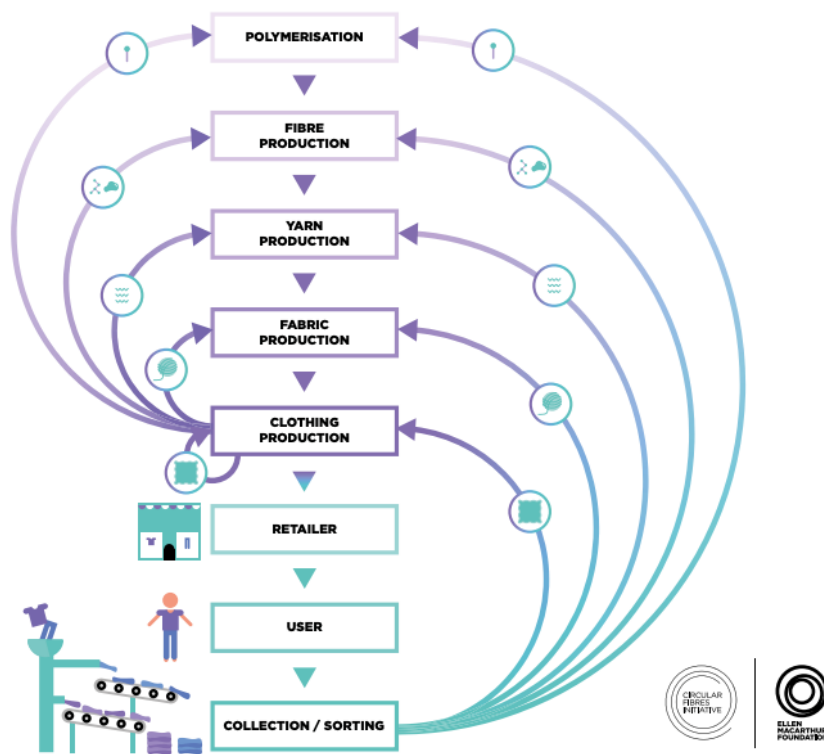


Figure 3. Value capture of textile recycling at various levels (Ellen McArthur Foundation, 2017)

Fabric Recycling (Inner Loop)

Fabric recycling reuses intact textile pieces—factory offcuts, deadstock, or large garment panels—to create new products. It requires minimal technology but remains limited in scale, as fabric pieces are often small or inconsistent. This method is more common in upcycling and small-batch production than in industrial systems.

Yarn Recycling (Second Loop)

Yarn recycling recovers yarns from knitwear or woven textiles. Frequently seen in small-scale creative practices (e.g., unraveling sweaters for re-knitting), it remains labour-intensive and limited to specific garment constructions.

Fiber Recycling (Intermediate Loop)

Fibre recycling—often referred to as mechanical recycling—is one of the most widespread forms of textile recovery. Garments are sorted by colour and composition, shredded, carded back into fibre form, and then respun.

Mechanical recycling is widely applied to wool, cotton, and polyester. It offers scalability and relatively low energy input compared to chemical processes. However, significant limitations remain:

- It cannot separate blended fibres (e.g., cotton-polyester mixes).
- It cannot remove dyes or finishes, affecting colour consistency and purity.
- The shredding process shortens fibres, reducing strength and softness.

To maintain fabric quality, mechanically recycled fibres are often blended with virgin fibres such as long-staple cotton or polyester. While this maintains performance, it introduces new raw materials into the system.

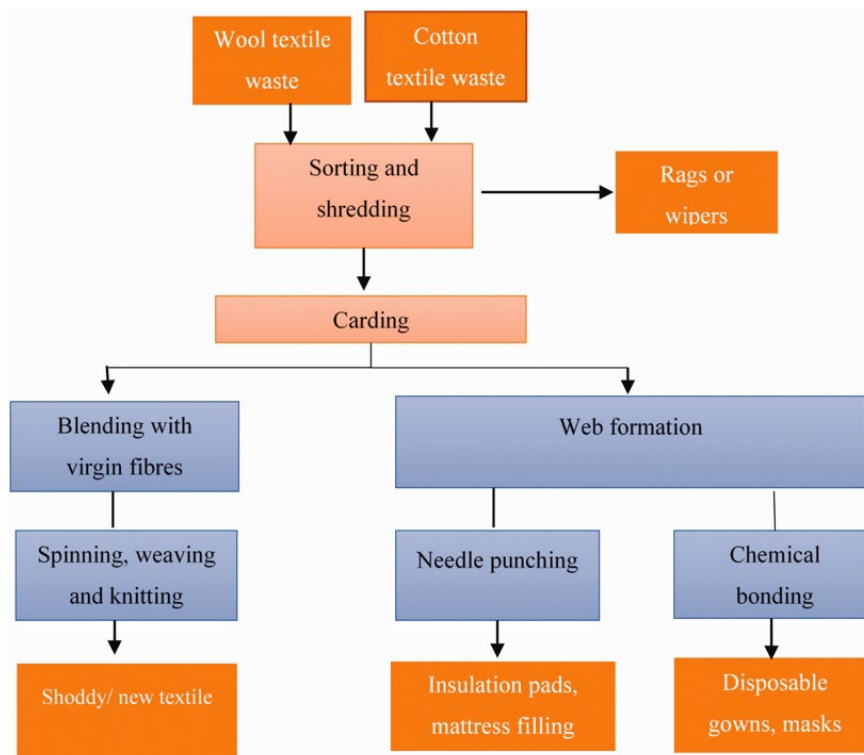


Figure 4. Mechanical recycling technologies for natural origin fiber (Baloyi, 2023)

Polymer Recycling (Outer Loop)

Chemical recycling breaks fibres down to the polymer or monomer level and is applicable to synthetics (e.g., PET, PA) and certain cellulosics (e.g., cotton, viscose).

Polymer recycling destroys fibre structure but preserves polymer chemistry. Two main pathways exist:

Mechanical polymer recycling – Melting and extruding mono-material synthetics such as polyester or nylon.

Chemical polymer recycling – Dissolving textiles with solvents to separate cellulose-based fibres (e.g., cotton, viscose) from synthetics (e.g., PET, PA). The recovered cellulose pulp and synthetic polymers can be reconstituted into virgin-equivalent fibres, with dyes and contaminants removed.

Monomer Recycling (Outermost Loop)

Monomer recycling breaks polymers down into their basic monomer units, enabling the creation of virgin-quality fibres. It represents the most advanced form of fibre-to-fibre circularity. Despite its potential, it remains costly, chemically intensive, and limited by infrastructure constraints (Ellen MacArthur Foundation, 2017).

To scale textile recycling effectively, design and recycling systems must be aligned (Ellen MacArthur Foundation, 2017). Designers can accelerate progress by selecting recyclable materials, reducing incompatible blends, and implementing transparent labelling systems that support accurate sorting.

When brands commit to recycled feedstock, they generate market demand that stimulates investment and technological innovation within recycling industries. Design decisions made at the beginning of a garment's life therefore directly influence its recovery potential.

3.2 Recyclability by Fiber Type

It is important to distinguish between biodegradable fibres and recyclable fibres. Biodegradable fibres decompose naturally and return to the ecosystem, as seen in natural fibres such as cotton, silk, hemp, bamboo, and wool. Synthetic textiles may degrade over extended periods but often contain chemical additives and do not biodegrade in environmentally beneficial ways.

Natural fibres that are biodegradable can also be recycled and retained within circular systems. Typically, natural fibres are recycled mechanically, while synthetic fibres undergo chemical or thermomechanical recycling (Close the Loop, 2025).

Fiber	Mechanical	Chemical	Key Issues
Cotton	Yes	Yes (via cellulose dissolution)	Dye contamination
Wool	Yes	Limited	Fiber length loss
Polyester	Yes (limited)	Yes (depolymerization)	Blends, finishes
Nylon	Yes	Yes	Costly
Elastane	No	No	Contaminant in blends

3.3 Blends, Dyes, and Finishes

Fibre blends present one of the greatest obstacles to textile recycling. Because each fibre type has distinct chemical and physical properties—such as melting point, fibre length, and degradation behaviour—mixed textiles are difficult or costly to separate.

Elastane (spandex) is a particularly problematic example. Even at 2%, elastane can contaminate entire recycling batches. Denim jeans, often 97–99% cotton but containing small elastane percentages, are therefore extremely difficult to recycle at scale.

To address this issue, researchers are developing selective dissolution and chemical separation technologies capable of isolating fibre types, such as separating cotton from polyester. For example, Circ uses a water- and chemical-based process to recover up to 90% of original materials. The resulting high-purity cellulose can substitute for wood pulp in regenerated fibres such as lyocell and viscose. However, these processes remain energy-intensive and expensive, limiting scalability.

Designers are therefore encouraged to minimise fibre blends or use compatible blends (e.g., polyester-based materials) that can be processed together.

Dyes, coatings, and chemical finishes further complicate recyclability. Substances applied for colour, texture, or performance often introduce contamination into recycling streams.

Dyes and pigments: Dark or heavily pigmented textiles are difficult to recolour; dye removal requires additional processing.

Finishes and coatings: Water-repellent, stain-resistant, anti-wrinkle, and flame-retardant treatments introduce resins, silicones, or PFAS compounds that contaminate recycling processes.

Metallic and plasticised finishes: Foils, glitter, and polyurethane coatings are extremely difficult to separate from base textiles.

Emerging innovations include digital and waterless dyeing, bio-based pigments, and recyclable dye systems designed to reduce contamination and improve fibre recovery. Lighter, undyed, or naturally coloured fibres can also improve recycling efficiency by reducing the need for colour stripping.

4. Design Principles for Recyclability

Translating fibre science into practice requires deliberate design strategies. Recyclability is not achieved through material selection alone but through coordinated decisions about construction, trims, colour, finishing, and information systems. This section outlines the core design principles that enable garments to move efficiently through recycling infrastructures while retaining material value.

4.1 Mono-Material Design

Sorting and recycling are significantly more effective when garments are made from mono-material textiles—that is, constructed from a single fibre type such as 100% cotton or 100% polyester. Mono-materiality simplifies identification, sorting, and reprocessing, whether through mechanical or chemical recycling. By contrast, blended materials complicate recovery, as separating fibre types is labour-intensive, technologically complex, and often economically unfeasible.

Designers frequently choose blended fibres for legitimate performance reasons. Blends can enhance comfort, strength, resilience, stretch, or drape. For example, incorporating elastane into cotton denim improves stretch and shape retention, while adding polyester or acrylic to wool increases durability and abrasion resistance. The challenge lies in achieving these functional benefits without compromising future recyclability.

Where possible, garments should be made from a single dominant fibre or from chemically compatible materials that can be processed together. When blends are unavoidable, responsibility shifts toward transparent labelling, documentation, and digital traceability so recyclers can correctly identify compositions at end-of-life.

4.2 Design for Disassembly

Design for disassembly ensures garments can be easily taken apart at end-of-life, allowing components to be recycled or reused separately. When integrated from the outset, disassembly principles reduce labour costs, minimise contamination, and support higher-value recovery.

Designers can facilitate disassembly by:

- Avoiding adhesives and fused interlinings that permanently bind materials,
- Using mechanical fasteners—snaps, screws, ties, stitched channels—instead of irreversible joins,
- Standardising attachment methods so garments can be dismantled predictably.

These strategies also support repairability. The features that allow disassembly for recycling often make garments easier to service or modify during use. In this way, design for disassembly reinforces circular strategies across the product's entire lifespan.

4.3 Component and Trim Simplification

Material simplification extends beyond fabrics to notions, trims, and accessories. Zippers, buttons, threads, elastics, interfacings, and labels all influence recyclability.

Using compatible trims—for example, 100% polyester zippers paired with polyester garments—allows materials to be processed together without extensive manual separation. Polyester is particularly advantageous because it can be chemically reduced to monomers and reconstructed into virgin-quality fibres when used consistently across the garment.

Even small elements can disrupt recycling streams. Labels and tags made from incompatible substrates complicate processing. More circular alternatives include:

- Printing care and fibre information directly onto the garment interior,
- Using labels composed of the same fibre as the primary textile.

By considering every component, designers help ensure garments remain recyclable after reuse, repair, and remanufacturing cycles.

4.4 Color and Finish Considerations

Colour, dyes, and finishing treatments significantly affect recyclability. Substances applied for aesthetic or functional purposes can introduce contamination risks or interfere with fibre breakdown (Baloyi et al., 2023; Egan et al., 2023).

Dyes and pigments:

Dark, heavily saturated, or multi-coloured textiles often require additional processing to neutralise colour during recycling. Because colour consistency is critical for high-quality recycled fibres, heavily dyed textiles frequently enter lower-value streams or are recoloured into darker shades.

Finishes and coatings:

Water-repellent, stain-resistant, anti-wrinkle, and flame-retardant treatments introduce resins, silicones, waxes, or fluorinated compounds (PFAS). These substances may interfere with mechanical or chemical recycling and can introduce toxicity into recycling effluents.

Metallic and laminated finishes:

Foils, glitter, metallic pigments, and polyurethane laminations are particularly problematic. Once applied, they are extremely difficult to remove and can render the base textile non-recyclable.

Innovations in dyeing and finishing technologies offer alternatives. Digital printing, waterless dyeing, and bio-based pigments reduce chemical inputs, while recyclable dye systems allow colours to be more easily stripped during recycling. Choosing undyed, lightly dyed, or naturally coloured fibres can further improve end-of-life recovery.

For designers, colour and finish decisions must balance aesthetics and performance with long-term recovery potential. Prioritising non-toxic and easily removable treatments preserves fibre integrity for future regeneration.

4.5 Labeling and Digital Traceability

Accurate and transparent labelling is essential for effective textile recycling. Clear fibre content information allows facilities to identify materials and determine appropriate processing pathways.

Digital tools such as Digital Product Passports (DPPs) enhance this process by embedding lifecycle data directly into garments. Using QR codes, NFC tags, or RFID chips, DPPs can store:

- Detailed fibre compositions,
- Manufacturing and supply chain information,
- Care, repair, reuse, and recycling instructions.

However, digital identifiers introduce practical challenges. RFID or NFC hardware may need removal prior to recycling, increasing labour and complicating disassembly. Printing QR codes directly onto textiles offers a promising alternative, maintaining transparency without introducing foreign materials.

The EU's ESPR regulation will require textile products placed on the EU market to include a Digital Product Passport (DPP) (EPRS, 2024). This will strengthen traceability, support standardised recycling systems, and empower consumers with material information.

By improving sorting accuracy and data transparency, DPPs connect design, production, use, and recovery—ensuring garments are not only recyclable in theory but identifiable within real-world recycling infrastructures.

5. Industry Practices and Standards

Design for recyclability does not operate in isolation; it depends on alignment with industry standards, certification systems, and regulatory frameworks. As circularity becomes embedded in policy and market expectations, third-party verification plays a critical role in ensuring transparency, traceability, and material integrity.

5.1 Certification and Standards

In the transition toward a circular fashion economy, industry certifications and standards verify environmental claims, enable traceability, and align design and production with recyclable practices. By committing to recognised standards, brands and manufacturers demonstrate transparency, support material-recovery infrastructures, and build consumer trust—essential in a sector where circularity requires coordinated supply-chain action.

The following certifications are among the most influential in the textile sector:

Global Recycled Standard (GRS)

The Global Recycled Standard (GRS) is a voluntary full-product certification that verifies recycled content in textiles—both pre-consumer and post-consumer—while tracking chain of custody and establishing environmental and social criteria for production (Textile Exchange, n.d.). GRS-certified products must contain at least 20% recycled material and comply with strict chemical management and transparency requirements.

For design for recyclability, GRS ensures that recycled fibres originate from traceable sources and meet defined quality standards. This strengthens confidence in upstream material choices and reduces risks associated with mislabelled or uncertified recycled content.

Cradle to Cradle Certified® (C2C Certified®)

Cradle to Cradle Certified® evaluates textiles across full lifecycle criteria, including material health, circular design, water and energy stewardship, and recovery potential (Cradle to Cradle Products Innovation Institute, n.d.). The more recent C2C Certified® Circularity framework is specifically tailored to apparel and textiles, emphasising design for disassembly, recoverability, and system readiness.

For designers, C2C Certified® provides a structured framework for selecting materials and components that are safe and compatible with future recycling pathways. It shifts focus from isolated sustainability attributes to integrated product design.

OEKO-TEX® STeP (Sustainable Textile & Leather Production)

OEKO-TEX® STeP certifies production facilities rather than finished products. It evaluates manufacturing processes across chemical management, environmental performance, worker protection, and resource efficiency (OEKO-TEX®, n.d.).

In terms of recyclability, STeP certification helps ensure that production conditions do not compromise future recovery—for example, by limiting hazardous chemical finishes or incompatible dye systems that could contaminate recycling streams. It therefore supports alignment between production practices and circular design goals.

5.2 Application in Practice & Implications for Design

When designers integrate certified materials and recognised sustainability frameworks, several implications emerge for recyclability:

GRS certification supports the selection of traceable and chemically compliant recycled fibres, strengthening material integrity in future processing stages.

C2C Certified® reinforces the importance of choosing materials, trims, and finishes designed for safe recovery and recirculation.

OEKO-TEX® STeP ensures that manufacturing processes do not introduce substances that hinder end-of-life recovery.

Collectively, these certifications reduce greenwashing risks, strengthen credibility with consumers and industry partners, and support compliance with evolving EU regulatory frameworks that increasingly require third-party verification and due diligence.

By integrating certification criteria into the design brief, designers ensure alignment with regulatory demands and create documentation that can be audited transparently. Beyond compliance, standards offer a structured roadmap for responsible innovation. Rather than restricting creativity, they provide a framework within which circular design strategies can be implemented systematically.

6. Design for Recyclability vs. Other Circular Strategies

Recyclability is one of several circular design strategies available to fashion designers. While often presented as a central solution to textile waste, it operates within a broader ecosystem of approaches that address different phases of a garment’s lifecycle. Understanding how recyclability relates to durability, repairability, and biodegradability allows designers to make informed decisions that balance material recovery with performance and longevity.

6.1 Comparative Framework

Circular design strategies address distinct stages of a product’s lifecycle, each aiming to preserve material value, reduce waste, and extend usability. Although their objectives overlap, their methods and end-of-life implications differ. The table below outlines key distinctions among common strategies in fashion design.

Strategy	Focus	Example
Durability	Longevity	High-quality stitching, reinforcements
Repairability	Maintenance	Modular zippers, replaceable parts
Biodegradability	Natural decomposition	100% organic cotton, no synthetics
Recyclability	Material recovery	Mono-material garments

Each strategy contributes differently to circularity. Durability extends the time garments remain in use. Repairability enables maintenance and restoration. Biodegradability returns materials to the biosphere under appropriate conditions. Recyclability focuses on recovering material value when further use is no longer viable.

6.2 Integration and Trade-offs

In practice, circular strategies frequently intersect—and sometimes conflict. Durability and recyclability, for instance, may require different material solutions. A cotton-polyester blend can enhance strength and comfort but becomes difficult to recycle due to incompatible fibre types. Conversely, a mono-material garment simplifies recovery but may not achieve the same functional performance as a blend.

The objective is not to prioritise one strategy at the expense of others but to identify synergies that allow multiple circular goals to coexist. The Ellen MacArthur Foundation’s Butterfly Diagram clarifies this hierarchy: inner loops—care, maintenance, durability, repair, and reuse—retain the highest material value, while recycling represents a later recovery stage.

Even the most durable garment will eventually reach a point where recycling becomes the most viable option. Designing with this final stage in mind ensures that materials can retain value beyond their initial lifecycle.

A multi-strategy approach offers the most resilient pathway. A garment can be:

Durable, through reinforced construction and high-quality materials;

Repairable, through modular components and accessible assembly methods;

Recyclable, through mono-material construction, simplified trims, and design for disassembly.

Replacing fibre blends with layered mono-material systems—each selected for performance but individually recyclable—provides one solution. This approach maintains durability while preserving material purity for future recovery.

As designers incorporate innovative materials—coated textiles, bio-based synthetics, performance composites—they must assess recyclability from the outset. Functional innovation should not undermine circular integrity. The long-term objective is to embed recyclability within an integrated circular framework, allowing garments to retain value across multiple cycles of use, repair, and material regeneration.

7. Future Directions and Innovation

The evolution of recyclability is closely tied to advances in material science, biotechnology, and digital infrastructure. As traditional recycling systems encounter technical and economic limitations, emerging innovations aim to increase material purity, enable blended-fibre recovery, and integrate traceability across the textile lifecycle. The future of design for recyclability therefore depends not only on better materials, but on smarter systems.

7.1 Material and Technological Innovation

Bio-based synthetics

Bio-based synthetics are emerging as alternatives to fossil-fuel-derived fibres. Produced from renewable feedstocks such as corn, sugarcane, algae, or bacterial fermentation, these materials are engineered to replicate the performance of conventional synthetics like polyester or nylon.

Some bio-based fibres are also designed to be biodegradable, offering potential reductions in microplastic pollution and reliance on chemical-intensive recycling processes. However, performance limitations remain. Currently, polylactic acid (PLA) is the only fully bio-based synthetic fibre available at commercial scale. While PLA biodegrades under controlled composting conditions, it does not yet meet the durability, elasticity, or moisture-management requirements of many apparel applications (Joint Research Centre, 2024).

Research into polyhydroxyalkanoates (PHA) and bio-PET may provide higher-performance alternatives, potentially enabling synthetics that are recyclable, biodegradable, and functionally comparable to petroleum-based fibres.

Enzymatic recycling

Enzymatic recycling applies biological processes to material recovery. Using naturally occurring or engineered enzymes, polymers can be broken down through biological depolymerisation, enabling selective separation of blended fibres (Egan et al., 2023).

Cotton–polyester blends—representing a significant proportion of global textile production—pose major challenges for conventional recycling. Enzymatic systems can selectively degrade cellulose while leaving polyester intact, producing purified streams that can be regenerated into new textiles.

As enzymatic recycling moves toward pilot-scale implementation, its potential to address blended-fibre waste is substantial. If scaled effectively, it could transform one of the most persistent technical barriers to circular textile systems.

Closed-loop mechanical recycling and AI-based sorting

One of the most significant bottlenecks in textile recycling remains sorting accuracy. Without reliable identification of fibre composition and construction, large volumes of textiles are downcycled or discarded.

AI-driven systems such as Valvan's Fibersort and Trimclean address this challenge by detecting fibre composition, colour, texture, seams, embellishments, and coatings. Using:

- Near-infrared spectroscopy,
- High-resolution imaging,
- Machine-learning algorithms.

These systems achieve sorting precision beyond manual methods. Improved material purity increases both the yield and quality of recycled fibres.

By integrating automation and artificial intelligence, closed-loop recycling becomes more viable at scale, supporting the infrastructure required for a traceable textile economy (Texpertise Network, 2024).

7.2 Digital Systems and Traceability

Digitalisation is increasingly central to circular fashion systems. Technologies such as blockchain, Digital Product Passports (DPPs), and AI-assisted design tools create data flows that connect raw material sourcing with end-of-life recovery.

Blockchain and digital product passports

Blockchain provides a secure, decentralised system for documenting each stage of a garment's lifecycle—from fibre sourcing and dyeing to assembly, distribution, and collection. Because blockchain records are immutable, they support verifiable claims within complex global supply chains.

Digital Product Passports operationalise this information through scannable data carriers such as QR codes, NFC tags, or RFID chips embedded within garments. DPPs may contain:

- Fibre composition and finishes,
- Manufacturing data and supply chain traceability,
- Repair and reuse guidance,
- Recycling and disposal instructions.

For recyclers, DPPs enable rapid material identification. For consumers and brands, they increase transparency across the lifecycle.

AI-assisted design tools

Digital platforms such as CLO and Browzwear, alongside emerging AI-supported systems, allow sustainability metrics to be integrated directly into the design process. These tools can model:

- Fibre-level recyclability,
- Fabric performance,
- Lifecycle impacts,
- Carbon and water footprints,
- End-of-life compatibility.

In future systems, DPP and blockchain data may feed directly into design environments, creating feedback loops where recycling outcomes inform new product development. Such integration establishes a digital architecture in which materials are traceable, recoverable, and continuously optimised for circularity.

Key Insights

- Recyclability is determined primarily at the design stage.
- Mono-material construction significantly improves recovery potential.
- Fibre blends, elastane content, and chemical finishes remain major barriers to recycling.
- Mechanical, polymer, and monomer recycling operate at different value-retention levels.
- Design for disassembly reduces contamination and labour at end-of-life.
- Certification systems (GRS, C2C, OEKO-TEX® STeP) support transparency and system alignment.
- AI-based sorting and enzymatic recycling may transform blended-textile recovery.
- Digital Product Passports will become central to traceable circular systems.
- Recyclability must be integrated with durability and repairability within a multi-strategy approach.
- Effective circular design requires material literacy, traceability, and systems thinking.

Summary

The fashion system is transitioning from a linear take–make–dispose model toward circular frameworks centred on design–use–recover–renew. At the centre of this transition stands the designer, whose decisions influence not only aesthetics and performance but also the environmental trajectory of each garment.

Research indicates that most of a product’s environmental impact is determined during the design phase. Choices regarding fibre composition, construction, finishes, repairability, and end-of-life potential shape future recovery pathways.

Design for recyclability is therefore not merely technical; it is a practice of foresight and responsibility. It requires designers to anticipate how garments will be worn, maintained, and ultimately reintroduced into material cycles.

Three foundational pillars support this approach:

Material literacy enables informed fibre and finish selection compatible with recycling technologies.

Product traceability, supported by labelling and digital systems such as DPPs, ensures garments can be accurately identified and processed.

Systems thinking situates design within a broader ecosystem of manufacturers, recyclers, consumers, and policymakers.

Recyclability should not be treated as a corrective measure applied after production. Instead, it must be embedded at the beginning of the creative process. Strategies such as mono-material construction, trim simplification, design for disassembly, and transparent labelling reflect a broader principle: responsible design anticipates renewal.

As these principles become integrated into practice, fashion moves closer to a regenerative model in which materials circulate continuously, waste is minimised, and creativity contributes to ecological resilience.

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Part 2 – Case Study

Rifò Lab: Designing for recyclability within Prato's circular textile ecosystem

1. Introduction

In the fashion industry, waste production is one of the main environmental issues, with approximately 92 million tonnes of waste generated each year. According to data from the Ellen MacArthur Foundation (2017), less than 1% of textile materials are actually reintroduced into the production cycle in the form of new fibres. This limitation is mainly due to the complexity of clothing items, which are often composed of mixtures of different fibres, surface treatments and dyes that hinder the separation and recycling of materials.

Founded in 2017 in Prato by Niccolò Cipriani and Clarissa Cecchi, Rifò was created with the aim of renewing the Prato textile tradition through the production of clothing and accessories made from regenerated fibres.

The business idea took shape from Niccolò Cipriani's personal experience. During an assignment with the United Nations in Vietnam, he came into direct contact with the consequences of overproduction in the fashion industry: huge quantities of unsold garments destined for disposal. This awareness gave rise to the desire to create an alternative production model based on circularity and the enhancement of existing resources.

In 2020, the company obtained B Corp certification, a recognition reserved for companies that integrate social and environmental responsibility into their objectives. Today, Rifò distributes its products not only through e-commerce channels, but also in over 400 stores internationally, establishing itself as an example of the circular economy in the textile sector.

2. Context: Prato's Textile Recycling Heritage

The Prato textile district is one of the oldest examples of the circular economy applied to the fashion industry. Since the 19th century, the area has developed a high level of specialisation in the recycling of wool and other textile fibres through the regenerated carded process, which transforms used clothing and production waste into new yarns.

This practice significantly reduces the consumption of water, energy and raw materials, offering a sustainable alternative to the production of virgin wool.

Rifò is a contemporary interpreter of this tradition, collaborating with local businesses, carders and artisans still active in recycling.

3. Design for Recyclability in Rifò Products

3.1 Material choices: regenerated fibres as building blocks

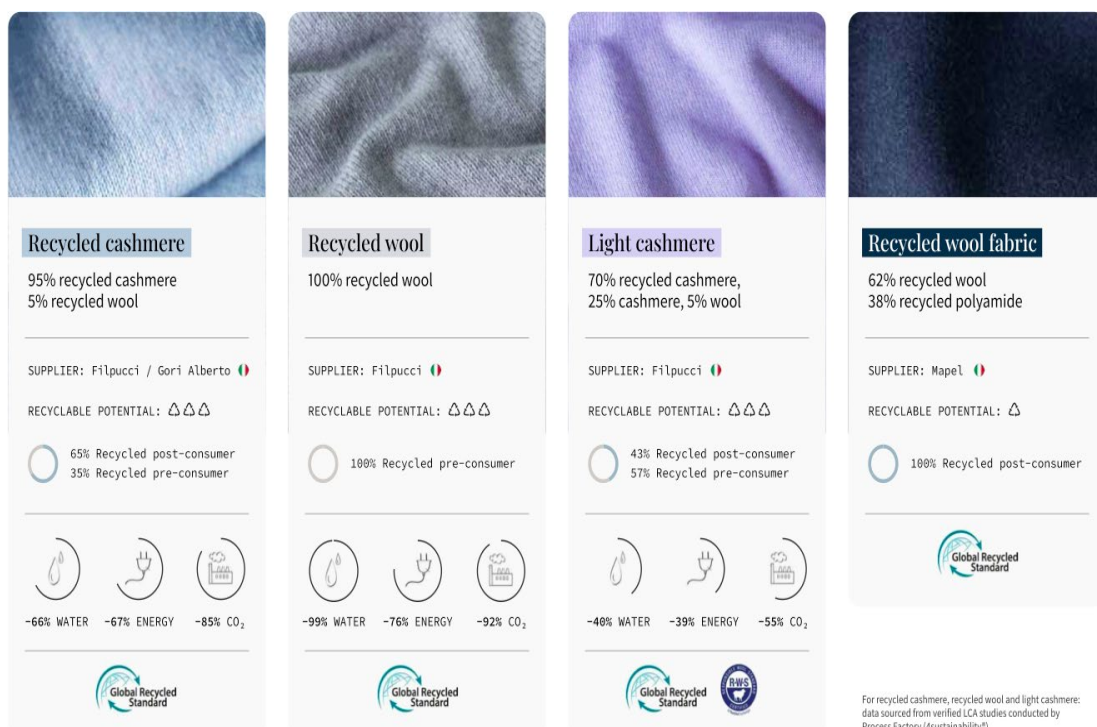
Rifò bases its production on the use of regenerated fibres, selected to guarantee quality, traceability and recyclability. The main materials include:

- Regenerated wool, sourced from pre- and post-consumer knitwear;
- Regenerated cashmere, obtained through mechanical recycling processes of carefully selected textile waste;
- Regenerated cotton, derived from production residues and denim fabrics.

Each yarn is designed as a single material or with a minimal percentage of blending in order to preserve recyclability in future life cycles.

In 2024, 97% of total production uses single-material yarns, of which only 3% consisted of mixed fibres.

The mechanical recycling of short fibres gives the fabrics a distinctive texture, which becomes an integral part of the brand's aesthetic language and sustainable identity.



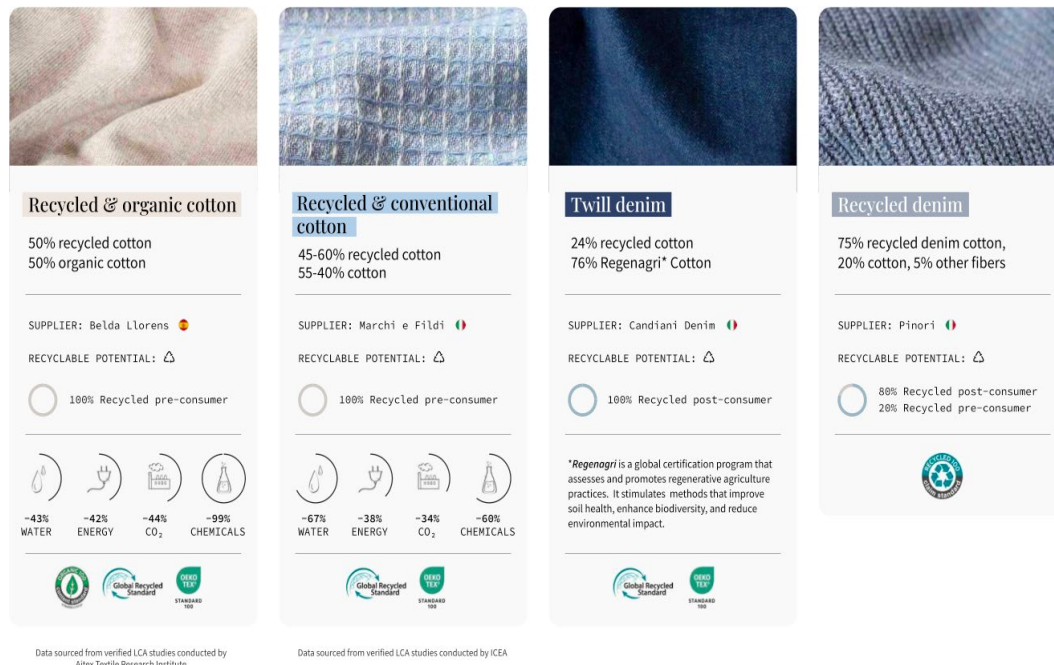


Image 1: Recycled fabric samples retrieved from https://cdn.shopify.com/s/files/1/0293/9627/1197/files/Sustainability_Report_2024_Rifo_circular_fashion_made_in_Italy-maggio-web.pdf?v=1748532366

3.2 Innovations in colour and finish

Rifò takes an innovative approach to colouring materials, based on the chromatic selection of pre-consumer textile waste rather than traditional chemical re-dyeing. Fabrics are sorted according to their original shades before the recycling process, thus eliminating the need for new dyeing stages.

This choice avoids the use of synthetic dyes and preserves the structural quality of the fibres, which remain more suitable for subsequent recycling cycles.

3.3 Product life cycle and take-back system

Rifò is a circular economy initiative based on collaboration and active community participation. It invites citizens to contribute directly to the textile regeneration process by handing in their old garments to be transformed into new sustainable yarns.

Launched in 2019, the collection service was designed to offer a concrete alternative to textile waste, rewarding those who return their used garments with an incentive in the form of a discount code. Today, the take-back system stands out for its transparency and accessibility, operating both online and through physical points, and accepting garments of any brand made of wool, cashmere and denim. The company only selects jumpers made from 100% pure cashmere or wool and jeans made from at least 95% cotton. This choice stems from the need to ensure that the materials collected can actually be recycled, as current recycling technologies are only effective with fabrics that are almost single-material in composition.



Image 2: Rifò's textile recycling process retrieved from https://cdn.shopify.com/s/files/1/0293/9627/1197/files/Sustainability_Report_2024_Rifo_circular_fashion_made_in_Italy-maggio-web.pdf?v=1748532366

4. Collaboration and transparency

4.1 Collaboration and integration of ecosystems

Rifò adopts a production model based on collaboration with local recycling consortia, small manufacturers and artisans in the area, promoting environmental, economic and social sustainability. Since its foundation, Rifò has chosen to concentrate its activities in the textile district of Prato, where in 2024 approximately 90% of production took place within a 30 km radius of the company headquarters. This short supply chain strategy allows us to:

- Minimise the environmental impact of transport, reducing logistics-related emissions;
- Support the local economy, enhancing the productive and artisanal fabric of the territory;
- Optimise production times, which average between three and five weeks from the availability of yarns
- Ensure quality and traceability through direct relationships with local suppliers
- Preserve the local textile tradition, contributing to the promotion of sustainable Made in Italy.

The Rifò model demonstrates how proximity to production, combined with a circular vision of fashion, can generate shared value and represent a paradigm of regenerative economics applied to the textile sector.

4.2 Traceability and communication of materials

The product label provides detailed information on fibre composition, the origin of recycled materials and the geographical area of production.

Through clear and narrative communication about the materials used, the brand promotes greater consumer awareness of the recyclability potential of garments.

Product traceability plays a key role in terms of transparency and social responsibility. Rifò attaches great importance to these aspects, aiming for short supply chain production, where every stage, from fabric to finished product, takes place close to its factories.

The origin of the materials is verified through GRS (Global Recycle Standard) certified suppliers, who guarantee the origin of the regenerated cashmere, while regular checks on the yarn ensure its purity and quality. This approach allows for the development of a transparent production process, with weekly monitoring throughout the entire supply chain.

Key points for designers

Designing with a focus on recyclability involves not only the final product, but also integration with local suppliers. Key elements of this strategy include the quality and purity of the fibres, colour harmony and structural simplicity of the design, which facilitate the recovery and reuse of materials.

Collaboration throughout the entire value chain, from designers to spinners to recyclers, is crucial to ensuring that every product can be effectively recycled.

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Parte 3 –Toolkit

Introduction to the Toolkit: translating theory into practice

Purpose

This toolkit was created with the aim of translating the theoretical concepts of design for recyclability into practical tools and methods that can be applied in the creative and production process. The toolkit supports designers in making decisions about material selection, construction techniques and labelling systems.

Learning outcomes

Upon completion of this toolkit, students will be able to:

1. Identify materials and components suitable for fibre-to-fibre recycling.
2. Apply the principles of single-material and design for disassembly to their work.
3. Assess the recyclability potential of garments.
4. Prototype a design (or redesign an existing garment) in line with the principles of recyclability.

According to Mindful Fashion New Zealand (2025), when designing a garment, designers should consider:

1. What recycling options are available in your city, region, country?
2. What characteristics must your product have or not have in order to enter these recycling streams?
3. How will you communicate the recycling routes for which you have designed your garment to the user?
4. What decisions can you make now to enable the wearer to participate in the recycling solution?

Step-by-step methodology: applying design for recyclability

Step 1: Map the life cycle

Start by visualising the garment's life cycle: material sourcing → production → use → end of life.

Identify where recycling can realistically take place in your context (mechanical, chemical or hybrid systems).

Life cycle stage	Current process	Design for recyclability	Notes / Partners involved
Material sourcing		Use single material, certified fibre	
Fabric production		Ensure that dyes and finishes are recyclable	
Garment construction		Simplify seams and finishes	
Use phase		Promote durability and repair	
Collection/Take-back		Collaborate with the recycler or brand system	
Recycling process		Compatible with mechanical/chemical system	

Step 2: Select appropriate materials

Choose single-material or low-blend fibres compatible with recycling streams:

- 100% cotton, 100% polyester, 100% wool, 100% nylon.
- Avoid blends such as fabrics containing cotton-polyester or elastane.

Evaluate materials using recyclability criteria:

1. Is this fibre recyclable in existing systems?
2. Will dyes or finishes affect recyclability?
3. Is the supplier transparent about the origin of the fibres?

Fibre type	Recycling method	Compatibility with other fibres	Common issues	Best practices
Cotton	Mechanical/ Chemical	Poor with synthetics	Contamination from dyes	Use natural or undyed colours
Wool	Mechanical	Poor with synthetics	Fibre shortening	Use single-fibre carded yarns
Polyester	Chemical/M echnical	Compatible with polyester finishes	Additives, finishes	Use single-material polyester systems
Nylon	Chemical	Compatible with nylon finishes	High costs, limited structures	Use for entire garments and finishes
Elastane	None	Incompatible	Degrades during processing	Avoid altogether

Step 3: Simplify construction

Minimise elements made from different materials:

- Replace metal zips with plastic ones (same polymer as the main fabric).
- Use stitching made from the same family of fibres as the main material.
- Avoid glued or fused interlinings.

Checklist for designing for disassembly:

1. Are the finishes detachable?
2. Are the components compatible for recycling?
3. Can the garment be easily separated into single-material parts?

Objective: to enable easy disassembly and recycling by minimising mixed material components.

Tip: Use sewing threads, buttons or trims made from the same polymer family (e.g. polyester thread for polyester fabric).

Garment element	Material	Compatible with the main fibre?	Removable?	Action/redesign suggestion
Main fabric				
Sewing thread				
Zips/fastenings				Replace with compatible material
Labels				Print directly onto fabric
Interlining / bonding				Replace with sewn construction

Step 4: Optimise colour and finish

- If possible, use colour selection or undyed materials.
- Prefer water-based dyes or natural colour palettes that do not interfere with fibre recovery.
- Avoid laminated prints or metallic coatings.

Objective: choose finishes that preserve the purity and recyclability of the fibres.

Tip: Where possible, avoid deeply dyed synthetic fabrics, as they require extra bleaching and degrade more during recycling.

Appearance	Current design choice	Impact on recyclability	Alternative option
Dye type	Reactive, pigmented or natural		Water-based or natural dyes
Printing type	Plastisol/metallic/sublimation		Use water-based printing or laser engraving
Finish	Coating, lamination, treatment		Use untreated or recyclable finishes
Colour range	Light/dark/natural		Lightweight or undyed fibres for colour selection

Step 5: Label and communicate transparently

- Include detailed labels on fibre composition (avoid generic 'fabric blends').
- Use QR codes or NFC tags to store information digitally (in anticipation of the EU digital product passport).
- Communicate recyclability potential to consumers ("This garment is 100% recyclable in mechanical systems").

Objective: to provide clear, standardised information to ensure that the product can be correctly sorted and recycled.

Tip: Design your own personalised 'Recyclable Clothing Passport' that combines labelling and storytelling.

Name of garment	[Insert project name]
Main material	100% recycled wool
Finishes	None / compatible
Recyclability potential	Mechanical recycling (wool fibre recovery)
End-of-life instructions	Return to brand / textile recycling centre
QR Code / Digital link	[Insert or design placeholder]

Step 6: Design for collection and return

Imagine how the garment will be collected after use:

- Can it be part of a brand collection programme?
- Is it durable enough to survive sorting and recycling processes?

Goal: close the loop by planning post-use recovery systems.

Tip: Encourage repair and return behaviours through incentives or storytelling.

Phase	Partner/Channel	Action/Process	Design consideration
Retail	Brand / shop	Encourage returns	Label communication
Collection	Collection / collection box	Sorting by fibre type	Colour coding
Recycling	Local mill/recycler	Fibre recovery	Compatible materials
Regeneration	Yarn production	Reuse of fibres	Fibre length retention
New product	Design/brand	Reusing regenerated yarn	Closed-loop storytelling

Assessment tools and checklists

Recyclability preparation checklist

Category	Key question	Yes / No	Notes
Material	Is the main fabric made from a single material?		
Finishes	Are the finishes made from the same material or compatible materials?		
Construction	Can the garment be easily taken apart?		
Colour/Finish	Are the dyes and finishes non-toxic and recyclable?		
Labelling	Is the fibre composition clear and traceable?		
Return system	Is there a take-back or collection mechanism?		

Scoring system:

5-6 'Yes' = Highly recyclable

3-4 "Yes" = Moderately recyclable

1-2 "Yes" = Low recyclability, redesign required

Visual assessment tool

Instructions: Use this tool with sketches or garment samples.

Category	Score (1-5)	Comments/Sketch notes
Purity of materials		
Simplicity of construction		
Compatibility of finishes		
Recyclability of colours/finishes		
Labelling and transparency		
Take-back potential		

Practical activity: “Recyclable Redesign Challenge”

Objective

Apply design principles for recyclability by evaluating and redesigning an existing garment.

Time: 2–3 hours, suitable for individual or small group work.

Materials: An existing garment (preferably a fast fashion or mixed fibre garment).
Scissors, pins, sketchbook, fibre identification labels, camera.

Step-by-step activity

Part 1 – Analyse

1. Select a garment.
2. Identify each material (fabric, thread, finish).
3. Use the Recyclability Readiness Checklist to assess design barriers.
4. Assign a recyclability score (1–5).

Part 2 – Redesign

1. Reinvent the garment using single-material or recyclable substitutes.
2. Simplify construction and replace incompatible fittings.
3. Redesign the garment in sketch form or annotate the original photo.
4. Propose labelling and end-of-life plan (e.g., collection, repair, trimming).

Optional extension:

If materials are available, students can make a prototype of a redesigned section (e.g., a single-material sleeve or a recyclable fastener).

Food for thought

- What were the biggest design obstacles to recyclability?
- How did your redesign improve recyclability?
- How could industrial infrastructure support your design?

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