Study on recycling disruptors and facilitators in Clothing, Household linen and Footwear

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Re_fashion

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1. Introduction

1.1. Background and purpose of the study

Under its 2023-2038 PRO accreditation, Refashion is required to conduct studies on the recyclability of non-reusable post-consumer **Clothing, Household linen and Footwear** (CHF).

To conduct these studies, Refashion has undertaken a **comprehensive review of disruptors and facilitators to CHF recycling** for the different recycling routes.

A previous study was published by the eco-organisation in July 2014, based on research undertaken by the École Nationale Supérieure des Arts et Industries Textiles (ENSAIT) on disruptors and facilitators to textiles recycling[1]. Refashion wanted to update this study by widening the scope to include disruptors and facilitators to footwear recycling.

1.2. Methodology

This purpose of this document is to list disruptors and facilitators to CHF recycling, to explain their impacts on each recycling process and to evaluate their level of disruption in each process.

This updated review was carried out in 2 stages:

- Literature review primarily based on the study conducted by ENSAIT;
- Interviews with relevant stakeholders (sorting, sorting for recycling, preprocessing, recycling, etc.).

Research was undertaken with French and European material sorting operators, material preprocessors and recyclers (see appendix 6.21). **It should be noted that recycling capacities and efficiencies change very quickly, and that this summary refers to work undertaken at the end of 2023 and in 2024.**

Textiles (clothing, household linen) recycling processes and footwear recycling processes being distinct processes, recycling disruptors and facilitators for these 2 product categories are presented separately.

For textiles, 3 main recycling routes have been studied:

- Mechanical recycling;
- Thermomechanical recycling;
- Chemical and enzymatic recycling.

For footwear, 2 processes have been studied:

- Shredding of the whole shoe for recycling the whole shoe if it is made from a single material, or for the recycling of its different materials after sorting of the shreds.
- Separation of the shoe upper from the sole by slicing, tearing or delamination, for material recovery of the different components.

1.3. General description of the CHF recycling sector

The following diagram (see Fig. 1) summarises the different stages from collection to the recycling of post-consumer CHF.

[1] *Étude des perturbateurs et facilitateurs au recyclage des textiles et linges de maison, Refashion, 2014 (French only)*

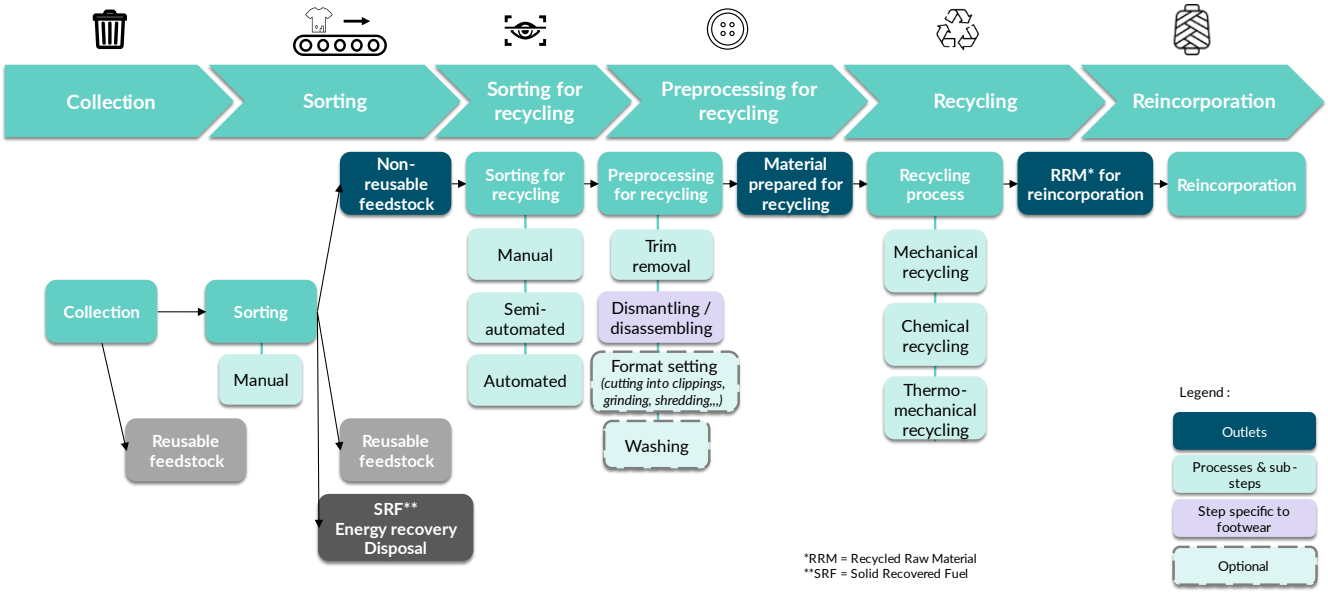


Figure 1 : Diagram showing the CHF recycling value chain - Source: Refashion

Following the collection of post-consumer CHF, sorting operators sort the reusable feedstock from the non-reusable feedstock. The non-reusable feedstock is either prepared for recycling or is directed to energy recovery. In 2023, only 0.15% of the sorted CHF waste was not recovered (incinerated without energy recovery or landfilled), mainly consisting of soiled and/or wet items.

Depending on their material composition, colour and other characteristics, non-reusable post-consumer textiles may be directed towards different recycling processes for closed-loop applications or open-loop applications (building, automotive or plastics industries).

Three main recycling routes can be distinguished: mechanical, thermomechanical and chemical recycling. Mechanical recycling is predominant, thanks to existing industrial facilities in France and in Europe (cutting into wiping cloths, tearing/garnetting or unravelling for yarn spinning). The other recycling routes are currently being developed in France and in Europe.

Recycled raw materials (RRM) are produced from these processes, for incorporation into new products as shown in the Refashion mapping of products made from recycled textile waste (see appendix 6.3.1).

As shown in Figure 1, two preliminary stages are required in the recycling of non-reusable post-consumer CHF. These are sorting for recycling[2] and material preprocessing[3] stages.

All these stages are included in this study to list the different types of disruptors (and facilitators) for the entire CHF recycling chain and their different disruption levels (see chapters 3 and 4).

[2] *Additional sorting* of non-reusable CHF waste according to their material composition and/or color in accordance with a recycler's material specifications, in order that recycling can be performed without any further sorting being required.

[3] *Preprocessing of non-reusable CHF waste includes textiles trim removal, footwear dismantling and formatting.*

2. General categorization of recycling disruptors and facilitators

Recycling disruptors or facilitators may be: distinct components, a fabric specific weave or structure, material composition, finishing, the general aspect of the item or its conditions of use.

Disruptors or facilitators are found in the different stages of the non-reusable post-consumer CHF recycling value chain: sorting for recycling, material preprocessing and recycling. An element can be a disruptor at one or several stages, but also for one recycling process and not another. **Each recycling process is therefore analysed individually in the following chapters,** to clearly explain the different disruption levels.

The definitions below are based on those in the 2014 Refashion study on disruptors and facilitators undertaken by ENSAIT.

2.1. Recycling disruptors

A **recycling disruptor** (also called **a contaminant** or **an unwanted element**) is an element, a material or a substance that, when present, may cause disruption in the recycling process, potentially even blocking it.

These disruptors may lead to:

- a lower quality of the recycled raw material;
- reduced efficiency and performance of the recycling process;
- potentially considerable damage to the recycling equipment (even the risk of fire) and/or to the equipment used for incorporating the recycled material.

These disruptors may be grouped into two main categories: external and internal disruptors.

2.2. External disruptors

External disruptors are elements external to textile fabrics or to footwear components. They are stitched or glued directly onto the item. They are commonly known as “hard points” when made of metal or rigid plastic. These elements vary in number and in composition according to designers’ intention or to their function in the item. They can be functional, aesthetic or both.

External disruptors cause disruption in almost every recycling process and are generally removed from textiles during trim removal in the preparation for recycling stage. The aim of this operation is to remove all elements on textile items (external disruptors such as buttons, zips, straps, rivets, etc.). Trim removal may be carried out manually using scissors (manual or electric), a saw (circular or band), puncher/cutters, etc., or performed mechanically (integrated into garnetting/tearing lines, automated trim removal on clippings).

According to the characterisation study of the incoming and outgoing streams from sorting facilities[4], 78% of textile items have at least one external recycling disruptor made of metal, plastic, fabric or another material (ivory, wood, etc.).

[4] *Refashion. Characterisation study of the incoming and outgoing streams from sorting facilities, 2023*

Table 1: Distribution of external recycling disruptors, by material type and by end destination of the sorted streams (in weight)

	Total	Tearing/Garnetting	Wiping rags	Solid recovered fuel (SRF)	Ultimate waste
number of pieces	74287	32351	25828	10609	5502
margin of error (max)	0,4%	0,5%	0,6%	1,0%	1,3%
none	22,3%	20,8%	27,5%	19,2%	17,8%
metal	6,6%	7,9%	4,2%	3,8%	12,4%
textile	22,7%	21,1%	25,3%	24,7%	36,4%
other	35,8%	36,8%	30,7%	44,2%	25,8%
plastic	11,8%	12,6%	11,8%	7,4%	7,4%
unknown	0,7%	0,8%	0,5%	0,7%	0,2%
Total	100,0%	100,0%	100,0%	100,0%	100,0%

External disruptors that can be found on clothing and household linen may also be found on shoe uppers. Some external disruptors are also specific to footwear. These are listed in Table 2 below.

Table 2: Non-exhaustive list of external disruptors found in clothing, household linen and footwear

Category	External disruptors	Function	Possible composition
Clothing, household linen and footwear			
Functional	**Zip fastener**	Fastens/ties two parts	Polyamide, metal/cotton, polyamide/cotton
	Button		Metal, pearl, wood, ivory, polyester, resin, leather
	Brandeburg buttons		Leather, wood, polyester
	Hook and eye fastener		Metal, polyester, resin
	Fastener		Metal, resin
	Buckle		Metal, polyester, resin
	Snap button		Metal, polyester, resin
	Hook and Loop fastener		Polyamide, polyester
	Stitching yarn/stitch		Polyester, cotton
	Snap hook (carabiner)		Metal, resin, polyester, polyamide
	Hook		Metal, polyamide
	Braiding/string/cord		Polyester, cotton, polyamide
	Eyelet	Circular reinforcement in which laces, braids, etc. are passed through	Metal, plastic
	Product information label and washing instructions	Provides information on the product's material composition (EU requirement) and washing instructions.	Polyester
	RFID tag	Transcribes information and anti-theft device.	Copper, polyester, polyamide, paper, etc.

	Reflective strip	Reflects/emits light	Pigment, polyamide, various textile base materials
	Phosphorescent strip		
	Slip-resistant strip	Provides support	Polyamide, elastane
	Elastic strip	Provides elasticity to material	Elastodiene (= *synthetic elastomer polymer*)
	Cord stopper	Used to block and adjust the cord's length	Metal, polyamide, polyester
	Boning	Provides support and rigidity	Metal, plastic
	Binder rings	Used as fixing rings or to reinforce the structure	Metal, wood
	Foam	Gives structure to the item	Polyurethane
	Pocket lining	Creates the pocket space	Polyester, cotton
Aesthetic or functional	**Label/logo**	Provides information about the brand or is purely aesthetic	Polyester, polyurethane, synthetic leather
	Pattern print (flocking)		PVC, polyurethane
	Badge		Natural, synthetic or man-made fibres, leather, plastic
	Rivet	Provides structure to clothing or purely aesthetic	Metal
	Shoulder pad		Textile/nonwoven/foam based composite
	Multilayered items/Linings	Makes an item comfortable or purely aesthetic	Polyester, viscose
	Electronic or electrical components	Makes the item attractive or provides technical properties	Electronic or electrical components
Aesthetic *(Non-exhaustive list)*	**Lace**	For purely aesthetic purposes	Natural, synthetic, artificial fibres
	Embroidery		
	Patch		
	Pompom		
	Bows		
	Rhinestones/sequins		Metal, wood, plastic
	Bead		
	Pendant		Metal, plastic
	Charm, trinket		
Specific to footwear			
Functional	**Insole, heel-lining inserts**	Provides protection and durability	Leather or other material
	Reinforced toe, heel counter, toe cap and puncture-resistant plate		Metal, plastic or other material
	Shank	Provide support and durability	Metal, plastic, wood
Use	**Foreign objects (stones, nails, chewing gum, etc.)**	Related to use (in soles)	Metal, organic material, etc.

2.3. Internal disruptors

Internal disruptors are constituents or structural elements of a textile's main fabric or of a shoe component. These can be functional, aesthetic, or both.

These disruptors may be related to material composition, finishing or to the product's structure. They cannot be removed during a preprocessing for recycling stage, but some can be isolated during recycling (depending on the process) and in some cases, their presence can be tolerated in the recycled material within certain limits.

Some internal disruptors found on clothing and household linen may be also found in shoe uppers. There are also some internal disruptors specific to footwear, particularly in soles.

Table 3: Non-exhaustive list of internal disruptors in clothing, household linen and footwear

Internal disruptors		Function	Level of disruption
Clothing, household linen and footwear			
Functional	**Material composition >2**	May provide technical properties	Complicates recycling and/or limits applications
	Fabric made of high count yarn (fine yarn)	Makes fabric finer	Very difficult or impossible (*warp knit*) to open and tear fibres
	Woven / knit jacquard and warp knit	Gives technical properties to the fabric	
	Elastane > 5% **Stretch fabrics and knitwear**	Gives elasticity to the fabric	Complicates recycling and/or limits applications
Aesthetic or functional	**All-over coatings and plastic print**	Provides technical properties to the fabric or is simply aesthetic	May create impurities and hinder recycling
	Non-removable electronic or electrical components	Makes the item attractive or provides technical properties	Risk of fire during recycling
	Finishes	Finishing treatments that provide technical properties	Some finishes may hinder the spinning process
Aesthetic	**Multi-coloured textiles**	For aesthetical purposes only	Cannot be colour sorted for unravelling towards yarn spinning
	Certain dyes (black colours mainly)	Provides colour to the item, purely aesthetic	May hinder automated NIR sorting and make some chemical recycling processes more complicated
	Metallic-plastic yarns, spangles, sequins and paillettes	For aesthetic purposes only, gives a sparkly appearance to the item	Hinders the recycling process
	Items with several components/fabrics of different materials and/or structures	For aesthetic purposes only	Problematic items to categorise during sorting and to recycle without trim removal / disassembly of components
Specific to footwear			
Fillers and additives		Gives certain properties or makes the material cheaper	Difficult to identify and contaminates the recycled material

2.4. Multilayered textiles

A multilayered textile is a textile made up of several distinct layers, each possibly composed of different materials. Within Refashion's characterisation programme published in 2023, only items with a second layer representing at least 1/3 of the item's surface area were classified as "multilayers". According to this study, these items account for 8 to 9% (by weight) of the non-reusable textile feedstock.

Table 4 : Distinction between a multilayered and a single-layer item

Multilayer	Single layer		
			
2 layers	1 layer	1 layer + textile disruptor to recycling	1 layer + textile disruptor to recycling

2.5. Disruptors related to use or to collection

Other recycling disruptors may be introduced during the use or, for moisture content, also the collection of a textile or footwear item.

Table 5: Disruptors related to use or to collection

Disruptors related to use or to collection	Level of disruption
Clothing, household linen and footwear	
Moisture content	Wet or damp items cannot be recycled. Even if they are generally removed during the first sorting stage or directly at collection stage, it is essential to remove these items as they can facilitate mould growth, leading to degradation and contaminating the rest of the feedstock.
Excessive washing/drying	Excessive washing and drying (in tumble dryer) of textiles causes premature wear of the fibres, thereby reducing the quality of fibres in mechanical recycling. This problem is particularly important when unravelling textiles to create new yarns. Some detergents also cause the loss of technical properties in PA or PET.
Odour	Any odour present in items cannot be removed by thermomechanical or mechanical recycling processes and will remain in the resulting RRM.
Chemical pollution (traces of oil, paint, etc.)	Soiled items cannot be recycled.
Specific to footwear	
Deterioration of the material due to environmental factors (e.g. high temperature)	Deteriorates the material to be recycled (e.g. EVA in flip-flops)
Foreign objects (stones, nails, chewing gum, etc.)	Contaminate sole materials to be recycled and may cause deterioration to equipment if they are not removed

The following chapters explain and detail the level of disruption caused by the different types of disruptors for each recycling process.

2.6. Recycling facilitators

Recycling facilitators are all the elements or groups of elements that have a positive impact in at least one of the recycling processes or a stage of the recycling process. There are relatively few in number, but they are easy to implement and effective. These elements must also be considered according to their impact on the product lifespan (physical durability, repairability).

Thermoplastic yarns and adhesives can ease the disassembly of components in textiles or footwear, provided that the appropriate equipment for degrading these yarns and adhesives is available during the preparation to recycling phase.

The following chapters describe the textiles and footwear recycling facilitators identified in this study.

3. Analysis of textile recycling disruptors and facilitators

3.1. Summary

3.1.1. Recycling disruptors

The Table 6below summarises the **level of disruption caused by the different disruptors** in each textile (clothing and household linen) recycling process. The explanations of the analysis for this table are given in chapter 3.2 where it is described how the different elements cause disruption in each recycling process.

Table 6: Level of disruption of the different textile recycling disruptors

Disruptors	Optical sorting	Mechanical recycling		Thermo-mechanical recycling	Chemical recycling
		Cutting into wiping cloths	Tearing for producing nonwovens and unravelling for yarn spinning*		
EXTERNAL DISRUPTORS					
Metallic hard points	+ (if scanned on hard point)	++	+ to ++	++	++
Thermoplastic hard points	+ (if scanned on hard point)	++	+ to ++	Ø (if same material as the main fabric) to ++	+
Flocking pattern prints, embroidery, decorative positioned pattern elements[5]	+ (if scanned on these elements)	+	Ø to ++	+	+
Multilayered textiles	++	++	Ø to ++	+	+
INTERNAL DISRUPTORS					
Material composition >2	++	Ø (if cotton is predominant)	Ø to ++	+	++
All-over finishes, coatings, prints, sequins, spangles and paillettes[6]	++	++	++	Ø to ++ (if the material is the same as that of the main fabric)	+
Electrical and electronic components	+	++	++	++	++

[5] *Isolated elements* positioned *on the textile's surface*
[6] *Continuous and regular elements on the entire surface of the textile*

Disruptors	Optical sorting	Mechanical recycling		Thermo-mechanical recycling	Chemical recycling
		Cutting into wiping cloths	Tearing for producing nonwovens and unravelling for yarn spinning*		
Metallic-plastic yarns	+	++	++	++	++
Elastane	++ (if < 5%)	+	++ (if > 5%)	+	++ (if > 5%)
Multi-coloured textiles	Ø	Ø	Ø to ++	+	Ø
Certain dyes	++ (carbon black)	+	Ø	Ø	+
DISRUPTORS RELATED TO USE OR TO COLLECTION					
Wet or moist textiles	++	++	++	++	++
Excessive washing/drying	Ø	Ø	Ø to ++	Ø	Ø
Odour	Ø	+	++	++	Ø
Soiled textiles	++	++	++	++	++

**The required level is generally higher for unravelling for yarn spinning than for tearing for nonwovens*

Key to level of disruption:

Ø	No significant impact on the process or on the quality of the Recycled Raw Material (RRM).
+	Presence of a disruptor that may be managed by the process or removed during a preprocessing stage.
++	Presence of a disruptor that hinders the process or negatively alters the product's quality, which may result in its exclusion at the entry stage.

In summary:

Textile recycling disruptors identified in this study generally include those already identified in 2014. Indeed, since clothing design has evolved very little over the last 10 years, very few new disruptors have been identified. Carbon black dye is the main disruptor recently identified as problematic for optical sorting (NIR).

The elements identified as the most problematic, disrupting all recycling processes, include:

- **Metallic-plastic yarns** (e.g.: Lurex®): these yarns disrupt all existing recycling processes and are very difficult to manage by existing processes as well as those under development[7] posing fire risks during garnetting/tearing. Fire is the greatest risk in a sorting centre or a material preprocessing facility;
- **Electrical and electronic components**: similarly, these components, which may cause explosions or fires, are not tolerated in any recycling process.
- **Finishes, coatings, prints, sequins, spangles and paillettes in large numbers or covering a significant part of an item's surface:** these disruptors in all existing recycling processes are not managed by current processes (nor by processes under development);

[7] *Thermomechanical recycling for plastics processing and chemical recycling*

- **Metallic and plastic hard points in significant amounts or covering a large part of an item's surface:** when there are many, these elements result in a high amount of non-textile waste having to be removed. Operators manually removing these disruptors underline the high level of disruption caused by hard points when their position is not standardised for the same category of product.

The level of disruption from the other identified disruptors varies according to the recycling process. Among the most significant are **blends of more than 2 different materials as well as elastane > 5%**, both of which being disruptors for several recycling processes.

3.1.2. Recycling facilitators

Today, the **most easily recyclable** textile items **meet all the following criteria**:

- **Single-layer**;
- **Single-material;**
- **Monochrome (*for unravelling for yarn spinning*);**
- **Free from metallic-plastic yarns, spangles, thermoplastic prints or coatings covering the garment's entire surface** ("all-over").

Any item meeting all these criteria may directly be recycled in any recycling process (possibly with a preliminary trim removal + material/colour sorting stage).

To make textile recycling easier, **it is recommended to:**

- **Ensure the traceability of the articles' composition (primarily material composition) throughout their lifecycle**
- **Minimize the presence of components that may cause disruption** (hard points, metallic-plastic yarns, spangles, elastane > 5%);
- **Opt for single-material items** (or bi-materials that can be recycled together);
- **As far as is possible, avoid purely aesthetic finishes** and prioritize functional aspects;
- **As far as is possible, avoid purely aesthetical external disruptors** and opt for function. Standardise the elements' positioning (facilitating the faster handling and removal in manual trim removal).

In the following sections, disruptors are listed in an ascending order of disruption according to the level of disruption.

3.2. Details of disruptors and facilitators per recycling process

3.2.1. Preliminary stage to recycling : optical sorting

Description: in general, this stage involves material recognition technologies through analysis of its physical or chemical properties. The most common technology is Near infra-red spectroscopy (NIR). Sensors can be portable or integrated into a sorting table, but they can also be integrated in an automated sorting line and combined with colour recognition technology.

Table 7: Textiles optical sorting disruptors

DISRUPTORS	LEVEL OF DISRUPTION	EXPLANATIONS
EXTERNAL DISRUPTORS		
Multilayered textiles	++	Since spectroscopy is a surface detection technology, only the layer in contact with the sensor can be identified. If the material composition of the other layers in the item is different to the scanned fabric, this will lead to an increased level of impurities in the sorted output category.
Metallic and thermoplastic hard points	+	Some infra-red recognition devices (such as manual spectrometers) analyse articles on a single point measurement. When hard points are present in large amount and/or big (>2cm), optical sensors may analyse those instead of the main fabric, thereby resulting in classification and sorting errors.
Flocking pattern prints, embroidery, decorative positioned pattern elements	+	Spot-measurement spectrometers analyse items in a single measuring point. If decorative elements are abundant, optical sensors may analyse those instead of the main fabric, resulting in classification and sorting errors.
INTERNAL DISRUPTORS		
Material composition >2	++	During the identification of a blend containing more than two materials, it becomes difficult to identify each material during the spectrum analysis[8].
All-over finishes, coatings, prints, sequins, spangles and paillettes **Knitwear/double-sided fabrics**	++	As spectroscopy is a surface detection technology, only the layer in contact with the sensor can be identified. The under-layers will not be identified.
Material <5% in a blend's composition	++	The difficulty in detecting the presence of materials accounting for less than 5% of the overall composition is one of infra-red recognition technologies' limitations[8].
Carbon black dye	++	Carbon black absorbs light, thereby making it impossible to detect the material's spectrum (only synthetic or MMCF).
Gimped yarn (e.g. elastane)	++	Gimped yarns are yarns in which the core is wrapped with another material. A classic example is elastane yarn covered with cotton or polyester; the detection of "hidden" elastane in the yarn's core is thereby impossible.
Wet/moist textiles	++	Moisture content can cause detection errors or prevent detection.
Metallic-plastic yarns	+	Metallic-plastic yarns reflect light and can interfere with the detection of the main fabric material.

[8] *Refashion, April 2023 "European technical monitoring on optical sorting, textile recognition and trim removal technologies"*

Electrical and electronic components	+	On the surface, these components may disrupt optical sorting. If these components are hidden under the surface, they cannot be detected.
FACILITATORS		
Digital identifier	A digital identifier (QR code, RFID tag, etc.) can contain detailed information on materials and components used in textiles, including fibre blends, the applied finishes and trims. Implementing reading processes for these identifiers would enable sorting centres to perform precise sorting for recycling, without the need for optical sorting.	

3.2.2. Mechanical recycling

3.2.2.1. Cutting into wiping cloths

Description: **Cutting** consists of cutting up textiles into wiping cloths. It is carried out by using (manual or electric) scissors, a (circular or band) saw or puncher/cutters.

Table 8: Disruptors and facilitators in cutting into wiping cloths

DISRUPTORS	LEVEL OF DISRUPTION	EXPLANATIONS
EXTERNAL DISRUPTORS		
Multilayered textiles	++	These items are generally not accepted in this recycling process because if the different layers are glued together, then they cannot be separated.
Metallic and thermoplastic hard points	++	Wiping cloths cannot tolerate any hard points. If these are present on a large surface area, they slow down their removal and increase loss of material.
Electrical and electronic components	++	These components must be removed.
Flocking pattern prints, embroidery, decorative positioned pattern elements	+	These elements reduce the material's absorbent properties and may damage the surfaces to be cleaned.
INTERNAL DISRUPTORS		
All over finishes, coatings, prints, sequins, spangles and paillettes	++	These elements reduce the material's absorbing properties and may damage the surfaces to be cleaned.
Metallic-plastic yarns	++	These elements reduce the material's absorbing properties and may damage the surfaces to be cleaned.
Synthetic compositions	++	Except for polyester microfibre fabrics especially designed for wiping purposes, synthetic textiles are set aside because they are not suitable for this application (non-absorbent).
Certain dyes	+	Colour bleeding of some dyes may contaminate the surfaces to be cleaned.
Elastane (>5%)	+	The fabric's elasticity makes it complicated to cut.

FACILITATORS	
Standardisation of the positioning of disruptors to be cut	Items having disruptors systematically located in the same places makes it easier and quicker for cutting operators to process them.

3.2.2.2. Garnetting/tearing for nonwovens production and unravelling for yarn spinning

Description: The **garnetting or tearing** process is the mechanical transformation of textiles into fibres for various applications. Textiles are cut up before being processed in a tearing line containing several cylinders with spikes that tear the textile clippings until they become fibres.

Unravelling requires the same technology as garnetting/tearing except that the fibres are torn more gently so that the length of output fibres is as long as possible and thereby suitable for spinning.

Table 9: Disruptors and facilitators in textiles garnetting/tearing and unravelling

DISRUPTORS	LEVEL OF DISRUPTION	EXPLANATIONS
EXTERNAL DISRUPTORS		
Metallic and thermoplastic hard points	+ to ++	The presence of metallic hard points may cause fires and damage to equipment. Although the presence of residual hard points (≤ 2cm) may be tolerated in the production of some nonwovens, hard points are not tolerated in yarn spinning.
Labels	+ to ++	Composition labels are generally made from polyester (quite dense so that the print is legible). They may cause the production of "stars", unopened pieces of fabric that are found in garnetted fibres.
Flocking pattern prints, embroidery, decorative positioned pattern elements	Ø to ++	Small flocked prints (such as logo prints) may be tolerated, but fibres that are bonded together by the print will not be garnetted (forming "stars"). This may be tolerated in the production of nonwovens but not in spinning processes.
Multilayered textiles	Ø to ++	Multilayered textiles may be composed of different material and contain hard points. The variety of materials within a single article increases the variability of the recycled material composition, complicates recycling, and limits potential applications.
Stitches	+	**For unravelling for yarn spinning only**: if the fabric to be recycled is not polyester, the stitching yarns, being mostly in polyester, will contaminate the recycled material.
INTERNAL DISRUPTORS		
Woven / knit jacquard Warp knit	++	These structures with interlaced yarns are impossible to garnet/tear. According to their material composition, thermomechanical or chemical recycling are the preferred recycling routes for these types of items.
All-over coatings, sequins, spangles and paillettes	++	Coatings stick to fibres and prevent garnetting/tearing. All-over sequins, spangles and paillettes complicate the garnetting/tearing process and contaminate equipment.

Electrical and electronic components	++	If these components are not removed during trim removal, they risk causing a fire.
Metallic-plastic yarns	++	Metallic-plastic yarns, such as Lurex®, are synthetic yarns covered with metal that may cause sparks during garnetting/tearing and risk causing a fire.
Elastane (>5%) **Stretch fabrics and knitwear**	++	Elastane makes textiles elastic and therefore difficult to garnet. Elastane breaks down under the heat of mechanical friction and causes the formation of unopened "stars" that form undyed clumps in the recycled product. The tolerance level of elastane in yarn spinning depends on the type of the final recycled yarn.
Multi-coloured textiles	Ø to ++	It is not possible to categorise multi-coloured textiles during colour sorting. These textiles are problematic for yarn spinning, if the colour of the recycled yarn is required to be uniform. In this regard, nonwoven production is less demanding.
Material composition >2	Ø to ++	It is important to obtain a RRM with a known material composition, especially to produce new yarns. In this regard, nonwoven production is less demanding.
Fabrics made from fine yarns	+	Fabrics made from fine yarns are difficult to garnet/tear properly.

FACILITATORS	
Single-material and monochrome textiles	Limiting the number of materials and colours in a same textile item means that, when it has reached its end of life, it can be sent for unravelling to produce yarn. Nevertheless, items that do not meet these criteria - if they can be garnetted/teared - can be directed to the production of nonwovens.

It should be noted that small-sized textiles are generally discarded because they contain little material compared to the level of disruptors.

3.2.3. Thermomechanical recycling

Description: **Thermomechanical recycling** refers to a set of preprocessing and fusion processes targeting primarily synthetic materials, that are combined with one or more mechanical treatments (extrusion, injection, etc.) to produce granules intended for plastics manufacturing.

Table 10: Disruptors and facilitators in thermomechanical recycling

DISRUPTORS	LEVEL OF DISRUPTION	EXPLANATIONS
EXTERNAL DISRUPTORS		
Metallic hard points	++	Metallic hard points lead to the deterioration or even breakage of production tools.
Thermoplastic hard points	Ø to ++	If made from a material that is different to that of the main fabric, these elements are disruptors.
Multi-layered textiles	+	If made from material that is different to that of the main fabric, these different layers are disruptors.
Flocking pattern prints, embroidery, decorative positioned pattern elements	+	If made from material that is different to that of the main fabric, these elements cause impurities in the RRM.
INTERNAL DISRUPTORS		
Metallic-plastic yarn	++	Any element in metal is prohibited in thermomechanical recycling.
Electrical and electronic components	++	These components are prohibited in thermomechanical recycling.
Wet/moist textiles	++	Wet or moist textiles prevent efficient thermomechanical recycling and may damage equipment.
Acrylic, chlorofibers and PVC	++	Acrylic, chlorofibers, and PVC can release odours and toxic gases when exposed to high temperatures.
All-over finishes, coatings, sequins, spangles and paillettes	Ø to ++	The presence of sequins, spangles or paillettes causes blockages in machinery and disrupts the fusion process, thereby compromising the quality and purity of RRM. If the material is different from that of the main fabric, finishes and coatings will contaminate the finished product.
Material composition >2	+	If the blends are made from well-identified thermoplastic materials, then they can be recycled using thermomechanical processes. Nevertheless, this affects the process' profitability and the resulting RRM will be a blend of materials.
Elastane	+	The presence of elastane complicates material preprocessing (shredding) due to it stretchiness.
Multi-coloured textiles	+	Multi-coloured textiles will result in RRM with a mix of colours and the only way to resolve this is by dyeing the RRM.

Natural fibres residues	+	These residues are carbonised in the extruder and are not filtered at the beginning of the extruder because they are too fine. Some recyclers may however manage to treat these residues.

FACILITATORS	
100% synthetic, without any finishes and monochrome textiles	Limiting the use of different colours in the same textile and choosing 100% synthetic materials without any finishes means that the item can be sent for thermomechanical recycling at the end of its life, with lower risk of contamination in the RRM and no need to dye it.

3.2.4. Chemical or enzymatic recycling

Description: **Chemical or enzymatic recycling** covers all processes that transform polymer materials (synthetic or cellulosic) into purified polymers (dissolution) or into compounds resulting from these polymers (monomers or oligomers). This is often termed as chemical recycling or enzymatic recycling when enzymes are used.

Table 11: Disruptors and facilitators in chemical or enzymatic recycling processes

DISRUPTORS	LEVEL OF DISRUPTION	EXPLANATIONS
EXTERNAL DISRUPTORS		
Metallic and plastic hard points	+	Rigorous removal of hard points is necessary to prevent equipment from being damaged and the RRM from being contaminated. Plastic hard points of the same composition as the main fabric to be recycled may be tolerated by some processes.
Flocking pattern prints, embroidery, decorative positioned pattern elements	+	These elements increase the level of impurities in the RRM.
Multi-layered textiles	+	If these are made from material that is different to that of the main fabric, these different layers become disruptors.
INTERNAL DISRUPTORS		
Material composition >2	++	Above a certain level of purity, treatment costs and risks to the final product's quality significantly increase, thereby jeopardising the recycling process' economic viability.
Metallic-plastic yarn	++	Made from blends of plastic and metallic materials, it is difficult to breakdown these effectively chemically.
Electrical and electronic components	++	Recycling processes using chemicals or enzymes cannot handle these components.
Wet/moist textiles	++	Wet textiles inhibit the effectiveness of chemical or enzymatic recycling processes.

Elastane > 5%	+ to ++	Most processes are disrupted when the amount of elastane is higher than 5%.
All-over finishes, coatings, sequins, spangles and paillettes	+	These elements degrade or even inhibit the effectiveness of recycling processes and increase the level of impurities in the RRM.
Some types of dye	+	Some types of dyes cannot be broken down chemically. Purification techniques may add costs and complexity to the recycling process.

FACILITATORS	
Single material, single layer and light-coloured textiles	Mono-material textiles in light colours allow better efficiency in most chemical or enzymatic recycling processes. Single-material multi-layered textiles may be accepted.

4. Analysis of footwear recycling disruptors and facilitators

4.1. Composition of footwear and problems with recycling

4.1.1. Footwear anatomy

A wide variety of footwear models exist, ranging from sneakers to boots, from high heels to sandals, etc. The shoe upper and the sole are elements present in all household footwear.

The shoe upper and sole are themselves made up of many different elements that vary according to the model. The CTC [9] diagram shows the structural parts of footwear (here is an example of a “derby” shoe):

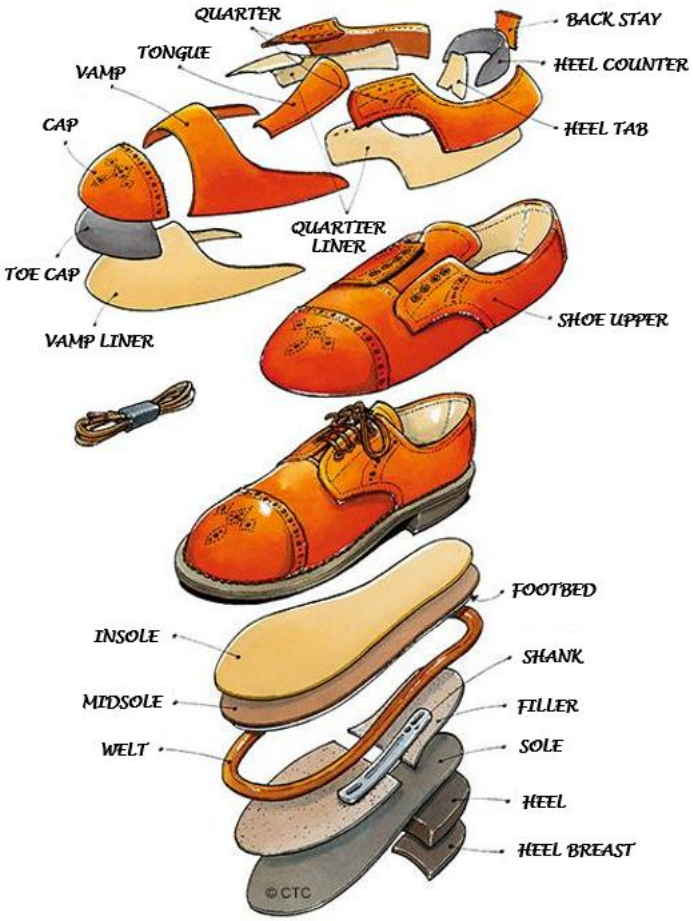


Figure 2 : Footwear description, CTC

Their assembly may vary and can be cementing, sewn/stitched or injection-moulded.

[9] *THE CTC (Centre Technique du Cuir - French Leather Technical Centre) is a research and training centre specialised in leather, footwear, leather items and related trades.*

4.1.2. Cementing assembly

This method consists of attaching the shoe upper to the sole using adhesives. The surfaces to be glued together are first prepared in order to increase bonding properties. The adhesive is then uniformly applied on both parts to be assembled which are then pressed together.

4.1.3. Sewn/Stitched assembly

The shoe upper and the sole are assembled with stitches. Generally, the shoe upper is first assembled to the midsole, after which an outsole is added and stitched to the rest of the shoe.

4.1.4. Injection-molded

This method uses machines that inject material into moulds that form the shape of the sole. The shoe uppers are fixed to the stations in a rotary machine while the mobile moulds turn around the injector. The polymer, often PU (polyurethane) is injected into the mould under high pressure forming the sole. Single density or dual density injection can be performed in order to adjust hardness and comfort.

The shoe upper contains many visible or invisible materials and components some of which are identical to those present in garments (e.g. textile, zips, rivets, etc.). Although the sole is made up of a single material it is generally composed of two or more materials (e.g. PU, TPU, EVA etc.).

4.2. Review of recycling preparation processes

Contrary to textiles, the post-consumer footwear recycling industry is still in its early stages. Non-reusable post-consumer footwear is mainly recovered as SRF (Solid Recovered Fuel).

Today, two main approaches to prepare footwear for recycling exist:

a) Footwear is entirely shredded and the different materials are then sorted using various techniques (density separation, infra-red scanning, etc.) and sent to recovery processes. Residual contaminants limit the purity of the material streams.
b) Footwear is disassembled to allow the separate recycling of the sole (mainly) and the upper. Various disruptors hinder the separation of the shoe upper from the sole.

4.2.1. The entire shredding of footwear

The entire shredding of the footwear is a process where post-consumer footwear is cut into small pieces (shredded material) using a shredder. This method enables shredded material to be obtained if footwear is made of single material or different materials from footwear such as leather, rubber, plastic, textile, etc.

The shredded materials obtained are then sorted (densimetric sorting or optical sorting), then undergo additional stages in the recycling process until they are incorporated into the manufacturing of new products.

Several solutions like this have been developed. The SOEX[10] shredding line, completed in 2017, can treat nearly all types of footwear[11]. This line is located at the SOEX recycling factory in Wolfen, Germany. Following shredding, the materials are separated according to their density thereby isolating the materials from the different components which are then extracted to form of granules or powder for recycling.

[10] *SOEX "Innovation"*

[11] *Except for footwear with large metallic parts (caps, studs)*

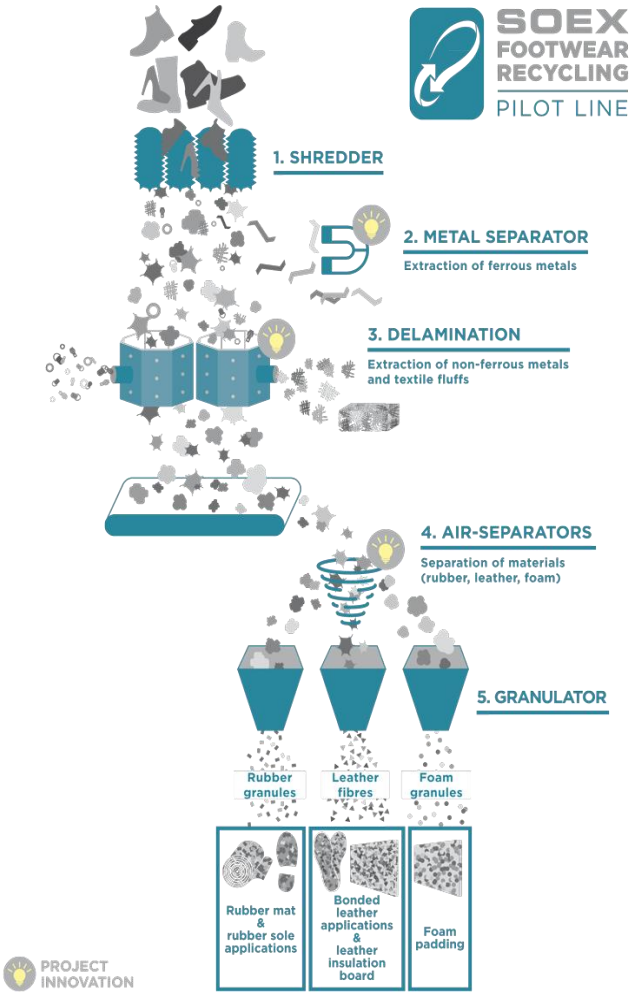


Figure 3: Diagram of the pilot line in the Air SOEX project

The Dutch company Fast Feet Grinded[12] has developed a recycling preparation line that operates on a similar principle to that of the SOEX line. The company can recover foam, textile fibres and rubber for various open loop uses (such as yoga mats, sports ground surfacing, etc.) as well as for the creation of new footwear.

The Spanish innovation centre, INESCOP[13], has developed a demonstrator that operates in a similar way: after the footwear has been shredded, densimetric sorting separates the foam, rubber and textiles in order to recover each fraction.

In France, The 8 Impact has also developed a process where footwear (mainly sneakers) is shredded following sorting by footwear type. The patented eight-step mechanical process utilizes density separation (without any water) to isolate rubber, EVA foam, and textile "fluff," which can then be recovered separately.

[12] *Scott."Fast Feet Grinded".*

[13] *"Rafael Climent to inaugurate a recycling plant for the footwear, textile, and toy sectors at INESCOP - INESCOP." Centre for Technology and Innovation »*

4.2.2. Shoe upper and sole separation processes

Separating the shoe upper from its sole for recycling is a method that has been developed to facilitate the recycling of individual parts. Today different technologies exist to separate the shoe upper from the sole in the most appropriate way according to how they are assembled. Soles are then shredded and sorted (using spectrometry) so that each material is recovered using the most suitable process.

Among the automated separation solutions identified, three key technologies stand out:

Tearing separation, which consists of using mechanical devices to separate the shoe upper from its sole once the adhesives have been reactivated. It is possible to separate these manually, as seen in the case of ReValorem's process where unsold footwear and luxury brand prototypes are disassembled manually. CETIA has an automated tearing line (developed for the Reshoes Project[14]) in which thermobonded soles are automatically separated by a robotic arm following treatment in an oven to reactivate the adhesive.

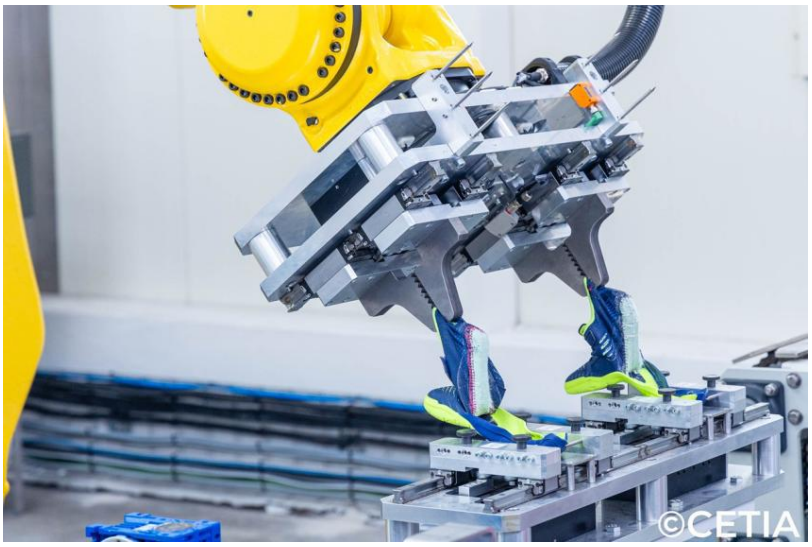


Figure 4: CETIA tearing process

Cutting, which requires specialised machines to precisely cut out the shoe upper and sole with the help of blades or other cutting tools (e.g. water jets). CETIA now has a water jet cutting machine for sewn footwear.

Lastly, **delamination using supercritical CO_2,** is a pre-pilot scale method using carbon dioxide in a supercritical state in order to selectively dissolve adhesives allowing the separation of footwear components (Project of IDELAM start-up [15]).

Today, no economically viable outlets for soles exist because these are highly complex elements (few materials but many disruptors). However, metallic elements may be isolated and recovered separately.

[14] *FashionNetwork."Reshoes: le nouveau programme français innovant de recyclage de semelles". (Reshoes: the new French innovative programme to recycle soles.)*

[15] *"IDELAM intervient dans la vidéo du CNRS le Journal sur le recyclage à l'aide des fluides supercritiques" (IDELAM intervenes in a video by the "CNRS Le Journal" on recycling processes using supercritical fluids). IDELAM.*

4.3. Summary of recycling disruptors and facilitators in footwear recycling preparation

4.3.1. Disruptors

The table below summaries **the level of disruption caused by the different disruptor categories** for each of the various footwear recycling preparation processes.

This summary table is the result of an analysis that describes how the different elements disrupt the recycling preparation processes cited in chapter 4.2.

The elements identified as the most disruptive ones for all preprocessing for recycling stages are:

- **Electrical and electronic components** that may cause fires;
- **Metallic and plastic parts** in the shoe upper and sole (zips, reflective strips, metal parts, shank, eyelets, heels, etc.) These disruptors make shredding complicated resulting in a significant amount of waste to be treated and in a low amount of material that can be recycled.

Table 12: Level of disruption caused by the different disruptors in the preparation of footwear for recycling

DISRUPTORS	Shredding of entire footwear		Separation of the sole and shoe upper	
	Shredding stage	Sorting of shreds for recycling	Separation of the shoe upper and sole	Sorting of sole for recycling
EXTERNAL DISRUPTORS				
Metallic hard points (shanks, caps, eyelets, etc.).	+ to ++	+	+	+
Plastic hard points	Ø	+	+	+
INTERNAL DISRUPTORS				
Electrical and electronic components	++	+	++	+
Material composition >2 Fillers and additives	Ø	++	Ø	++
Dyed with carbon black	Ø	++	Ø	++
All over finishes, coatings, prints, sequins, spangles and paillettes (shoe upper)	Ø	++	Ø	Ø

Key to level of disruption:

Ø	No significant impact on the process' operation or on the quality of the Recycled Raw Material (RRM).
+	Presence of a disruptor may be managed by the process or removed during a material preparation stage.
++	Presence of a disruptor that hinders the process or which negatively alters the product's quality, possibly resulting in it being rejected from entering the recycling process.

DISRUPTORS RELATED TO USE OR COLLECTION	
Foreign objects	Foreign objects (such as stones, nails, chewing gum, etc.) may contaminate the RRM if they are not removed upstream.
Chemical pollution	Chemical pollution from oils, cleaning products, paint and solvents, negatively interferes in the recycling process.
Environmental conditions	Exposure to salt and sand may alter the material's composition, for example flip-flops worn on the beach and made from EVA.
Wet items	Wet items may encourage the growth of mold which may lead to degradation and contamination of the rest of the materials to be recycled.
Odour	Any remaining odours may be found in the RRM.

Disruptors linked to use or collection may cause significant problems for recycling processes or RRM quality. Foreign objects and wet or soiled footwear are also problematic in optical sorting for recycling. It is therefore essential to remove or even isolate all the footwear concerned in order to minimise its negative impact on the recycling process.

4.3.2. Facilitators

In contrast to the problems caused by external and internal disruptors, certain facilitators that aid in the preparation of footwear for recycling can be cited:

Absent or removable electric and electronic components	Integrating these components into a module that could be separated would, in theory, allow these to be easily removed before depositing the footwear at a collection point **providing clear instructions to consumers**. Alternatively, the manufacturer could recover and repair or recycle this footwear. Ideally, the best solution would be to avoid electric and electronic components.
Traceability of precise information on footwear composition and components	With detailed information on composition and the footwear assembly method, it would become possible to recycle footwear in specific batches according to material types and to produce better quality recycled materials. Information on the footwear's materials can be integrated into shoes in several different ways. For example, the addition of a recycling symbol on the sole could also indicate the outside sole's composition. **The proposal in the European regulation on the implementation of a Digital Product Passport (DPP) for all new products placed on the market in 2030 could constitute a method in which more detailed information on composition could be conveyed.**[16]
Soles affixed using hot-melt adhesives or yarn	With the same product durability, soles assembled to the rest of footwear using hot-melt adhesives or yarn will be easier to disassemble during the shoe upper/sole separation phase (providing that suitable equipment is used). However, priority should be given to footwear durability and assembly.
Single-material footwear	With the same product durability, limiting the types of different materials in footwear will increase the possibility of recovering better quality materials and to produce purer RRM.

[16] *European Commission. "New Proposals to Make Sustainable Products the Norm".*

Overall, **the most recyclable footwear today is footwear combining the following criteria:**

- **Single-material, one-piece sole;**
- **Single material shoe upper without any finishes or hard points.**

Any item meeting all of these criteria could theoretically be recycled once the shoe upper and sole have been separated, given that the materials have been correctly identified and that recycling processes exist.

To make footwear recycling easier, **it is recommended to:**

- **Ensure the traceability of the information of the components** (essentially material composition) **throughout the shoes' lifecycle;**
- **Introduce a minimum number of components that hinder recycling** (electrical or electronic components, coatings, paillettes);
- **Opt for single material products** (or with at least a shoe upper in a single material and a one-piece sole in a single material);
- **Opt for shoe upper/sole assembly that uses hot-melt adhesives or yarn** (providing that this does not affect the product's durability).

4.4. Detail of disruptors per footwear recycling preparation process

4.4.1. Shredding of entire footwear item

The following elements are mainly sourced from feedback gained from the Air SOEX project. Limited consolidated information from the industry's stakeholders is currently available because footwear recycling is still in the R&D or pilot phase. Therefore, the information below may change.

Table 13: Disruptors in the shredding of entire footwear item

DISRUPTORS	LEVEL OF DISRUPTION		EXPLANATIONS
	SHREDDING STAGE	SORTING OF SHREDS FOR RECYCLING	
EXTERNAL DISRUPTORS			
Metallic hard points (shanks, caps, eyelets; etc.)	++	+	Shredders may be damaged by large pieces of metal (caps or studs). Even after non-ferrous metals[17] have been removed, aluminium eyelets may still contaminate recycled matter.
Plastic hard points	ø	+	Even after having been shredded, these residual pieces of plastic are not entirely detected or removed by sorting and removal machines. The presence of plastic hard points may lead to lower quality RRM.
INTERNAL DISRUPTORS			
Electric and electronic components	++	+	To prevent risks of explosion or fire, electrical and electronic components in footwear cannot be shredded. They may contain toxic substances (in particular lithium batteries) preventing footwear from being recycled.
Material composition >2 Fillers and additives	Ø	++	A high number of materials in footwear as well as fillers and additives present in some certain soles make the sorting process more complicated.
Dyed with carbon black	Ø	++	As for the second sorting of textiles, near infra-red optical sensors used for material recognition may not detect the characteristic spectra of materials in the presence of carbon black.
All over finishes, coatings, prints, sequins, spangles and paillettes	Ø	++	Like textiles, these elements, most often present on the shoe upper, disrupt optical second sorting that characterises the material.

FACILITATORS	
Single material shoes, without hard points	Single material shoes allow the recovery of pure material quality after shredding, without the need for further sorting. The absence of hard points facilitates the shredding process and reduces the risk of contamination in the recycled material.

[17] *With an Eddy current separator that utilizes magnetic fields to generate currents in non-ferrous metals, enabling them to be separated from other materials.*

4.4.2. Separation of the shoe upper from the sole

Table 14: Disruptors in shoe upper and sole separation operations

DISRUPTORS	LEVEL OF DISRUPTION		EXPLANATIONS
	SEPARATION OF THE SHOE UPPER FROM THE SOLE	SOLE SORTING FOR RECYCLING	
EXTERNAL DISRUPTORS			
Metallic and plastic hard points	+	+	The presence of rigid elements between the shoe upper and sole such as shanks or anti-perforation strips may make separating the shoe upper and sole complicated. These elements may also disrupt second sorting operations.
INTERNAL DISRUPTORS			
Electrical and electronic components	++	+	To prevent risks of explosion or fire, electrical or electronic components integrated into footwear cannot be torn out or cut out. They may contain toxic substances in particular lithium batteries thereby preventing the footwear from being recycled.
Material composition >2 Fillers and additives	Ø	++	A high number of materials in footwear as well as fillers and additives present in certain soles make the sorting process more complicated.
Dyed with carbon black	Ø	++	As for textiles, near infra-red optical sensors used for material recognition may not detect the characteristic spectra of materials in the presence of carbon black.
Use of certain types of adhesives	+	Ø	The use of certain types of adhesives makes disassembly operations difficult (a higher heating temperature is required than that for hot-melt adhesives).

FACILITATORS	
Single material and one-piece shoe soles	Single material and one-piece shoe soles allow the recovery of pure material quality after shredding, without the need for further sorting.
Single material upper shoe, without finishes or hard points	Single material upper shoe, without finishes or hard points the recovery of pure material quality after shredding, without the need for further sorting
Hot-melt adhesives or yarns	Upper-sole assemblies using hot melt adhesives or yarns can be more easily dismantled with an appropriate oven. However, these adhesives or yarns must ensure the upper-sole bond remains intact during use to prioritize the durability of the shoes.

5. CONCLUSION

Overall, the identification of disruptors in recycling processes enables a better understanding about which elements are the most problematic and which elements make recycling easier.

It should be first reminded that non-reusable post-consumer textiles and footwear must be discarded in a drop-off point, and that they should be clean (at least not soiled) and dry so that they can be recycled.

The **main textile recycling disruptors** are:

- **Metallic-plastic yarns**
- **Electrical and electronic components**
- **Finishes, coatings, prints, sequins, spangles and paillettes that are present on the entire surface or on a significant part of the item**
- **Metallic and plastic hard points in significant numbers or covering a large part of an item's surface**
- Blends containing **more than 2 different fibres**
- **Elastane content exceeding 5% in the fabric composition**

The most easily recyclable textiles are:

- **Single-layer,**
- **Single-material,**
- **Monochrome (*for unravelling for yarn spinning*);**
- **Free from metallic-plastic yarns, spangles, thermoplastic prints or coatings covering the garment's entire surface** ("all-over").

To facilitate textile recycling, **it is recommended to:**

- **Ensure the traceability and communication of the articles' composition (primarily material composition) throughout their lifecycle**;
- **Minimize components that may cause disruption** (hard points, metallic-plastic yarns, spangles, elastane > 5%);
- **Opt for single-material items** (or bi-materials that can be recycled together);
- **As far as is possible, avoid purely aesthetic finishes** and prioritize functional aspects;
- **As far as is possible, avoid purely aesthetical external disruptors** and opt for function.

For footwear, **the main disruptors for all preprocessing for recycling stages** are:

- **Electrical and electronic components**
- **Metallic and plastic parts** on the shoe upper and sole

In addition, many of the disruptors identified for shoe uppers are common to those identified for clothing and household linen, including the presence of hard points and complex blends.

The most recyclable footwear today is footwear combining the following criteria:

- **Single-material AND one-piece sole;**
- **Single-material shoe upper without any finishes or hard points.**

To facilitate footwear recycling, **it is recommended to:**

- **Ensure traceability and communication of the information on the items' composition** (essentially material composition) **throughout their lifecycle**;
- **Introduce a minimum number recycling disruptors** (electrical or electronic components, hard points);
- **Opt for single material products** (or as a minimum a single-material shoe upper and a single-material one-piece sole);
- **Opt for shoe upper/sole assembly that uses hot-melt adhesives or yarn** (providing that this does not affect the product's durability).

It is important to remember that designing CHF products with a view to making them recyclable may sometimes compromise their durability. **Priority should be given to durability and to the possibility of repairing products with a view to extend their use.**

This updated review may be used as a basis by any stakeholders working on textiles and footwear eco-design with a view to improving their recyclability.

This review should be updated as R&D and industrialization progress in sorting and recycling processes.

6. APPENDICES

6.1. Acronyms

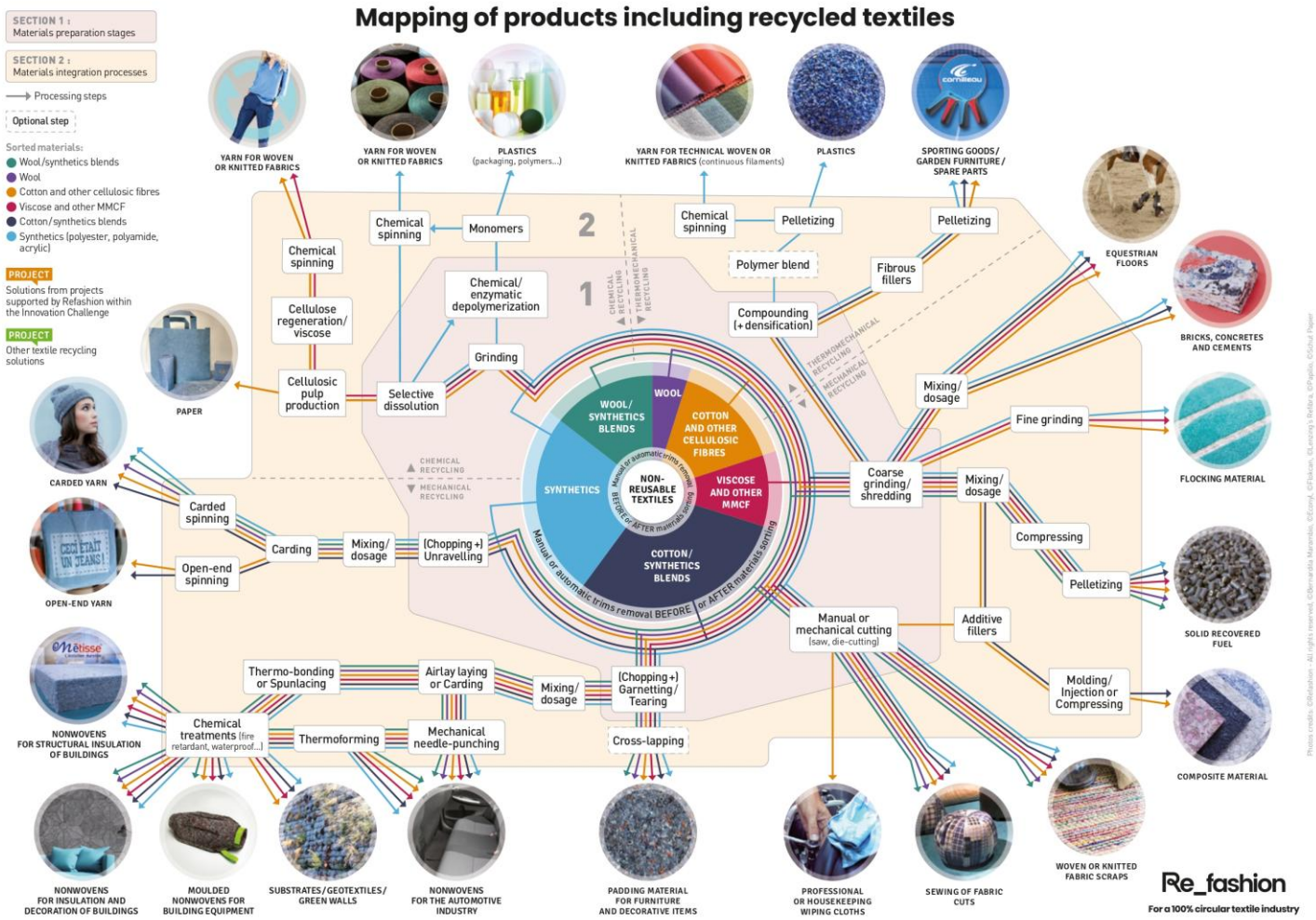
CHF	Clothing, Household linen and Footwear
CH	Clothing and Household textiles
EVA	Ethylene Vinyl Acetate
NIR	Near Infra-Red
PA	Polyamide
PET	Polyethylene terephthalate
PP	Polypropylene
PVC	Polyvinyl chloride
R&D	Research & Development
RFID	Radio Frequency Identification
RRM	Recycled Raw Material

6.2. Interviewed companies

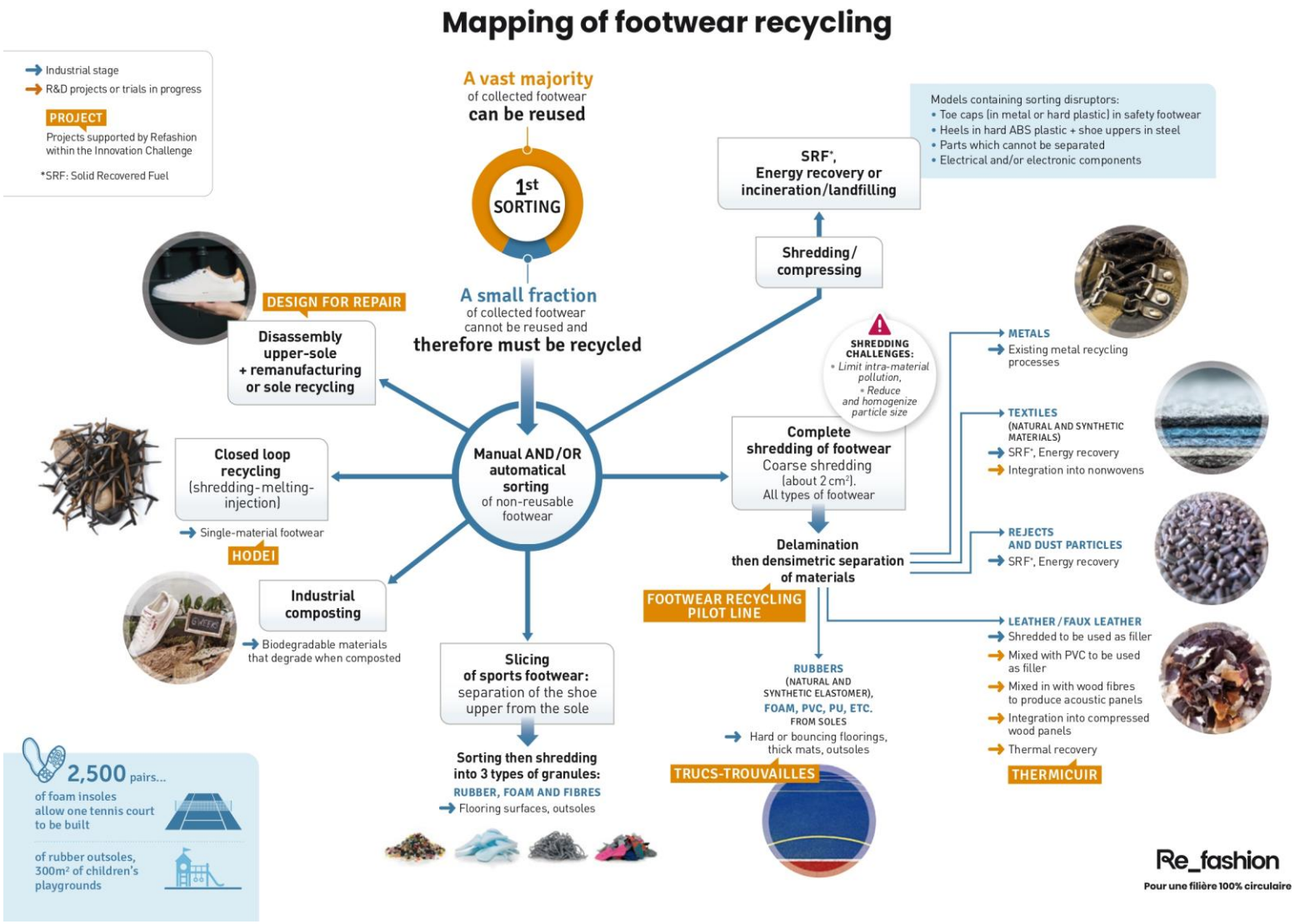
COMPANY NAME	COMPANY PROFILE
GEBETEX	Sorting operator
Le Relais	Sorting operator
Synergies TLC	Sorting operator
SOEX	Sorting operator
VERTEX	Sorting operator
CETIA	Textiles trim removal and footwear dismantling company
The 8 Impact	Footwear dismantling and recycling company
BUITEX	Garnetting/tearing operator and nonwovens producer
Minot Recyclage Textile / Le Relais Métisse	Garnetting/tearing operator and nonwovens producer
Frankenhuis	Garnetting/tearing operator and nonwovens producer
Les Filatures du Parc	Spinning operator
UTT Yams	Spinning operator
BIC	Wiping cloths manufacturer
MAPEA	Plastics processing company
Cycl-add	Plastics processing company
Renewcell	Chemical recycler (cellulosic fibres)
Södra	Chemical recycler (cellulosic fibres)
Eastman	Chemical recycler (synthetic fibres)
Worn Again Technologies	Chemical recycler (synthetic and cellulosic fibres)

6.3. Recycling mappings

6.3.1. Clothing and household linen



6.3.2. Footwear



6.4. Elements on the composition of non-reusable CHF

In 2022-2023, Refashion conducted a characterisation study on the incoming and outgoing streams from the sorting facilities. Below, there are the key findings related to the non-reusable textile composition.

Material composition

Overall, cotton is the dominant material in the non-reusable waste textile analysed (43% in weight, single material + blends). Polyester follows (19%), then acrylic (12%) and cellulose-based artificial fibres, wool and polyamide. Other fibres account for less than 1% of the amount analysed (elastane accounts for 0.7% of the weight, other materials 0.7%, silk 0.4% and acetate 0.2%).

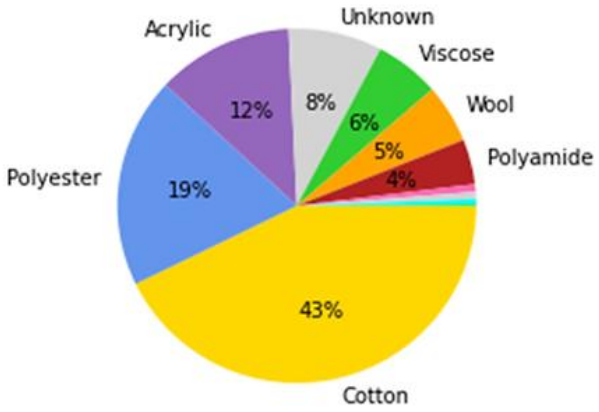


Figure 5: Global material composition of non-reusable textile streams analysed (in weight)

Single material textiles account for 55% of the textiles and blends for 45%. 100% cotton is the most commonly found composition at slightly less than 30% of textiles. 100% of polyester comes in second place (11%). The most found blends are:

- cotton/polyester (accounting for nearly 9% of the textiles feedstock analysed);
- cotton/elastane accounts (nearly 5% of the textiles;)
- the most common three-material blend is cotton/polyester/elastane.

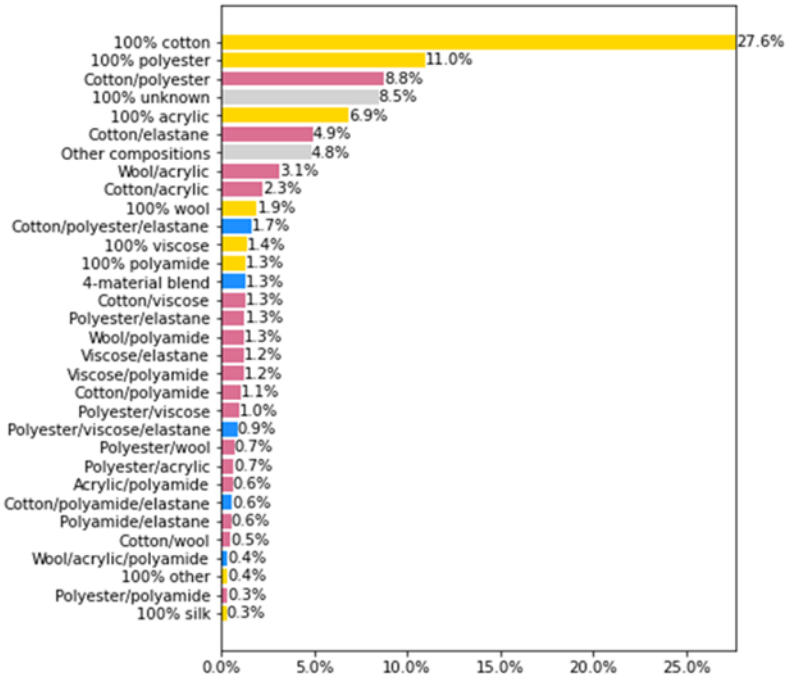


Figure 6: Main non-reusable waste textile compositions analysed (accounting for 95% of textiles, in weight)

*Colour code: **yellow** = pure material; **pink** = two-material blend; **blue** = three or more material blend*

Multilayers and external disruptors

To gain a better understanding of the recycling potential of non-reusable textiles, certain characteristics have been identified: single layer or multilayer, presence of external disruptors, colour.

- Multilayered items represent 8.5% of the textiles analysed (in weight). Among articles with a single layer, a large majority have at least one external recycling disruptor.
- The simplest items to recycle (single layer and without disruptors) account for less than a quarter of the items (22%).

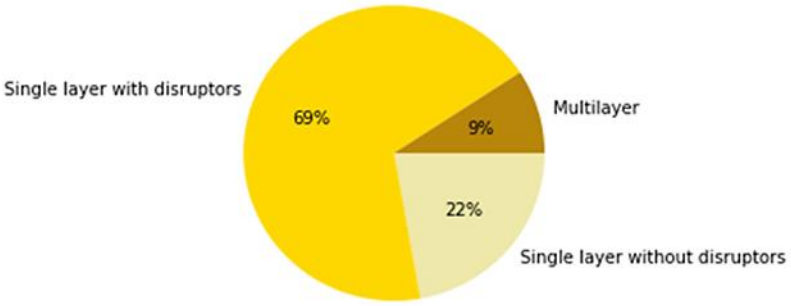


Figure 7: Breakdown of multilayer items or with at least one recycling disruptor in the streams analysed (in weight)

Product information sheets were created in this program in order to supply additional information on the different textile product categories, in particular the number of multilayers and the level of external disruptors in each category.

6.5. List of tables

6.6. List of Illustrations

6.7. Bibliography

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