Small change, Big impact.

Resortecs, Recycling made Easy.

A comparative Life Cycle Assessment of disassembly & recycling methods in closed-loop denim production

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Table of Contents

Glossary

ACTIVE DISASSEMBLY

Active Disassembly is a developing technology to allow complex items to be easily disassembled in a cost-effective manner. A wide range of new methods are being validated for use in AD. These methods generally require the use of smart materials - capable of changing shape or size under the right stimulus - to facilitate material disassembly.

CIRCULARITY
CIRCULAR ECONOMY

A circular economy (also referred to as «circularity») is an economic system that enables to decouple growth from impact, addressing global challenges like climate change, biodiversity loss, waste, and pollution while responding to the needs of the world's growing population. A circular economy employs reuse, sharing, repair, refurbishment, remanufacturing and recycling to create a closed-loop system. This reduces the use of resource inputs and the creation of waste, pollution and carbon emissions[1].

CLOSED-LOOP
PRODUCTION OR RECYCLING

Under a closed-loop system, the same materials are (re)used over and over again to create new products. It's a way to conserve natural resources and divert waste from the landfill. In the textile industry, closed-loop production or recycling refers to textile-to-textile processes.

DfD

Design for Disassembly is a design approach looking to minimize value loss at a product's End-of-Life (EoL) by facilitating future changes and (partial or complete) dismantlement, allowing the recovery of systems, components and materials.

DfE

Design for the Environment is a design approach to reduce the overall human health and environmental impact of a product across its life cycle.

EoL

End-of-Life

[1] · Geissdoerfer, Martin; Savaget, Paulo; Bocken, Nancy M. P.; Hultink, Erik Jan (2017-02-01). «The Circular Economy – A new sustainability paradigm?». Journal of Cleaner Production. 143: 757–768. doi:10.1016/j.jclepro.2016.12.048. S2CID 157449142.

Glossary

EPR	Extended Producer Responsibility (EPR) is a policy approach under which producers are given a significant responsibility – financial and/or physical – for the treatment or disposal of post-consumer products[2].
GHG	Greenhouse Gasses
GWP 20A	Global warming potential for 20 years' time frame
Kg CO_2 eq.	Kg of CO_2 equivalent
LCA	Life Cycle Assessment
MECHANICAL DISASSEMBLY	Process of shredding input materials (e.g garments) to sort automatically and by gravity the components that obstruct the recycling process (e.g metallic trims such as rivets and zippers). It is also known as «délissage»
PURFI RECYCLING	PurFi's patented recycling process
THERMAL DISASSEMBLY	Resortecs' patented disassembly process

[2] · OECD . link

Glossary

TEXTILE DOWNCYCLING

Downcycling, or cascading, is the recycling of waste where the recycled material is of lower quality and functionality than the original material - for example making insulation material from old garments.

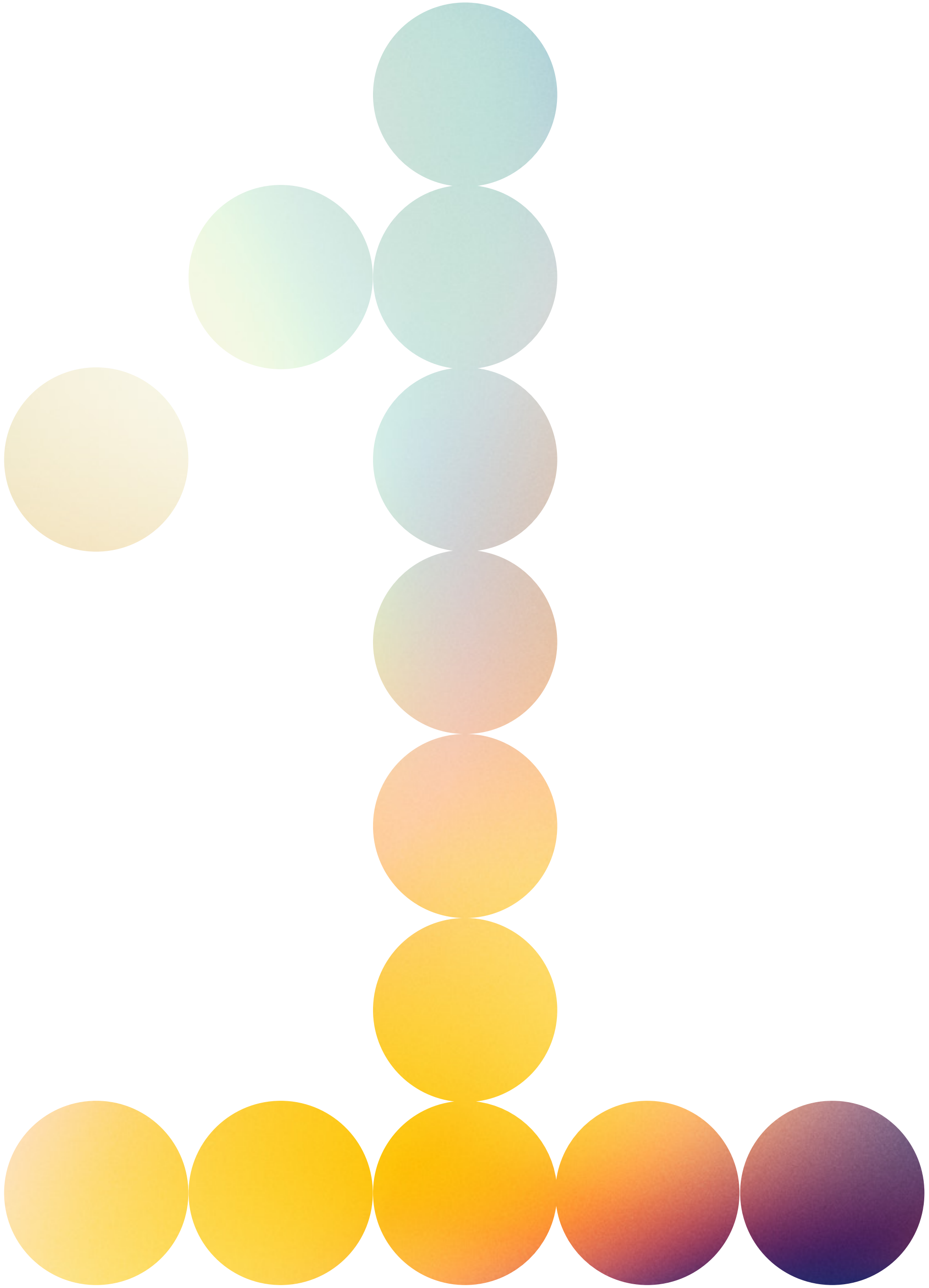
TEXTILE RECYCLING

The process of converting textiles into fibers that can be reused in the making of new textiles with the same quality and functionality as the original material (i.e. intrinsic value).

UPCYCLING

The process of reusing discarded material with minor modifications to create a product of higher intrinsic value - for example making a bag from old truck tarps like Freitag.

Executive Summary



THE PROBLEM

- The textile industry is one of the world's top 5 most polluting sectors, generating over 1.2 billion tons of CO_2 eq./year (5-10% of global emissions) and accounting for a material loss worth € 432 billion/year.

- Every second, one truck full of textile is wasted across the globe - this represents 34 million tons per year.

- On average, an EU citizen consumes 26 kg of textile and generates 11 kg of waste each year, yet only 1%[3] of the material used in textile production is recycled.

- The costly complexity of most disassembly and recycling processes lead fashion brands to adopt polluting and unsustainable options such as landfill and incineration for the remaining 99%.

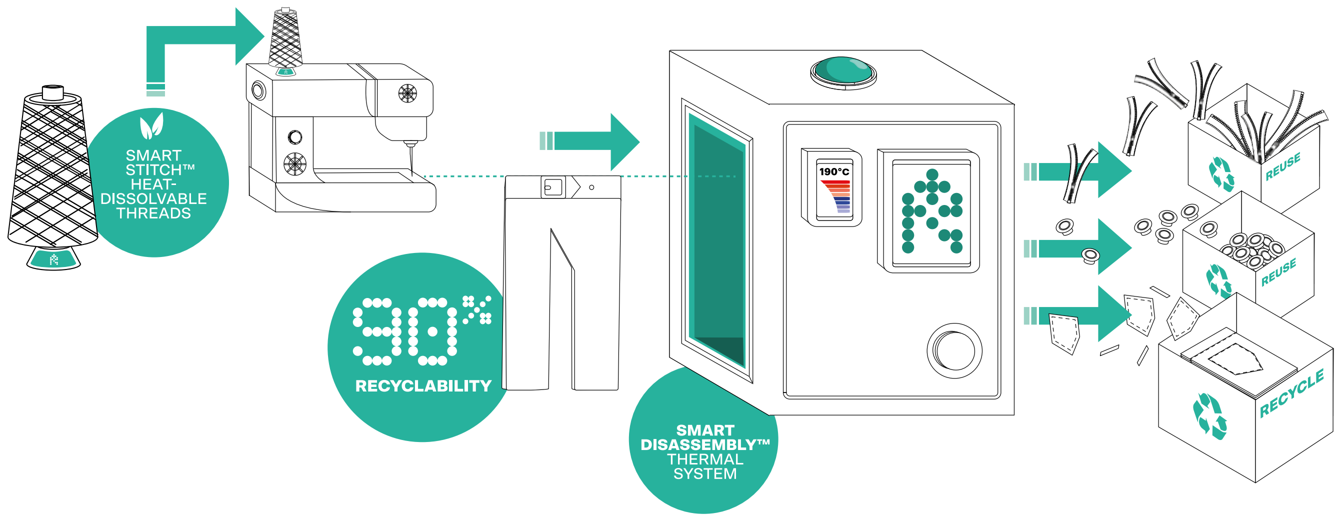
- Over 40% of all textile materials produced for fashion are discarded before ever being sold to end-consumers [4].

- Textile products are not designed for disassembly and the existing recycling solutions are inefficient, complicated and expensive. Disassembly processes are done manually or mechanically, wasting up to 52% of the original fabric material.

[3] · Transformed into fibers that can be reused in the making of new textiles with the same quality and functionality as the original material (i.e. intrinsic value).

[4] · 15% of fabrics are discarded as cut-off waste, factories overproduce 5% garments, and on average 20% of garments remain unsold in shops at the end of the season.

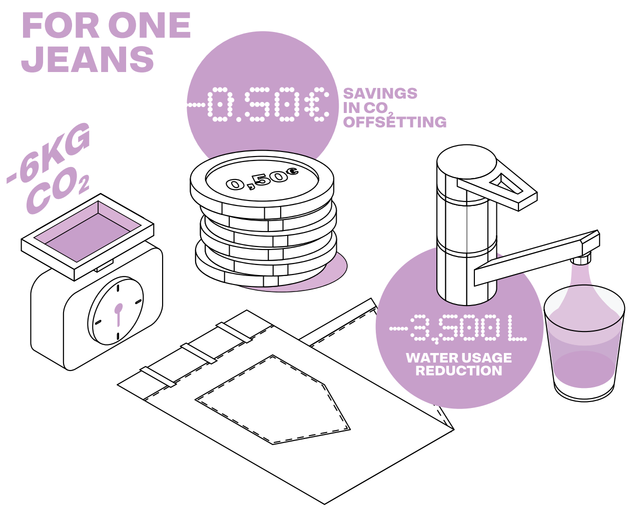
THE SOLUTION

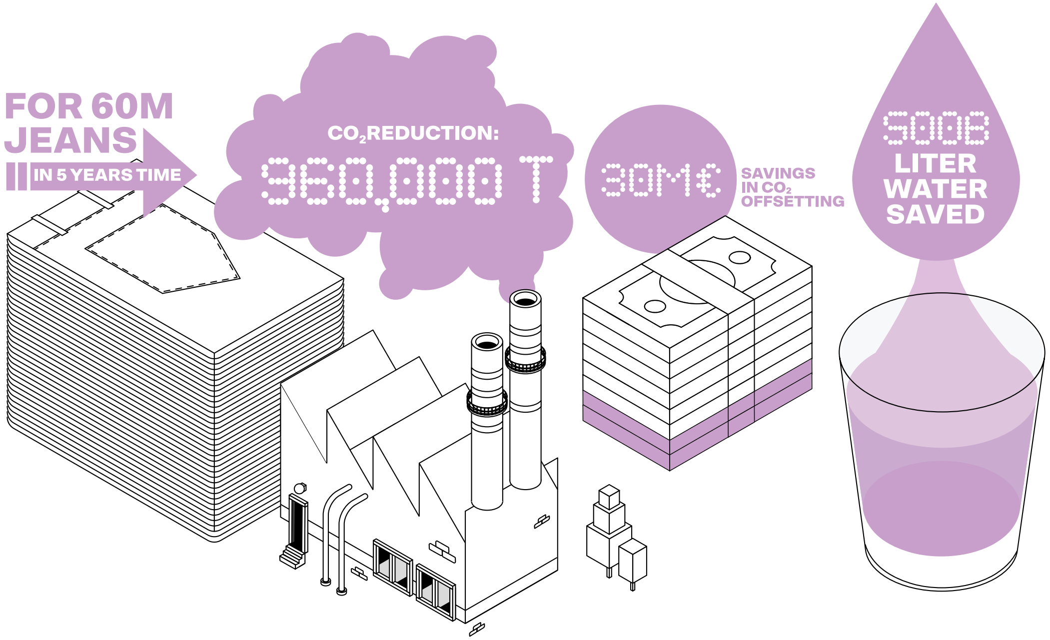


Resortecs' globally patented thermal disassembly solution is 5X faster than traditional disassembly methods and makes it possible to recycle up to 90% of the original fabric material:

- **Smart Stitch™,** our heat-dissolvable stitching thread with different melting points (150°C, 170°C and 190°C), enables brands to transform their products into recyclable, circular pieces from design.
- **Smart Disassembly™**, our thermal disassembly system, enables recyclers to unlock higher volumes of premium-quality material, processing up to 4M garments/year with low emissions and no material damage, so that fabrics can be used over and over again.

THE CONCLUSION





- Our proprietary thermal method can reduce water usage by 3,500 L and free up to 4.5 m^2a [5] of land for crop production when compared to traditional disassembly + recycling processes used in closed-loop denim production.
- When compared to other common end-of-life processing such as incineration or landfill, our solution reduces textile waste by 80% and generates 6 to 7 kg less CO_2 equivalent per pair of denim jeans.
- Translated into business figures, these eco-impact metrics mean reducing raw material loss by 50%, cutting CO_2 offsetting costs by 50%, and saving over € 0.50 per pair of denim jeans.
- Using these calculations, our goal is to have 60 million pieces of clothing made and disassembled with the Resortecs solution in the next 5 years.
- This would reduce CO_2 emissions by over 900,000 tons; save up to 600 billion L of water; and potentially free up to 82,000 hectares of land for crop production, providing food security for 405 families/year.
- If the European garment share were thermally disassembled and recycled, the fashion industry would generate 60.3 million less tons of CO_2 and save up to € 2.3 billion per year. At global level, the world's fashion industry could reduce its CO_2 emissions by 204 million tons/year over the next 10 years.

[5] · Land use occupation is measured as area time (m^2a)

About Resortecs

Resortecs – **RE**cycling, **SOR**ting, **TEC**hnologie**S** – is an award-winning startup that develops technology to empower smart, industrial-scale textile disassembly, sorting and recycling – driving full circularity in the fashion industry without creative nor quality trade-offs.

Awarded by :

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RESPOND
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ELLEN MACARTHUR FOUNDATION Member

Certified by:

SOLAR IMPULSE EFFICIENT SOLUTION

Externally reviewed by:

GreenDelta

About the authors

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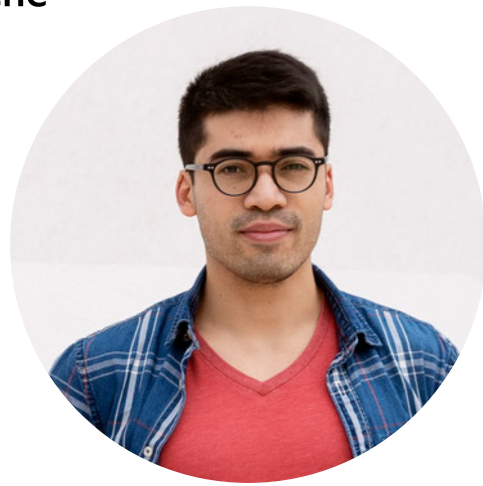
Rawaa is Resortecs' Sustainability and Impact Lead since 2019. She holds a Ph.D in Earth and Environmental Sciences from the Université Libre de Bruxelles in Belgium and is a visiting professor at the Lebanese University in Beirut. Rawaa has over 10 years of experience in scientific research, fieldwork and environmental risk assessment. Her research focus areas are: anthropogenic pollution, remediation, heavy metals impurities, Fe biogeochemistry in ocean and the link to atmospheric CO_2 emissions.

Cédric Vanhoeck

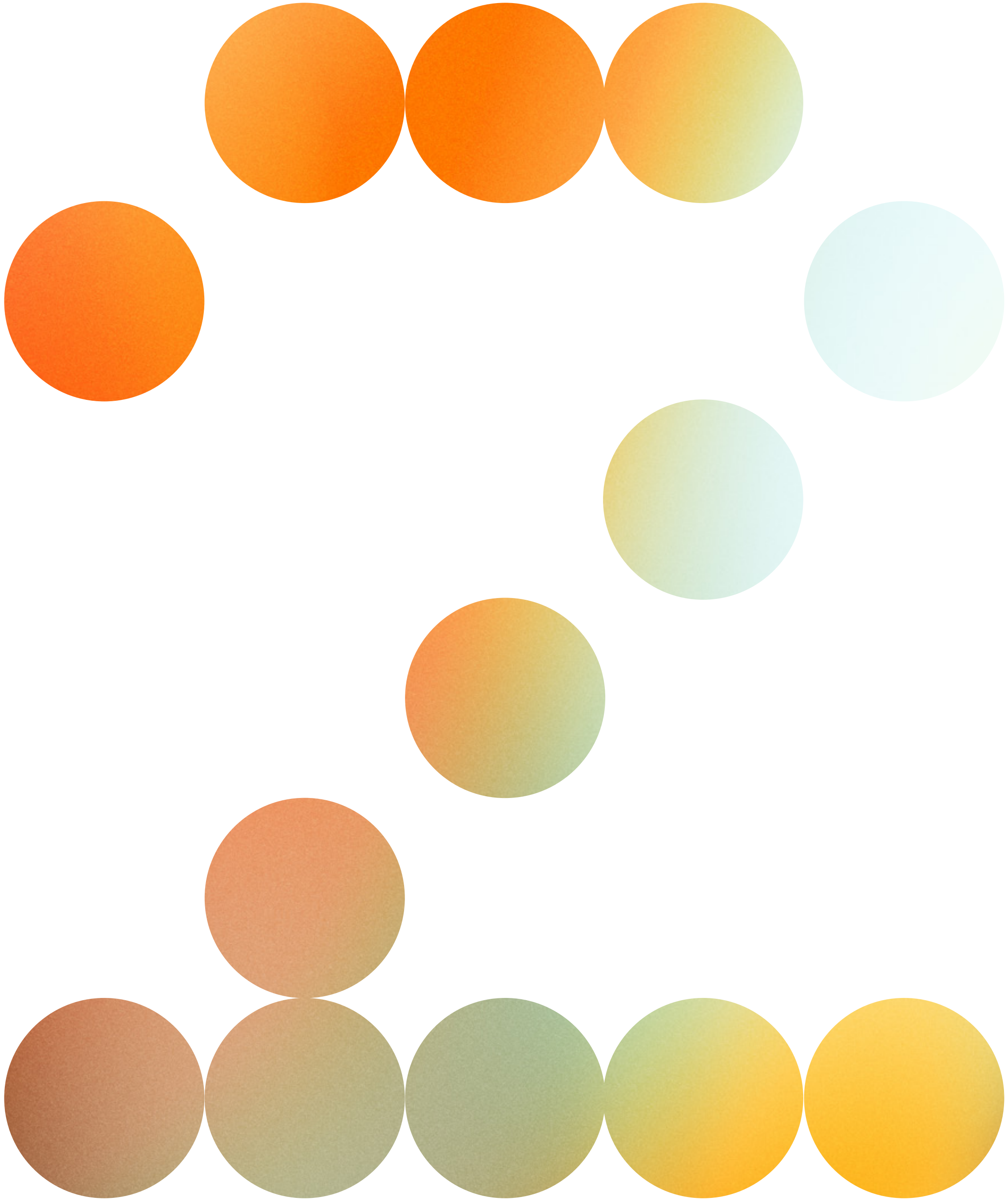
Cédric is Resortecs' co-founder and Executive Lead. He holds an Industrial Design Engineering degree from TU Delft and a Brand Management Master's degree from the Domus Academy Milan. After joining the Antwerp Fashion Academy and seeing first-hand how much fashion wasn't sustainable, he decided to dedicate his time and expertise to tackling the environmental challenges of the textile industry.

William Allouche



William is Resortecs' Technical Lead for Disassembly since 2019. He holds a Master's Degree in Mechanical Engineering from the Université de Technologie de Compiègne in France. Before joining Resortecs, he first acquired experience in innovation and project engineering by developing technological solutions in the automotive industry.

Introduction: the size of the problem



The impacts of the way we consume and transform our planet's resources is one of humanity's biggest challenges. Between 1950 and 2010, the world saw our population grow by 174%[6], jumping from 2.01 to 3.5 billion in only 60 years. This rapid growth was quickly translated into a damaging production rhythm, increasing greenhouse gases (GHG) emissions by 79 ppm and raising the average global temperature by 0.73°C[7]. By 2015, over 98 million tons of non-renewable resources were consumed each year[8].

The textile industry plays a central role in those alarming figures: it is one of the top 5 most polluting sectors, accounting for 5-10% of global emissions[9] and generating over 1.2 billion tons of CO_2 equivalent per year[8].

Every minute, 60 trucks full of textile are wasted across the globe. This represents 34 million tons of textile waste per year[8]. If industrial practices do not change, these numbers might increase even further as the global fiber production is estimated to grow up to 145 million m³ tons by 2030[10].

Textile overproduction, unsold inventories and the complexity of most disassembly and recycling processes drive fashion brands to polluting options such as landfill and incineration. On average, a citizen of the EU consumes 26 kg of textile and generates 11 kg of waste each year[11],

yet only 1% of the material used in textile production is recycled.

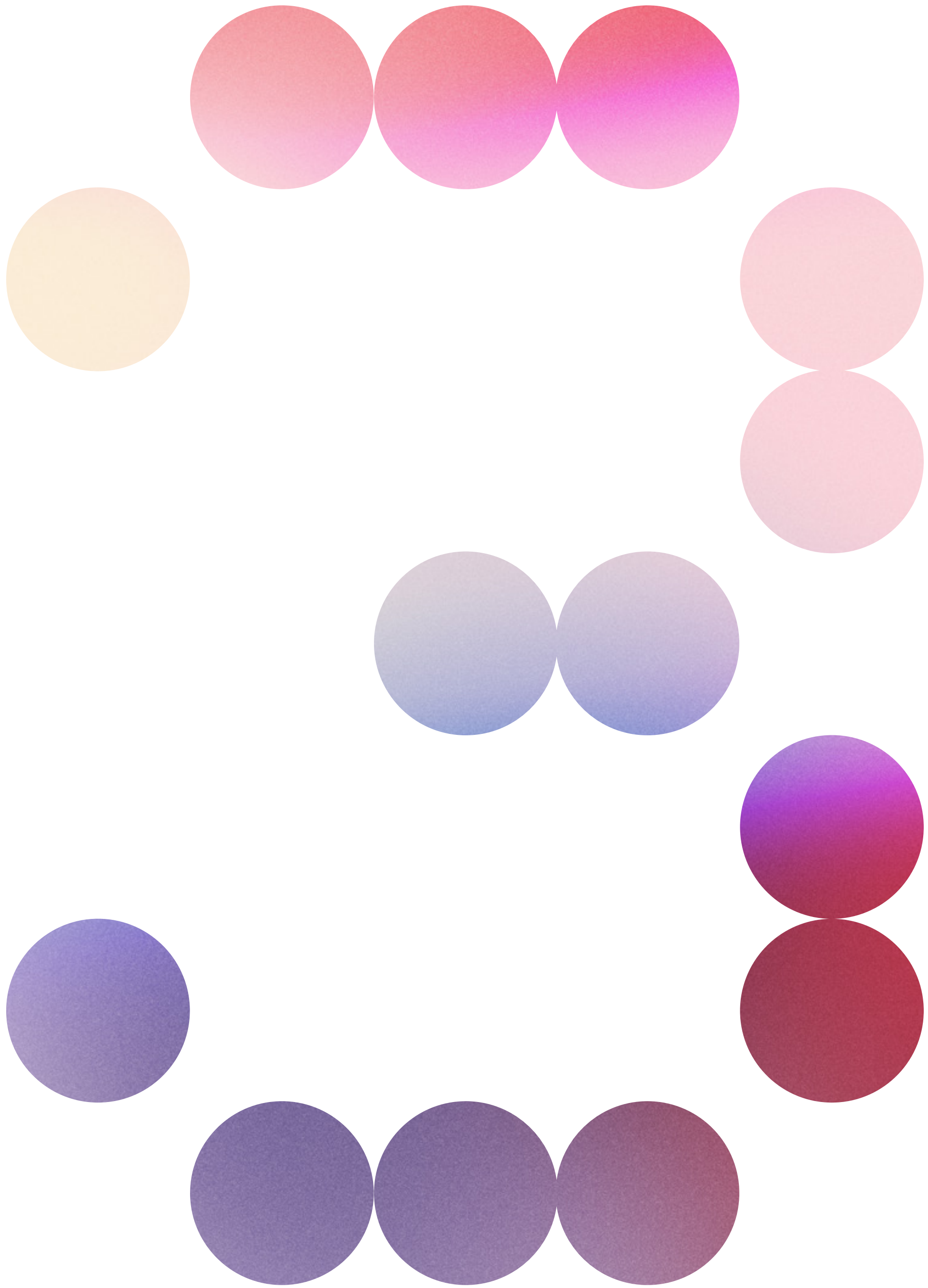
This represents a loss of €432 billion worth of material per year[8], and it doesn't stop there: textile production requires large portions of land, high water consumption, extensive chemical application, and is identified as a significant source of plastic microfibers in the oceans[12].

The EU Green Deal and the UN's Sustainable Development Goals (SDGs) are proof that regulatory organizations around the globe already recognize the textile industry as a key sector to reduce CO_2 emissions.

However, to fully reach the current decarbonization goals, action must be taken beyond targeting brands. We must address upper and lower stream activities in the fashion supply chain – from raw material sourcing and garments manufacturing to End-of-Life (EoL) processing – which currently account for over 85% of the sector's emissions[9].

6 · https://www.pewresearch.org/global/2014/01/30/chapter-4-population-change-in-the-u-s-and-the-world-from-1950-to-2050/
7 · https://ourworldindata.org/CO2-and-other-greenhouse-gas-emissions
8 · A new textile economy: redesigning fashion's future (Ellen MacArthur Foundation) - Circular Fibers Initiative analysis.
9 · Net zero challenge: The supply chain opportunity, Insight report- World Economic Forum; Jan 2021.
10 · Preferred Fiber & Materials Market Report 2019.
11 · Textiles in Europe's circular economy, EEA, 19 Nov 2019.
12 · Plastic in textiles: potentials for circularity and reduced environmental and climate impacts; Eionet report-ETC/WMGE 2021/1

Closing the loop: disassembly & recycling



Understanding the dimensions of the challenge makes it easier to explain why any discussions on true sustainable fashion now include concepts such as Extended Producer Responsibility (EPR), Circularity and Closed-loop Recycling. In 2021, the World Economic Forum listed circularity and recycling, followed by material and process efficiency, at the top of their 8 levers to transform the fashion industry[13].

When we zoom into the closed-loop ecosystem,
there are two major textile-to-textile recycling methods:

01 Mechanical recycling is usually achieved by shredding fabrics into small pieces that are later processed back into fiber. Unfortunately, in most cases, this method reduces the fiber's length and, consequently, offers an output of lower-quality.

02 Chemical recycling, on the other hand, consists of a series of chemical treatments that depolymerize the fabric's material into monomers and extrude it again as a filament or fiber of upper quality. The challenges here are usually the high costs and the common reluctance to work with highly chemical processing.

Better-performing processes are constantly being developed for both recycling methods. That's the case of PurFi, a global recycler that combined mechanical and chemical recycling to create a proprietary hybrid process without the usual fiber length reduction (from mechanical recycling) nor the high costs and heavy chemical presence (from chemical recycling). Regardless of the method of choice or any technological advances, all recycling processes still share the same imperative bottleneck: disassembly.

Any textile product must be disassembled and sorted prior to any recycling process. Currently, this can be done in three different ways: manually (using scissors to remove buttons, zippers, etc.), mechanically (shredding) or thermally (heat treatment) as represented in Figure 1. With the technology and processes presently available, manual disassembly is way too expensive, making mechanical disassembly the most adopted method.

→ *Unfortunately, in both cases, up to 52% of the original garment mass is cut away and burned or landfilled, while only 48% of the original garment mass remains fit for recycling.*

This is due to the difficulty of disassembling and sorting multi-material textile products, which is the case of most garments nowadays. Recycling a pair of denim jeans, for example, requires stripping away its pockets, zippers and any parts with rivet buttons, leaving less than half of the original material for the next step. Thermal disassembly is the only method able to preserve 90%[14] of the original fabric material in an automatic, time-efficient way.

13 · Net zero challenge: The supply chain opportunity, Insight report- World Economic Forum; Jan 2021
14 · Figures valid for jeans and other denim products.

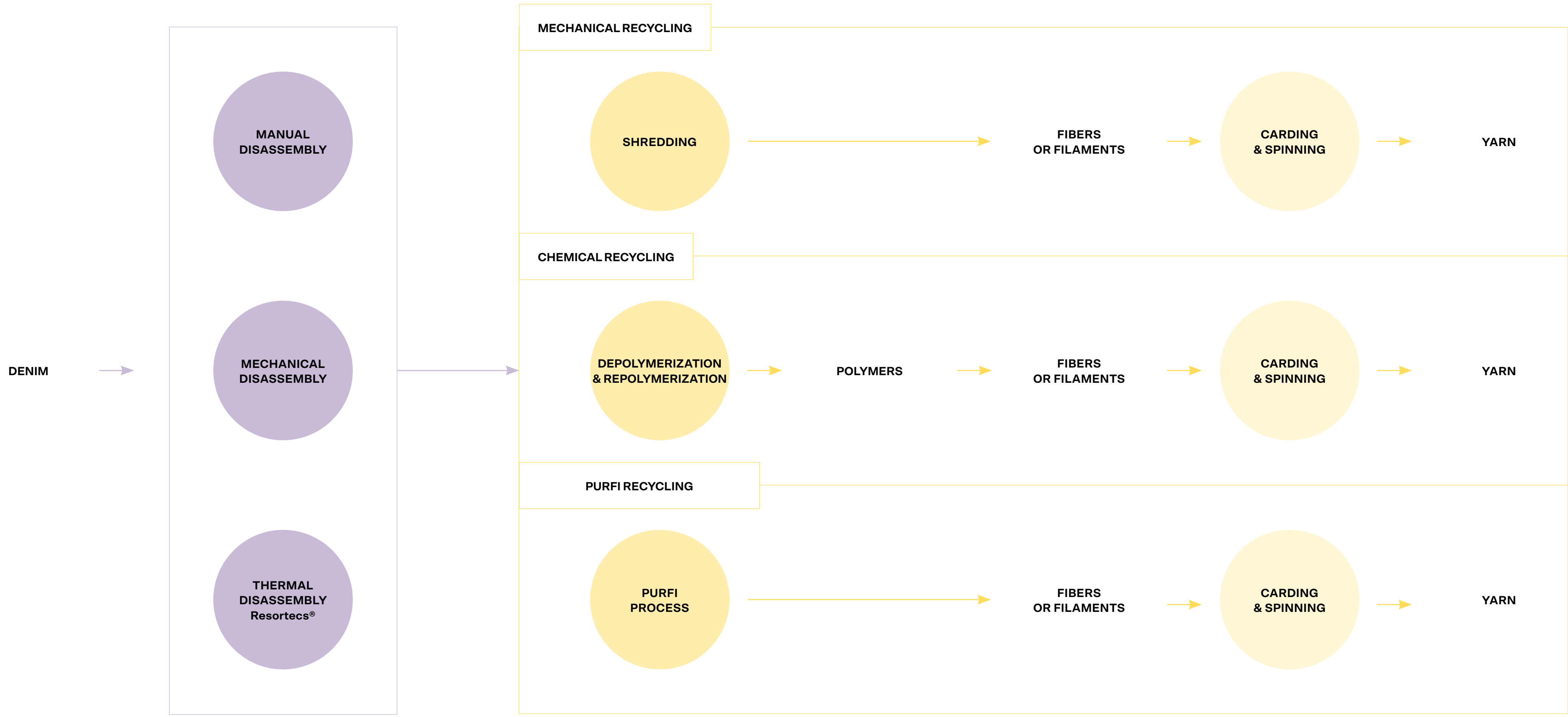


Figure 1: Textile to Textile recycling steps.

When comparing the combined efficiency of different disassembly and recycling methods (Table 1), it becomes clear that the key to enhancing recycling lies in optimizing and automating the disassembly and sorting stages:

Table 1: Comparative table of the existing (textile-to-textile) recycling and disassembly technologies

	MANUAL DISASSEMBLY		**MECHANICAL DISASSEMBLY** (Shredding, delissage)		**THERMAL DISASSEMBLY** (Resortecs®)	
	PROS	**CONS**	**PROS**	**CONS**	**PROS**	**CONS**
MECHANICAL RECYCLING	• Compatible with multi-material input	• High costs • Low-quality fiber output • Time-consuming	• Cost-efficient	• Low-quality fiber output • High material loss (up to 52%) • Requires virgin material in the blend • Impure process and potential presence of remaining hard pieces (e.g. zippers) • Generates dust particles	• Time-consuming (5x faster) • Cost-efficient • Low material loss during disassembly • Compatible with multi-material input	• Low-quality fiber output • Requires virgin material in the blend • Products must be stitched with the Resortecs stitching thread® • Requires additional energy
CHEMICAL RECYCLING	• High-quality fiber output	• High costs • Time-consuming • Heavy use of chemicals in recycling process • Requires pure mono-material input	• Not possible due to the excessively high levels of material contamination.		• High-quality fiber output • Time-consuming (5x faster) • Cost-efficient • Low material loss during disassembly • Compatible with multi-material garments	• Products must be stitched with the Resortecs stitching thread® • Requires additional energy • Heavy use of chemicals in recycling process
PURFI RECYCLING	• High-quality fiber output	• High costs • Time-consuming	• Cost-efficient	• High material loss (up to 52%) • Low-quality fiber output • Requires virgin material in the blend • Impure process and potential presence of remaining hard pieces (e.g. zippers)	• High-quality fiber output • Time-consuming (5x faster) • Cost-efficient • Low material loss during disassembly • Compatible with • multi-material input	• Products must be stitched with the Resortecs stitching thread® • Requires additional energy

A . Why are we comparing disassembly & recycling methods?

Driving innovation at the end of a life cycle requires disruptive, smart technologies at its beginning. This means that effective disassembly relies on smart assembly. Design for Disassembly (DfD) is an important outlet of Design for the Environment (DfE) that encloses a series of techniques deployed at any product's creation to maximize original material recovery and minimize value loss at the end of its life cycle. Under the DfD umbrella, the most relevant technology for the textile supply chain is Active Disassembly – the use of smart materials to allow complex items to be easily disassembled in a cost-effective manner [15].

Looking to address the biggest challenge in textile recycling through Active Disassembly, Resortecs empowers brands and manufacturers with a range of bio-based [16] and synthetic dissolvable stitching threads and dismantlable rivet buttons. Our threads and rivet buttons melt at 150°C, 170°C or 190°C and allow for effective multi-material sorting and recycling without impacting their integrity nor requiring substantial technical adaptation.

Closing the loop in the entire textile supply chain, products stitched with our dissolvable components can be disassembled at industrial scale with low emissions in one of our textile disassembling ovens. Combined, our threads and disassembly ovens make it possible to recover up to 90% of the fabric's raw material, enabling not only recycling but also upcycling.

Presently, most studies on textile recycling focus on only one recycling method and don't consider key factors such as material loss during disassembly nor the need to include virgin raw material in the final blend. There's a clear gap in recycling literature when it comes to comparing different recycling methods combined with different disassembly processes [17].

The purpose of this study is to conduct a comparative Life Cycle Assessment (LCA) between the different disassembly and textile recycling methods available. The LCA will quantify the environmental impact (CO_2 emissions, water use, land use and chemical use) of recycling a pair of denim jeans using a combination of different technologies. The research question this LCA aims to answer is: what disassembly process drives the most efficient textile-to-textile recycling?

15 · Abuzied et al., 2020. A review of advances in design for disassembly with active disassembly applications.
16 · Resortecs' Smart Stitch 190 °C is made of bio-based polyamide 11, which is composed of 100% renewable resources, certified by JORA, The Japan Organics Recycling Association.
17 · Sandin and Peters, 2018. Environmental impact of textile reuse and recycling -A review.

Methodology

A . LCA & Database

This LCA was created with the OpenLCA software (10.3) and the Ecoinvent database 3.6 (2019), using a cut-off system Model. The cut-off model is designed for allocating the credits of recycled material in such a way that the primary user doesn't receive any credit and the recycled material is considered burden free. The LCA covers the life cycle of a pair of denim jeans from cradle to grave and has been reviewed by GreenDelta.

B . Goal

The goal of this LCA is to provide a comprehensive understanding of the environmental burden of different textile recycling technologies and highlight the impact of disassembly on their efficiency.

C . LCA intended use and audience

This LCA was made to serve as a data-driven environmental management tool. Providing an overview of the impact of different recycling options and empowering different stakeholders to make well-informed decisions. This LCA is directed to a wide audience of policy makers, brands, recyclers and end users.

D . System boundary

This LCA covers the environmental burden during raw material acquisition (cotton, nylon, polyester, steel and brass); raw material processing (cotton spinning, weaving, yarn dying, zipper/button moulding); garment manufacturing (sewing, washing, drying and finishing); disposal (either incineration or landfill); disassembly (manual, mechanical or thermal); and mechanical, chemical and PurFi recycling, along with all the stages of transportation routes between each point of the life cycle. This LCA excludes the product use and the transport from factory to customer, as the environmental impact of the usage is considered equivalent for all products. A summary of the system boundary is depicted in Figure 2.

GENERAL SUPPLY CHAIN
TEXTILE PRODUCT

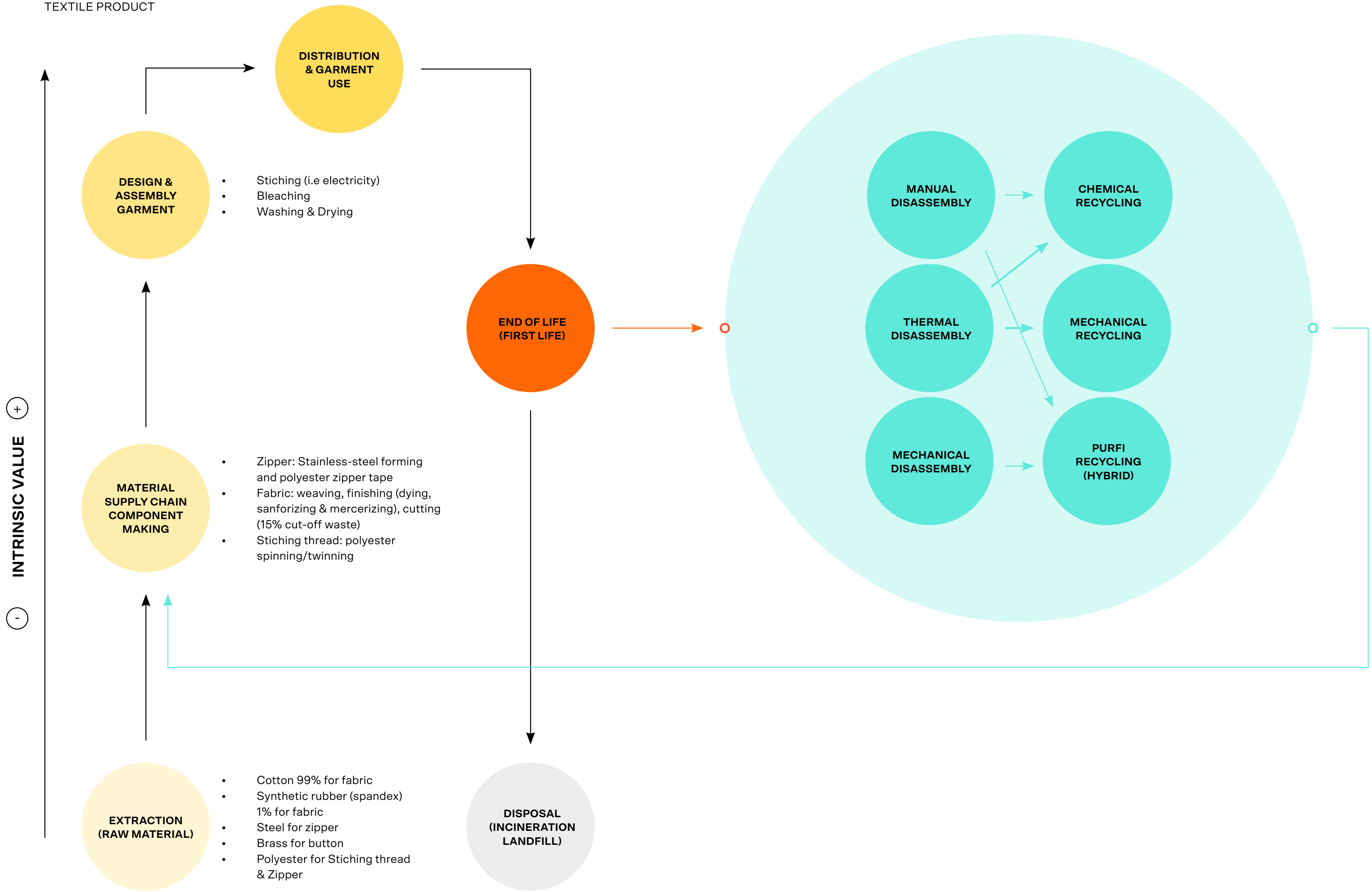


Figure 2 : System boundary of the product systems assessed in this LCA

E . Bleached denim impact

Since recycled denim doesn't need to be bleached, none of the proposed scenarios and calculations in this LCA considered bleaching. Nevertheless, information from the ecoinvent database as well as data from our partner unspun revealed that bleached denim has a higher impact on CO_2 emissions and resources exploitation: a benchmark pair of bleached denim jeans will release 7.9 kg of additional CO_2 eq. compared to non-bleached denim jeans (Figure 3). Bleaching a pair of denim jeans requires additional 0.3 m^3 of water and 1.2 m^2 of crop eq. per pair of jeans compared to non-bleached denim. The highest negative impact coming from bleaching is linked to the release of hazardous, carcinogenic chemicals, as each bleached denim jeans will release double the amount of 1,4-dichlorobenzene (1,4-DCB eq.), that is additional 28 kg.

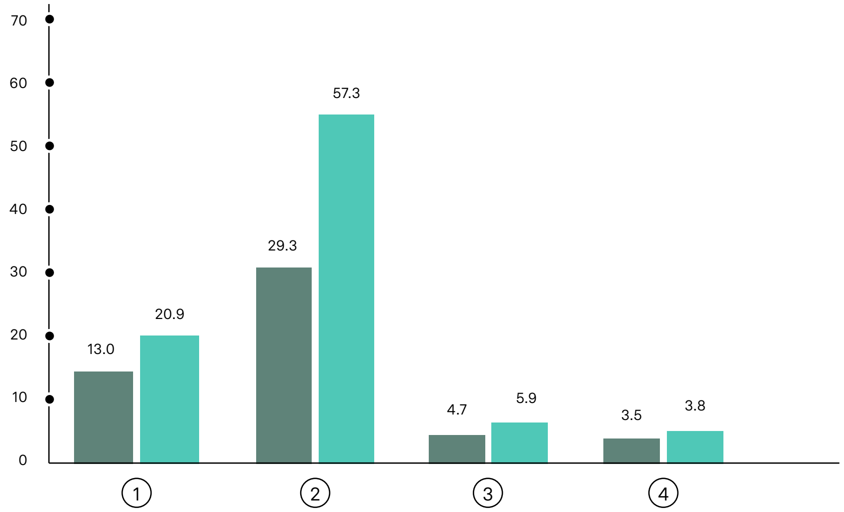


Figure 3: Bleaching has higher CO_2 emissions, releases more hazardous material and requires more water and land. A comparison between bleached and non-bleached benchmark denim jeans.

1. Kg CO_2 eq.
2. Human carcinogenic toxicity (Kg 1,4-DCB eq.)
3. Land use (m^2a crop eq.)
4. Water Consumption (m^3)

Benchmark denim not bleached

Benchmark denim bleached

F . Benchmark denim jeans & disassembly-recycling scenario

In order to produce a benchmark pair of denim jeans composed of 99% virgin cotton and 1% spandex (along with brass button, stainless steel zipper and polyester stitching thread), almost 150% of raw material is extracted. In other words, it takes 1.5x the amount of raw material (virgin cotton) to produce the required quantity of textile found in a finished pair of denim jeans. This is because 120% (100% finished product + 20% unsold) of the material will be required for component making (general fabric, zipper, button molding, denim designing and finishing), 15% is lost during cutoff and approximately 10% is wasted during manufacturing. This part of the supply chain is common to all the scenarios below (Table 2) the only difference is the fate of the denim jeans at EoL. The fate of a pair of denim jeans following the different scenarios covered in this LCA is summarized in Table 2.

Table 2: Summary of the key differences in the project systems tackled in this LCA.

	INCINERATION/LANDFILL	MANUAL DISASSEMBLY	MECHANICAL DISASSEMBLY (Shredding, delissage)	THERMAL DISASSEMBLY
BENCHMARK DENIM JEANS	**01** • 100% pre- & post-consumer market waste (mix incineration & landfill)	—	—	—
MECHANICAL RECYCLING	—	**02** • 52% of pre- & post-consumer garment wasted during disassembly (subjected to mix incineration & landfill) • 48% of the garment is recycled but only 15% of the fibers are fit for use in a 25% recycled denim and 75% virgin material jeans. • 35% of recycling waste is used as insulation material, 50% lost as dust.	**05** • 30% of pre- & post-consumer garment wasted during disassembly (subjected to incineration/ recuperated energy) • 70% of the garment is recycled but only 15% of the fibers are fit for use in a 25% recycled denim and 75% virgin material jeans. • 35% of recycling waste is used as insulation material, 50% lost as dust	**07** • 10% of pre- & post-consumer garment wasted during disassembly (subjected to incineration/recuperated energy) • 90% of the garment is recycled but only 15% of the fibers are fit for use in a 25% recycled denim and 75% virgin material jeans • 35% of recycling waste is used to insulation material, 50% lost as dust • Additional energy for thermal disassembly
CHEMICHAL RECYCLING	—	**03** • 52% of pre- & post-consumer garment wasted during disassembly (subjected to mix incineration & landfill) • 48% of the garment is recycled, of which 67% is reused in closed-loop production, 33% is wasted. • Return transportation route (Europe - SE Asia)	—	**08** • 10% of pre- & post-consumer garment wasted during disassembly (subjected to incineration/recuperated energy) • 90% of the garment is recycled and 67% is reused in closed-loop viscose trousers • Additional energy for thermal disassembly
PURFI RECYCLING	—	**04** • 52% of pre- & post-consumer garment wasted during disassembly (subjected to mix incineration & landfill) • 48% of the garment is recycled, of which 70% is reused in closed-loop production, 20% used in insulation and 10% are downcycled • Return transportation route (Europe - SE Asia)	**06** • 30% of pre- & post-consumer garment wasted during disassembly (subjected to incineration/ recuperated energy) • 70% of the garment is recycled, of which 70% is reused in closed-loop production, 20% used in insulation and 10% are downcycled	**09** • 10% of pre- & post-consumer garment wasted during disassembly (subjected to incineration/recuperated energy) • 90% of the garment is recycled of which 70% is reused in closed-loop production, 20% used in insulation and 10% are downcycled • Additional energy for thermal disassembly

Footnotes:

[18] Minimum fiber length required for reuse.

[19] It's impossible to make denim exclusively out of viscose (the final product obtained from chemically recycled cotton).

01 BENCHMARK DENIM JEANS – INCINERATION/LANDFILL

Pre- & Post-market denim jeans are expected to be either incinerated or landfilled in the marketed region (Europe) at EoL.

02 MANUAL DISASSEMBLY – MECHANICAL RECYCLING

Pre- & Post-market denim jeans are transported from Europe to South East Asia to be manually disassembled and only 48% of each pair of denim jeans is returned to Europe to be mechanically recycled. The remaining 52% is either incinerated or landfilled in Asia (India in this case). Upon recycling, only 15% of the content is fit for use (minimum required fiber length: 15-50 mm) and will be repurposed in the production of new multi-composition denim jeans: 25% recycled content mixed with 25% of virgin material spinning waste and 50% virgin material. The remaining 35% of recycling waste is used for insulation material, while 50% is lost as dust during the process.

03 MANUAL DISASSEMBLY – CHEMICAL RECYCLING

Pre- & Post-market denim jeans are transported from Europe to South East Asia to be manually disassembled and only 48% of each pair of denim jeans is returned to Europe to be chemically recycled. The remaining 52% is either incinerated or landfilled in Asia (India in this case).

04 MANUAL DISASSEMBLY - PURFI RECYCLING

Pre- & Post-market denim jeans are transported from Europe to South East Asia to be manually disassembled and only 48% of each pair of denim jeans is returned to Europe to be recycled using the PurFi method (hybrid process: mechanical + chemical). The remaining 52% is either incinerated or landfilled in Asia (India in this case).

05 MECHANICAL DISASSEMBLY – MECHANICAL RECYCLING

Pre- & Post-market denim jeans are mechanically dissembled in a shredder (délissage) and 30% of each pair of denim jeans is incinerated in Europe, where energy is recuperated. The remaining 70% is mechanically recycled. Upon recycling, only 15% of the content is fit for use (minimum required fiber length: 15-50 mm) and will be repurposed in the production of new multi-composition denim jeans: 30% recycled content and 70% virgin material.

06 MECHANICAL DISASSEMBLY – PURFI RECYCLING

Pre- & Post-market denim jeans are mechanically dissembled in a shredder (délissage) and 30% of each pair of denim jeans is incinerated in Europe, where energy is recuperated. The remaining 70% is recycled using the PurFi method (hybrid process: mechanical + chemical). Upon recycling, only 20% of the content is fit for use (minimum required fiber length: 15-50 mm) and will be repurposed in the production of new multi-composition denim jeans.

07 THERMAL DISASSEMBLY – MECHANICAL RECYCLING

Pre- & Post-market denim jeans are thermally disassembled in the Resortecs textile disassembling oven® (patent number BE2018/5146, PCT/IB2019/051994, WO2019/175766A1 US16/979.319, CN201980022646.0, HK62021026053.0 and EP19717196.0) in Belgium. Only 10% of each pair of denim jeans is incinerated in Europe, where energy is recuperated. The remaining 90% is mechanically recycled. Upon recycling, only 15% of the content is fit for use (minimum required fiber length and will be repurposed in the production of new multi-composition denim jeans: 30% recycled content and 70% virgin material.

08 THERMAL DISASSEMBLY – CHEMICAL RECYCLING

Pre- & Post-market denim jeans are thermally disassembled in the Resortecs textile disassembling oven® in Belgium. Only 10% of each pair of denim jeans is subjected to incineration in Europe, where energy is recuperated. The remaining 90% is transported from Belgium to Sweden (location of recycler), where it's recycled and 67% is reused in closed-loop viscose trousers.

09 THERMAL DISASSEMBLY – PURFI RECYCLING

Pre- & Post-market denim jeans are thermally disassembled in the Resortecs textile disassembling oven® in Belgium. Only 10% of each pair of denim jeans is subjected to incineration in Europe, where energy is recuperated. The remaining 90% is using the PurFi method (hybrid process: mechanical + chemical). Over 70% is reused in closed-loop denim production. From the remaining 30%, 20% is used in insulation and 10% are downcycled.

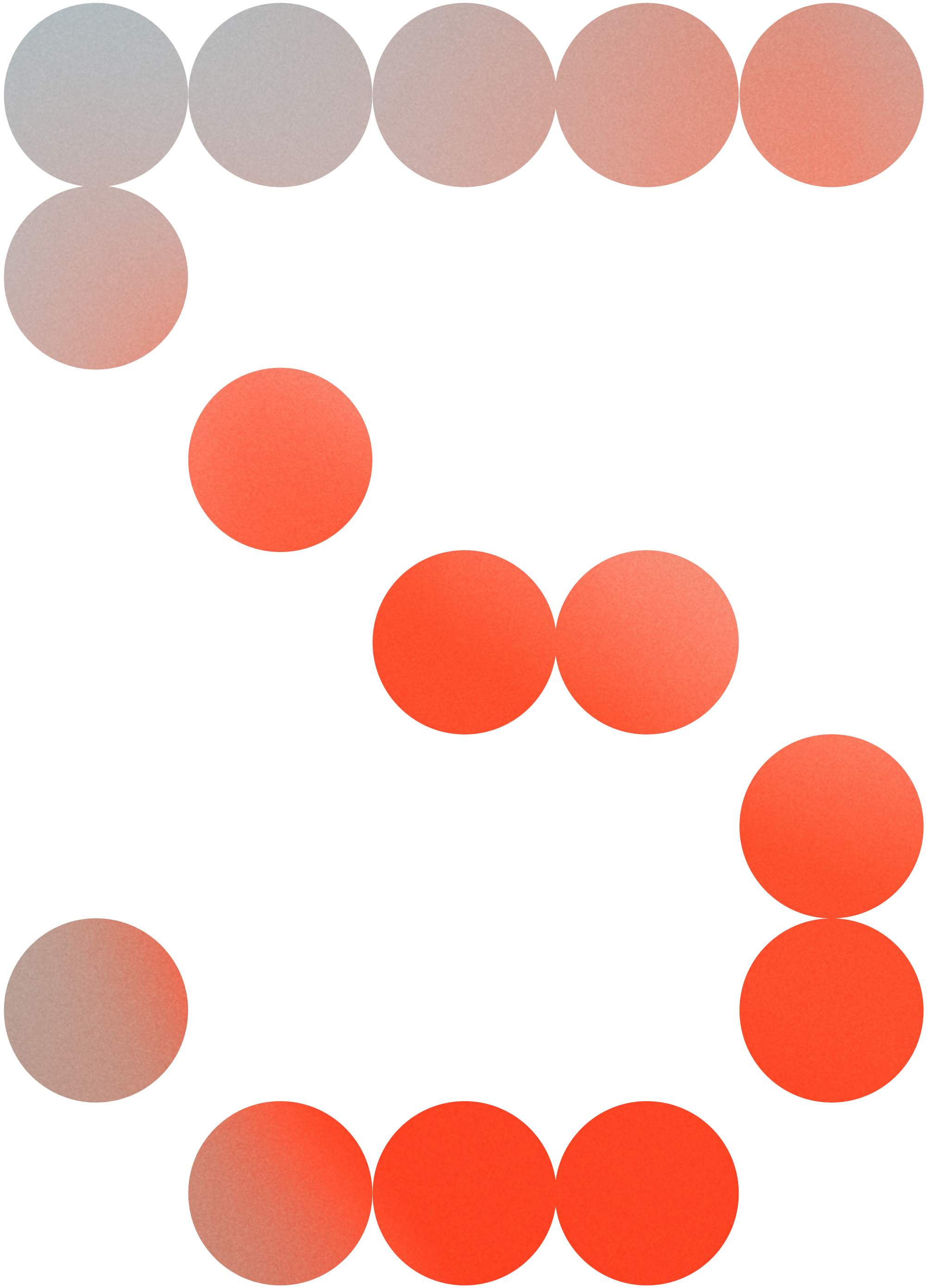
G . Functional unit

Since this LCA is for comparative purposes, all products should use the same definition of the functional unit [20] . The functional unit of this LCA is the mass of one pair of men's denim jeans: ~520 g.

[20] · European Environment Agency, Environmental Issue Series no.6. Life Cycle Assessment (LCA). A guide to approaches, experiences and information sources 2016.

— In this LCA, for the sake of comparison, we assume to be able to make a pair of denim jeans out of 100% viscose.

Life cycle inventory



A . Input and output description

The input of each product system includes: the raw material type and amount, the raw material processing, component making, and the product finalization along with transportation. Electricity and elementary flows such as water and fuel are also quantified per weight of a pair of denim jeans. The output is represented by the waste flows of the different materials. The parameters, percentage and main material covered in these input and output flows for producing one pair of denim jeans are summarized in Table 3 and Table 4.

For each scenario involving chemical recycling, the CO_2 calculations were based on a (market) benchmark viscose production process: using the required volume of softwood input as a reference for the hypothetical volume of denim input needed. The same basis was used for the weight and type of waste generated calculated as output.

Table 3 : Parameters utilized in the LCA for each component of one pair of denim jeans.

COMPONENT	PARAMETER	DESCRIPTION
BUTTON	8 g	BRASS
ZIPPER	6 g	1/3 POLYESTER + 2/3 STEEL
STITCHING THREAD	200 m	60TEX= 60 g/km 90TEXT=90 g/km
FABRIC	500 g	99% COTTON + 1% SPANDEX

Table 4: Summary of input and output for each product system.

PRODUCT SYSTEM	INPUT	OUTPUT	DATA DESCRIPTION	DATA SOURCE
COMMON IN ALL PRODUCT SYSTEMS	• Brass • Casting brass	• Button • Waste button (scrap copper)	• Manufacturing market value	• Ecoinvent database 3.6 • Button weighted by Resortecs
	• Polyester fiber, dyeing, electricity • Construction of industry building	• Stitching thread • Waste yarn	• Manufacturing market value • Polyester manufacturing India	• Ecoinvent database 3.6
	• Fiber polyester • Wire drawing - Steel • Weaving	• Zipper • Waste zipper	• Manufacturing market value	• Ecoinvent database 3.6 • Zipper weighted by Resortecs
01 BENCHMARK DENIM –INCINERATION LANDFILL	• Yarn cotton • Woven cotton • Synthetic rubber • Sanforizing • Mercerizing • Finishing • Washing, drying and finishing • Electricity for sewing	• Denim (1st life) • Fabric • Rubber waste • Yarn waste • Waste textile, soiled	• Synthetic rubber was used as equivalence for Lycra or Spandex • Electricity needed for sewing one denim	• Ecoinvent database 3.6
02 MANUAL DISASSEMBLY MECHANICAL RECYCLING	• Cotton fiber from wasted denims (1st life). • Lubricating oil • Construction recycler's building • Diesel • Weaving • Synthetic rubber • Sanforizing • Mercerizing • Finishing • Washing, drying and finishing • Electricity for sewing • Transport	• Denim (2nd life) • Recycled Fabric • Rubber waste • Yarn waste • Waste textile, soiled • Waste mineral oil, wastewater • Water vapor	• Manufacturing market value • Electricity needed for sewing one denim • Recycled fabric viscose • 3.5 denims needed for 1 recycled denim 25% recycled content mixed with 75% virgin cotton. Because: • 52% of the denim is wasted during disassembly • 85% of denim fabric is wasted during recycling	• Ecoinvent database 3.6

PRODUCT SYSTEM	INPUT	OUTPUT	DATA DESCRIPTION	DATA SOURCE
03 **MANUAL DISASSEMBLY CHEMICAL RECYCLING**	• Viscose fiber from wasted denims (1st life) • Lubricating oil • Construction recycler's building • Diesel • Weaving • Synthetic rubber • Sanforizing • Mercerizing • Finishing • Washing, drying and finishing • Electricity for sewing • Transport	• Denim (2nd life) • Recycled Fabric • Rubber waste • Yarn waste • Waste textile, soiled • Waste mineral oil wastewater • Water vapor	• Manufacturing Market value • Electricity needed for sewing one denim • Recycled fabric viscose • 3.1 denims needed for 1 recycled denim Because: • 52% of the denim is wasted during disassembly • 33% of denim fabric is wasted during recycling	• Ecoinvent database 3.6 • The data point for viscose was based on the Ecoinvent data point for sulfide pulp and textile was used instead of wood • Manual disassembly % is based on partner recycler's confidential communication with Resortecs
04 **MANUAL DISASSEMBLY PURFI RECYCLING**	• Waste textile avoided • Construction recycler's building • Diesel • Weaving • Synthetic rubber • Sanforizing • Mercerizing • Finishing • Washing, drying and finishing • Electricity for sewing • Transport	• Denim (2nd life) • Recycled Fabric • Rubber waste • Yarn waste • Waste textile, soiled • Waste mineral oil wastewater • Water vapor • Treated textile waste	• 3.0 denims needed for 1 recycled denim Because: • 52% of the denim is wasted during disassembly • 10% of denim fabric is downcycled after recycling	• Ecoinvent database 3.6 • Internal measurement by Resortecs • Energy and water usage based on PurFi confidential communication with Resortecs
05 **MECHANICAL DISASSEMBLY MECHANICAL RECYCLING**	• Waste textile avoided • Construction recycler's building • Diesel • Weaving • Synthetic rubber • Sanforizing • Mercerizing • Finishing • Washing, drying and finishing • Electricity for sewing • Transport	• Denim (2nd life) • Recycled Fabric • Rubber waste • Yarn waste • Waste textile, soiled • Waste mineral oil wastewater • Water vapor	• 2.4 denims needed for 1 recycled denim 25% recycled content mixed with 75% virgin cotton Because: • 30% of the denim is wasted during disassembly • 85% of denim fabric is wasted during recycling	• Ecoinvent database 3.6 • Internal measurement by Resortecs

PRODUCT SYSTEM	INPUT	OUTPUT	DATA DESCRIPTION	DATA SOURCE
06 **MECHANICAL DISASSEMBLY PURFI RECYCLING**	• Waste textile avoided • Construction recycler's building • Diesel • Weaving • Synthetic rubber • Sanforizing • Mercerizing • Finishing • Washing, drying and finishing • Electricity for sewing • Transport	• Denim (2nd life) • Recycled Fabric • Rubber waste • Yarn waste • Waste textile, soiled • Waste mineral oil wastewater • Water vapor • Treated textile waste	• 1.4 pairs of denim needed for 1 recycled denim 70% recycled content mixed with 30% virgin cotton Because: • 30% of the denim is wasted during disassembly. • 30% of denim fabric is downcycled after recycling	• Ecoinvent database 3.6 • Internal measurement by Resortecs • Energy and water usage based on PurFi's confidential communication with Resortecs
07 **THERMAL DISASSEMBLY MECHANICAL RECYCLING**	• Waste textile avoided • Construction recycler's building • Diesel • Weaving • Synthetic rubber • Sanforizing • Mercerizing • Finishing • Washing, drying and finishing • Electricity for sewing • Transport • Resortecs® disassembly (machine building, water and required energy needed)	• Denim (2nd life) • Recycled Fabric • Rubber waste • Yarn waste • Waste textile, soiled • Waste mineral oil Wastewater treatment • Water vapor	• 1.8 pairs of denim needed for 1 recycled denim 25% recycled content mixed with 75% virgin cotton Because: • 10% of the denim is wasted during disassembly • 85% of denim fabric is wasted during recycling	• Ecoinvent database 3.6 • Internal measurement by Resortecs • Machine building and operating costs were computed to cover one pair of denim over 15 years of the machine's life
08 **THERMAL DISASSEMBLY CHEMICAL RECYCLING**	• Waste textile avoided • Construction recycler's building • Diesel • Weaving • Synthetic rubber • Sanforizing • Mercerizing • Finishing • Washing, drying and finishing • Electricity for sewing • Transport • Resortecs® disassembly (machine building, water and required energy needed)	• Denim (2nd life) • Recycled Fabric • Rubber waste • Yarn waste • Waste textile, soiled • Waste mineral oil Wastewater treatment • Water vapor	• 1.7 denims needed for 1 recycled denim Because: • 10% of the denim is wasted during disassembly • 33% of denim fabric is wasted during recycling	• Ecoinvent database 3.6 • Internal measurement by Resortecs • Machine building and operating costs were computed to cover one denim over 15 years of the machine's life

PRODUCT SYSTEM	INPUT	OUTPUT	DATA DESCRIPTION	DATA SOURCE
09 THERMAL DISASSEMBLY PURFI RECYCLING	• Waste textile avoided • Construction recycler's building • Diesel • Weaving • Synthetic rubber • Sanforizing • Mercerizing • Finishing • Washing, drying and finishing • Electricity for sewing • Transport • Resortecs® disassembly (machine building, water and required energy needed)	• Denim (2nd life) • Recycled Fabric • Rubber waste • Yarn waste • Waste textile, soiled • Waste mineral oil Wastewater treatment • Water vapor	• 1.6 denims needed for 1 recycled denim Because: • 10% of the denim is wasted during disassembly • 30% of denim fabric is downcycled after recycling	• Ecoinvent database 3.6 • Internal measurement by Resortecs • Energy and water usage based on PurFi's confidential communication with Resortecs • Machine building and operating costs were computed to cover one pair of denim over 15 years of the machine's life

B . Calculation methods

The IPCC (Intergovernmental Panel on Climate Change) has set guidelines that are recognized as the default method for assessing greenhouse gasses (GHG) emissions and variations [21]. Similarly, the Environmental Protection Agency (EPA) recommends using the global warming potential (GWP 100) to calculate the GHG including CO_2 emissions effect. The GWP 100 was developed in such a way that the lifetime of different GHG in the atmosphere will be absorbed compared to CO_2 lifetime in the atmosphere. In this LCA, a GWP 20a (20-year time frame) was used as an alternative to GWP 100, as the objective of this study is to prioritize gases with shorter lifetime, with energy absorbed in the next 20 years [22]. Consequently, IPCC 2013 [23] GWP 20a was the calculation method of choice for assessing the CO_2 emissions (kg CO_2 equivalence) of the different project systems.

As the supply chain of the textile industry has a global footprint, the choice of the impact assessment method should be considered on an international scale. The life cycle impact assessment on resource scarcity, quality of the ecosystem and human health are covered by the ReCiPe 2016 calculation method at a global scale [24] and recommended by the European Commission [25]. This study followed ReCiPe 2016 Midpoint characterization factor along the cause-effect chain before the endpoint is reached namely to cover the impact on:

01 CO_2 emissions in kg CO_2 equivalence based on IPCC 2013 GWP 20a

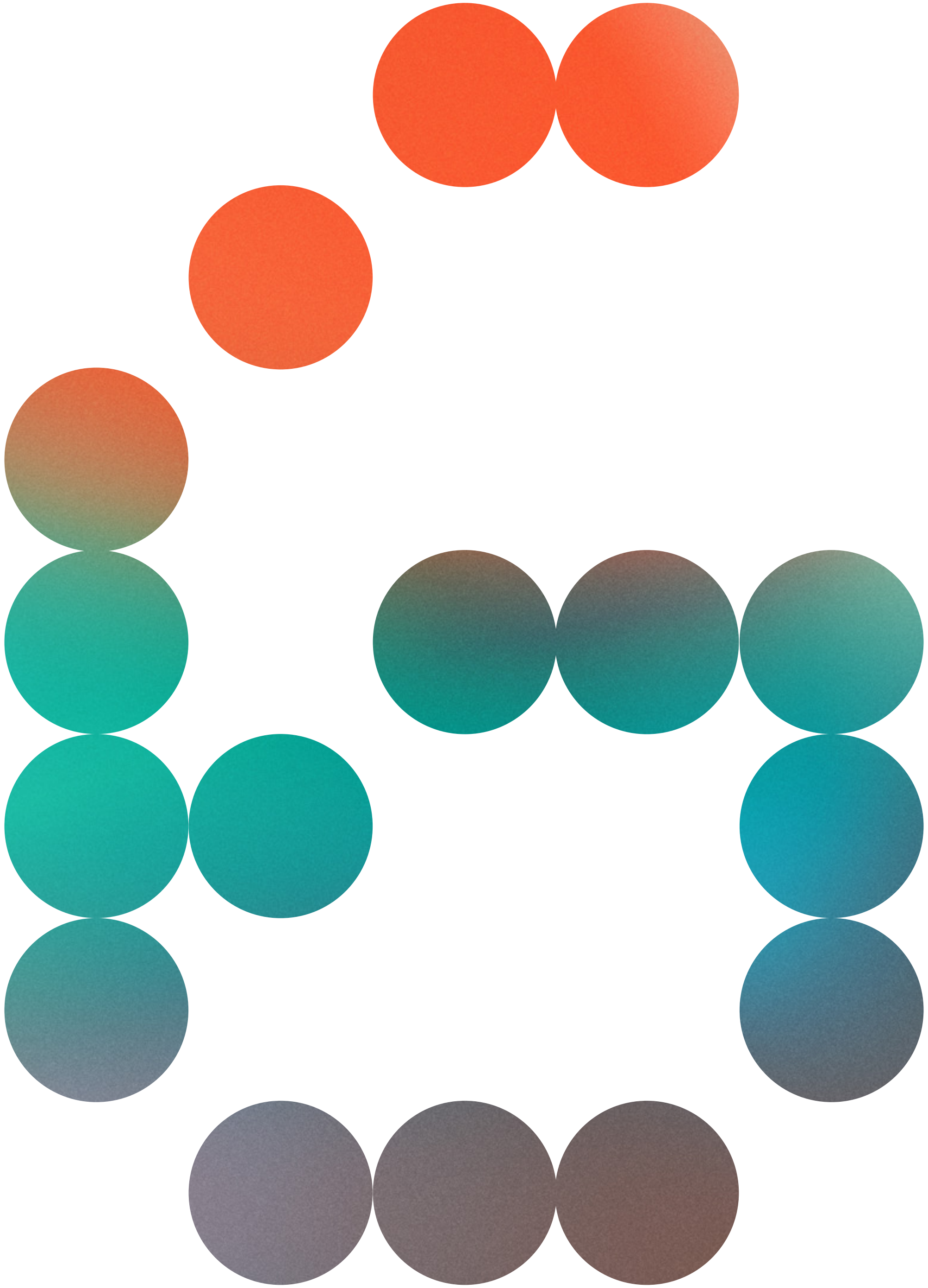
02 Water use in m^3 for each m^3 of extracted water

03 Land use in m^2a annual crop equivalent that accounts to specific species loss as a result of land conversion.

04 Toxicity denoted to the fate and effects of chemical discharges in equivalent 1,4-DCB eq. for human toxicity, specifically human carcinogenic toxicity.

[21] EIB Project Carbon Footprint Methodologies; Methodologies for the Assessment of project GHG emission variation, European Investment Bank, July 2020.
[22] Understanding Global Warming Potentials | Greenhouse Gas (GHG) Emissions | US EPA
[23] IPCC 2013 is the successor of IPCC 2007.
[24] Huijbregts et al., 2016. ReCiPe2016: a harmonized life cycle impact assessment method at midpoint and endpoint level.
[25] Angelstam et al., 2016 Comparative LCA Viscose vs Cotton T-shirts, Division of environmental strategies research.

Results and discussion



A . The CO_2 impact: an overview of different EoL scenarios

Comparing the 9 selected disassembly/recycling scenarios, there's a clear difference on the CO_2 footprint linked to each EoL processing (Figure 4):

- If a pair of denim jeans is incinerated or landfilled at EoL, 13 kg of CO_2 eq. is emitted per denim jeans from cradle to grave.
- Due to the additional energy required in the process, chemically recycling a manually disassembled pair of denim jeans is expected to release more CO_2 emissions in the short term – 14.8 kg of CO_2 eq. (GWP 20a) [26]. However, if the same pair of denim jeans were thermally disassembled prior to being chemically recycled, its carbon footprint would drop to 11.8 kg CO_2 eq. – approximately 20% less CO_2.
- The CO_2 footprint linked to mechanically recycling a pair of denim jeans also varies significantly according to the disassembly method adopted: 18.2 kg of CO_2 eq. if mechanically disassembled, 16.6 kg of CO_2 eq. if manually disassembled, and 15.2 kg of CO_2 eq. if thermally disassembled.

Like in other scenarios, if a pair of denim jeans is recycled under PurFi's proprietary process after being thermally disassembled, its carbon footprint is 33% smaller than that of a manually disassembled pair of jeans and 45% smaller than that of a mechanically disassembled pair of jeans.

DENIM EOL SCENARIO

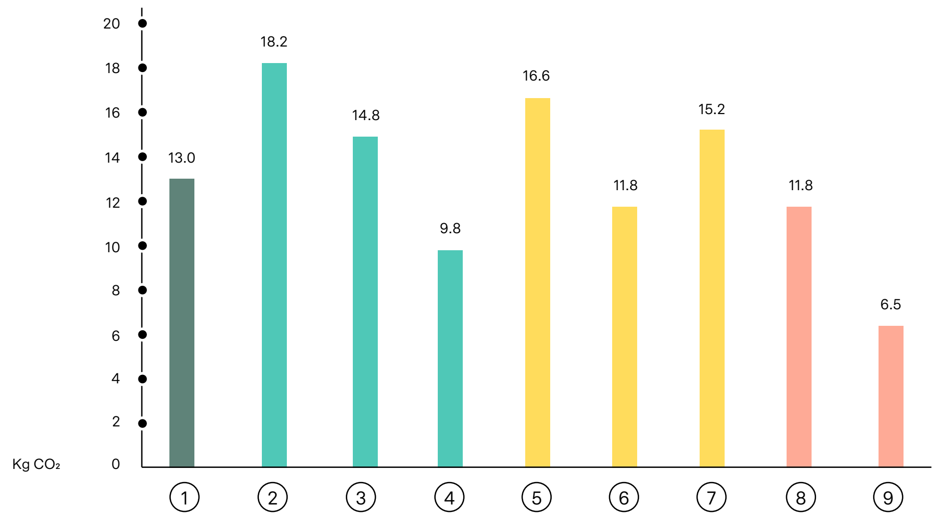


Figure 4: The CO_2 impact of different disassembly methods coupled with different recycling processes.

1. Benchmark denim Incineration/landfill
2. Manual dissassembly Mechanical recycling
3. Manual dissassembly Chemical recycling
4. Manual dissassembly PurFi recycling
5. Mechanical dissassembly Mechanical recycling
6. Mechanical dissassembly PurFi recycling
7. Thermal dissassembly Mechanical recycling
8. Thermal dissassembly Chemical recycling
9. Thermal dissassembly PurFi recycling

[26] It's important to note that if the product system for chemical recycling were computed using GWP 100a, the values would be lower than those of disposing a benchmark pair of denim jeans as the gasses released during raw material sourcing and incineration/landfill have a longer lifetime in the atmosphere.

B . The main CO_2 sources

The CO_2 reduction achieved due to thermal disassembly is mainly attributed to waste reduction (Figure 5 and Table 2). The activities that generate the most emissions in each of the comparative scenarios used in this LCA are linked to electricity generation, crop production, coal extraction, steam production, waste treatment, and additional transportation routes (Figure 5):

- CO_2 emissions linked to crop production result from sourcing virgin raw material, including the cotton to compensate for mechanical disassembly's low-quality fiber output.
- CO_2 emissions linked to (regular) transportation are similar across all scenarios compared in this LCA and have, therefore, been considered under the "others" umbrella in Figure 5. Manual disassembly, however, normally takes place in South East Asia mainly India and Pakistan. This requires additional transportation (from Europe to Asia for disassembly and from Asia to Europe for recycling) and generates additional CO_2 emissions.
- CO_2 emissions linked to waste treatment are one of the most significant across all EoL scenarios. Manual disassembly has the highest associated emissions (3.0 to 6.8 kg of CO_2 eq.), followed by mechanical (shredding) disassembly (~1.0-6.4 kg of CO_2 eq.), and thermal disassembly, which has the lowest volumes of associated emissions: ~ 0.16 kg of CO_2 eq. per pair of denim jeans recycled with PurFi's method and 3.7 kg of CO_2 eq. per pair of denim mechanically recycled.

DENIM EOL SCENARIO

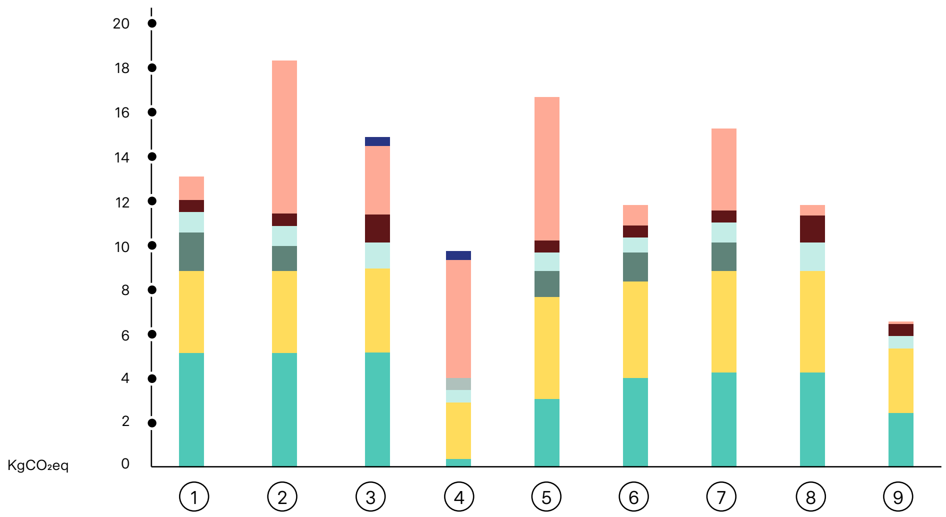


Figure 5: CO_2 impact analysis of the major sources of CO_2 in each scenario of the denim's end of life.

1. Benchmark denim Incineration/landfill
2. Manual dissassembly Mechanical recycling
3. Manual dissassembly Chemical recycling
4. Manual dissassembly PurFi recycling
5. Mechanical dissassembly Mechanical recycling
6. Mechanical dissassembly PurFi recycling
7. Thermal dissassembly Mechanical recycling
8. Thermal dissassembly Chemical recycling
9. Thermal dissassembly PurFi recycling

- Other
- Electricity
- Crop Growing
- Coal
- Steam
- Waste Treatment
- Additional transport

C . Land use, water consumption and carcinogenic toxicity

When it comes to water consumption and land use impact, the worst-performing EoL scenarios are the benchmark pair of denim jeans and those mechanically disassembled or recycled. Manually and thermally disassembled pairs of denim require the least resources across all analyzed EoL scenarios (Figure 6):

- Producing a benchmark pair of denim jeans from 100% virgin raw material requires 3,524.5 L of water and 4.66 m^2 of land – releasing 13 kg of CO_2 eq.
- In the case of a mechanically disassembled (shredding) pair of denim jeans, 80% of the fabric content must be of virgin material blended with the recycled denim. This requires ~2,500 L to 2,900 L of water and >3.4 m^2 of land – releasing from 11.8 kg to 16.6 kg of CO_2 eq. per pair of recycled denim jeans (mechanically or PurFi recycled).

Compared to the virgin benchmark pair of denim jeans, thermal disassembly + PurFi's recycling is the most optimal EoL scenario: reducing water consumption by more than 98% and cutting off land use by over 95% (freeing up land for agriculture or reforestation).

The human carcinogenic toxicity, on the other hand, is primarily linked to the heavy metals and chemical solvents used in the manufacturing and recycling process:

- As with water and land use, manual and thermal disassembly coupled with PurFi recycling show the lowest human toxicity across all the compared scenarios: 18.5 kg 1,4-DCB eq.
- Zooming into the comparison between thermal and manual disassembly for chemical recycling, thermal disassembly is still the most optimal process, reducing the impact of chemical recycling as it allows the recovery of more raw material: 31.2 kg 1,4-DCB eq. are generated by the combination of chemical recycling and with manual disassembly vs. 30.8 kg 1,4-DCB eq. generated by chemical recycling coupled with thermal disassembly.
- Excluding the benchmark pair of denim jeans, mechanical disassembly and mechanical recycling show the most harmful results when compared to other disassembly & recycling combinations.

Figure 6 clearly demonstrates the positive impact of effective disassembly of closed-loop denim made of 100% recycled material.

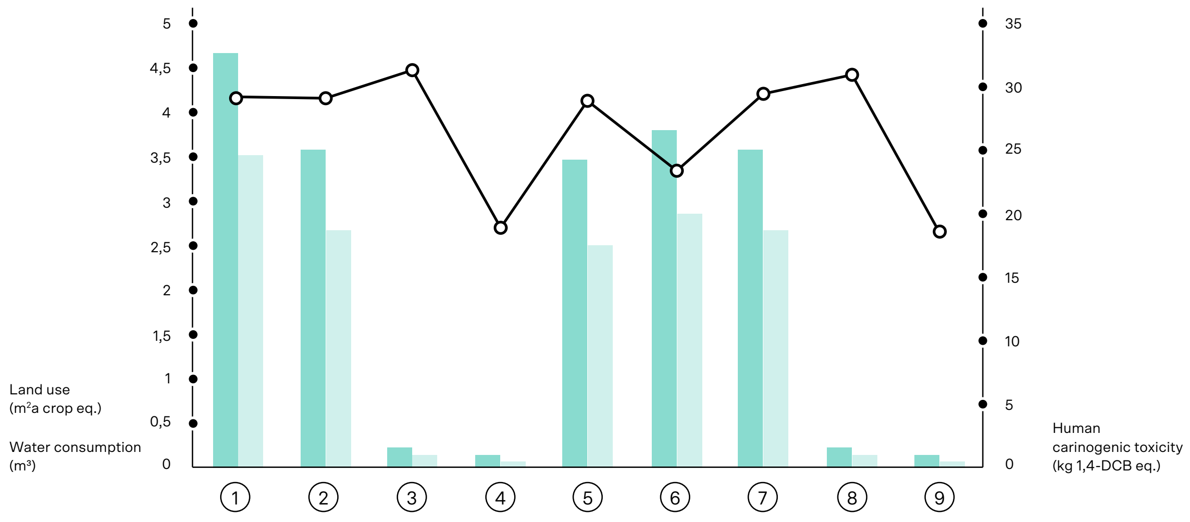


Figure 6: The impact of Denim EoL on water consumption and land use vs. human carcinogenic toxicity.

(1) Benchmark denim Incineration/landfill
(2) Manual dissassembly Mechanical recycling
(3) Manual dissassembly Chemical recycling
(4) Manual dissassembly PurFi recycling
(5) Mechanical dissassembly Mechanical recycling
(6) Mechanical dissassembly PurFi recycling
(7) Thermal dissassembly Mechanical recycling
(8) Thermal dissassembly Chemical recycling
(9) Thermal dissassembly PurFi recycling

Land use (m^2a crop eq.)
Water consumption (m^3)
Human carcinogenic toxicity kg 1,4-DCB eq.

D . The right disassembly choice: key factors & impact projections

Comparing all scenarios used as reference in the LCA, the importance of the right disassembly process to drive more efficient recycling becomes significantly clear. This is mainly due to how the different disassembly methods can result in different amounts of kg of CO_2 eq., water consumption and land use. Table 5 shows the key differences between different disassembly and recycling combinations.

Thermal disassembly coupled with PurFi's recycling method demonstrates the most advantages over all other disassembly + recycling scenarios:

- *It generates 90% less waste and 50% less CO_2 emissions*
- *It requires 50% less energy and 50% less virgin raw material*

On average, the European fashion industry releases 5 collections per year[27], or 20% to 30% of the global production of garments - representing 150 billion pieces per year[28]. This means that, if the European garment share were thermally disassembled and properly recycled, up to 60.3 million tons[29] of CO_2 could be avoided and over € 2.3 billion[30] could be saved per year.

Since the textile industry accounts for 5-10% of the global emissions, 2.11 billion tons of CO_2 could be reduced by 2050 by the textile industry alone, bringing it closer to the 1.5°C target[31]. If the textile industry adopted Resortecs thermal disassembly, an absolute reduction of 204 million tons per year (10% of the 2.11 billion tons) of global emissions could be achieved in 10 years by simply switching the stitching thread used during assembly.

27 . Style that's sustainable: A new fast-fashion formula | McKinsey 2016
28 . Apparel and Fashion Overproduction Report with Infographic
29 . The CO_2 footprint for energy need is derived from the CO_2 emissions from electricity, coal and steam as represented in Fig 4.
30 . The CO_2 cost is based on the amount of Kg of CO_2 eq. released by each EoL processing (Figure 4) multiplied by the CO_2 price of € 42.77 (value for 11th of mar 2021) provided daily by the EU ETS carbon market price
31 . CO_2 mitigation curves to meet a 1.5C target by Our World In Data

Table 5: Comparative table of the impact and costs of existing recycling and sorting technologies (textile to textile).

	MANUAL DISASSEMBLY					**MECHANICAL DISASSEMBLY** (Shredding, delissage)					**THERMAL DISASSEMBLY** (Resortecs®)				
	01	**02**	**03**	**04**	**05**	**01**	**02**	**03**	**04**	**05**	**01**	**02**	**03**	**04**	**05**
MECHANICAL RECYCLING	6.85	4.65	2.68	3.57	CO_2 = € 0.7 Material = € 0.5	6.43	5.42	2.51	3.47	CO_2 = € 0.7 Material = € 0.5	3.72	5.45	2.68	3.58	CO_2= € 0.6 Material= € 0.5
CHEMICAL RECYCLING	3.06	6.21	0.14	0.22	CO_2= € 0.6 Material = € 0.5	Not possible due to too high levels of material contaminations					0.56	5.5	0.14	0.22	CO_2= € 0.5 Material= € 0.01
PURFI RECYCLING	5.36	3.15	0.06	0.14	CO_2= € 0.4 Material = € 0.5	1.02	4.97	2.86	3.80	CO_2= € 0.5 Material= € 0.3	0.17	3.43	0.06	0.14	CO_2= € 0.3 Material= € 0.01

01 WASTE TREATMENT KG CO_2 EQ.

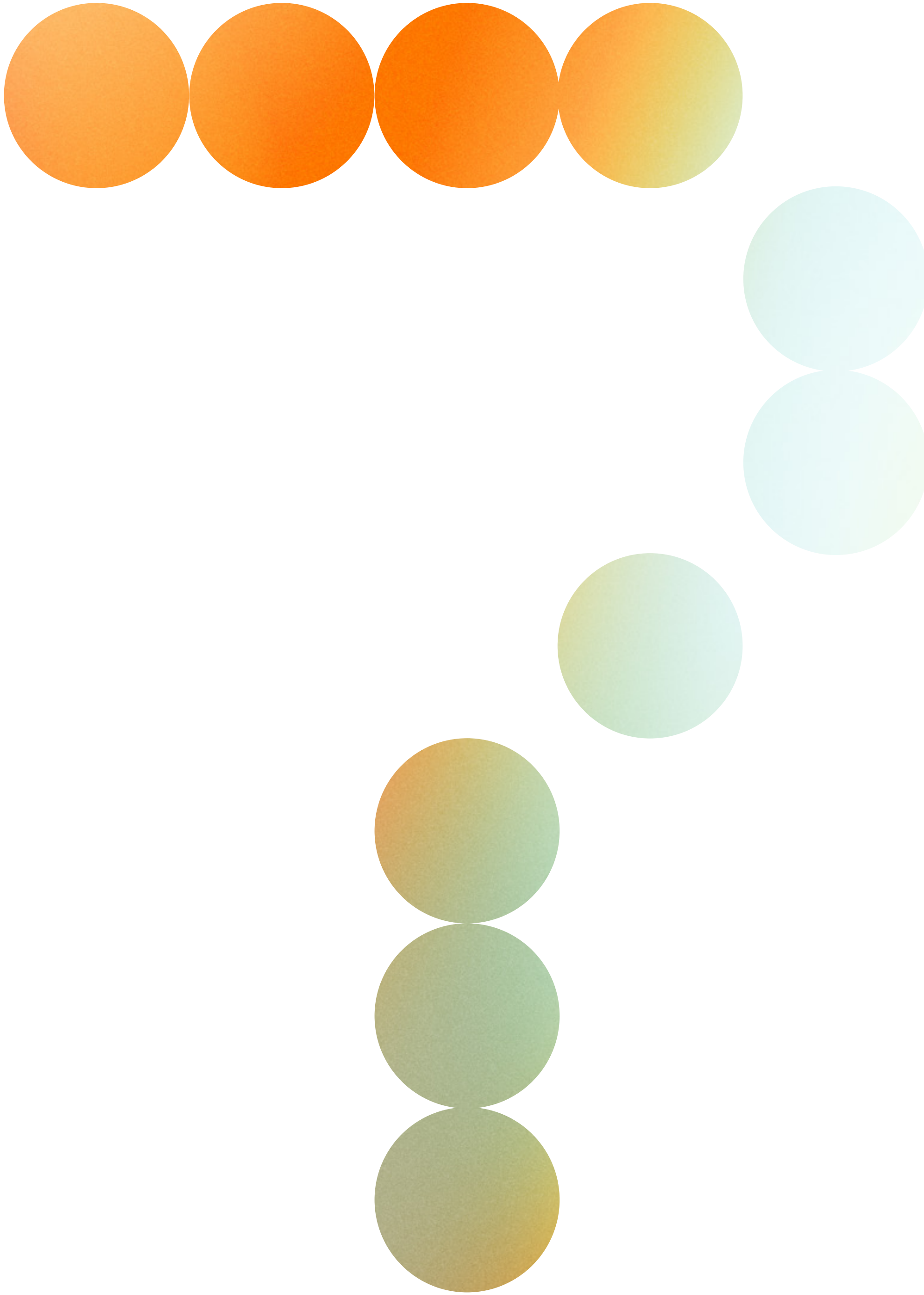
02 ENERGY GENERATING NEED KG CO_2 EQ.

03 WATER CONSUMPTION M^3

04 LAND USE M^2A CROP EQ.

05 COST CO_2 AND LOSS OF MATERIAL

Conclusion



The current textile industry practices are not future-proof.

It is estimated that the textile industry alone used up to 98 million tons of non-renewable resources such as mineral oil, fertilizers and chemicals. These numbers are expected to increase to 300 million tons by 2050 if there is no disruption to the current textile industry.

Recycling is key to decarbonize the textile supply chain, but only if coupled with the right disassembly method.

While it's already encouraging to see brands using sustainably sourced or recycled materials, their effort won't make a substantial difference if sustainable garments are still being burned or dumped in landfills. The LCA results show that thermal active disassembly is the method with the lowest waste generation rates, allowing for the highest volumes of recycled content.

Adopting thermal active disassembly can reduce CO2 emissions by 50%, water consumption by 98%, and land use by almost 95% compared to landfill and incineration.

Sustainability can be affordable and mainstream. While it is currently approached by the textile industry as an expensive, niche-focused initiative, the LCA figures show that's a mistake.

By shifting from linear to circular supply chains, brands can tap into an additional cost reduction potential while still meeting their environmental targets. The technology to make the textile industry truly circular already exists - and it doesn't take much to adopt it.

Resortecs' bio-based and synthetic dissolvable threads and dismantlable rivet buttons are ready to be used by brands, without creative nor quality trade-offs. They require minimal to no technical adaptation and are currently being tested by over 20 global players in the fashion industry.

Small change, Big impact.

Resortecs

A comparative Life Cycle Assessment of disassembly & recycling methods in closed-loop denim production

Rawaa Ammar
Cédric Vanhoeck
William Allouche