

InnovateUK

# Automatic-Sorting for Circular Textiles Technology Market Review

January 2024



Innovate  
UK

## Executive Summary

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- The Automatic-Sorting for Circular Textiles project aims to catalyse the development of an Automated Textile Sorting and Pre-processing facility (ATSP) for Non-Reusable Textiles (NRT). Work packages 3 and 4, presented in this document, were focussed on conducting a market review of the commercially available technologies for Conveyance, Fibre Identification, Size Reduction and Disruptor Removal, in the context of the ATSP.
- This report shares the findings of interviews with key players in the textile industry, from university & academia to collectors and sorters to textile recyclers and reviews the technologies for the aforementioned areas. In addition, the challenges of each process are highlighted as potential limiting factors in the overall efficiency of the facility.
- The review has emphasised that the textile recycling market is a developing landscape and in general, there is not a one-size-fits-all solution for any of the technology areas. Automated Fibre Identification Technology is the most developed, with some technology providers expanding their municipal waste recycling technology into the textiles market, but all technology areas face challenges with throughput. A key insight from the interviews that affects both Size Reduction and Disruptor Removal technology surrounds the feedstock specification for recyclers, particularly chemical recyclers, and the lacking specification for physical swatch sizes due to technology still being in its infancy.
- In summary, there are many technologies available that *could* be utilised in an automated textile sorting and pre-processing facility, and the specification for the facility is critical in selecting the correct equipment, accompanied with an experienced plant designer to combine and configure the equipment in a layout that satisfies the specification.

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Abbreviation	Meaning
ACT	Automatic Sorting for Circularity of Textiles
AI	Artificial Intelligence
ANN	Artificial Neural Networks
ATSP	Automated Textile Sorting and Pre-processing facility
CNN	Convolutional Neural Networks
F2F	Fibre-to-fibre
ID	Identification
MIR	Mid-Infrared
MMCF	Manmade Cellulosic Fibres
ML	Machine Learning
MTC	Manufacturing Technology Centre
NIR	Near-Infrared
NRT	Non-reuseable Textiles
PA	Polyamide
PET	Polyethylene terephthalate
RGB	Red, Green, and Blue
RT	Reusable Textiles
TBC	To be confirmed
TRL	Technology Readiness Level
UV-Vis	Ultraviolet-Visible
VIS	Visible

## Project Aim

To catalyse the development of an Automated Textile Sorting and Pre-processing facility (ATSP) for Non-Reusable Textiles (NRT).

## Project Goals

- Create a world class, state-of-the-art blueprint for an ATSP.
- Build understanding of the next-generation sorting and recycling landscape.
- Incentivise regional material recycling versus export/dumping of NRT.
- Drive the transition from linear to circular textiles in the UK.
- Create new markets, jobs and foreign, direct investment opportunities whilst cementing the UK's position as a global leader in innovation and textiles circularity.

This InnovateUK consortium is formed of 18 companies.



## MTC Deliverables

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### 1. Partner and Supplier Interviews

Conduct one-to-one interviews with key sorters, collectors, recyclers and leading technology suppliers to identify, discuss and assess existing and in-development technologies, as well as broader information surrounding the textiles recycling markets.

### 2. Market review of available technologies in context of the ATSP

Report on the technologies available for Textile Fibre Identification, Conveyance, Size Reduction & Disruptor Removal. Highlight strengths and weaknesses of the technologies, and potential areas with further opportunities for development & trials.

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IMPORTANT: Information / recommendations in this document are based on information available at the current stage of the project. Some aspects are liable to change during the life of the project due to the iterative nature of the design process and external factors.

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# Background Information

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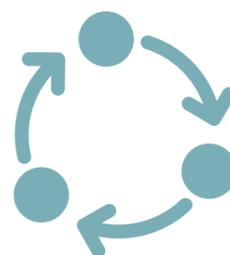
## Need & Challenge

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More than 15 kilograms of textile waste is generated per person in Europe, with discarded clothes and home textiles from consumers accounting for approximately 85% of the total waste<sup>[1]</sup>. In the UK, it's estimated that less than 1% of material used to produce clothing is recycled into new clothing<sup>[2]</sup>, with most textile waste sent to landfills and incineration.

While methods like mechanical textile recycling of pure fibres into new yarns or mechanical/open loop recycling into other applications (insulation, rags, mops etc) are already established, there is an opportunity to leverage new technologies in chemical recycling to enable fibre-to-fibre recycling – turning textile waste into new fibres of the same quality that can be used to create new textile products of the same value and performance.

To enable fibre-to-fibre recycling to be scaled, the technologies to collect, sort and pre-process textile waste into suitable feedstock need to be developed and made efficient. To aggregate and sort non-reusable textile (NRT) waste in the UK into feedstock for F2F recycling requires the development of a cost-effective, high volume, automated fibre sorting and pre-processing facility.



[1] McKinsey, *Scaling textile recycling in Europe- turning waste into value* (2022)

[2] Ellen MacArthur Foundation, *A new textiles economy: Redesigning fashion's future* (2017)

# Current Routes of Textile Recycling

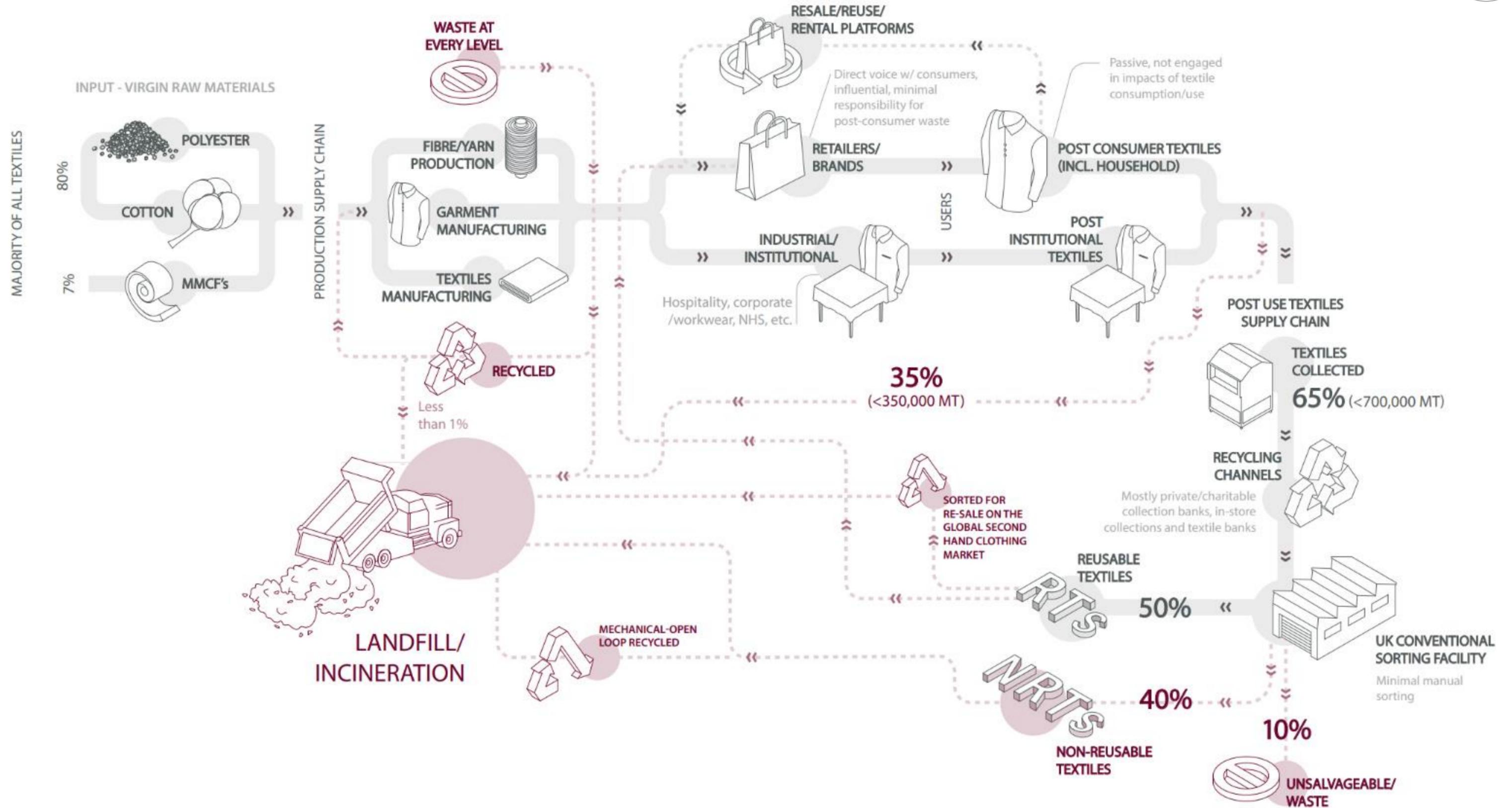


Image source: Circle-8 textile ecosystems

## The Aim of the Automated Sorting & Pre-Processing Facility

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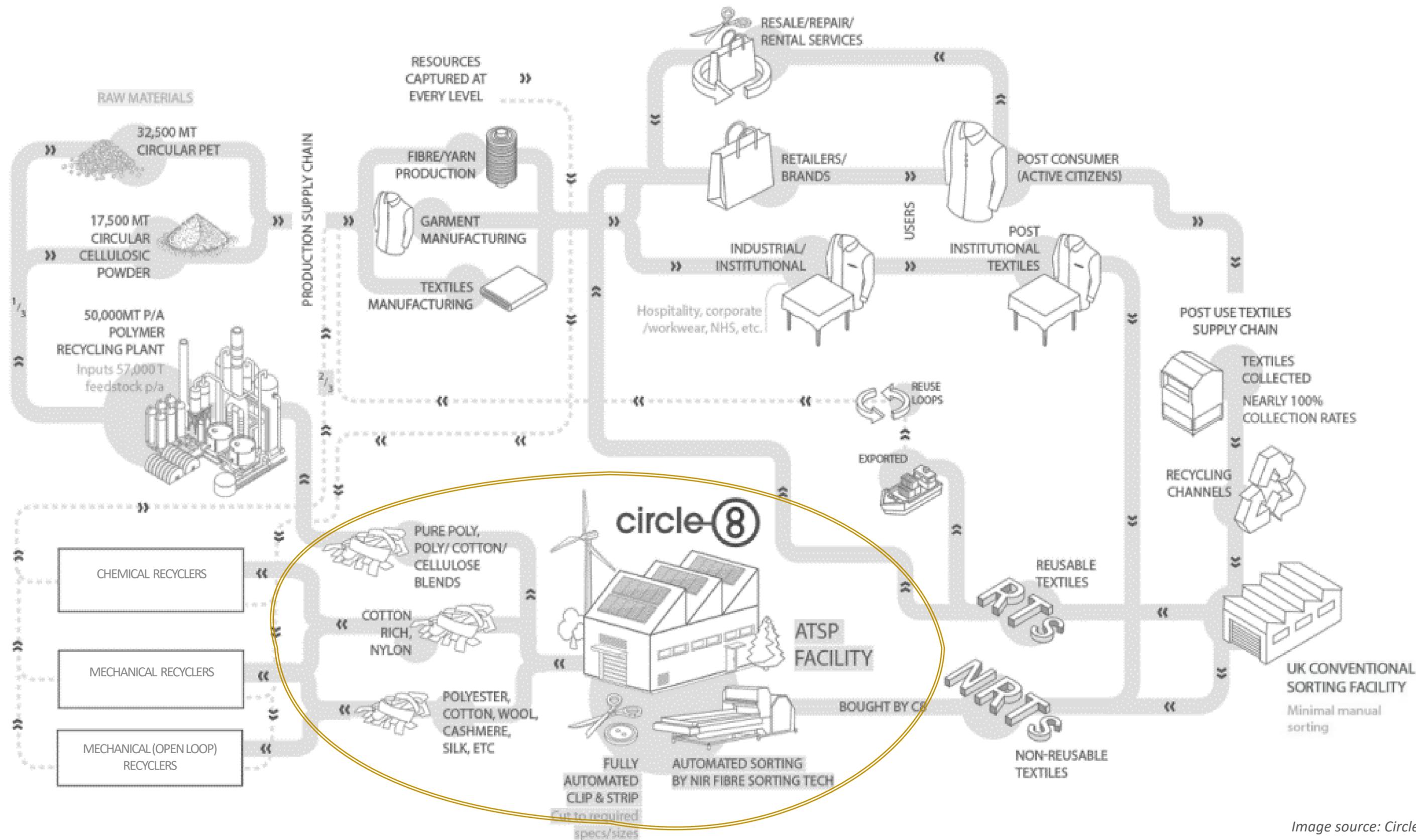
Of the over 1 million tonnes of used textiles generated every year in the UK, estimates suggest that a third of these are non-reusable textiles (NRT) which are currently being lost to landfill/incineration or are being exported in regions with lower labour costs. [3]

While there are some UK-based sorters and markets available for extending the life of NRTs (wiping rags, insulation, etc), closed loop fibre-to-fibre recycling in the UK requires a transition from exporting and manual sorting of NRTs to automated sorting in the UK.

The primary (mechanical) and emerging (chemical) recycling routes for NRTs require their feedstock to match certain specifications, such as fibre contents and physical size. Chemical recyclers in particular face difficulty in acquiring consistent and reliable feedstock for their recycling process at production volumes large enough to allow for financial sustainability.

The objective of the ATSP is to sort these NRTs into categories based on their fibre contents & colour (if required), and then process them to remove any disruptors, such as buttons and zips, before cutting the textiles to the specific size requirements of the recycler(s) and supplying the feedstock to close the loop of fibre-to-fibre recycling.

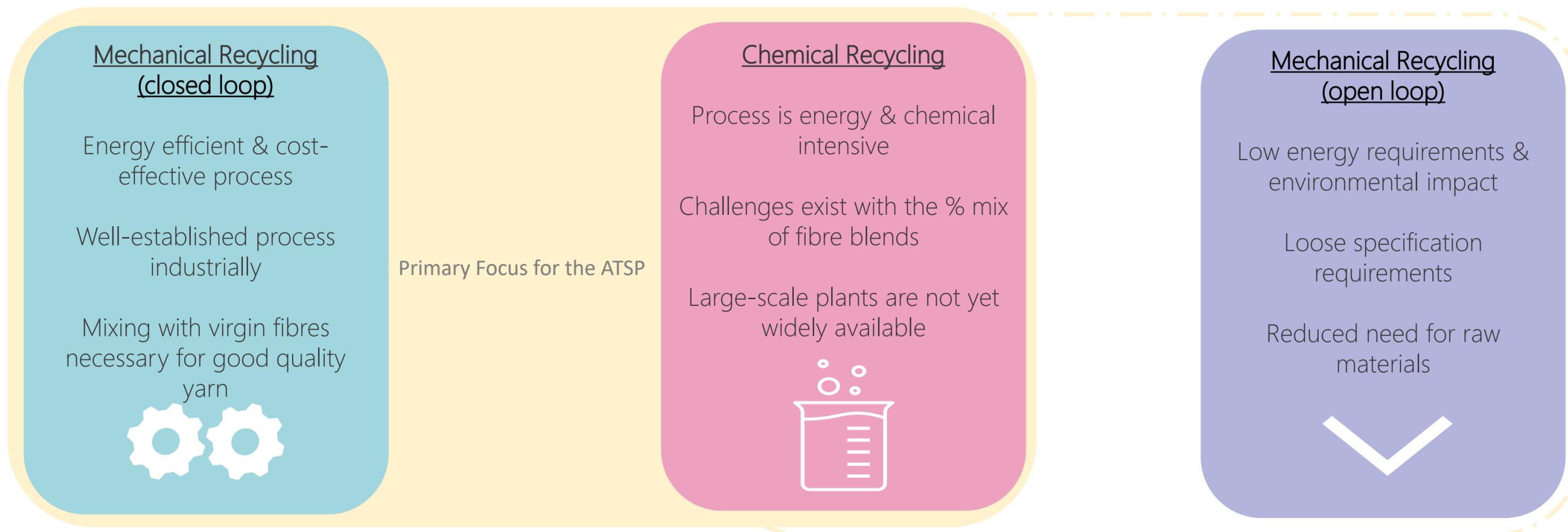
# The Aim of the ATSP



## “Customers” of the ATSP

The ATSPs will initially have three potential output routes for their feedstock. For fibre-to-fibre recycling there are two options, Mechanical (closed loop) Recycling and Chemical Recycling, both of which have different feedstock specifications for their processes but aim to maintain or increase the overall value of the raw material. The third potential customer is open loop mechanical recyclers, who break down textiles into material of a lower quality and functionality, which can be used in non-wovens, wiping rags, or insulation stuffing.

While the textile recycling market is developing, the ATSP needs to be adaptable to supply to any customer, though it is hoped and expected that the industry will see a shift to more chemical fibre-to-fibre recycling.



# Mechanical Recycling



Mechanical recycling is the process of recycling the textile fabric back into fibres without the use of any chemicals. This process includes shredding and carding to extract fibres from the fabric, and then spinning these extracted fibres into new yarns. Mechanical recycling requires long fibre lengths to maintain quality. For some fibres, such as cotton, this process can have a negative effect on the quality as the individual fibre lengths are shortened during the shredding process. This problem can be addressed by spinning the recycled fibres with virgin fibres to increase the strength and quality of the yarn. <sup>[4]</sup>

**Feedstock Requirements:**

- Textiles must be sorted based on Fibre Composition **and** Colour
- Hard Trims must be removed

Input Composition	Other Fibres	Output
100% Cotton	N/A	rCotton
> 95% Cotton	5% Other, inc. Elastane	rCotton
> 85% Cotton, 10% Cellulose Fibres	5% Other, inc. Elastane	rCotton
> 95% Wool	5% Other, No Elastane	rWool
> 95% Cashmere	5% Other, No Elastane	rCashmere
50% Wool 50% Acrylic	N/A	rWool/Acrylic Blend
> 80% Wool	< 20% Other, No Elastane	rWool Blend

[4] Saha, S. (2020b) Textile Recycling: The Mechanical Recycling of Textiles Wastes, Online Clothing Study.

## Chemical Recycling



Chemical recycling is any process that changes a polymer's chemical structure to produce substances that can be used as raw materials to manufacture new products. Sometimes called advanced recycling, chemical recycling is a generic term that includes several recycling processes (Gasification, Pyrolysis, Depolymerization).

Depending on recycling processes: energy consumption, yield and output can vary broadly; reaction outputs are syngas, oils, monomers, polymers, cellulose pulp. The recycling process produces substances that can be used as raw material to manufacture new material.<sup>[5]</sup>

Process	Input Composition	Other Fibres	Output
Thermomechanical	100% Polyester	N/A	rPET
	97% Nylon	3% Other	rNylon (rPA)
Solvent Dissolution	>95% Cotton	5% Other, inc. Elastane	rMMCF Pulp
	>85% Cotton, 10% MMCF	5% Other, Inc Elastane	rMMCF Pulp
	>60% Cotton, <40% Polyester	5% Other, Inc Elastane	rMMCF Pulp, rPET
	>60% Polyester, <40% Cotton	5% Other, Inc Elastane	rMMCF Pulp, rPET
Chemical Hydrolysis	<95% MMCF	5% Other, Inc Elastane	rMMCF
	>70% Polyester	<30% Other, Inc Elastane	
Enzymatic Recycling	Nylon, Polyester, Elastane		rNylon (rPA), rPET, rElastane

Source: ACT UK WP6

MMCF: Man-made cellulosic fibres (Viscose, Lyocell, Modall, Tencell, Bamboo Viscose, etc.)

### Feedstock Requirements:

- Textiles must be sorted based on Fibre Composition
- Hard Trims must be removed
- Contaminants in the process (paper, dirt, tape, etc.) must be removed\*

\*Contaminants can be dealt with in the chemical recycling process, but this comes at a commercial cost which can affect an already slim margin.

# Automated Sorting Facilities in Europe

A brief review of current automated sorting facilities across the EU revealed a growing number of projects across Europe tackling the textiles recycling challenge, and identified the main technology providers who are offering & developing solutions for automated textile recycling, such as Valvan, Tomra, PellencST and Picvisa. Further research is required into the classification of these facilities, and how much of their capacity is relating to RT/NRT to provide clear comparisons for the target volumes of ATSP facility in this project – focusing on NRTs only. In addition, this research identified R&D projects including Cetia, Soex, and the ReHubs Euratex initiative.\*

**Technology Provider:** Valvan

**Technology:** Fibersort

**Facilities:**  
The Salvation Army, UK  
(1000 T/Year – NRT)

Cetia, France  
(Capacity TBC)

Wieland Textiles, Netherlands  
(10,000 T/year – RT & NRT)

**Technology Provider:** TOMRA

**Technology:** Autosort

**Facilities:**  
Siptex, Sweden  
(24,000 T/Year – design target)

**Technology Provider:** PellencST

**Technology:** Mistral Connect

**Facilities:**  
Nouvelles Fibres Textiles,  
France  
(3,000 T/Year, increasing to  
25,000 T/year by 2025)

**Technology Provider:** Picvisa

**Technology:** Ecosort Textil

**Facilities:**  
Coleo, Spain  
(5,000 T/Year, targeting 25,000  
T/year by 2025 – RT & NRT)



\*Information Source: Refashion Technical monitoring of optical sorting, recognition and disassembly technologies for textiles at European scale, [2023]

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# Partner & Supplier Interviews

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## Partner/Supplier Interviews

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Interviews were conducted with other partners in the ACT consortium, as well as suppliers of relevant ATSP technology and other stakeholders in the industry (detailed in the next slide).

Interviews were semi-structured with pre-arranged questions relating to the four ATSP-technology areas (Fibre identification & sorting, Size reduction, Disruptor removal, & Conveyance).

A combination of open and closed questions were asked to ascertain interviewees knowledge on specific existing technologies and broader knowledge of in-development technologies and market considerations (see [Appendix 02](#)).

Questions were adapted and omitted accordingly dependent on the interviewees' particular area of expertise or stake in the supply chain (for example, questions posed to textile recyclers re: different ATSP steps were adapted to understand how the technologies used in each step affects their processes).





# Future State Circular Textile Supply Chain

Interviews by stakeholder area



## COLLECTORS & SORTERS



Take post-consumer and post-industrial textiles and sort into recycling grades



## TRADE ASSOCIATION/NGO

- Textile Recycling Association
- WRAP



## ACADEMIA

- University of Huddersfield
- University of Leeds
- Dr. Mike Lee



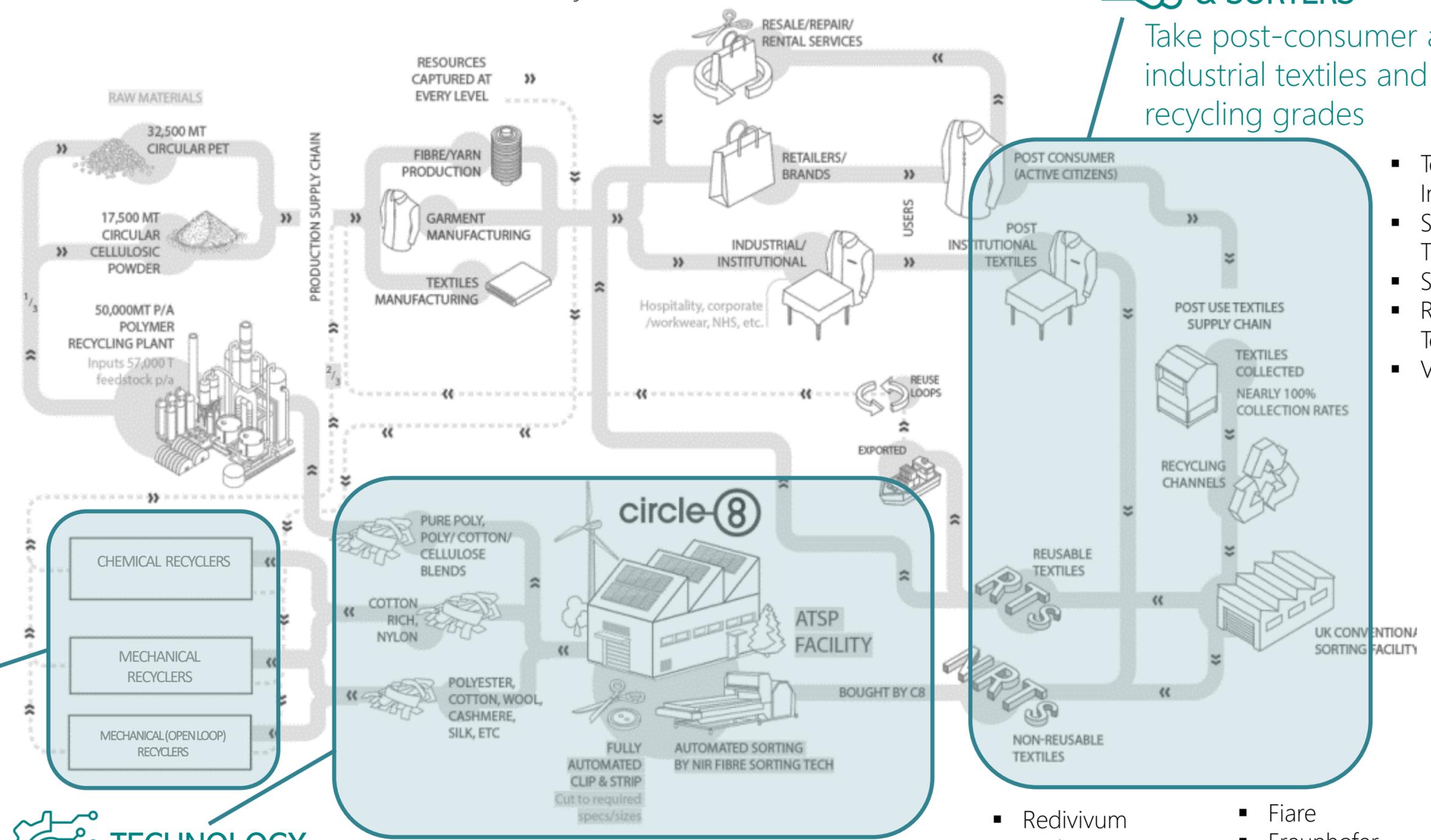
## TEXTILE RECYCLERS

- WornAgain (UK)
- Renewcell (Sweden)
- Södra (Sweden)
- BASF/ Loopamid (Germany)



## TECHNOLOGY PROVIDERS

Industry 'standard' and start-up technology and equipment providers for ATSP processes

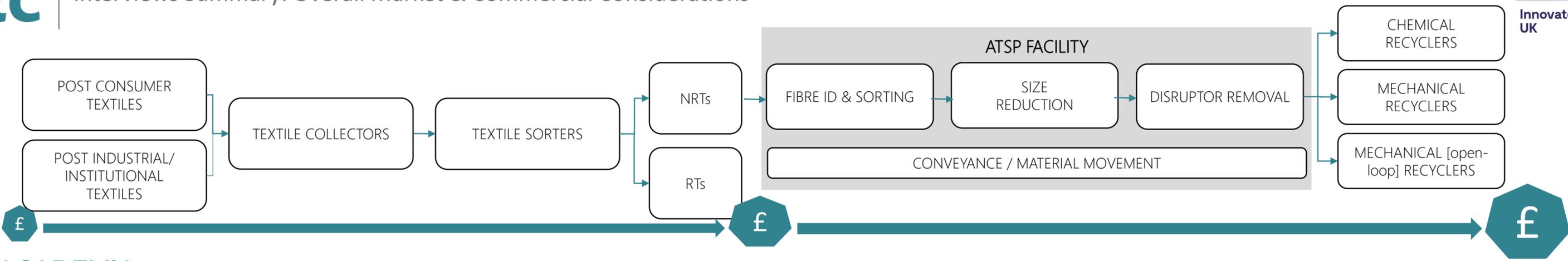


- Textile Recycling International
- Salvation Army Trading Co.
- Shred Station
- ReSkinned/ LMB Textiles
- Veolia

- Circle-8
- Valvan
- Tomra
- PellencST
- PicVisa
- SONY
- Optikan
- Matoha
- KAPDAA
- Resortecs

- Redivivum
- Basler
- Imec
- Specim
- CASSEL Inspection
- Eslando

- Fiare
- Fraunhofer
- Ken Mills Engineering
- Dell'Orco Villani
- National Physical Laboratory
- Border Technologies



## ACADEMIA

Research has proven that technologies exist to recycle all textile waste, but research is lacking around **understanding the industry to make economic sense out of recycling** re: speeds and yields needed, and costs of implementing new technologies. Academia has also identified a gap to quantify recycling feedstock streams in order to develop strategies for each.

## TRADE ASSOCIATION/ NGO

Similarly to academia, stressed that technology for sorting and segregating textiles is there, but biggest commercial challenge to the textile industry is having **markets for recycling grades**, to make the collecting and sorting of them lucrative.

## COLLECTORS & SORTERS

Used textile collector-sorter organisations have ambitions to see their NRT products be recycled as circularly as possible, but are **under extreme pressure to make profit**. They are incentivised to sell their waste textiles to the highest payer, often 'down-cycled' (e.g. wiper rags) markets with shorter life cycles.

Several shared their hesitation to make big capital investments into recycling pre-processing equipment if the ROIs are not proven and would like to see an ATSP be able to **de-risk the pre-processing technologies** for the industry.

## TECHNOLOGY PROVIDERS

The lack of commercially viable fibre sorting technology limits the options for recycling textile waste. Technology providers bemoaned the notion that it is simple and easy to mechanically-open loop recycle "any random textiles" – when in fact there are many barriers and expense to do so and little market value at present. Insulation and filling materials must be accurately sorted to meet safety standards, so it costs more to do than using virgin material.

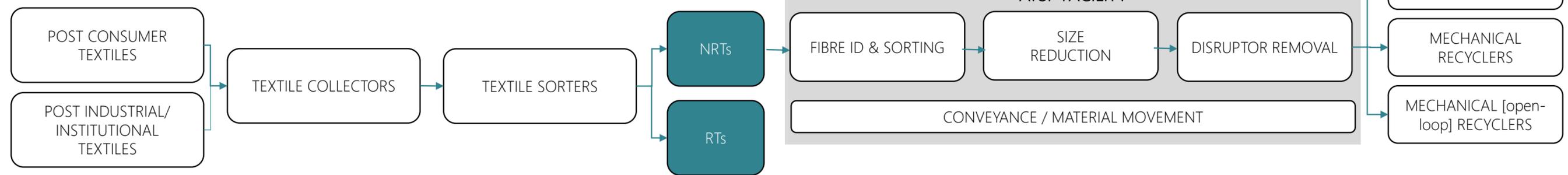
Shared that **customers with textile waste want to pay for 'their problem to go away'** – Estimate that customers would pay approximately 10% more to know their product is going to be recycled rather than incinerated – but are not prepared to pay 20%-plus more.

## TEXTILE RECYCLERS

The post-consumer textile waste supply chain today is not set up to supply to recycler's demands. Recyclers require a transition in the economics of NRTs to **enable the output of high volume, consistent, fibre-sorted, contaminant-free, low-cost feedstock**.



# Interviews Summary: Pre-sort NRTs from RTs



## ACADEMIA

Post-consumer NRTs pose the greatest challenges for recycling; the lack of information about the textile’s history, washing and chemical use will affect processes downstream. Academics are beginning to explore how **material structure and material history impact the fibre outcome that comes out of the recycling process.**

## TRADE ASSOCIATION/ NGO

All interviewees stressed the need to **automate sorting of NRTs from RTs to increase the amount of sorting that occurs within the UK.**

Most countries in the world allow for used textile products to be imported into their countries. However, UK legislation prohibits the export of textile waste to most non-OECD countries when this would otherwise be destined for viable recycling routes. It is therefore vital that NRTs are removed before shipments to these countries take place and this means that these need to be sorted here

## COLLECTORS & SORTERS

All collector/sorters spoken to share that they focus on sorting for re-use, their NRT recycling streams usually operate at a financial loss.

Several shared that more legislation needs to be implemented requiring mandatory recycled content in new products to incentivise wide-scale investment in recovering NRTs which are otherwise sent to waste/incineration streams.

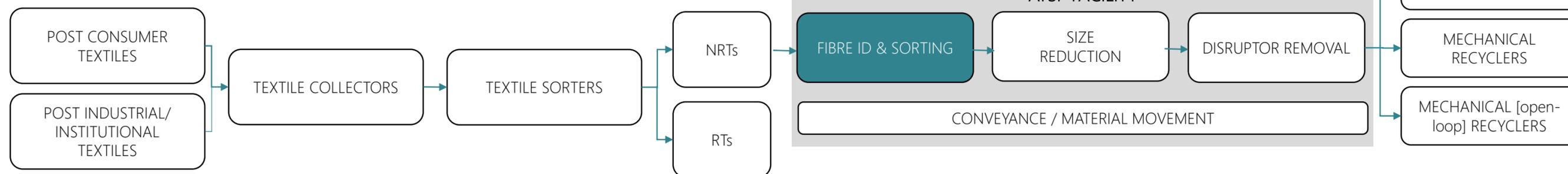
NRTs of similar fibre compositions would likely need to be aggregated from various sorters in the UK to meet recyclers’ feedstock MOQs ; this was also reiterated by trade associations/ NGOs

## TECHNOLOGY PROVIDERS

Early-stage start-ups are developing solutions to use AI and machine learning to identify and sort NRTs from RTs- but nothing is commercially available and there are **limitations with singulating and flattening garments to be scanned.**

## TEXTILE RECYCLERS

Most chemical recyclers have developed and demonstrated their processes with homogenous post-industrial waste, but anticipate that **to meet future demand, their feedstock will be supplied from up to 70% post-consumer NRT.**



## ACADEMIA

Highlighted gaps and areas of weakness in existing Fibre ID technology (*more details given in [State-of-the-Art Technology Market Review section](#)*).

Several academics interviewed stressed the obstacles of dyes and finishing in the recycling process, and that **technology to remove dyes would make it easier to achieve economies of scale** on mono-colour feedstock, but at a huge chemical footprint cost



## TRADE ASSOCIATION/ NGO

Highlighted the pros and cons of the main established suppliers in Fibre ID/sorting systems (*more details given in [State-of-the-Art Technology Market Review section](#)*), but expressed **interest in trialling Tomra technology at the front of end of the process and Valvan technology at the back end** – as the Tomra trummel system was effective at separating textiles and feeding them onto the conveyor.

It was discussed that the various Fibre ID systems' reported accuracies are difficult to compare against each other as they are based off of different proprietary data sets. It's understood that these suppliers have collaborations with textile mills/manufacturers to validate their readings to improve accuracy.



## COLLECTORS & SORTERS

The main established providers in the field started in general waste sorting and plastics recycling and have adapted their technologies for textiles, but there are numerous start-ups and other industries adapting technology for textile recycling uses.

The technology available has been optimised for detecting mostly polyester and cotton plus elastane blends as these are most applicable fibre types for end-of-life textiles and ensuring elastane % is within recyclers' tolerances. There is a **balance to be struck between the level of sophistication in a spectroscopy scanner, footprint of the devices needed, and costs.**



## TECHNOLOGY PROVIDERS

Highlighted the pros and cons of the main established suppliers in Fibre ID/sorting systems (*more details given in [State-of-the-Art Technology Market Review section](#)*). Several collector/sorters shared their initial impressions and preferences based on factors important to their facilities –

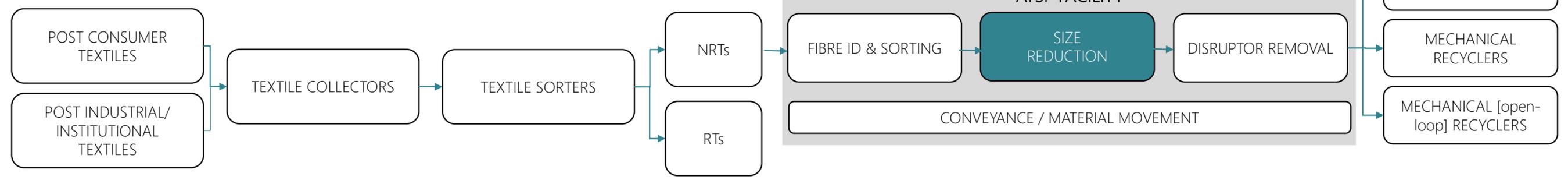
- **space constraints** – value systems that can navigate 90 degree turns
- **sorting accuracy** – capability to scan an entire garments vs a single isolated location
- **sorting breadth** – want a tech that can sort all NRT collected – not have large quantities in a 'other'/'general' bin.



## TEXTILE RECYCLERS

Recyclers **reported differing levels of accuracy which were suitable for their processes.** While some reported that the quality of feedstock from NIR automatic sorting systems was excellent with no failures reports, other recyclers stated that they still verify feedstock with lab tests as NIR-scanned info for bales was not accurate enough.

One recycler shared that they are investigating further into how different fabric structures (woven vs knitted) affects how much waste generated in their process.



## ACADEMIA

Highlighted challenges in size reduction in knitted vs woven textiles and also managing dust generated from the process.

Stressed that as **demand from recyclers for feedstock grows, recyclers will find ways to deal with size reduction themselves to be competitive.** This was reiterated by discussions with leading recyclers who have made the decision to invest in size reduction and disruptor removal themselves.

## TRADE ASSOCIATION/ NGO

Stressed the benefits of having size reduction/shredding carried out at a central ATSP – as too difficult and costly for individual collector/sorters to take on themselves.

Also highlighted that **size reduction techniques remain a limitation for mechanical recycling** – lack of size reduction capability that retains fibre integrity requires most mechanically recycled fibres to be spun into yarns with at least 80% virgin fibres to achieve same performance.

## COLLECTORS & SORTERS

Numerous collector/sorters have enquired into purchasing size reduction equipment, but **are daunted by the size of capital investment,** and are pleased that chemical recyclers are now more willing to do this pre-process themselves.

Similarly to the trade associations, highlighted the desire to see fibre-opening technologies that can retain fibre integrity for mechanical recycling so materials can be closed-loop/not down-cycled.

## TECHNOLOGY PROVIDERS

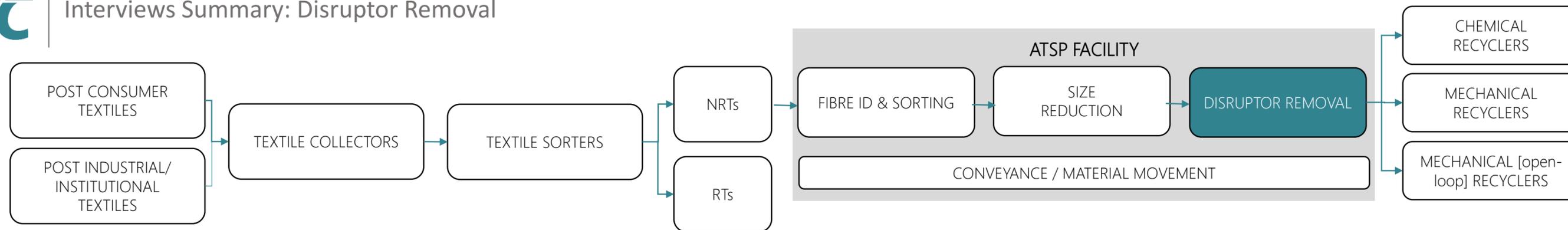
Expressed some frustration with the variation in recyclers’ size requirements and trial and error process in trying meet their precise needs – **need higher demand volumes to be able to set up machinery to make efficient** and economical.

Several stated that **service contracts with providers are the most important aspect** re: size reduction equipment – maintaining blades, and re-welding knives are critical when handling many variations of post-consumer textiles.

## TEXTILE RECYCLERS

The recyclers interviewed all shared differing requirements – **some willing to do all size reduction themselves while others want feedstock partially size-reduced.** Those willing to the size reduction themselves shared that they invested in this step to open themselves up to more feedstock sources.

Dust generation and safety implications is a concern when dealing with small swatch sizes and requires separating the size reduction operations from the chemical plant operations.



## ACADEMIA

Whilst dyes are not considered ‘trims’/disruptors, academics stressed that dyes are disrupting to the recycling process. While research is ongoing for removing and recycling dyes, no commercial equipment exists.

With trim removal, it was highlighted that **work has been done for many years to get a garment flat with robots/automation but has not been achieved yet.**



## TRADE ASSOCIATION/ NGO

Stressed that vastly different methods of disruptor removal would be needed for different recycling outputs and could require different ATSP facilities with different pre-processing steps.

Also highlighted that **yield loss from disruptor removal should be considered** for a future ATSP and business model, as well as an energy consumption comparison between different removal methods.



## COLLECTORS & SORTERS

Several emphasized that **disruptor removal is the top challenge to address in a future ATSP**- any done to date is done manually at a small scale – not enough to be commercially efficient.

One shared their opinion on Valvan’s TrimClean system – as ‘impressive, but slow’ – and far too expensive to put all NRT through.

Collector/sorters shared that it is commercially ideal to work with recyclers who do the disruptor removal themselves – but if not possible, would like to see trials on disruptor removal to improve efficiency and remove waste.



## TECHNOLOGY PROVIDERS

Air separation techniques, over-band magnets, and binary sorting systems on pre-size reduced swatches are all available for automated disruptor removal with varying degrees of speed and accuracy (more details given in [State-of-the-Art Technology Market Review section](#)).

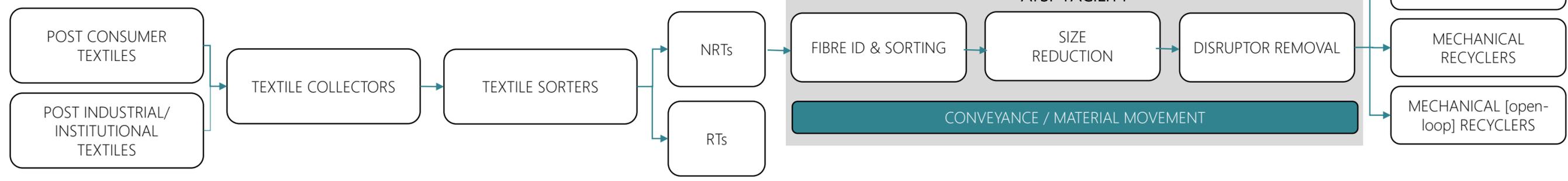
**Start-up companies are developing AI-assisted laser disruptor removal** and technology to disassemble garments with dissolving thread to reduce waste, but these are not yet commercially available.



## TEXTILE RECYCLERS

All chemical recyclers will require a massive increase in textile aggregation (volumes) and efficiencies in sorting and processing to *bring the cost of feedstock down*, which will likely involve centralised processing facilities (ATSPs) rather than individual recycling plants having to invest in their own pre-processing steps.

They shared that they are **interested in emerging disruptor removal technologies, particularly if this could be done in a central location more efficiently than themselves.**



## ACADEMIA

While conveyance is not a particular research area for the academics interviewed, it was shared that **pneumatic processes and chute feeds should be considered as they are useful for soft textiles** rather than conveyor belts for overhead handling.

## TRADE ASSOCIATION/ NGO

Shared that they have heard from industry that **automatic and robotic feeding systems do not have the speed needed.**

## COLLECTORS & SORTERS

Highlighted the pros and cons of existing conveyance options and robotic arm feeding systems (more details given in [State-of-the-Art Technology Market Review section](#)). Several collector/sorters shared their initial impressions and preferences based on factors important to their facilities –

- **space constraints** – value systems that can navigate 90 degree turns
- **speed**- including ability to reduce labour headcount
- **overlap** – singulation on conveyor reiterated by most collectors as a large challenge
- **snagging/wrapping** – particularly where requires constant human monitoring

## TECHNOLOGY PROVIDERS

Several shared that conveyance technology is the limiting factor in the size of garments which can be inputted.

Also reiterated that the speed of feeding the sorting system and **singulation of textiles is the biggest limiting factor/bottleneck in the entire process.**

Leading suppliers in textile processing equipment estimate that segregating to single items can be done at 1 garment/second but is very difficult to achieve.

## TEXTILE RECYCLERS

Recyclers emphasized that their **processes require as minimal manual handling as possible.**

Some recyclers do not even de-bale their inputs so require that any bale coverings and strappings also meet their fibre specifications/weight tolerances.

# Interviews: Key Themes

Overall Market & Commercial Considerations

An ATSP is desired to de-risk sorting and pre-processing technologies for all stakeholders in the textile recycling supply chain. By helping to alleviate the 'chicken and egg' conundrum, this should also support the goal to make economic sense out of circular textile collection, sorting, pre-processing and fibre-to-fibre recycling by making new markets for NRT more lucrative.

Pre-sort NRTs from RTs

Automating sorting of NRTs from RTs is an ongoing challenge in the industry with limited early-stage technologies available. This step shares the same challenges as sorting NRTs, particularly around singulation and flattening of garments.

Fibre ID & Sorting

Automated Fibre-ID systems on the market have proven useful for sorting good quality feedstock for established recyclers but there are up-and-coming technology competitors aiming to provide feasible solutions at a lower cost.

Size Reduction

Size reduction equipment should be invested in as part of working hand-in-hand with a recycling partner's requirements – the method of size reduction is dependent on the output needed for recycling process.\*

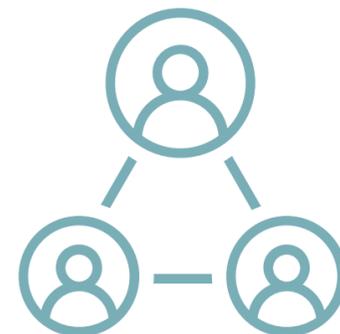
Disruptor Removal

Improving efficiency and minimising waste is the main consideration for a future ATSP. Just as with size reduction, the method of disruptor removal is dependent on the output needed for recycling process.\*

\*Advancing methods of size reduction and disruptor removal has the potential to unlock more opportunities for mechanical recycling by maintaining fibre integrity.

Conveyance/Material Movement

Conveyance and the speed of feeding any sorting system is the biggest limiting factor for the throughput of the entire process.



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# State of the Art Market Review

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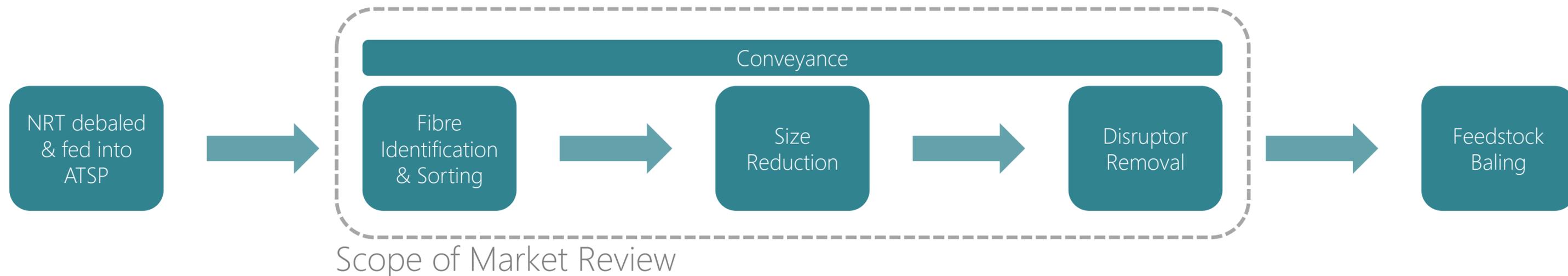
## State of the Art Market Review

This section of the report conducts a market review that researches the available - commercially ready - technologies for Textile Fibre Identification, Conveyance, Size Reduction & Disruptor Removal and assesses their suitability for the ATSP. It highlights strengths, weaknesses, and challenges that have been identified through the interview process and technology reviews.

Each process step has specific technology requirements, extracted from high-level documentation provided by work pack lead Circle-8.

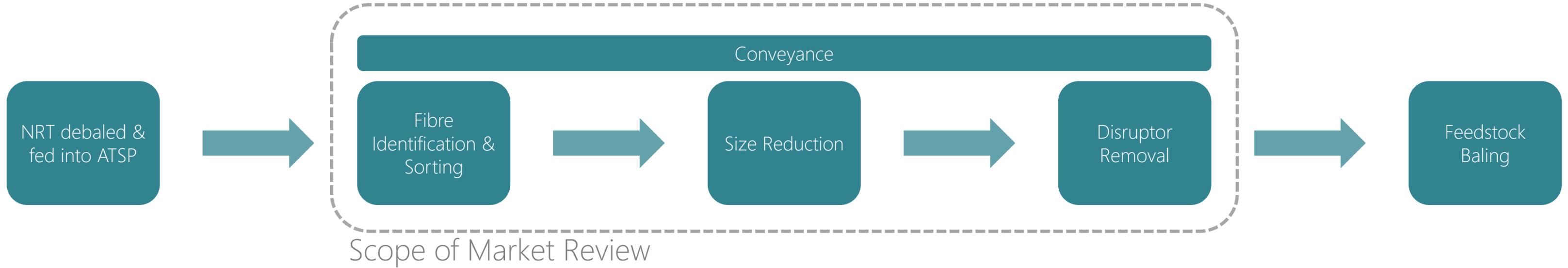
Key technology providers were interviewed to discuss their technologies and developments, and this information has been collated and reviewed against the technology requirements for the ATSP.

*In a future report, emerging and in-development technologies will be explored further.*



IMPORTANT: This simplified process flow is used for convenience of explanation in this report. The process steps may not necessarily be in sequential order in relation to a full-scale ATSP.

# High-Level ATSP Requirements & Scope of Market Review



The main driver behind the ATSP facility is to provide high volumes of feedstock for textiles recyclers. This throughput requirement will be the base criteria for all technology areas.

*Note: Technology requirements for the market review have been extracted from documentation provided by lead partner Circle-8.*

## ATSP Throughput Requirements

*Initial Target Volume: 25,000 Metric Tonnes per Annum*

*Future Target Volume: 50,000 Metric Tonnes per Annum*

*No. of Shifts: 3*

*Annual Hours per Shift: 1,800\**

*Initial Implied Factory Vol. Output: 4.6 Metric Tonnes per Hour*

*Future Implied Factory Vol. Output: 9.2 Metric Tonnes per Hour*

*\*based on 225 working days, and 7.5 "productive" hours per shift.*

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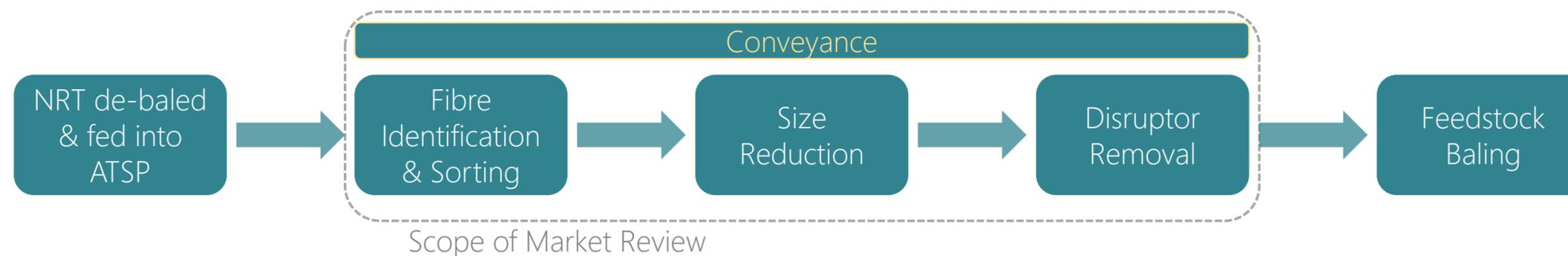
# Conveyance

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## Conveyance

Conveyance connects all processes across the ATSP facility. There are several considerations surrounding conveyance to ensure reliability and efficiency for following processes. Conveyance dictates the throughput of the facility and provides the conditions for the Technologies (Fibre Identification, Disruptor Removal and Size reduction) to operate.

Technology Requirement	
Metric Tonnes per Hour	4.6
Garments Per Second (Initial Target)*	Approx. 4
Challenges	Singulation (Bulk to Individual Garments)
	Garment Handling - Presentation to scanners
	Garment Handling – Sorting into Aggregate Bins



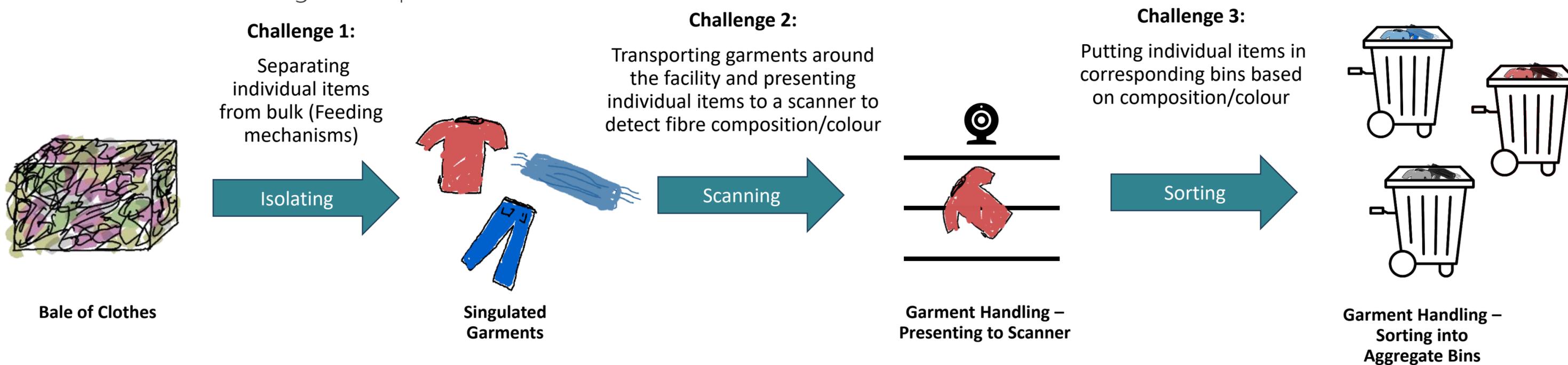
\*Based on an average garment weight: 300 grams

# Background

A fully automated ATSP facility would require the transfer of textiles between different modules to effectively process a large volume of textiles. The whole process can be broken down into 3 distinct conveyance challenges:

1. Feeding & Isolating – *Out of original scope*
2. Conveyance & Scanning
3. Handling & Sorting – *Out of original scope*

Although this market review focussed on assessing suitable conveyance options, it is important to consider all challenges of conveyance when reviewing equipment for the ATSP. As such, a small insight into feeding and handling options has been provided for consideration despite being outside of the original scope of work.



## Structure of Review

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There are high-TRL solutions available for solving the challenges outlined in the previous slide, including multiple types of conveyors, bespoke automation solutions, as well as robotic arms; all of which are discussed in the following slides. These include:

- An introduction to main types of **conveyor systems**.
- An introduction to main types of **feeding systems**.
- An introduction to main **gripper types** suitable for textile manipulation.

The interviews held by the MTC highlighted in slides 17 – 25 gave key insights from industry stakeholders and revealed notable drawbacks in current technology. A summary of the outputs from the literature search and interviews are shared in the slides.

Investigating low-TRL options for these challenges could be helpful to support some of these challenges. Equally, learning from material handling strategies in industries outside of textiles might be advantageous. These will be investigated in further detail in a later edition of this report.

# Horizontal Conveyors

Simple horizontal conveyors are the industry standard and have been proven as a reliable method for textile transportation. They often have lower initial cost and are more accessible for maintenance. This is an efficient transportation method, with a simple loading mechanism and natural versatility, capable of handling all types of garments.

The most relevant conveyor sub-types include Belt and Slat conveyors. Other horizontal conveyor types include roller and chain conveyors however these are not a good fit for textile movement.

Advantages	Disadvantages
Industry standard. Easy to load and unload objects	Low visual surface area of garments & risk of overlapping
Easily adaptable to changes in production layout. Modifications can be made without major disruptions to the existing floor plan	Textiles can potentially wrap around the conveyors and cause disruptions
Versatile and capable of handling a wide range of materials/garment lengths	Positioned at floor level, making them easily accessible. But takes up significant floor space
Generally easier to access and maintain. Repairs and routine maintenance tasks can be performed at ground level	Does not provide any garment control and relies on a separate feeding mechanism
Generally lower initial cost compared to overhead conveyors	
Easier to integrate with existing workflows	



**Belt Conveyor**  
Source: JRMHoldings.co.uk [2023]



**Slat Conveyor**  
Source: SpaceGuard.co.uk [2023]



**Roller Conveyor**  
Source: AlbionConveyors.co.uk [2023]



**Chain Conveyor**  
Source: HRD-Automatic.com [2023]

## Overhead Conveyors

Overhead conveyors cost more but provide some additional benefits such as freeing up valuable ground space, more precise positioning of individual parts and allowing more versatile layouts in 3 dimensions.

Overhead conveyors are better suited to processes that require the products to be hung (paint line, garment line, cooling/curing etc) but efficacy is yet to be demonstrated for loading inconsistent form factors e.g. Towels, Bedsheets, from bulk volumes to single items due operational complexity.



**Trolley Transport Systems**  
Source: PSB-GMBH.com [2023]



**SPIRA – Hanging Conveyor with Curve**  
Source: Vetter-foerdertechnik.com [2023]

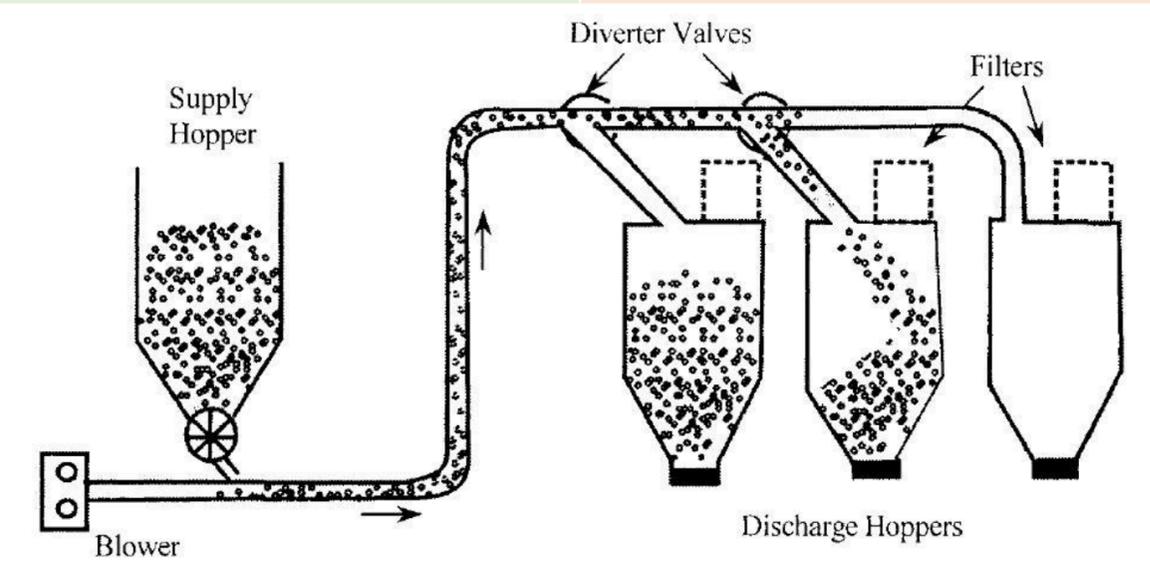
Advantages	Disadvantages
Mounted above the working area, optimizing floor space and reducing overall footprint	May require more careful integration due to the need for a stable and properly designed overhead support system.
Increased visual surface area of the garment for following processes – potentially enabling more efficiencies	May require specialized equipment or access platforms for maintenance.
Individually hung garments	More complex installation process due to the need for overhead support structures.
Less risk of Mechanical disruption/tangles.	Higher initial cost due to the need for an overhead support structure.
	Requires additional safety measures to prevent falling objects.
	Hanging and loading items onto them can be complex.
	Untested technology for inconsistent form factors e.g. Towels, Bedsheets

# Pneumatic Conveyors

Pneumatic conveyors use air pressure or vacuum to transport materials through pipelines. Pneumatic conveying systems are widely used in the chemical, pharmaceutical and food industries, aiming to transport particulate materials between storage locations using either positive pressure, negative pressure, or a combination. [6]

Pneumatic conveyors typically work with particulates, so some consideration to the form factor of the garments should be considered when assessing pneumatics. For textiles, large garments may not be handled efficiently by a pneumatic conveyor. This would likely mean that size reduction would have to occur to allow this method to be used. The ATSPs current process flow would limit pneumatic conveyors to being used at the end of the process, after the size reduction step.

Advantages	Disadvantages
Flexible routing, allowing for an optimised floor layout	High energy consumption, contributing to higher operational costs
Dust-free operation, promoting a cleaner working environment which may be a consideration when working with fibres	Distance limitations, impacting the layout of the facility
High throughput	Noise Generation
Gentle material handling, maintain the integrity of the material during transport	High upfront cost
No risk of entanglement	Limit on size of garments



**A Typical positive pressure Pneumatic Conveyance system**

Source: Handbook of Pneumatic Conveying, David Mills [2023]

[6] Levy, A. (2001) 'The influence of a bend on the flow characteristics in pneumatic conveying systems', in *Handbook of Powder Technology*. Elsevier Science B.V., pp. 403–409.

## Market Review Summary

### Technology limitation

The input mechanism of feeding the textiles onto conveyors needs to allow for high levels of control of the garments dispensing position, to maximise the efficiency of later processes - this has been noted as the **largest bottleneck for fibre identification as garments need to be singulated**, and selecting a conveyance method that affords more control over the input method of the garments could see large increases in throughput efficiency of the facility.

### Floor Conveyors

- Industry standard, and offers a **versatile, cost-effective and simple** solution for transporting textiles.
- An expandable option when looking at increasing the throughput of the ATSP facility from 25,000 to 50,000 metric tonnes.
- Has a **large footprint so may face difficulty if the layout of the facility becomes complex**, with potential for interference or congestion in busy layouts.
- Have known issues surrounding maintenance, such as chain stretch, as well as **the potential for entanglement with textiles which was evident on some of the site visits** conducted in this project.

### Overhead Conveyors

- Offer an **efficient use of space**, and potentially smaller overall footprint of the facility.
- As garments would be attached via fixed runners, it is more suited to complex layouts and cornering, as well as providing more visible surface area of the garments for later processes such as identifying and removing disruptors.
- **Limited flexibility for layout changes once installed** and has a higher initial investment when compared to floor conveyors.
- **No automated solutions for loading garments** from bulk bales onto an overhead conveyor.

### Pneumatic Conveyors

- Typically operate with particulates/small sized material.
- May not be suitable for whole garment transport but **could offer a solution that optimises the use of space via intricate routing of piping, after the textiles have gone through size reduction**
- The piping could allow for increased utilisation of floor space, reducing the overall footprint of the ATSP.

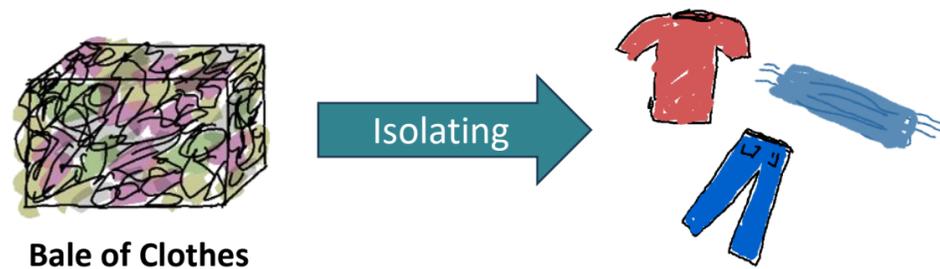
### Future Opportunities

Available floor space, flexibility requirements, expansion capability, garment presentation and budget constraints are the top considerations for an ATSP. A **combination of conveyance methods in different areas will provide the most efficient use of resources**, but other complementary technologies such as **robotic grippers and material unloading** should be explored further.

# Feeding & Isolating

Multiple high TRL systems exist that are capable of unbaling, isolating, and feeding textiles onto a (conventional) conveyor. The two most used methods are described here i.e. Robotic feeding systems and Roller based feeding systems.

Some industry and partner interviews pointed to the limitations of successfully implementing robot arms as a feeding system. Issues surrounding speed, accuracy and tangles were concerning and the technology is still under-development. Similarly, roller-based feeding systems come with their own set of challenges so there are distinct advantages and disadvantages for each. Depending on the operational requirements, site design, complexity of operation and compatibility with technology being used down the chain, either one can potentially be a good fit for the ATSP.



	Robotic Feeding System	Roller Feeding System
Advantages	Ability to handle individual items with high precision.	Cost effective to implement
	Smaller footprint	Easy setup and operation
Disadvantages	Expensive and requires advanced programming and robotics expertise..	Reduced control over individual items
	Slower processing speed compared to a rotating drum due to individual item picking.	Items are randomly engaged and hence are not individually isolated.
	Speed is slow enough to be a limiting factor.	Tangling of multiple pieces
		Larger footprint

Rough Cost: €200,000

Rough Cost: TBC



**THOR | Robot Separator**  
Source: Inwatec.dk [2023]



**Spiked Roller**  
Source: Stadler-Engineering.com [2023]

## Handling & Sorting

There are different gripper types used for grasping and manipulating workpieces. The most common gripper types are:

- Vacuum Grippers
- Mechanical Grippers
- Soft Grippers

A comparative analysis of various gripper types, including Needle Grippers (designed specifically for textiles), is presented in the table, outlining their strengths and weaknesses in textile handling.

Many additional gripper designs exist in the market to address distinct needs, and there is potential to develop a hybrid gripper for textile sorting in the ATSP facility.



**Flat garment handling Soft Grippers**

Source: YouTube.com/rochusoftrobotic [2023]



**Bernoulli's gripper on paper mask**

Source: YouTube.com/b-tacchannel7325 [2023]

Getting a Grasp of Grippers [7]				
	Vacuum Grippers	Mechanical Grippers	Soft Grippers	Needle Grippers
<b>Manipulation Method</b>	Suction force from vacuum creates a secure grip.	Mechanical clamping provides a strong, stable hold.	Flexible surfaces conform to the shape of the object.	Needles penetrate and secure textiles.
<b>Surface Compatibility</b>	Excellent on flat surfaces; may struggle with folded or textured fabrics.	Versatile on a wide range of textured surfaces.	Adaptable to irregular shapes and various fabric textures.	Suitable for most fabrics.
<b>Precision</b>	High precision on flat surfaces, less on irregular shapes.	Good precision for defined shapes; may struggle with irregularities.	Moderate precision; may not be as accurate as others.	Moderate precision, influenced by needle design and placement.
<b>Complexity of Setup</b>	Relatively simple setup with minimal adjustments.	May require precise adjustments for different shapes.	Simple setup but may need tuning for specific applications.	May require fine-tuning for different fabric types.
<b>Maintenance</b>	Minimal maintenance with periodic checks on vacuum systems.	Regular maintenance required for mechanical components.	Minimal maintenance; resilient to wear and tear.	Regular maintenance required, especially for needles.

[7] The Manufacturing Technology Centre (2023) *Getting a Grasp of Grippers*. UK.

## Challenges of Conveyance

Conveyance methods in the recycling industry are typically reliant on tried and tested conveyor belts to handle large volumes of material in a consistent and reliable manner. For textiles recycling, belt conveyors (and alternate technologies) pose some challenges for how the materials are presented for the following processes.

Common challenges that are faced across all conveyance technologies are:

- Controlled feeding onto the conveyor (or other conveyance technology)
- Bulk textile to singulated material
- Overlapping of textiles
- Material “hangup”
- “Double Picks” (when picking from bins)
- Transport to and from storage and Large Storage Areas



**Bulk Clothing on conveyor**  
Source: marenengineering.com [2023]



**Robot handling textiles**  
Source: kuka.COM [2023]



**Pneumatic Garment Sorting**  
Source: Sorting for Circularity Europe, Fashion for good [2023]

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# Fibre Identification & Sorting

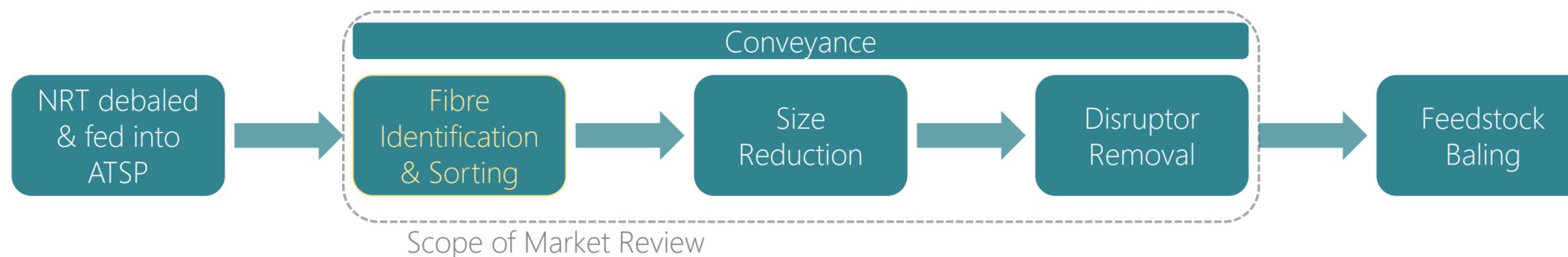
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# Fibre Identification & Sorting

NRTs are collected in mixed collection bins which include Reusable Textiles (RTs). ATSPs will require textiles to arrive at facilities with RTs already sorted out and/or will require a simple, manual or AI sort at the beginning of the sorting process to remove the RTs.

To allow the ATSP to produce consistent and high-quality feedstock the mixed textiles need to be categorised into aggregate bins based on their fibre composition and if required, their colour.

Technology Requirement	
Detectable Fabrics <i>(In any blend combination)</i>	Cotton Polyester Wool Viscose Nylon Acrylic
Accuracy	>95%
Colour Detection	Yes
No. of Sorting Bins	12+
Metric Tonnes per Hour	4.6
Garments Per Second (Initial Target)*	Approx. 4



\*Based on an average garment weight: 300 grams

## Background Information

The market review has shown that Fibre identification solutions utilise a few key technologies to accurately categorise and sort the textiles based on their material composition. Near-Infrared Spectroscopy, RGB Cameras, Ultraviolet-Visual Spectroscopy and Machine Learning will be briefly explained over the next few slides to provide context for the technology review.

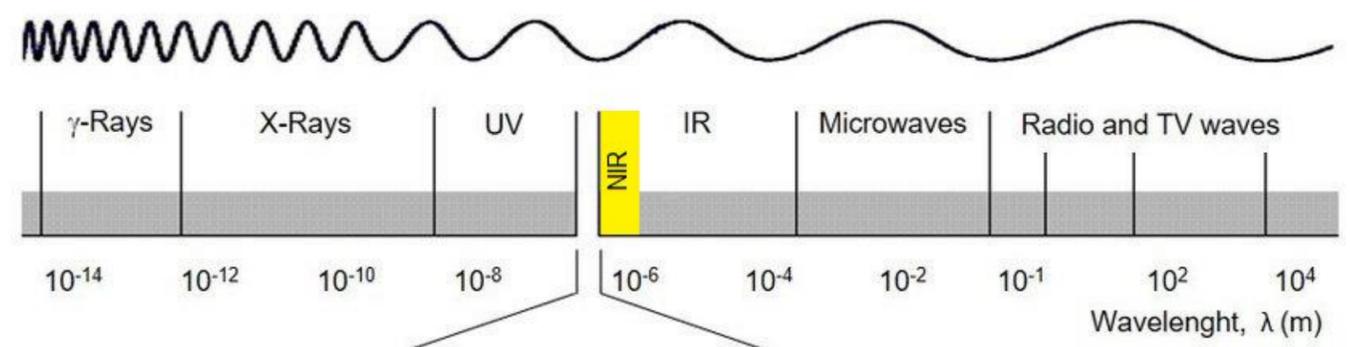
## Near-Infrared Spectroscopy (NIR)

Near-infrared spectroscopy is a type of spectroscopy operating between 780nm and 2500nm, the 'near-infrared' region of the electromagnetic spectrum. In general, spectroscopy can be characterised by its spectral and spatial resolutions.

For fibre identification, the NIR Camera takes an image of the material and produces a Spectrograph of the composition of the material, which can then be compared to a validated database to identify the material(s).

In the case of multi-spectroscopy each pixel covers several wavelengths and hyper-spectroscopy aims to provide a continuous spectrum for each pixel. Most of the ready solutions presented herein utilise a linear scanner which can produce the 2D image when the objects are moving on the conveyor. NIR is also commonly used in the food, chemical, agrochemical and petrochemical industries. [8]

Technique	Use case
NIR spectroscopy	Identify fibre type (often supported by ML techniques)



**Electromagnetic Spectrum, NIR Indicated in Yellow**  
 Source: Casimiro, M.H., Ionizing radiation for preparation and functionalization... [2023]



**NIR Camera**  
 Source: qd-Europe.com [2023]

[8] Scientific, T. *The use of near-infrared spectroscopy for raw material identification ...*, [2023]

## RGB Camera

A camera that captures the light across three wavelengths in the visible spectrum, corresponding to the colours: Red, Green and Blue (RGB). This allows to capture information such as colour of the material and its shape. Potentially image processing techniques can be used to identify objects in the image frame (including machine learning classification, object detection and segmentation techniques). This allows for classification based on colour as well as giving the potential for further object classification.

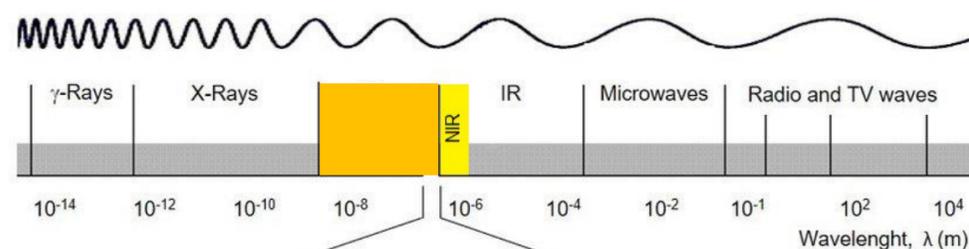
Technique	Use case
RGB camera	Identify colour (and potentially shape and position of materials)



**RGB Camera**  
Source: jai.com [2023]

## Ultraviolet-Visible Spectroscopy (UV-Vis)

UV-Vis is imaging that uses multiple bands across the electromagnetic visual spectrum, typically 190nm to 900nm. While RGB camera covers three wavelengths (Red, Green, Blue), VIS spectroscopy encompasses a wider variety of spectral bounds beyond RGB. This allows for further classification based on colour.



**Electromagnetic Spectrum, UV-VIS Indicated in Orange**

Source: Casimiro, M.H., Ionizing radiation for preparation and functionalization... [2023]

Technique	Use case
VIS spectroscopy	More comprehensive information than RGB camera - Identify colour, shape and position



**UV-VIS Camera**  
Source: maxmax.com [2023]

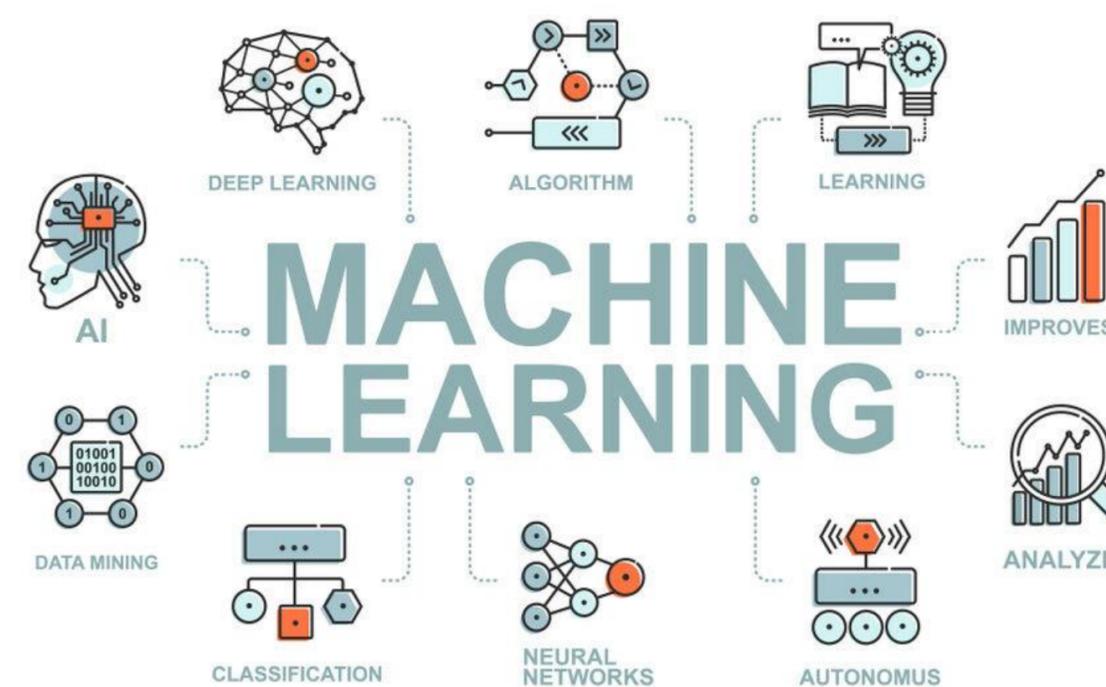
## Machine Learning

Machine Learning (ML) is a field of computer science that “gives computers the ability to learn without being explicitly programmed”.[9] It is often considered a subset of Artificial Intelligence (AI). Compared to conventional programming, where the rules to solve the problem are provided by the programmer, in ML the user/programmer provides examples (data) and the rules are supposed to be found/formed by the algorithm.

A common sub-field of ML are Artificial Neural Networks (ANN) where the learning process is inspired by the functionality of the brain neurons. Types of ANN include Convolutional Neural Networks (CNN) which are utilised to process image data. Convolution operation in the hidden layers allows the network to interpret the data as 2D or 3D structure – the model takes into account the spatial arrangement of the inputs (not just their values). Different types of CNNs are used for image classification, object detection and segmentation.

All Fibre Identification solutions utilise Machine Learning to compare the images taken by the system to a database of known fibre compositions.

Technique	Use case
Machine Learning	Fibre classification based on the spectral input, object detection, localisation, and type classification



**Machine Learning Graphic**

Source: fsm.ac.in [2023]

[9] Samuel, Arthur L. "Machine learning." The Technology Review 62, no. 1 (1959): 42-45.

### Tomra: AUTOSORT® NIR VIS

Facility: SIPTex – 4 AUTOSORT Machines

The AUTOSORT uses near-infrared and visual spectroscopy (NIR / VIS). Textiles are sorted by fibre composition and colour. A Single AUTOSORT can process **4.5 tonnes per hour**. The incoming material is delivered in bales, typically weighting 350 to 500 kg, and requires debaling and feeding onto the AUTOSORT machine. <sup>[10]</sup>

Tomra technology originates from sorting other waste materials such as, packaging waste, plastics etc. There are several add-ons available for the AUTOSORT, but they typically do not have applications for fibre identification. Technologies and add-ons AUTOSORT offer:

- DEEP LAISER sensors (add-on) – to improve performance, laser 3D object detection (detection of black polymers, glass, overlapping objects)
- Electromagnetic (EM) sensors (add-on) – to detect metal fractions
- GAIN, AI-based camera sensor – classification previously inseparable objects

For textile sorting in SIPTex only **NIR and VIS are used**.



**Tomra Autosort**  
Source: Tomra.com [2023]

Sensor Deck	Purpose
Near-Infrared spectroscopy – hyperspectral linear scanner	Identify fibre
Visual Spectroscopy – hyperspectral imaging	Identify colour
Machine Learning – no more details provided	Classification based on the spectral input

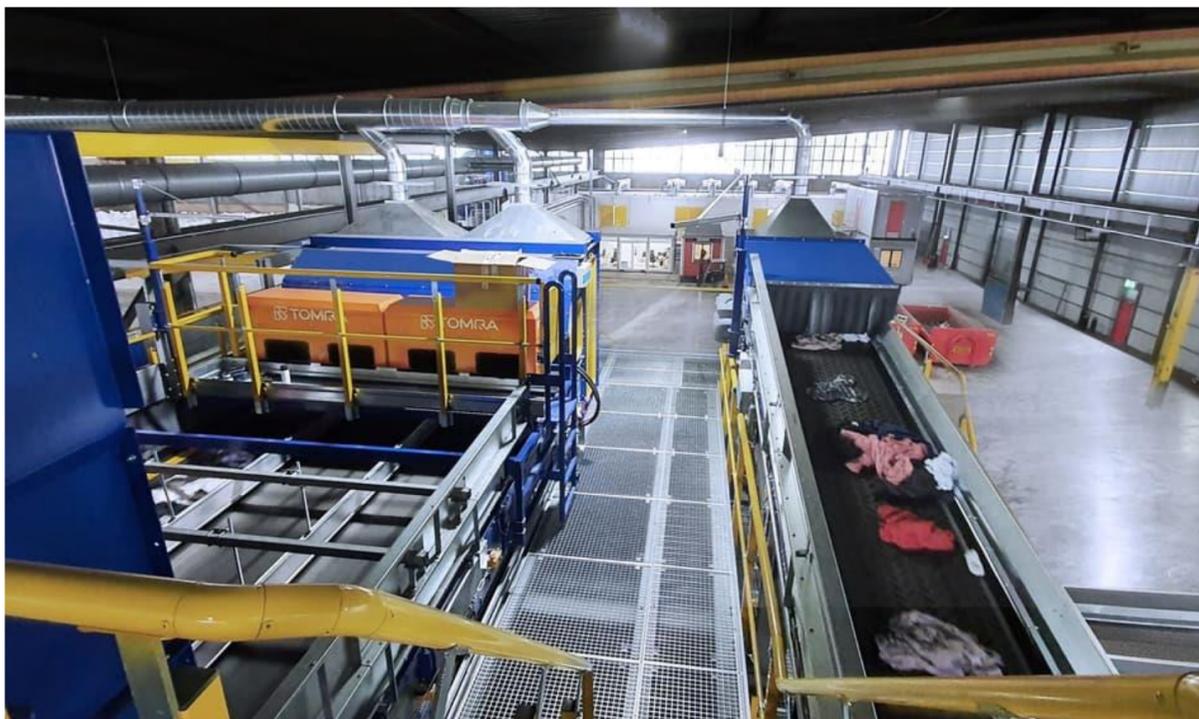
Accuracy/Purity	Categories Sorted Per Machine	Conveyer Speed	Throughput	Cost
95%* or above	2 (up to 3)**	SIPTex: 3.2 m/s Standard: 3 m/s	4.5 tonnes/hour (per Autosort machine)	£130k – £304k (150k – 350k euros)

\* Accuracy of the whole process, including scanning, detection and sorting, corresponds of the purity of final samples  
 \*\* One category - unsorted

[10] <https://www.tomra.com/waste-metal-recycling/products/machines/autosort>

Tomra: AUTOSORT® NIR VIS

Facility: SIPTex



**Tomra equipment in SIPTex**  
Source: Tomra.com [2023]

Advantages	Disadvantages
Sorting solution proven in other waste industries	Could be limited to the manufacturer's technology – difficult to add external modules or request nonstandard changes
Autosort used in another high throughput textile facility - SIPTex	NIR spectroscopy might not work correctly for fibre blends of 3 or more
Tomra claims they can detect elastane blends (even 1% elastane in cotton)	Carbon black dye affects the scanning results
Highest throughput of the main solution providers	Multiple machines needed to categorise different textile fibres (1-2 blends per machine)
Hyperspectral Line scanner gathers large datasets per garment	Materials cannot overlap for scanning

### Initial Recommendations & Remarks

This solution is well established in the waste market from a reputable company who are now branching into the textiles market.

The TOMRA Sensor deck and capabilities are advanced and shows good potential for further throughput increases if an appropriate feeding/singulation method could be developed.

Some technological details were not provided during enquiries due to IP related concerns, around the classification methods and accuracies

The Autosort machine is modular with a number of add-ons being available - although they have limited applicability to textiles at the moment.

Due to the limited number of categorisation bins per machine, and the high number of categorisation bins required in the ATSP facility, the overall cost for a Autosort solution could be higher than expected.

TOMRA are setting up a dedicated textiles machinery department which could see textiles-specific developments occurring in the next 12 months

### Valvan: Fibersort™

**Facilities:** The Salvation Army, Cetia, Wieland Textiles

The Technology is based on a combination of near-infrared (NIR) spectroscopy and RGB camera. Textiles can be sorted by fibre type and colour. Nominally 6 fibres have been distinguished: wool, cotton, polyester, viscose, acrylic and nylon – this can be extended as long as there is sufficient data for new fibres to teach the system. A single Fibersort line is designed to process 1 textile per second. There is also a semi-automated offering with the average capacity (where feeding is manual) is ± 1.200 kg/h. [11]

The length of the sorting conveyor and the number of blower positions depend on the number of different fibre/colour compositions the customer wishes to distinguish. The sorting conveyor has a minimum of 6 categories and extra categories can be added optionally (max. 50 categories). Different layouts are available upon request.

The algorithm returns a precise estimation of the fibre concentration in a textile. Mature and well-trained systems can achieve accuracies as high as 95%, provided that there is enough clean data in the library.

*The Fibersort is sold as a complete solution, including deballing, robotic pick and singulation and the fibersort system.*



**Render of a Fibersort line**  
Source: Valvan.com [2023]

Sensor Deck	Purpose
Near-Infrared spectroscopy – hyperspectral linear scanner	Identify fibre
RGB Camera	Identify colour
Machine Learning – Convolutional Neural Network	Classification based on the spectral input

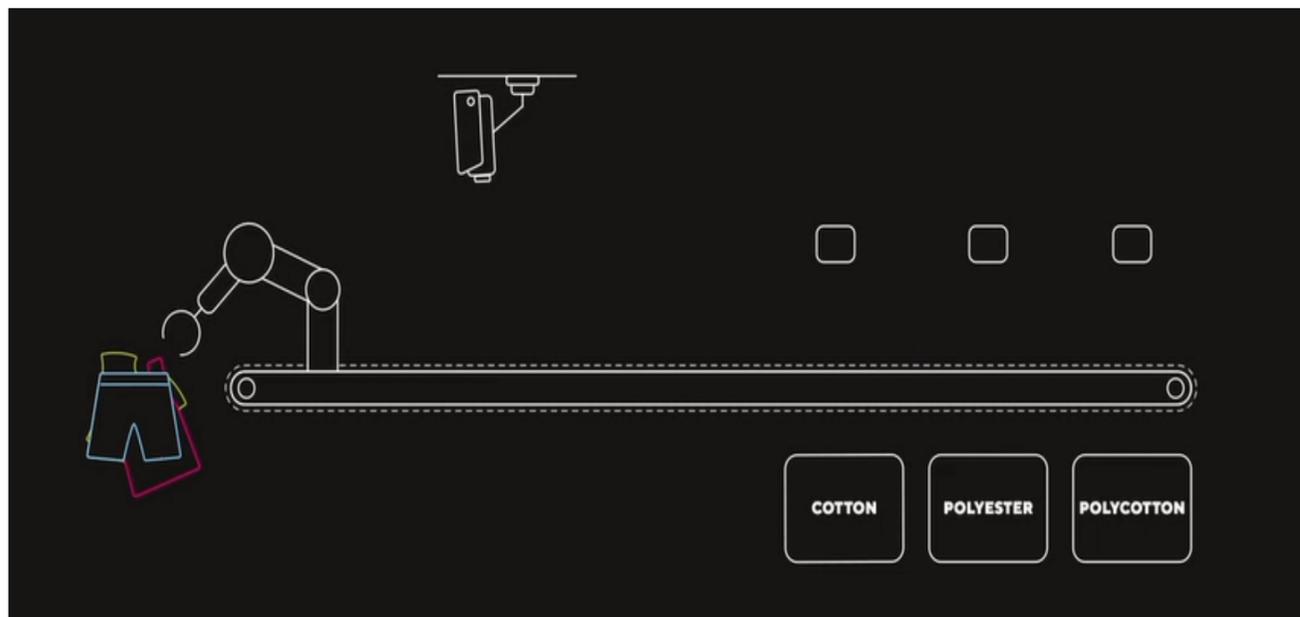
Accuracy/Purity	Categories Sorted Per Machine	Conveyer Speed	Throughput	Cost
Single fibre blend: up to 99%* 2 Fibre blend: up to 95%*	Up to 50 (for dual conveyer)	0.7 m/s	1.2 tonnes/hour ** (per machine)	£1 Million per Complete Line

\* Accuracy of the whole process, including scanning, detection and sorting, corresponds of the purity of final samples  
\*\* The limiting element in speed is the feeding system (if two prototype feeding robots used, each can provide 600 kg/h)

[11] <https://www.fibersort.com/>

Valvan: Fibersort™

Facilities: The Salvation Army, Cetia, Wieland Textiles



[Animation showing pneumatic sorting](#)

Source: Valvan.com [2023]

Advantages	Disadvantages
Flexible solution, with manufacturer support in the design process	NIR might not work correctly for fibre blends of 3 or more
Customizable number of fibre/colour categories	Each fabric needs to be singulated before scanning
Many fabric blend types sorted/detected using one scanner (up to 50 types)	Carbon black dye affects the scanning results
Additional system for wet material detection	Relatively low throughput for the machine
Valvan solely dedicated to textiles development	Elastane blends in cotton are difficult to be detected

### Initial Recommendations & Remarks

- This solution can detect up to 50 defined blends, aligning with the high number of categories that are required for the ATSP
- Fibersort solution was designed directly for textile sorting, and Valvan seems very flexible with making changes and adapting the system to customers requirements
- Two step classification process provides information about the percentage of each fibre type in the blend
- Valvan were relatively open with information about their technology and are flexible to adapt their solution
- The throughput of the Fibersort is below the requirement of the ATSP and would require multiple lines to meet requirements
- The company have developed a robotic feeding system that singulates garments for a fully automated solution
- Valvan developed another system – TrimClean, that cuts the fabric in to smaller pieces and removes disruptors

## Pellenc ST: Mistral Connect

**Facility:** Nouvelles Fibres Textiles

Nouvelles Fibres Textiles Pilot line is the first to implement PellencST's automated sorting technologies to process high volumes of post-consumer textile waste and turn it into industrial grade feedstock.

The Mistral Connect utilises a unique spectrometer for complete coverage of the NIR/VIS spectra.<sup>[12][13]</sup> The Machine also offers a multi-stream spectrometer that utilises focused light to increase the accuracy of the signal, and this option increases the number of output categories as it allows for two conveyor streams.

The same machine is used in Spain for Insertega, capable of 4 tonnes/hour with purity levels of more than 98% (for natural fibres and petroleum).<sup>[14]</sup>

Note: The Feeding system is the bottleneck of the system, with an estimated throughput capability of 6 – 7 Tonnes per Hour, if the feeding mechanism could provide this.

Main features of Mistral Connect:

- Multi-stream spectrometer
- Focused light for accurate signal
- Complete coverage of NIR VIS spectra
- 2D object stabilisation



**Mistral Connect**

Source: PellencST.com [2023]

Sensor Deck	Purpose
Near-Infrared spectroscopy – hyperspectral linear scanner	Identify fibre
Visual Spectroscopy – hyperspectral imaging	Identify colour
RGB Camera ( <i>Future Addition</i> )	Improve sorting efficiency by providing higher resolution
Machine Learning	Classification based on the spectral input

Accuracy/Purity	Categories Sorted Per Machine	Conveyer Speed	Throughput	Cost
Single fibre blend: 97%* - cotton, above 90% polyester; 2 Fibre blend: above 75%	2 (up to 3)** Or 4** categories when multi-stream	3 m/s	3-4 tonnes/hour (per machine)	TBC

\* Accuracy of the whole process, including scanning, detection and sorting, corresponds of the purity of final samples

\*\* One category – unsorted

[12] <https://www.nouvellesfibrestextiles.com/>

[13] <https://www.pellencst.com/andritz-nouvelle-fibres-textile-new-partnership/>

[14] <https://www.pellencst.com/textile-recycling>

Pellenc ST: Mistral Connect  
Facility: Nouvelles Fibres Textiles



**Mistral Connect**  
Source: PellencST.com [2023]

Advantages	Disadvantages
The solution can handle 15 types of blends, and depending on the market demand their solution can be expanded to include more blends	NIR spectroscopy might not work correctly for fibre blends of 3 or more
New development utilises Mid-Infrared (MIR) to combat the challenge of Carbon Black Dye	Multiple machines needed to detect higher number of textile fibres (only a few blends per machine)
Relatively high throughput of the machine	Materials cannot overlap for scanning
Multi-channel conveyer stream available – allowing one machine to detected more fibre blends categories	

Initial Recommendations & Remarks
This technology is tried and tested across multiple waste streams, and proven in textiles through the Nouvelles facility.
Limited number of aggregating bins would require multiple lines to meet the ATSPs requirements, but the Multi-stream option provides additional output bins compared to traditional ballistic separators
Additional option of a multi-stream spectrometer and prototype technology for black carbon dye detection.

### PICVISA: ECOSORT TEXTIL optical sorter

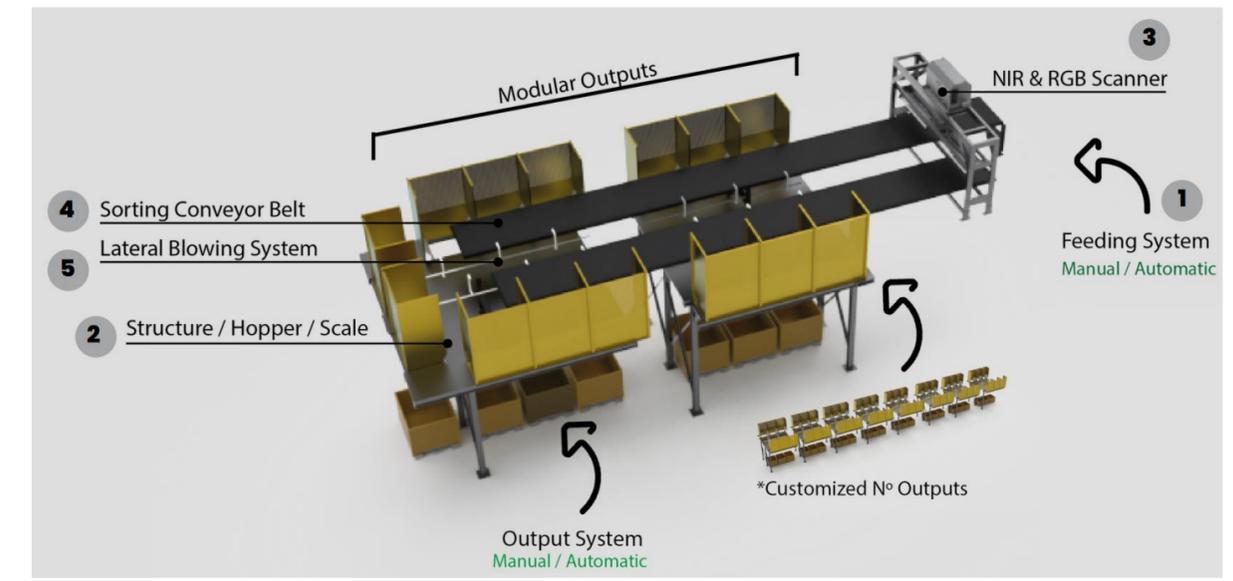
Facility: Coleo

The ECOSORT TEXTIL optical sorter allows the automatic classification and separation of textiles by composition (NIR), colour (VIS) and/or shape (deep learning). Can be configured to make quick changes in the automatic classification of the different textile materials.

ECOSORT TEXTIL is designed to work on 1000 mm belts and can be combined with both a pneumatic sorting system and a robotic arm such as ECOPICK (an artificial intelligence (AI) based robot that recognizes and classifies a wide variety of objects on a conveyor belt) to separate the different textile categories.<sup>[15]</sup> A Single sensor-based scanner can have from 6 (for single conveyor) up to 38 outputs (double conveyor) with throughput for the double conveyor of up to 2000 kg/h (air consumption 2400 lpm).

The design options include automatic feeding, automatic sorting and a double conveyor.

PICVISA also offer solutions for Disruptor Removal (reviewed on [slide 78](#)) and waste recycling, The ECOPACK optical sorter – A Ballistic Separator similar to the Autosort and Mistral Connect



**Ecosort Optical Sorter**  
Source: Picvisa.com [2023]

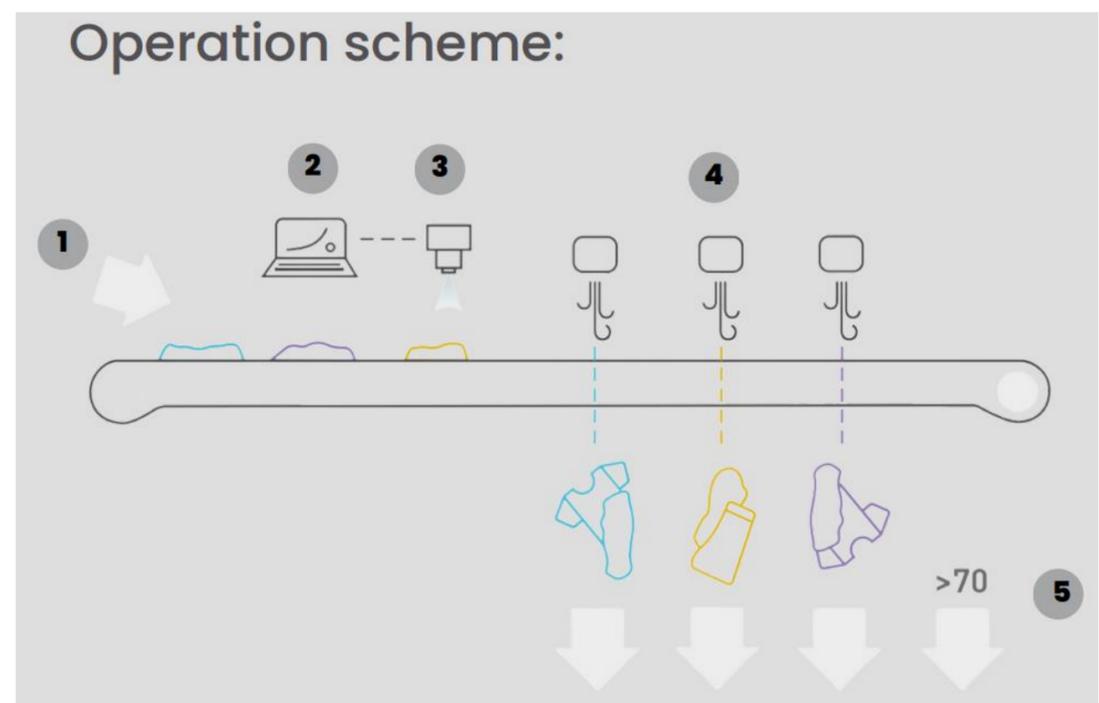
Sensor Deck	Purpose
Near-Infrared spectroscopy – hyperspectral linear scanner	Identify fibre
RGB Camera	Identify colour and shape
Machine Learning	Classification based on the spectral input

Accuracy/Purity	Categories Sorted Per Machine	Conveyer Speed	Throughput	Cost
95%*	38**	1.5-2m/s	Double Conveyer: 2 tonnes/hour Single Conveyer: 1-1.5 tonnes/hour	About £301k (350k €)

\* According to companies' online catalogue, depends on the training sample and this can include blends of more than two fibres  
\*\* The number depends on the conveyer configuration, and it can be higher, the presented number come from one implemented solution with double conveyer

[15] <https://picvisa.com/en/ecosort-textil/>

PICVISA: ECOSORT TEXTIL optical sorter  
Facility: Coleo



Graphic showing pneumatic sorting  
Source: Picvisa.com [2023]

Advantages	Disadvantages
Flexible solution, with manufacturer able to adjust the design to fit the customers requirements	Each fabric needs to be separated before scanning
Customizable number of fibre/colour categories	Carbon black dye affects the scanning results
Many fabric blend types sorted/detected using one scanner (up to 70 types)	Relatively low throughput for the machine
Several solutions available for sorting such as ECOSORT and ECOCLIP	Feeding the garments onto the conveyor is the bottleneck of the system
Established manufacturer in the waste sorting industry	

Initial Recommendations & Remarks
High number of categorisation bins meets the requirement of the ATSP
PICVISA offers several sorting solutions of varying scale and seems to be flexible in their design.
PICVISA offers a few solutions for textile sorting, for both whole garment sorting (Ecosort) and trimmings (Ecoclip, shown in slide 47)
Multiple (Min. of 2) systems would be required to meet the ATSPs throughput requirements
The company claims that can identify complex blends with 3 fibres, depending on the training sample

Summary Table				AUTOSORT <i>Tomra</i>		Fibresort <i>Valvan</i>		Mistral Connect <i>PellencST</i>		ECOSORT <i>Picvisa</i>	
Measures	Criteria			Specification		Specification		Specification		Specification	
	Lower Limit	Acceptable	Upper Limit								
Detectable Fabrics (Listed on slide 34)		Polyester, Cotton & Elastane	All	All		All		All		All	
Accuracy/Purity	75%	95%	>95%	95%* or above		Single fibre: up to 99% Dual-fibre blend: up to 95%		Single fibre: 90- 97%* Dual-fibre blend: above 75% (polycotton mixes)		95%*	
Categories sorted per machine	2	12	>12	2 (up to 3)*		Up to 50 (for dual conveyer)		2 (up to 3) Or 4* (with multi- stream)		38*	
Throughput per machine (Tonnes/hour)	1	4.5	>4.5	4.5		1.2		4.0		2.0	
Colour Sorting	No	Yes	Yes	Yes		Yes		Yes		Yes	
UK Support Offices	No	Yes	Yes	Yes, UK engineering support available		No		Sales only: Ireland		No	
Sensor Deck				NIR VIS Machine Learning		NIR RGB Machine Learning		NIR VIS RGB Machine Learning		NIR RGB	
Cost				£130k - £304k		Approx. £1M <i>per complete line, inc. feeding</i>		TBC		Approx. £301k	

Legend	
Suitable	
Potentially Suitable	
Not Suitable	

Disclaimer: All the equipment reviewed above are proven, commercially viable options. The RAG status reflects a brief assessment of the equipment specifications against the requirements of the ATSP and does not reflect the supplier or equipment's overall capability.

## HAND SCANNERS FOR QUALITY CONTROL AND ASSURANCE AUDITING

In addition to fully automated sorting solutions, there are a number of handheld spectrometers available.

Similar to the automated solutions above, these handheld spectrometers use a single point near-infrared scanner to assess the wavelength of the fabric and compare this to a database of known fabrics.

These handheld spectrometers, may be suitable for bulk-homogenous NRT lines, and can be used anywhere in the facility for quality control and quality assurance.



**FabriTell Textile Identification Device**

Source: Matoha.com [2023]

Scanner - Supplier	Sensor Deck	Resolution	Identifying Colour	Battery Operated	Measurement Time	Cost
FabriTell <i>Matoha</i>	Single point NIR WL: 1550 – 1950 nm	~ 10%	No	2600 mAh 6-8 hours battery life	~ 1 Second	£3,499 + VAT
SenoCorderSolid <i>Senorics</i>	Single point NIR WL: 1200 – 1700 nm		No	Yes	< 2 Seconds	TBC
Trinamix <i>Trinamix</i>	Single point NIR WL: 1450 – 2450 nm	1% of Wavelength	No	2600 mAh 11.1 V	Info Unavailable	TBC
Nirone Scanner <i>Spectral Engines</i>	Single point NIR WL: 1550 – 1950 nm	Info Unavailable	No	"10 Hours"	Info Unavailable	TBC

## Market Review Summary

### Technology Limits

Throughput is limited by the feeding of the garments into the fibre identification system, and not by the sensor deck. **If automated feeding can be improved, overall throughput will follow.**

The accuracy of the sorting system is entirely dependent on the validity and size of the data library that is being used as reference.

There are numerous hand scanner options available that are viable options for quality control and auditing.

### AUTOSORT® /Mistral Connect

The Ballistic Separator sorting technique, such as the AUTOSORT® and Mistral Connect, have been introduced to the textiles market from municipal recycling applications

They offer a **high throughput** but have limitations on the number of categories that each machine can sort. This would mean that **multiple machines would have to feed into each other to reach the desired number of categories**, increasing the overall cost of the system and the floor space requirements.

### Fibresort™/ECOSORT

The Fibresort™ and ECOSORT offer a **more compact design with better scalability** should more categorisation bins be required (by extending the output conveyor), giving a **potentially higher initial price point but may be a more futureproof option**. If more categorisation bins are required with AUTOSORT® or Mistral Connect, whole machines are required and additional floor space.

However, these systems **have a slower throughput and would require a minimum of 2 separate lines to meet the ATSPs requirement**. Again, the limiting factor on throughput is the singulation and feeding mechanism of the system.

### Future Opportunities

**No single technology on the market satisfies all the ATSPs requirements, and some collaborative opportunities should be explored.** Two interviewees commented that they would want to “put the Tomra bit (Sensing technology) in the front and the Valvan Fibresort™ (Sorting System) in the back.” When MTC were on a site visit with Tomra, the technology provider stated they would be “open to collaboration with other companies.”

# Fibre Identification & Sorting Conclusions

No single Fibre ID & Sorting system is specifically tailored to meet the needs of the ATSP. Of all the technology on the market reviewed, Tomra's AUTOSORT® and Valvan's Fibresort™ systems were the closest-fit suitable options for an ATSP, each with their own benefits and drawbacks.



- Long **proven track record in the recycling industry**
- Larger size company with dedicated textile R&D machinery facility
- Proven track record in world's first industrial-scale automated textiles sorting facility (SIPTex, Sweden) ; feedback from chemical recycler who uses feedstock from SIPTex- "[on arrival inspection] **Nothing has failed.**"
- **Open eco-system for integrating with other technology partners** willing to collaborate with other technology providers



- Long **proven track record in the textile sorting industry**, particularly in baling and conveyance systems
- Have been advised by industry experts that they are keen to enter the UK market
- Track record of automatic sorting demo plant collaborations in The Netherlands, Poland, and the UK
- **Offers a whole-system sorting solution**, including a debaling system, robotic garment singulation (in development), conveyance and the Fibresort™

## AUTOSORT®

- **Highest throughput, but struggles with scalability**- the limited number of categorisation bins available requires multiple machines to be integrated together, taking valuable floorspace [[four machines used at the SIPTex plant](#)].
- Claims that they can detect elastane blends (even 1% elastane in cotton) – useful for chemical recycler's requirements
- **Lower up-front investment** as individual machines are a fraction of the cost of one Fibresort™ system

## Fibresort™

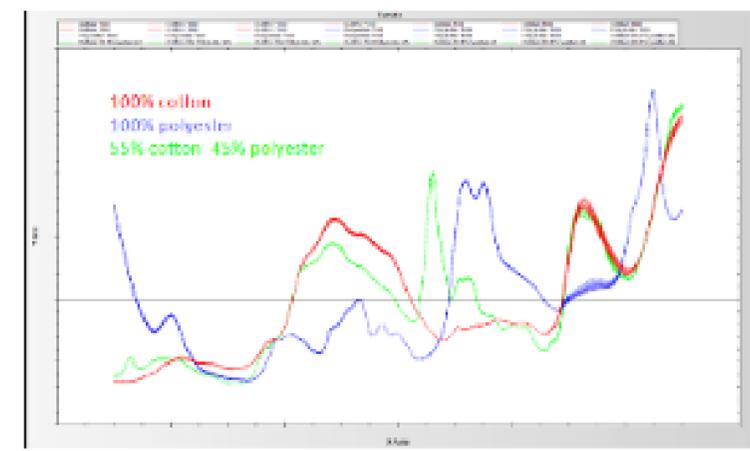
- **Throughput is slower** than Tomra's AUTOSORT®, **but system is customisable** in number of fibre/colour categories – potentially up to 50 sorting categories if dual conveyors used
- Throughput is limited only by garment feeding system. Increasing rate of feeding will increase throughput capacity.
- Compact but scalable design minimises floorspace requirements
- Elastane blends in cotton difficult to be detected.
- **Higher up-front investment** for one Fibresort™ system, however system is more adaptable and scalable for developing sorting needs

# Challenges of Fibre Identification & Sorting

The technologies on the market for fibre identification and sorting have been developing well, with more manufacturers particularly from a waste recycling background transitioning into textile sorting. Fibre classification appears to be of relatively high TRL, however each manufacturer faces distinct challenges that do not yet have solutions.

Common challenges that are faced across all the Fibre Identification technologies are:

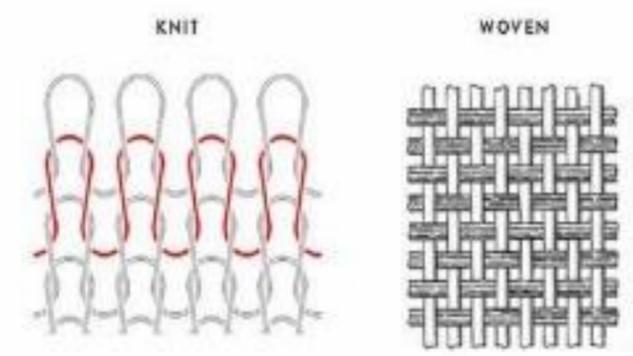
- Lack of availability of reliable fibre data for creating reference database
- Overlapping of Garments during scanning
- Multi-layer fibre identification
- Carbon Black Dye identification
- Elastane identification
- Pigment & Dye Classification
- Fabric Structure Identification (Knitted vs Woven)



**Composition Identification**  
Source: Valvan.com [2023]



**Pneumatic Garment Sorting**  
Source: Sorting for Circularity Europe, Fashion for good [2023]



**Fabric Structures, Knitted vs Woven**  
Source: AutoTextile.com [2023]

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# Size Reduction

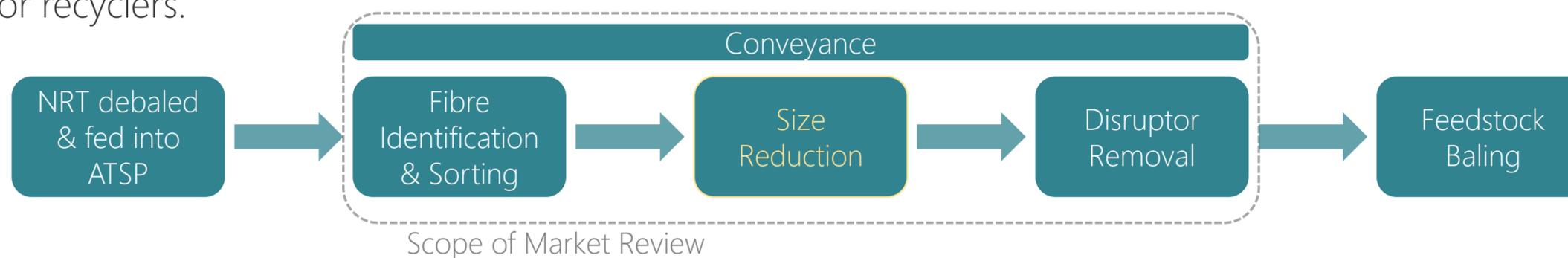
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# Size Reduction

Both mechanical recycling and some chemical textile recycling methods require the garments to be pre-processed into larger cut/filletted pieces (mechanical) or cut into smaller swatches (chemical). Feedstock requirements vary across the recycling methods, with mechanical recycling requiring long fibre lengths to be preserved and chemical recycling requiring small cut swatches which are easier to feed via high-volume hoppers, and then broken down chemically. Discussions with industry figures showed existing technologies but none tailored for the purpose of producing feedstock for textile recyclers. The greatest challenge currently is determining a clear feedstock specification for recyclers.

Technology Requirement	
Chemical Recyclers	Short Fibre Lengths, No individual Fibres <i>8mm<sup>2</sup> to 80mm<sup>2</sup></i>
Mechanical Recyclers	Individual, Long Fibre Lengths <i>TBD</i>
Metric Tonnes per Hour	4.6
Garments Per Second (Initial Target)*	Approx. 4

Existing manufacturers have been contacted to try and determine the best system for the role, including Andritz, Wagner Shredder, and Dellorco & Villani.



\*Based on an average garment weight: 300 grams

## Shredders

Similar to paper shredding, a single shaft or dual shaft shredder relies on either one bladed cylinder against a fixed edge or two cylinders rotating into each other, with a sieve-like grate underneath to allow sufficiently small material to pass through.

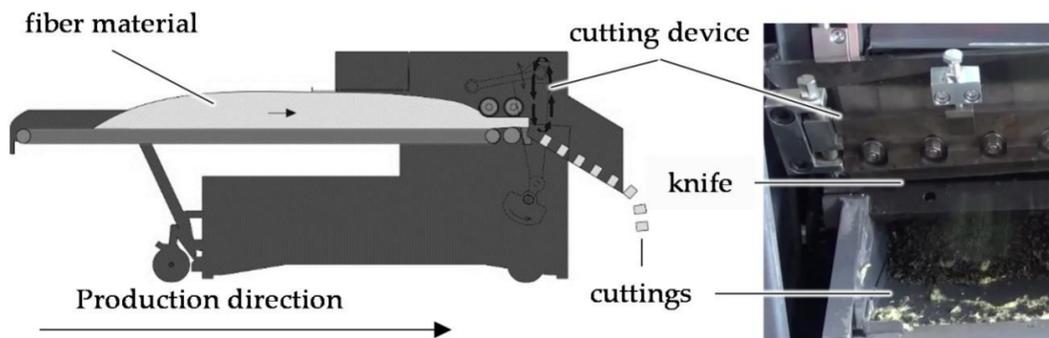


**Twin-shaft shredder, Proshed 800**  
Source: Wagner-Shredder.com [2023]

Advantages	Disadvantages
One of the highest throughputs out of available technologies, but information unavailable for textiles	Produces irregular output lengths with ragged edges and loose fibres
Shaft shredders tend to be easier to maintain	Limited precision, only allowing control over the "max" reduction size of the textile
Versatile, capable of handling a variety of fabrics including woven and knitted	Large amounts of loose fibres or textile 'dust'

## Guillotine Cutters

Relies on a scissor effect between a fixed blade and a second reciprocating blade edge, usually attached to a connecting rod and flywheel, with the distance between blades determining the output material size.



**Schematic of Guillotine Cutting**  
Source: Pierret.com [2023]



**Output Swatches from Guillotine Cutting Machine**  
Source: Dellorco-Villani.it [2023]

Advantages	Disadvantages
Precise cutting, with good control of output sizes	Typically a lower throughput compared to other continuous size reduction operations
Minimised fraying due to sharp cuts	
Versatile, capable of handling a variety of fabrics including woven and knitted	
Produces minimal 'dust' compared to alternative processes	

## Rotative Cutting Machines

The core of the operation involves a set of blades rotating rapidly, while textile material passes through the cutting area. The circular motion of the blades allows for continuous cutting along the length (or width) of the material.



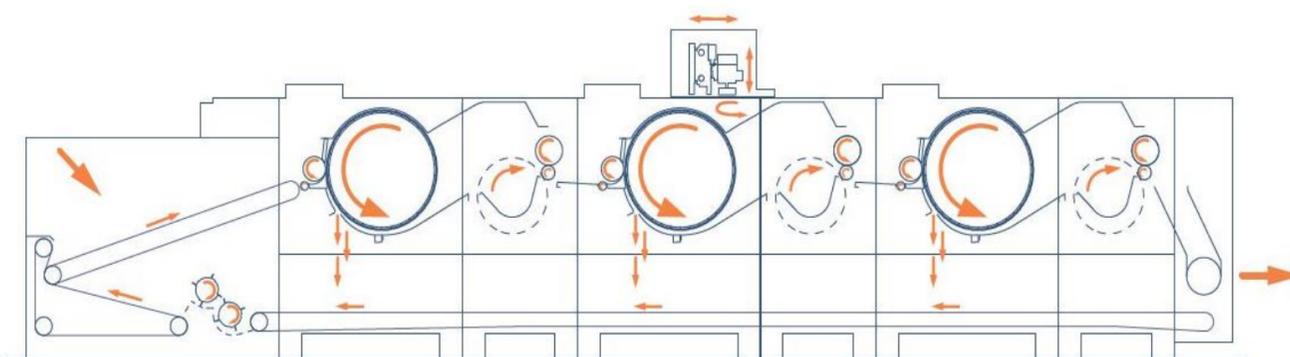
**TRM Rotative Cutting Machine**

Source: Dellorco-Villani.it [2023]

Advantages	Disadvantages
High throughput capabilities due to high-speed rotative cutters	High initial cost
Capable of handling a broad range of materials	Complex setup and maintenance, dependent on setup
Precision cutting	Large footprint

## Tearing Machines

Fabric passes between several tearing cylinders fitted with needle pins, increasing in number as material size is reduced to pass to each cylinder. This process reduces fabrics down to a stream of fibrous tufts



**Tearing Machine Schematic**

Source: Andritz.com [2023]

Advantages	Disadvantages
Often has a higher throughput compared to cutting or guillotine machines	Cannot perform precise cuts or produce specific sizing's of fabrics, 'swatches'
Aids in retaining fibre length for recycling	Process produces loose fibres and textile 'dust', requiring PPE for operators or pose a long-term hazard
	Not suitable for all fabric types
	Large footprint

### Dell’orco & Villani: MGC Guillotine Cutting Machine

Dell’orco & Villani sell complete recycling lines for specific output use cases as well as individual machines.

Their MGC Cutting Machine has a “medium scissor effect cut” which is capable of handling waste, textile fibres, paper, and various plastic materials. The process begins as the material is placed onto the feeding conveyor, which then employs a dual-pressing cylinder delivery system to position it in front of the cutting assembly. The "medium scissor effect cut" is an engineered blade mounted on a support connected to a unique linkage mechanism with an inertial flywheel, complemented by a counter blade securely affixed to the central, monolithic crossbar of the machine. This setup ensures a clean cut without any unsightly filaments, all while maintaining the efficiency and production capacity typically associated with high-cut machines boasting 700mm cuts, but with a significantly lower total power consumption.

The machine comes equipped with a mechanical blade-edge restoration system that functions while the machine is in operation, guaranteeing continuous performance. With the capability to handle materials stacked up to approximately 350mm in height on the feeding conveyor, this machine offers both flexibility and reliability. Users have the freedom to select their desired cut length, ranging from 10mm to 60mm.<sup>[16]</sup>

\*\* Dell’Orco & Villani representatives advised this machine is best suited for synthetics and filament waste – while rotative cutting machine is most suited for second hand clothes.

Installed Power	Precision	Cut Size	Throughput	Dimensions (L x W x H) + Working Width	Cost
12.85 kW		10mm to 60mm	up to 2 T/h	4164 x 1220 x 1587mm Working width: 700mm	~ £57,000

Advantages	Disadvantages
Good range of cut sizes, covering much of the specification for chemical feedstock	The cut size potentially needs to be customized to operate at smaller than 10mm to satisfy some chemical recyclers
Integrated blade sharpening, increasing up-time and reducing maintenance requirements	
Low power consumption	
Dellorco-Villani have been in the textile industry since 1964	



**MGC Guillotine Cutting Machine**  
Source: Dellorco-Villani.it [2023]

[16] MGC Guillotine Cutting Machine -Dell’Orco & Villani.

## Pierret: N45 & N60 Guillotine Cutting Machine

Cutting machine is driven by two three-phase asynchronous motors, advertising 405/290 cuts/min, respectively.

Border Technologies (UK supplier of Pierret) representative advised that N60 offers a higher overall throughput if you can feed it in at the maximum width.

Pierret's trial facilities in Belgium can run a trial for the ACT project to see what throughput is possible.

The material is conveyed on a feeding belt to an awaiting hardened steel roll assembly. The rolls compress the material on the feed table and draws it towards the cutting knives. The scissor effect produced between the mobile knife and the fixed knife edge guarantee a clean-edged, melt-free cut and the roll adjustments allow for easier loading of varying shapes of garment and textiles. **The flattening rollers mean that this system could handle bulkier garments or samples** with one less pre-processing stage whilst the rapid scissors effect provides accurate cuts. The fixed knife edge would result in clean edge cuts, reducing fibre size but ensuring a lack of frayed edges and loose fibres.<sup>[17]</sup>

Model:	Installed Power	Precision	Cut Size	Throughput	Dimensions (L x W x H) + Working Width	Cost
N45	7.1kW	±2.54mm at 3mm cuts	From 3mm to 125mm.	Up to 1.5 T/hr	3,700 x 1,080 x 1,330mm Working Width: 450mm	£47,500 for base unit, potential for additional options
N60	13 kW	± at 3.81mm at 4mm cuts	From 4mm to 118	Up to 3 T/hr	3,720 x 1,234 x 1,475 mm Working Width: 600mm	

Advantages	Disadvantages
Automatic cut-off in case of a material wrap up	Requires manual operator, no signs of automation integration
Very low power consumption	Lower throughput than other options available
Large cut size range, with high levels of precision	
Blades are much quicker to change compared to shredder blades – Pierret offer a blade swap service	
Pierret have specialized in guillotine cutting machines since 1925, dedicated for textiles preparation- UK service providers available, already several established customers in the UK	
Pierret offer an automatic feeder capable of being placed upstream	



**N45 Guillotine Cutting Machine**

Source: Pierret.com [2023]

[17] N45 Guillotine Cutting Machine - Pierret.

**WIPA: WGA/WGAD Guillotine**

Continuous guillotine cutter relying on one moving and one stationary blade resulting in a precise scissor effect. Materials can be fed into the cutter manually or by means of a specially conceived feeding device. This system is designed to shred fabrics and textiles, additionally able to process films, foils, fleeces, and nonwovens. Materials are transferred to a compression device to be moved towards the twin knives. The cutting gap can be adjusted by two handwheels during operation, perhaps an unnecessary addition to be able to adjust during running operations. The system can handle infeed material of thickness up to 500mm, making it a suitable system for thicker textiles found outside of fashion markets. [18]



**WGA Guillotine Cutting Machine**  
Source: wipa-germany.de [2023]

Installed Power	Precision	Cut Size	Throughput	Dimensions (L x W x H) + Working Width	Cost
22kW		10mm to 200mm	Up to 2.5 T/h	Working width: 600mm	

Advantages	Disadvantages
Highest throughput of the observed systems	Requires additional feeding devices for bulky materials
Good range of cut sizes, covering much of the specification for chemical feedstock	
A Metal detector can be equipped, supplied by WIPA	
Easily adjustable cutting sizes	



**WGA Guillotine Cutting Machine**  
Source: wipa-Germany.de [2023]

[18] WGA Guillotine Cutting Machine – WIPA Germany.

### Dell'orco & Villani: TRM 1000 Rotative Cutting Machine

Dell'orco & Villani sell complete recycling lines for specific output use cases as well as individual machines. Rotative cutting machines are sold as part of D&V's post-consumer clothing recycling line.

It is designed with blade longevity in mind, reducing the need for frequent blade replacements and maintenance. This not only enhances operational efficiency but also contributes to cost savings over time. The TRM 1000 Rotative Cutting Machine offers a powerful solution for efficiently managing textile waste while maintaining the highest standards of precision and productivity.<sup>[19]</sup>

**Post-consumer Clothings and Hard Wastes Recycling - HIGH CAPACITY**

- Auto feeder for cutter
- Rotary Cutters
- Mixing-Storage chamber
- Hopper Feeder
- Pre-Shredder 2 cylinder
- Cleaner-Removal machine BM
- Hopper Feeder
- Final Tearing 3 cylinder
- Metal Detector
- Bale Press Carousel type

**DELL'ORCO & VILLANI**  
Textile Recycling & Blending

Advantages	Disadvantages
Blades are designed for longevity, reducing maintenance and increasing operational efficiency	The cut size potentially needs to be customized to operate at smaller than 10mm to satisfy some chemical recyclers
Fair range of cut sizes, covering much of the specification for chemical feedstock	Higher installed power than Guillotine Cutting Machines
Dellorco & Villani offer demos and trials in their laboratory	



**TRM 1000 Rotative Cutting Machine processing textiles**  
Source: YouTube.com/Dellorco&Villani [2023]

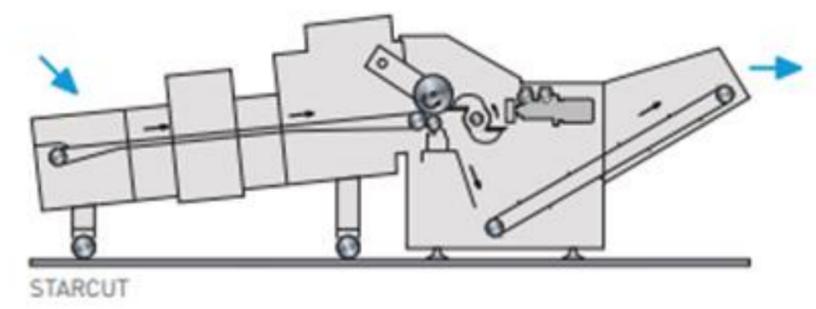
Installed Power	Precision	Cut Size	Throughput	Dimensions (L x W x H) + Working Width	Cost
18.7 kW		14mm to 68mm	up to 2 T/hr	5240 x 1580 x 1470 (H) mm Working Width: 980mm	£56,500

[19] TRM Rotative Cutting Machine - Dell'Orco & Villani.

### Andritz Laroche: Starcut 500"

Uses a rotary cutter machine that features a cutting head equipped with either 2 or 4 flying knives. The Laroche Starcut 500 is a rotary cutter designed to handle a wide range of processible materials, making it suitable for various industries and applications. Some of the materials that can be effectively processed by the Laroche Starcut 500 include: textiles, paper and cardboard, plastics, foam, rubber, fibrous materials, composite materials, films and laminate, and non-ferrous materials. It has a feeding conveyor that extends from the machine, allowing for easy access and hassle-free material placement and retrieval.<sup>[20]</sup>

Advantages	Disadvantages
Used in the Nouvelles Fibres Textiles facility	Lack of information online
Andritz have over 100 years' experience in developing automation equipment for natural fibres	Andritz have not responded to enquiries



**Laroche Starcut 500 Schematic**  
 Source: Andritz.com [2023]

Installed Power	Precision	Cut Size	Throughput	Dimensions (L x W x H) + Working Width	Cost
				Working Width: 500mm	



**Laroche Starcut 500**  
 Source: Andritz.com [2023]

[20] Laroche Rotary Cutting Machine - Andritz.

### Dellorco & Villani: Mondial M1900 Tearing Machine

Composed of a series of independent modular units, the first unit is equipped with two feed rollers, while the second unit is equipped with a cylinder wrapped on rigid wire as well as a dish feed. The series of independent units allow for easy extension simply by implementation of additional units if more tearing is required. An external device collects any unopened materials that get rejected by the machine and can return them to the hopper feeder for reprocessing. A device positioned on each unit can adjust the quality of returned material. The cylinder top covers can be opened in two parts that can easily slide onto the frame of the machine for ease of access.

Whilst well-suited for implementing in greater numbers, the tearing process proves unreliable in managing output quality and produces a mass of torn material of reduced fibre length, reducing the suitability for mechanical recycling.<sup>[21]</sup>

Advantages	Disadvantages
System configuration allows for ease of access for maintenance cycles, reducing downtime	Undefined output, not yet clear what size limitations the tearing can operate at
Direct drive motors eliminate the need for transmission belts or chains	Output generates large amounts of loose fibres, may not usable by recyclers
	Fibre 'dust' can present long term health hazard to operators if left unmanaged & is a potential fire hazard
	High installed power

Installed Power	Precision	Cut Size	Throughput	Dimensions (L x W x H) + Working Width	Cost
115.87 kW	N/A		2 T/hr	5050 x 3650 x 1660mm Working Width: 1900 mm	



**Mondial Tearing Machine**  
Source: Dellorco-Villani.it

[21] Mondial Tearing Machine – Dell'Orco & Villani.

**Wagner-Shredder:** Wagner Single Shaft Shredder Procut 1900  
 Unsorted textiles are fed into the single-shaft shredder, where a rotary drum fitted with 99 knives will reduce the material down to a size determined by a screening unit with varying holes, shapes and sizes to vary output. Each knife offers a quick-change system for shorter downtimes as well as a maintenance flap for quick and easy access to tools. Inside, a swing pusher shifts material towards the rotating drum to minimise material leakage.  
 The largest model in the Procut selection in order to ensure the throughput can meet demands from recyclers, the 1900 model has the greatest input feed but the throughput cannot be quantified at this time.  
 The single shaft shredder was determined to be more suitable than twin-shaft shredders due to an increased throughput and twin-shaft shredders being more susceptible to downtime from stray disruptors jamming the mechanism.<sup>[22]</sup>

Advantages	Disadvantages
Can be outfitted with an output conveyance method for constant movement of shredded textiles out of the system	Shredded output may not be suitable for chemical recycling needs due to loose fibres and 'dust' produced
Externally mounted motor unit to reduce time required for motor maintenance if overloading occurs	Shredded product cannot be cut to a specific size, only reduced to the minimum size required to fall through the screening filter
	High installed power

Installed Power	Precision	Cut Size	Throughput	Dimensions (L x W x H) + Working Width	Cost
1 x 110 / 1 x 132 kW		10mm to 80mm		3750x2300x2720 Cutting space volume: 3.7m <sup>3</sup>	



**Wagner Single Shaft Procut 1900**  
 Source: Wagner-Shredder.com [2023]

[22] Procut 1900 Shredder – Wagner-Shredder.

### Vecoplan: VAZ 1600

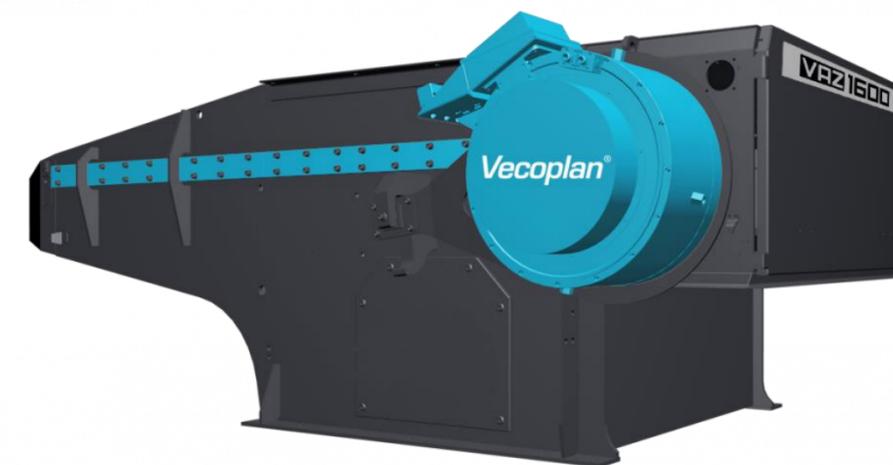
The VAZ range from Vecoplan offers a robust, powerful and energy efficient shredder capable of being adapted to meet a variety of requirements. The VAZ series has a wide range of configurations available, with rotor lengths ranging from 800 to 2500mm and associated throughputs ranging from 0.2T/hr up to 25T/hr.

The Vaz 1600 has been used by shredding companies for textiles, and can have output sizes as small as 6mm, determined by the design of the screen.

The VAZ series can be equipped with the “Flipper”, a pre-tensioned counter knife that prevents damage by tramp material.<sup>[23]</sup>

Advantages	Disadvantages
Can be equipped with the “Flipper” to prevent damage	Shredded output may not be suitable for chemical recycling needs due to loose fibres and 'dust' produced
High throughput options, matching the requirements of the ATSP	Shredded product cannot be cut to a specific size, only reduced to the minimum size required to fall through the screening filter
Verified by ACT Consortium member for textile shredding	

Installed Power	Precision	Cut Size	Throughput	Dimensions (L x W x H)	Cost
55 – 90kW		6mm to 80mm	6T/hr	4295x2625x1500	



**Vecoplan VAZ1600**  
Source: vecoplan.com [2023]

[23] VAZ Shredder for reusable material – Vecoplan.

Note: Information has been provided by technology suppliers and has not been validated through testing/trials.

Summary Table				MGC Guillotine <i>Dellorco &amp; Villani</i>	N45 Guillotine <i>Pierret</i>	WGA Guillotine <i>WIPA</i>	TRM 1000 RCM <i>Dellorco &amp; Villani</i>	Starcut <i>Andritz</i>	Mondial M/1900 <i>Dellorco &amp; Villani</i>	Procut 1900 <i>Wagner-Shredder</i>	VAZ1600 <i>Vecoplan</i>
Measures	Criteria			Specification	Specification	Specification	Specification	Specification	Specification	Specification	Specification
	Lower Limit	Acceptable	Upper Limit								
Machine Type	N/A			Guillotine Cutter	Guillotine Cutter	Guillotine Cutter	Rotative Cutter	Rotative Cutter	Tearing Machine	Shredder	Shredder
Throughput per machine (Tonnes/hour)	0.5	4.5	>4.5	2.0	1.5	2.5	2.0	TBC	2.0	TBC	6.5
Min Cut size (mm)	100mm	10mm	3mm	10 to 60	3 to 125	10 to 200	14 to 68	TBC		10 to 80	6 to 80
Installed Power (kW)	> 125	75	<50	12.85	7.1	22	18.7	TBC	114.87	110	55-90
UK Support Offices	No	Yes	Yes	No	No	No	No	Yes	No	No	Yes
Working Width (mm)				700	450	600	980	TBC	1900		
Dimensions (L x W x H) (mm)				4164 x 1220 x 1587	3700 x 1080 x 1330	TBC	5240 x 1580 x 1470	TBC	5050 x 3650 x 1660	3750 x 2300 x 2720	4295 x 2625 x 1500
Cost				£57,000	£47,500	TBC	£56,500	TBC	TBC	TBC	TBC

*MTC have faced some difficulty in obtaining information for some size reduction technologies due to the lack of understanding around feedstock size requirements for Chemical Recyclers. Many technology providers believe they can configure their systems to match the physical feedstock specification if it was provided.*

Disclaimer: All the equipment reviewed above are proven, commercially viable options. The RAG status reflects a brief assessment of the equipment specifications against the requirements of the ATSP and does not reflect the supplier or equipment's overall capability.

Legend	
Suitable	<span style="color: green;">■</span>
Potentially Suitable	<span style="color: yellow;">■</span>
Not Suitable	<span style="color: red;">■</span>

## Market Review Summary

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### Feedstock Requirements

Interviews with technology providers highlighted the lack of specification of feedstock for chemical recycling. There is not enough information surrounding physical feedstock requirements to provide a detailed specification to technology providers. Technology providers have stated that they **would be able to configure machinery to create a desired output, if the output specification was clear.**

### Cutting vs Shredding

The **guillotine cutting systems offer the most control over the swatch output size**, which is critical for some chemical recyclers, as well as offering moderate throughput that can be bolstered via multiple units running simultaneously.

**Shredders offer the greatest throughput option, but their design limits the control on output size**, with screening grates being the only control feature. This poses potential issues for the feedstock specification of some chemical recyclers.

### Health & Safety

Consideration must be given towards particulates and irritants that these systems will produce and whether a **production line using multiple systems should be contained within barriers to trap dust and loose fibres** that can be a fire hazard, as well as a long-term breathing hazard to operators in close proximity for extended periods of time. PPE can mitigate some of the operator's risk via respirators.

### Future Opportunities

No single size reduction machine can meet the needs of both chemical and mechanical recyclers. For the ATSP to be able to process feedstock for both, **multiple lines will be required depending on the feedstock specification**, and this may also vary from recycler to recycler meaning the **lines will need to be rapidly reconfigurable dependent on the recipient of the feedstock.**

## Challenges of Size Reduction

There are many existing technologies capable of reducing the size of textiles, but none are perfectly tailored for the purpose of producing optimal feedstock for the broad range of different types of textile-to-textile recycling processes.

The greatest challenge currently is being able to cater for the variety of different feedstock specifications for both mechanical and certain chemical recyclers.

Some technology providers have been running trials with chemical recyclers to try and determine the appropriate specification, although feedback on these trials showed little progress in defining the specification.

Further trials to determine a specification for feedstock will allow a more in-depth analysis of technologies and should explore the tolerances around the specification to allow for overlap between recyclers. Interviews with chemical recyclers suggested some uncertainty on whether the ATSP should be responsible for size reduction or if the individual chemical recyclers should own this step, respective to their own specifications.



**Shredded textiles**  
Source: trexproject.eu [2023]



**Long swatches of Denim**  
Source: sourcingjournal.com [2023]

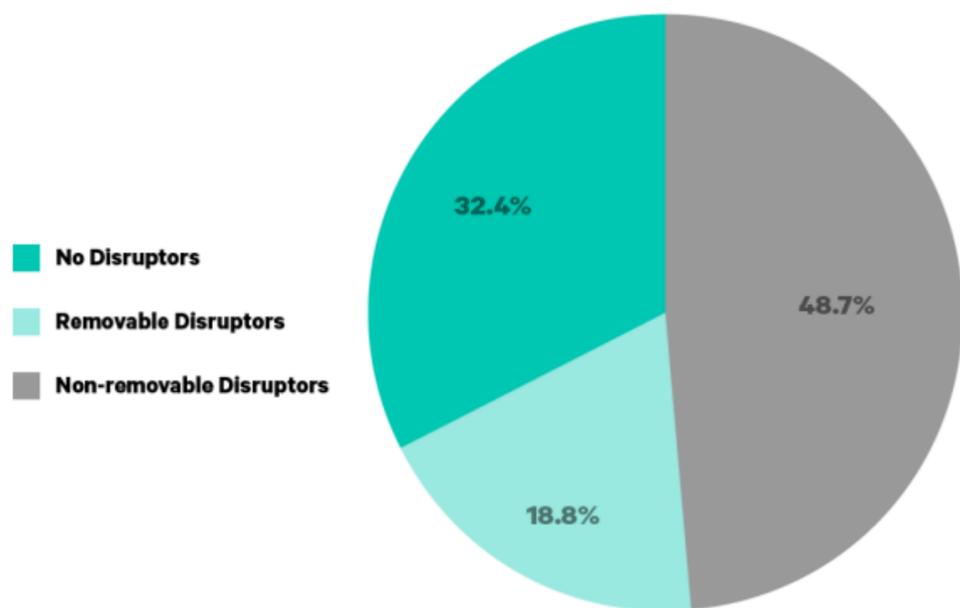
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# Disruptor Removal

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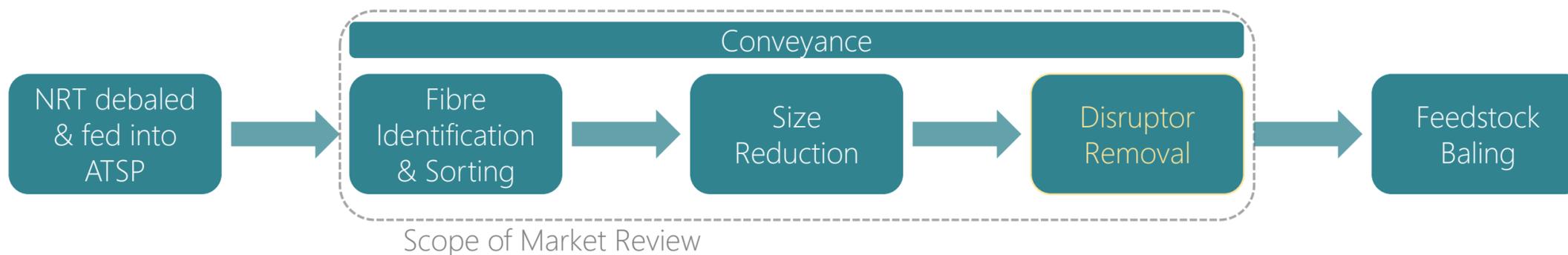
# Disruptor Removal

To prepare the textiles for the recycling process, all the disruptors (hard trims and soft trims) need to be removed.



Source: Circle Economy and Fashion for Good (2022)

Technology Requirement	
Identifiable Disruptors	Metal (Zipper, Button, Rivet, Buckle, etc.) Plastic (Button, Snap Button, Zipper, etc.) Fabric (Elastic, Embroidery, other fabrics, etc.) Other (Leather, Fur, Print, Sequin, etc.)
Metric Tonnes per Hour*	3.2
Garments Per Second (Initial Target)**	Approx. 3



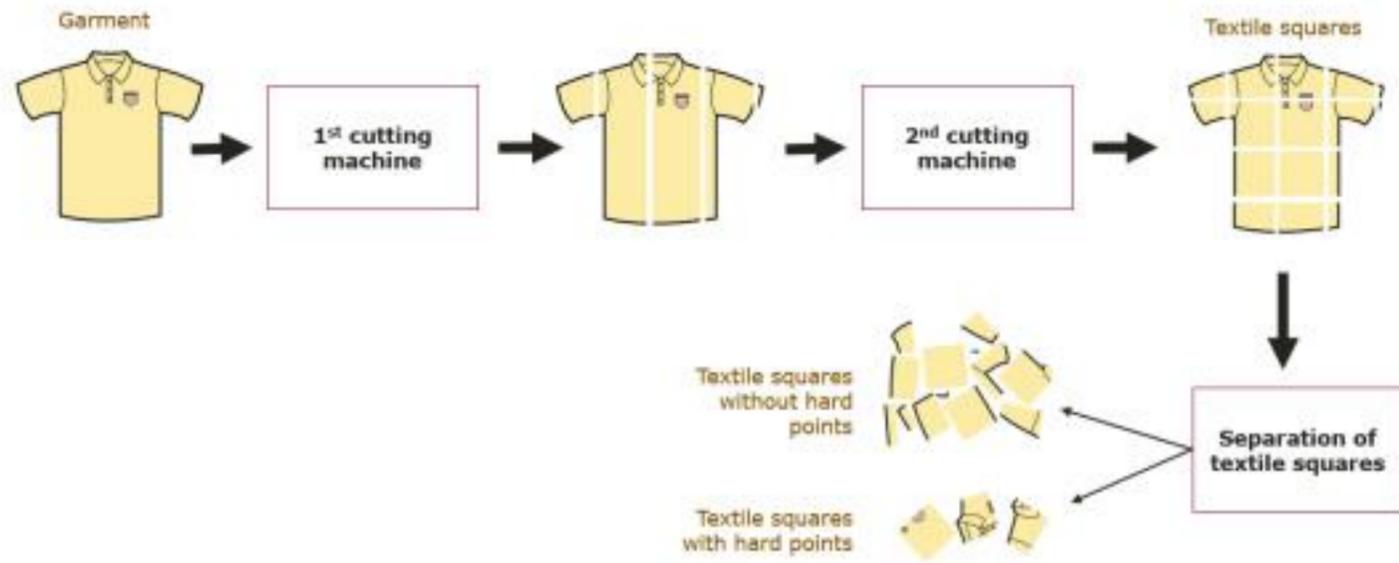
\* Approx. 70% of material have disruptors

\*\*Based on an average garment weight: 300 grams

## Ballistic Separators

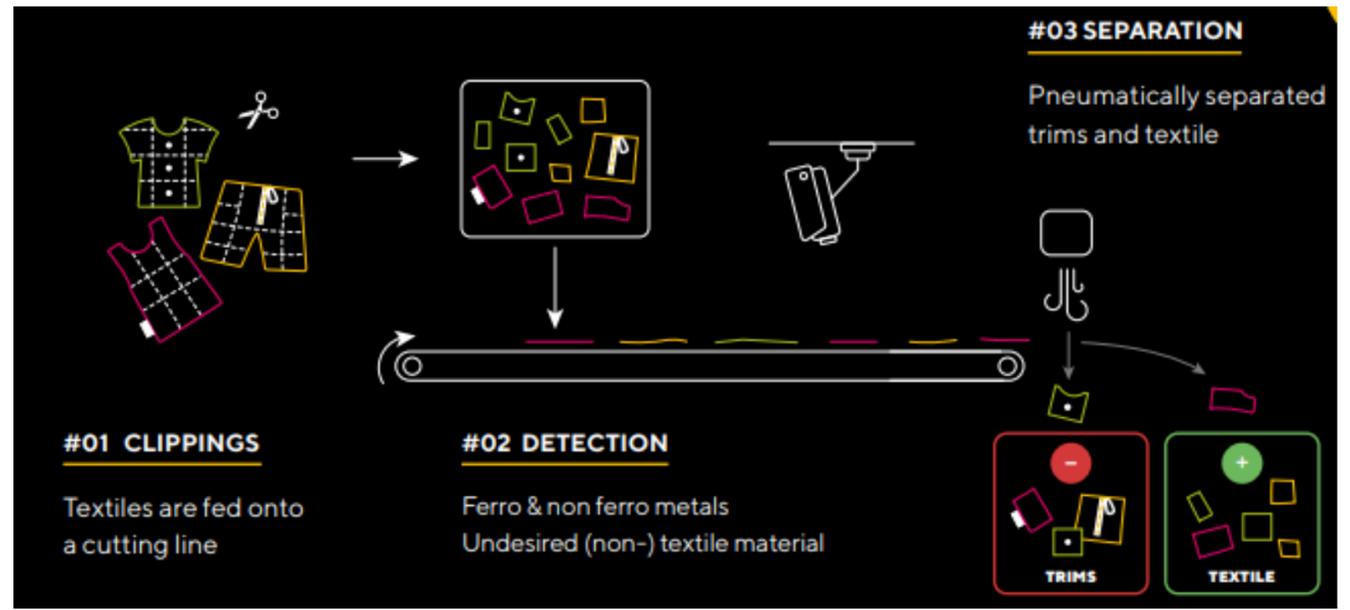
Ballistic separators are commonly used in waste recycling, for sorting municipal waste such as bottles, glass, metals, etc. This technology has been adapted to textile recycling, utilising a similar sensor deck to fibre identification (NIR, VIS) and including an additional electromagnetic sensor the system can identify disruptors and separate them. This technique requires the textile garments to be pre-cut into swatches (approx. 100mm x 100mm).

Advantages	Disadvantages
Technique proven in multiple recycling industries	Difficulty seeing both sides of the swatch – depending on how the swatch falls onto the conveyor will determine if the disruptor is seen by the sensor deck or not.
Emerging in the textile recycling market and has good scope for development	Requires pre-processing of garments (size reduction)
Both Metal and Plastic disruptors can be removed	Low material yield – Textiles are cut into swatches and if a disruptor is present the whole swatch is rejected



Size reduction for ballistic separators

Source: Technical monitoring of optical sorting, recognition and disassembly technologies for textiles at European scale, Refashion. (2023)



Trimclean operational process

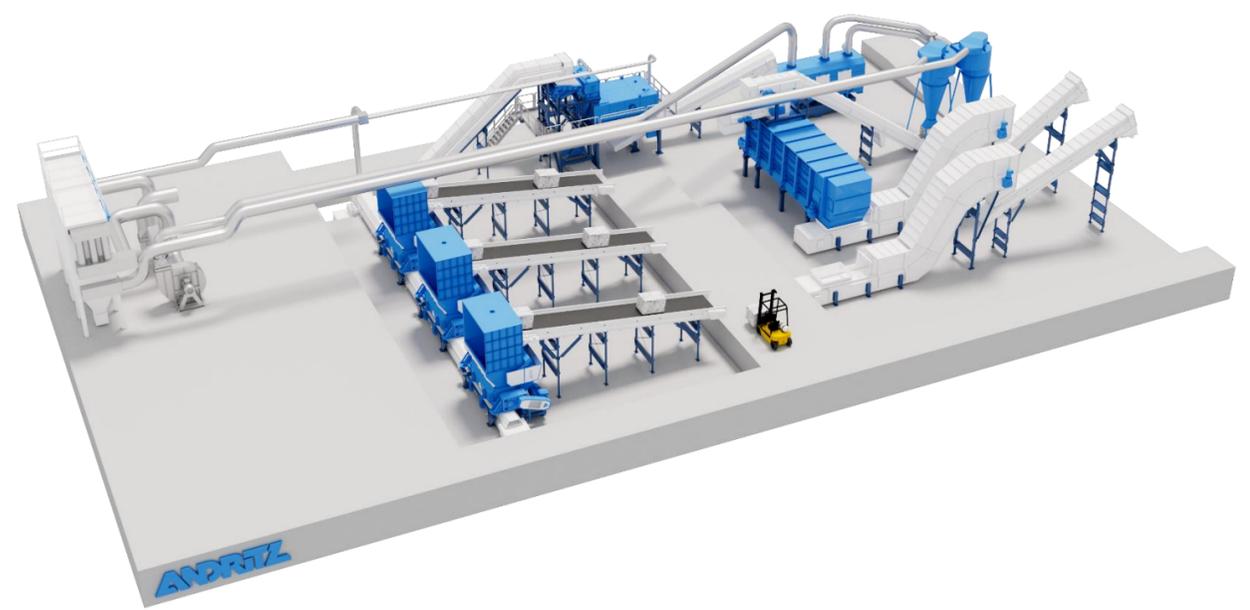
Source: Valvan.com [2023]

## Garnetting/Tearing

Garnetting is a method of mechanical recycling. Garnetting machines combine mechanical and air-based separation methods to create individual strands of fibres that can be collected and processed into recycled textiles.<sup>[23]</sup>

This technique can be used to remove disruptors from the textiles during the tearing process but requires the machine to be built for this purpose with multiple separation stages.

Separation stages may include; Magnets, Air Separation via Density, etc.



**Exemplary textile waste conditioning system**  
Source: Andritz.com [2023]

Advantages	Disadvantages
Mechanical process not reliant on vision or machine detection technology	Lack of control over the disruptor removal process
Both Metal and Plastic disruptors can be removed	Output of the process is likely not suitable for chemical recycling
Capable of handling large volumes (200T/day)	Requires pre-processing of garments (size reduction)
Already being used on an industrial scale	Requires fine tuning to get an optimised system
Most developed disruptor removal technology for textiles to date	Cannot differentiate some disruptors, such as logos, tags or alternate fibres

[23] What is garnetting? – Textile Glossary (2023)

### Valvan: Trimclean

#### Type: Ballistic Separator

The Trimclean is designed to extract trims like zippers, buttons and labels from fiber-sorted textile materials. The Trimclean system utilizes two optical cameras, both above and below the conveyor belt allowing for both sides of the trimmings to be viewed and assessed using object detection and further colour sorting if required. In addition, a metal sensor detects both ferrous and non-ferrous metals. Clippings with disruptors are pneumatically separated into 2 material flows – Sorted and Unsorted

The Trimclean is offered with a built-in size reduction unit capable of cutting the in-feed garments to swatches between 20 and 100mm.

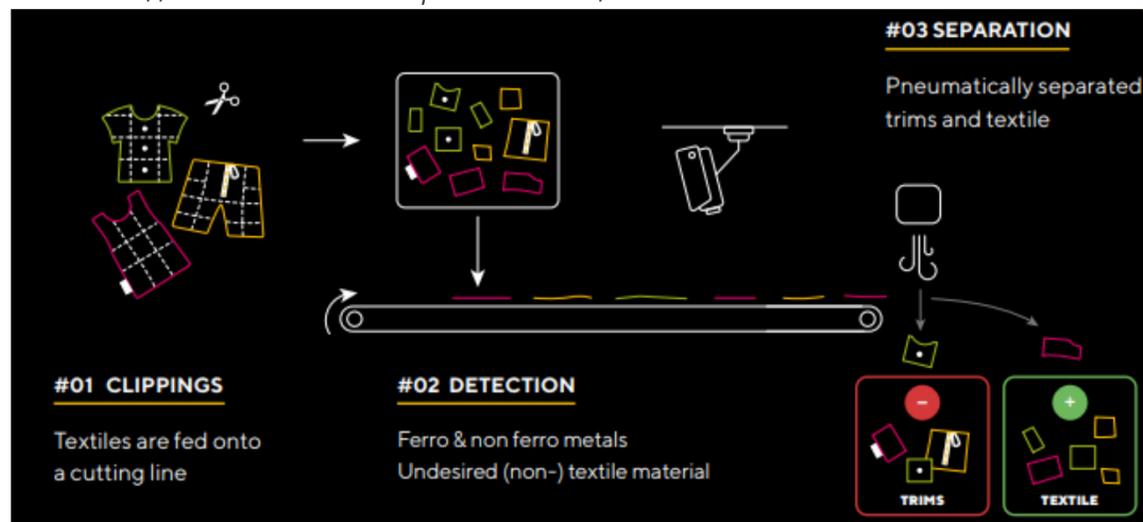
The Trimclean does not have an NIR sensor attached, and as such cannot provide any quality control on the fibre composition – assuming the pre-sort step has been 100% accurate.

*The Trimclean is a new product offering from Valvan and has not been commercially implemented to-date. Official roll-out planned for 2024.*



**Valvan Trimclean System**

Source: Valvan.com [2023]



**Trimclean operational process**

Source: Valvan.com [2023]

Technical Specification	
Sensors	2 VIS, Above and Below Electromagnetic
Ejection Method	Pneumatic
Ejection Bins	2
Conveyor Speed	?
Conveyor Width	2m
Footprint (LxWxH)*	7m x 6.5m x 4.5m
Throughput	1 Tonne/hour
Price	£300k - £500k

\* Includes size reduction equipment

### Tomra: Autosort

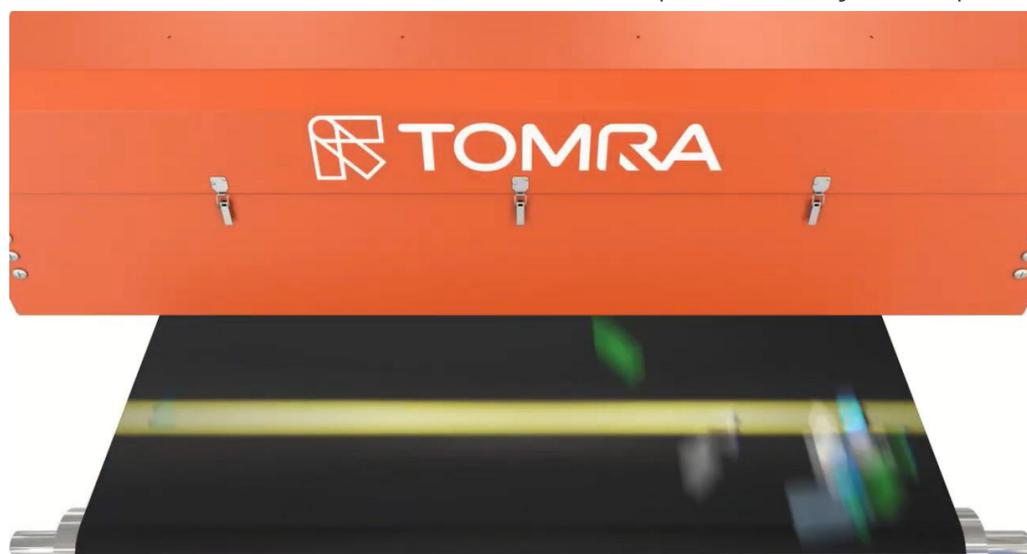
#### Type: Ballistic Separator

Tomra's Autosort originates from waste recycling, sorting other materials such as packaging waste, plastics etc. The system uses a combination of cameras, sensors and Artificial Intelligence to assess objects and sort accordingly.

This technology has been demonstrated to the MTC and Circle-8 team at the Tomra showroom. One limitation of the system may be that it can only view swatches from the top down, meaning there is a strong chance that the disruptor will be hidden on the underside of the swatch and need additional cycles.

The Autosort has a number of optional add-ons to tailor the system to the applications needs. Technologies and add-ons in AUTOSORT offer:

- DEEP LAISER sensors (add-on) – to improve performance, laser 3D object detection (detection of black polymers, glass, overlapping objects)
- Electromagnetic (EM) sensors (add-on) – to detect metal fractions
- GAIN, AI-based camera sensor – classification previously inseparable objects



Animation of Tomra Autosort Ballistic separation

Source: Tomra.com [2023]



Tomra Autosort

Source: Tomra.com [2023]

Technical Specification	
Sensors	NIR VIS Electromagnetic
Ejection Method	Pneumatic
Ejection Bins	2 or 3
Conveyor Speed	Up to 6 m/s
Conveyor Width	1m up to 2.8m
Footprint (LxWxH)*	0.55m x 2.3m x 0.6m
Throughput	4.5 Tonne/hour
Price	£130k - £300k

\* Based on conveyor width of 2m

### Picvisa: Ecoclip

Type: Ballistic Separator

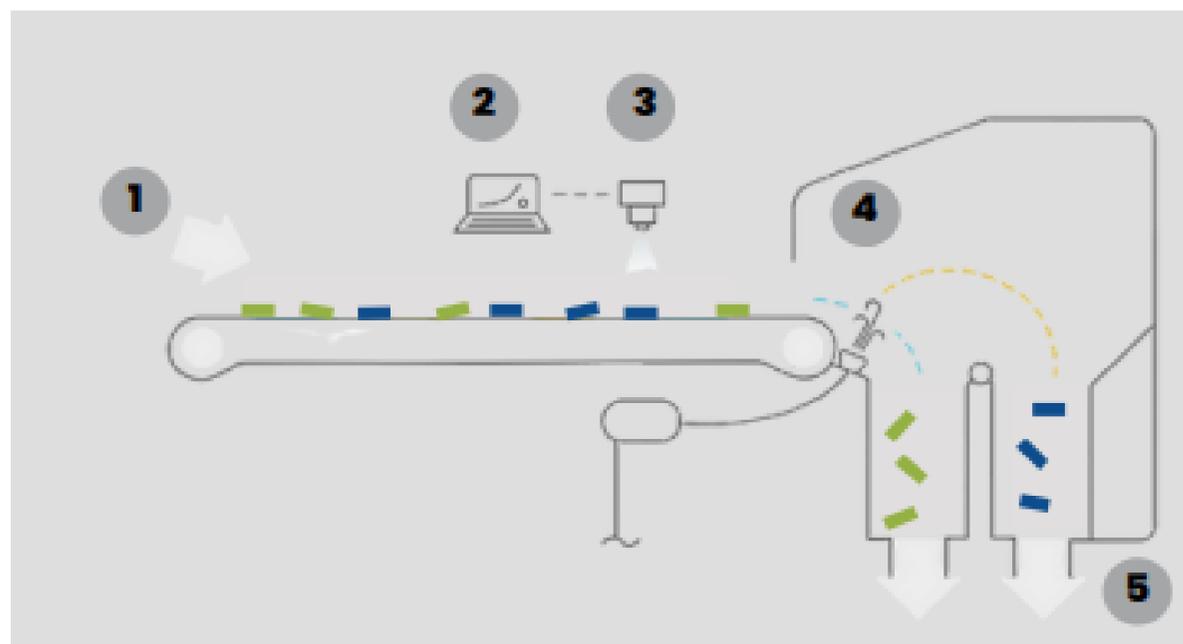
Picvisa's Ecoclip is an optical sorter that is capable of classifying disruptors, as well as fibre composition & colour, to separate textiles into the different output streams (Sorted and Unsorted). The Ecoclip is equipped with an NIR sensor which allows for further fibre composition classification, which can act as quality control on the pre-sorted batches that it will be processing.

The system utilises Artificial Intelligence to build the classification model, and as such can be "taught" what to recognise, with accuracy increasing as a larger dataset is created for referencing. **The Ecoclip requires a minimum clipping size of 25mm<sup>2</sup>.**

The Picvisa system utilises a camera from the top down, which has the limitation of only viewing one side of the swatch/garment and can lead to some trims/hardpoints being hidden, requiring additional cycles through the system to increase the accuracy of removal.



**Picvisa Ecoclip machine**  
Source: Picvisa.com [2023]



**Ecoclip operational process**  
Source: Picvisa.com [2023]

Technical Specification	
Sensors	NIR VIS Electromagnetic
Ejection Method	Pneumatic
Ejection Bins	2
Conveyor Speed	Up to 4 m/s
Conveyor Width	1.5m up to 3m
Footprint (LxWxH)*	1.9m x 2.6m x 2.1m
Throughput	2.5 Tonne/hour
Price	£175k - £275k

\* Based on conveyor width of 2m

## Dell'Orco & Villani

Type: Garnetting/Tearing

Dell'orco & Villani sell complete recycling lines for specific output use cases as well as individual machines.

As part of their post-consumer clothing & hard wastes recycling line, they offer a fibre opening and cleaning system.

The 'cleaning system' (also installed at Cetia) is equipped with a perforated grill positioned under the beating reel for the suction of the dust and small impurities connected to a suction fan and dust collector with filter bags. A high efficiency adjustable device allows the interception and removal of foreign matters such as iron particles, buttons, plastic impurities, etc. and their rejection into a collecting box [24].



**Dell'Orco & Villani machines at Cetia**

Source: [CETIA | From goods to materials](#)[2024]

## Ken Mills Engineering

Type: Garnetting/Tearing

Ken Mills Engineering offer machinery solutions to remove trims & disruptors via ballistic separation and density/air separation.

In addition, they offer solutions for textile recycling pre-processing including baling, bale-breaking, sorting, conveyance, and size reduction/disruptor removal.

Ken Mills Engineering's systems are tailor-made to suit each customer's requirements. Their customers include major mechanical recyclers in the UK, as well as key suppliers in automated textile sorting equipment.

UK based, they have over 40 years of experience in the industry and can provide initial concept and system design as well as installation and service support.



**Wiper rag metal detection with auto feed line**

Source: Ken Mills Engineering[2024]

## Andritz

Type: Garnetting/Tearing

Andritz has recently partnered with PellencST and Nouvelles Fibres Textiles to create an automated textile sorting and recycling facility.

Within this facility, Andritz have designed a system that is capable of removing “hard parts” such as buttons or zippers.

There is not much public information regarding the technology being used for this task, how accurate it is or how repeatable.

MTC have attempted to contact Andritz and are awaiting a response.



**Nouvelles Fibres Textiles Sorting Facility, France**

Source: Andritz.com [2023]

Note: Information has been provided by technology suppliers and has not been validated through testing/trials.

Summary Table				Trimclean Valvan		Autosort Tomra		Ecoclip Picvisa		Tearing / Garnetting	
	Criteria			Specification		Specification		Specification		Specification	
Measures	Lower Limit	Acceptable	Upper Limit								
Sensor Deck	N/A	VIS Electromagnetic Machine Learning	VIS NIR Electromagnetic Machine Learning	2 x VIS Electromagnetic Machine Learning		NIR VIS Electromagnetic Machine Learning		NIR VIS Electromagnetic Machine Learning		N/A	
Cost	£500k	£200k	£100k	£300k - £500k, including size reduction		£130k - £300k, excluding size reduction		£175k - £275k, excluding size reduction		Bespoke Machines	
Throughput per machine (Tonnes/hour)	0.5	3	>3	1.0		4.5		2.5		Bespoke Machines	
Categories sorted per machine	N/A	2	2	2		2 (up to 3)*		2		N/A	
UK Support Offices	No	Yes	Yes	No		Yes, UK engineering support available		No		TBC	

Legend	
Suitable	
Potentially Suitable	
Not Suitable	

Disclaimer: All the equipment reviewed above are proven, commercially viable options. The RAG status reflects a brief assessment of the equipment specifications against the requirements of the ATSP and does not reflect the supplier or equipment's overall capability.

# Market Review Summary

## Ballistic separation

Ballistic separation technology has good potential for disruptor removal but is **heavily reliant on the pre-processing of the textiles to create suitable swatches for detecting the disruptors.**

Valvan, Tomra and Picvisa technologies all use the ballistic separation technique that has been used in other waste recycling industries with high levels of success. There is little difference in the technologies being implemented by these companies, with the key distinguishing factor across them being their throughputs, generally correlating with the companies experience in other recycling industries.

## Ballistic separation limitations

**Material yield is a large problem** with ballistic separators as any swatch that has a disruptor present is rejected, taking a percentage of the textile with it.

There are also **limitations with the presentation of the swatches on the conveyor belt – with some of the disruptors being hidden from the sensor deck and being missed the first time they are processed.** Technologies such as X-Ray could increase the Right First Time percentage and will be explored further in the next edition of the report.

## Garnetting/Air Separation

Other disruptor removal techniques, such as garneting, using air-based separation have less information available relating to their function, throughput, technology and processes being used for disruptor removal. MTC have experienced some challenges finding this information to compare the technique’s accuracy. Further investigation into this method is being completed.

## Future Opportunities

Disruptor Removal is a **critical step in the purification process of the feedstock for recycling.** Emerging technologies utilising different methods of removal will be a key area of further research for the following edition of this report.

## Challenges of Disruptor Removal

There are limited technologies available on the market for disruptor removal with the level of throughput and control that will be required to create consistent and high-quality feedstock. Traditional disruptor removal methods are manual and time/labour intensive, while current automated methods have poor material yield and control over the disruptor removal. With more manufacturers moving into the textile recycling market, emerging technologies can play a substantial role in improving the efficiency of the disruptor removal.

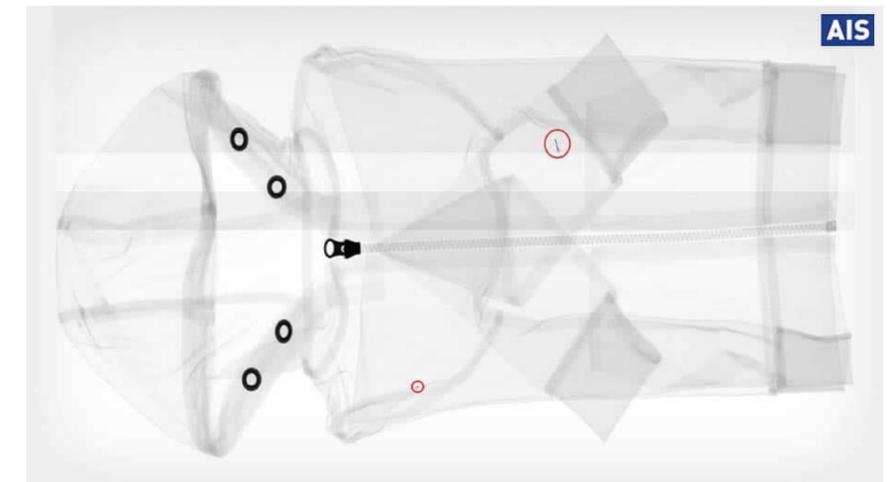
Common challenges that are faced across all the Disruptor Removal technologies are:

- Disruptor removal requires pre-processing (size reduction)
- Poor material yield
- Disruptors hidden from detection
- Feeding/orientating textiles
- Lack of control removing disruptors
- Lack of information/consensus regarding the physical output (feedstock) requirements for chemical recyclers



**Robot handling textiles**

Source: kuka.com [2023]



**X-Ray of Hoodie showing disruptors**

Source: AISXray.co.uk [2023]

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# SYSTEMS ENGINEERING

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## Equipment Morphology Overview

This report has reviewed the commercially available technology for Conveyance, Fibre Identification, Size reduction and Disruptor Removal. When considering the suitability of the equipment for use in the ATSP, the integration of the equipment and configuration of the layout is critical to achieve efficient operation of the facility.

A High-Level Overview table below highlights the input and output methods of the reviewed equipment. Standard Hopper/Conveyor inputs and outputs pose minimal challenges for machine bonding. Differences in throughput capacities of the equipment identifies some potential transitional bottlenecks from process to process depending on the equipment chosen.



	<i>FIBRE IDENTIFICATION &amp; SORTING</i>				<i>SIZE REDUCTION</i>				<i>DISRUPTOR REMOVAL</i>		
	Throughput Requirement: 4.6 T/hr				Throughput Requirement: 4.6 T/hr				Throughput Requirement: 3.2 T/hr		
	AUTOSORT	FIBRESORT	MISTRAL CONNECT	ECOSORT TEXTIL	SHREDDERS	GUILLOTINE CUTTERS	ROTATIVE CUTTING MACHINE	TEARING MACHINE	TRIMCLEAN	AUTOSORT	ECOPICK
Throughput	4.5 T/hr	1.2 T/hr	4.0 T/hr	2.0 T/hr	~ 6.5 T/hr	~ 2.0 T/hr	~ 2.0 T/hr	~ 2.0 T/hr	1.0 T/hr	4.5 T/hr	2.5 T/hr
Input Method	Conveyor Belt	Conveyor Belt	Conveyor Belt	Conveyor Belt	Hopper	Conveyor Belt	Conveyor Belt	Hopper Feeder	Conveyor Belt	Conveyor Belt	Conveyor Belt
Output Method	Aggregate Bin	Aggregate Bin	Aggregate Bin	Aggregate Bin	Aggregate Bin/Conveyor	Aggregate Bin/Conveyor	Aggregate Bin/Conveyor	Aggregate Bin/Conveyor	Aggregate Bin	Aggregate Bin	Aggregate Bin

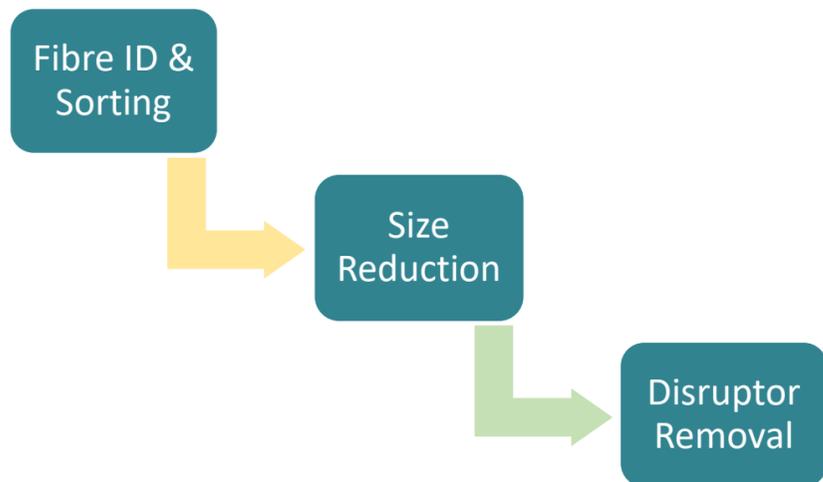
## Equipment Morphology Overview

When looking at the potential combinations of equipment, there are potential areas where bottlenecks may form. Bottlenecks can be overcome in design by introducing buffers and/or increasing the number of equipment/processing lines.

The systems engineering aspect of the facility design should not be understated. It is recommended to complete design studies and simulations of equipment combinations under various operational scenarios to inform the engineering design.

FIBRE ID TO SIZE REDUCTION	AUTOSORT	FIBRESORT	MISTRAL CONNECT	ECOSORT TEXTIL	SHREDDERS	GUILLOTINE CUTTERS	ROTATIVE CUTTING MACHINE	TEARING MACHINE
AUTOSORT	4.5 T/hr				6.5 T/hr	2.0 T/hr	2.0 T/hr	2.0 T/hr
FIBRESORT		1.2 T/hr			6.5 T/hr	2.0 T/hr	2.0 T/hr	2.0 T/hr
MISTRAL CONNECT			4.0 T/hr		6.5 T/hr	2.0 T/hr	2.0 T/hr	2.0 T/hr
ECOSORT TEXTIL				2.0 T/hr	6.5 T/hr	2.0 T/hr	2.0 T/hr	2.0 T/hr

*The colour coding in the tables highlights potential bottlenecks based on the throughput capacities of a single machine.*



SIZE REDUCTION TO DISRUPTOR REMOVAL	SHREDDERS	GUILLOTINE CUTTERS	ROTATIVE CUTTING MACHINE	TEARING MACHINE	TRIMCLEAN	AUTOSORT	ECOPICK
SHREDDERS	6.5 T/hr				1.0 T/hr	4.5 T/hr	2.5 T/hr
GUILLOTINE CUTTERS		2.0 T/hr			1.0 T/hr	4.5 T/hr	2.5 T/hr
ROTATIVE CUTTING MACHINE			2.0 T/hr		1.0 T/hr	4.5 T/hr	2.5 T/hr
TEARING MACHINE				2.0 T/hr	1.0 T/hr	4.5 T/hr	2.5 T/hr

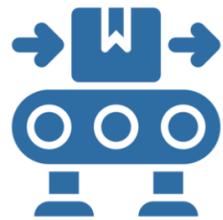
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# CONCLUSIONS, RECOMMENDATIONS & NEXT STEPS

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## Conclusion

Having reviewed the commercially available technologies for Conveyance, Fibre Identification, Size Reduction and Disruptor Removal, it is evident that there is generally not a one-size-fits-all solution for any technology area, and each has challenges that require further research and development. A combination of commercially available technologies and further-developed emerging technologies should be integrated into a further ATSP, dependent on the ATSP's output customers (continued next slide)



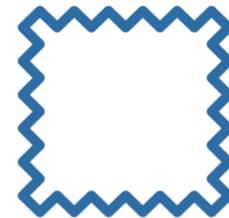
### Conveyance

- Horizontal belt conveyors are proven in industry and should be utilised in an ATSP in floor and overhead configurations dependent on the space available
- Pneumatic conveyors should be used in an ATSP after textiles have been size-reduced to control dust, fire risks, and optimise space.



### Fibre Identification

- Tomra & Valvan's equipment have been identified as the most viable candidates for this ATSP, [benefits and risks outlined on [slide 56](#)].
- The decision on which system to procure should be based on a detailed capacity and simulation of an ATSP to be completed in WP5



### Size Reduction

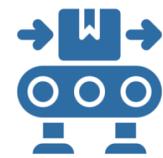
- To provide feedstock for recyclers who require a partially size-reduced 'rough cut', a rotating-shaft shredder would be most appropriate as it can achieve the highest throughput
- To provide feedstock for recyclers who have very specific requirements of their optimum swatch size, a guillotine-type cutter would be most suitable.
- To provide feedstock for certain mechanical recyclers, a tearing machine would be most suitable, as it best preserves the length of the fibres, although many mechanical recyclers would do this process in-house.



### Disruptor Removal

- The least developed technology area; no commercially available technology is entirely suitable for an ATSP.
- Ballistic separation technology has good potential but has high wastage and is heavily reliant on the pre-processing of the textiles to create suitable swatches for detecting the disruptors and challenges from singulation and presentation into the detector to eliminate overlaps and 'hidden' disruptors getting through.
- Garneting/Air separation disruptor removal could be utilised where textiles can be accurately pre-sorted into streams where the types of disruptor are known (metals & plastics).

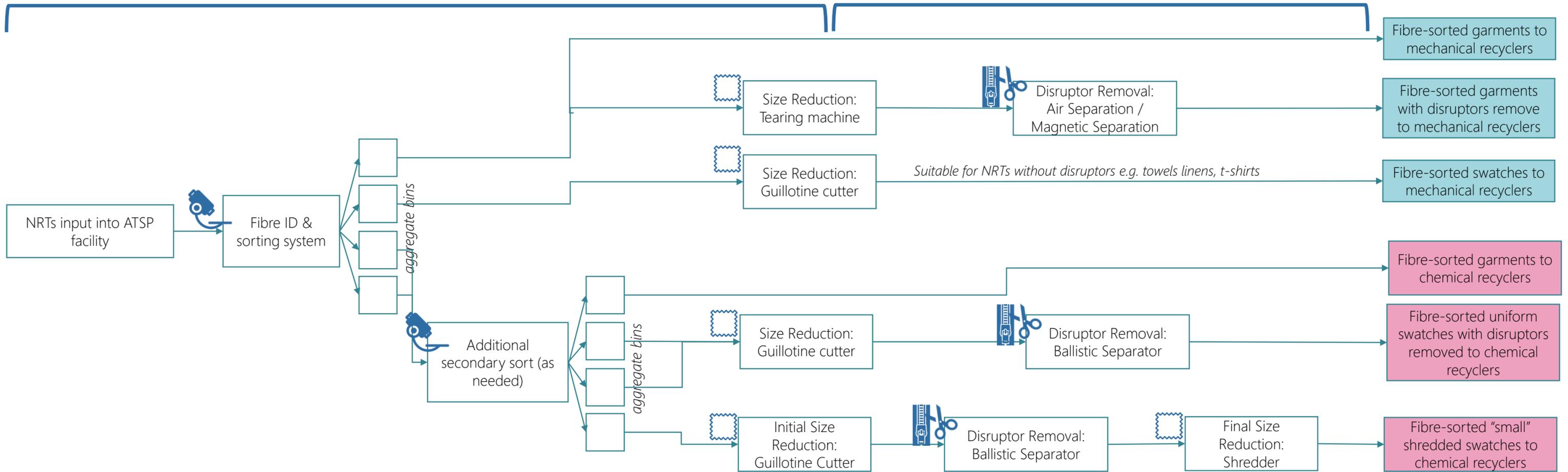
# Conclusion/Recommendations Process Flow Options – ILLUSTRATION ONLY



Horizontal belt conveyors for processes before Size Reduction



Pneumatic conveyors for processes after Size Reduction



## Conclusion

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The textile recycling landscape is still developing, and there needs to be open communication between recyclers and technology providers so that their feedstock requirements can be understood, and equipment can be configured appropriately.

When selecting equipment for use in an ATSP, with high throughput targets and multiple output streams, the chosen plant designer & systems integrator will be critical to design the layout and combination of equipment to meet the specification of the facility.

*In the next iteration of this report, Emerging Technologies will be explored to address some of the highlighted challenges of the technology areas [see next slide].*

***'It is not a "what came first, the chicken or the egg" situation. The system needs to be set up simultaneously. If there isn't a system to develop feedstocks to meet recycler specifications, there will be no recycling. If there is no recycling, we will not divert textiles from landfill and incineration.'***

***Karla Magruder, Accelerating Circularity,  
Textiles Issue 1 2024***

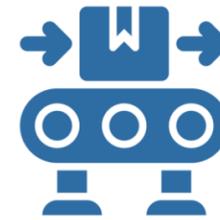
## Next Steps: Challenges for Further Research

Based on interviews with stakeholders in the industry, MTC advises that automating the movement of individual garments onto conveyor systems or bins is the most impactful technology area to be developed for a future ATSP.

Based on the feedback from textile recycler's spoken to, the most important aspect to them was to have **very accurate fibre-sorted feedstock that meets their feedstock specification tolerances.**

Industrial size reduction and disruptor removal processes would enhance the value of the feedstock. While the most commercially-developed chemical textile recyclers already have processes for handling size reduction and disruptor removal themselves, it's unclear which way the market will go. Some recyclers will expect the market to provide efficiencies in pre-processing steps via ATSPs, while others may not need them. As there will be more and more competition amongst textile recyclers, creating efficiencies in the system will be crucial for the success of ATSPs and fibre-to-fibre recycling overall.

So, the most important and urgent aspect for a future ATSP is to bridge the material movement/conveyance and fibre identification steps together to **singulate and sort post-consumer textiles as accurately and quickly as possible.**



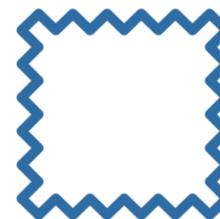
### Conveyance

- Robotic handling of high-variation textiles; bespoke grippers for textile feeding systems
- Controlled feeding and singulation onto conveyors
- Integrating fibre-ID with robotic picking and placing



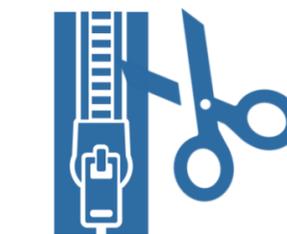
### Fibre Identification

- Verifying scanning systems' accuracies against a single data source
- Knitted vs woven classification
- Multi-layer fibre identification



### Size Reduction

- Dust management
- Modular/reconfigurable set up to adapt outputs



### Disruptor Removal

- Identifying presence of hidden disruptors
- Feeding and orientation of textiles into ballistic separators
- Alternate automated means of removing disruptors prior to size reduction
  - trials to determine if effort is worth the potential yield improvements

# ACKNOWLEDGEMENTS

*Many thanks to the Consortium Work Package partners for participating in interviews and sharing their industry knowledge.*



# User Requirement Brief

## ATSP Throughput Requirements

Initial Target Volume: 25,000 Metric Tonnes per Annum

Future Target Volume: 50,000 Metric Tonnes per Annum

No. of Shifts: 3

Annual Hours per Shift: 1,800\*

Initial Implied Factory Vol. Output: 4.6 Metric Tonnes per Hour

Future Implied Factory Vol. Output: 9.2 Metric Tonnes per Hour

Fibre Identification Technology Requirement	
Detectable Fabrics <i>(In any blend combination)</i>	Cotton Polyester Wool Viscose Nylon Acrylic
Accuracy	>95%
Colour Detection	Yes
No. of Sorting Bins	12+
Metric Tonnes per Hour	4.6
Garments Per Second (Initial Target)*	Approx. 4

Conveyance Technology Requirement	
Metric Tonnes per Hour	4.6
Garments Per Second (Initial Target)*	Approx. 4
Challenges	Singulation (Bulk to Individual Garments)
	Garment Handling - Presentation to scanners
	Garment Handling – Sorting into Aggregate Bins

Size Reduction Technology Requirement	
Chemical Recyclers - <i>Shredding</i>	Short Fibre Lengths, No individual Fibres <i>8mm<sup>2</sup> to 80mm<sup>2</sup></i>
Mechanical Recyclers - <i>Tearing</i>	Individual, Long Fibre Lengths <i>TBD</i>
Metric Tonnes per Hour	4.6
Garments Per Second (Initial Target)*	Approx. 4

Disruptor Removal Technology Requirement	
Identifiable Disruptors	Metal (Zipper, Button, Rivet, Buckle, etc.) Plastic (Button, Snap Button, Zipper, etc.) Fabric (Elastic, Embroidery, other fabrics, etc.) Other (Leather, Fur, Print, Sequin, etc.)
Metric Tonnes per Hour*	3.2
Garments Per Second (Initial Target)**	Approx. 3

\*based on 225 working days, and 7.5 "productive" hours per shift.

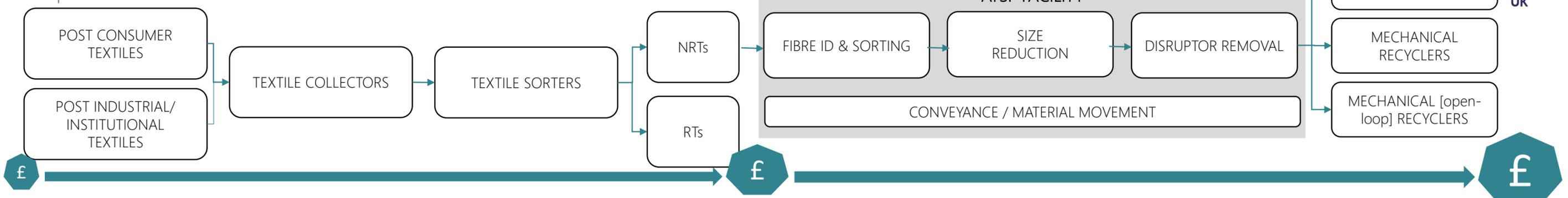


# Partner/ Supplier Interview Summaries

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# Interviews Summary: Overall Market & Commercial Considerations



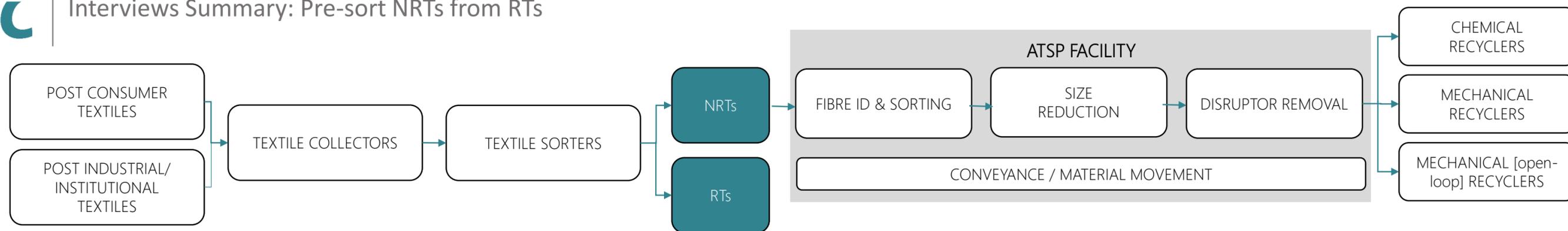
- Research focused on understanding local feedstock markets and achieving flexibility in plant management.
- **Recycling NRTs currently not economically valuable for sorters-** bottom end of market in terms of economics
- *"Textile recycling 200 years ago was a lot easier because there was a market for all this stuff".*
- There are technologies to recycle all textile waste components, even dust, nothing should go to waste, but the value decreases.
- See greater future economical opportunities with chem. recycling- as there are so many slow processes needed to retain fibre length for mech. recycling
- See need for a white paper quantifying what you are getting out of different recycling streams (not just HOW it is done) and developing strategies for each.
- Post-industrial waste is traceable, homogeneous, ensuring better identification and maintained quality.
- RFID tags for product passports face challenges: cost, size, effectiveness, tracking costs, and no legislative requirements.

- Biggest challenge for textile recycling industry is the need for new **MARKETS** for recycling grades.
- Most members sort for re-use (market value) v.s recycling because there is not enough value in it.
- Convinced that technology for sorting is there, but ability to do something with it [recycling grades] is not there because we don't have markets for it.  
*\* Reiterated by academic/start-ups: "The equipment set up [was] working, but couldn't do anything with outputs".*

- Hesitant to make big investments into equipment to provide for recycling streams - emphasized the need for industry wide de-risking and proving out recycling pre-processing technologies.
- Currently, lack of policy or economic incentives to incentivize collecting NRT-only streams.
- Sceptical about green-washing claims for mechanically 'down-cycled' textiles – most children's toys or insulation manufacturers won't put random textiles into them; need to have full traceability.
- Sorters under extreme pressure to make profit – need for their outputs to recoup the investment put into it- price is way too low for feedstock from big Scandinavian recyclers.
- 'Down-cycled' markets with shorter life cycle tend to be more commercially attractive than sending to chem. recyclers.

- Recognise business opportunities as European textile collection is increasing.
- Re: post-industrial shredding – estimated that currently costs for meeting a chem. recyclers' requirements are almost double the cost of shredding to incinerate and clients are not willing to pay this.
- Estimate customers would pay approximately 10% more to know their product going to be recycled rather than incinerated.
- Recycled fibres face economic challenges as virgin fibres are produced in such high volumes/ at lower cost- foresee that Extended Producer Responsibility (EPR) schemes will help to offset costs.
- Technology available for advanced detection- but market in textiles is not there yet- most enquiries don't have a proper business case.

- Some recyclers require high-volume shipments (approx. 5 metric tonnes or higher)
- Require an ATSP to facilitate economies of scale to get efficiencies in feedstocks from NRTs. If left to individual collector/sorters, there is an added margin to feedstock prices that is not commercially workable for recyclers.



## ACADEMIA

- Challenges with post-consumer NRTs due to unknown history, washing, and chemical use.
- Post-industrial/"pre-consumer" NRT waste poses their own circularity challenges – as there is no obvious second-life market for it.
- Sorting project involving Soex in Berlin (manually) grades clothing into 1st, 2nd, and 3rd grades for reuse.
- Skilled workers pre-sort high-value second-hand clothing with vintage labels, cashmere, and wool.



## TRADE ASSOCIATION/ NGO

- There is a need to improve sorting process efficiency (Within RTs and between RTs and NRTs) due to significant manual labour and associated costs, which often are outsourced to countries with lower labour costs.
- Estimates that only 120K tonnes of textiles are sorted a year in the UK, despite approx. 400K-450K tonnes being collected, as most is being sorted abroad due to labour costs.
- Practice of sending mixed RT and NRTs abroad to be sorted can only be done by showing there is a high % of re-used textiles – as more countries are prohibiting the importing of waste.



## COLLECTORS &amp; SORTERS

- Facilities primarily focus on sorting for re-use, currently operating at a financial loss in recycling.
- Aspire for the ATSP to become efficient enough to generate revenue from NRTs/ recycling processes.
- NRTs need to be aggregated from various sorters in the UK to meet recyclers' feedstock MOQs- **\*\* also reiterated by trade associations/NGOs**
- Need for a visual system to determine re-wearability; integration challenge – some early research into using AI to identify brand logos for grading for re-use markets.
- Would like to see more handheld fibre-ID devices for pre-sorting in donation centres.
- Believe more legislation needs to be implemented requiring mandatory recycled content in new products to incentivise wide-scale investment in recovering NRTs otherwise sent to waste/incineration streams.



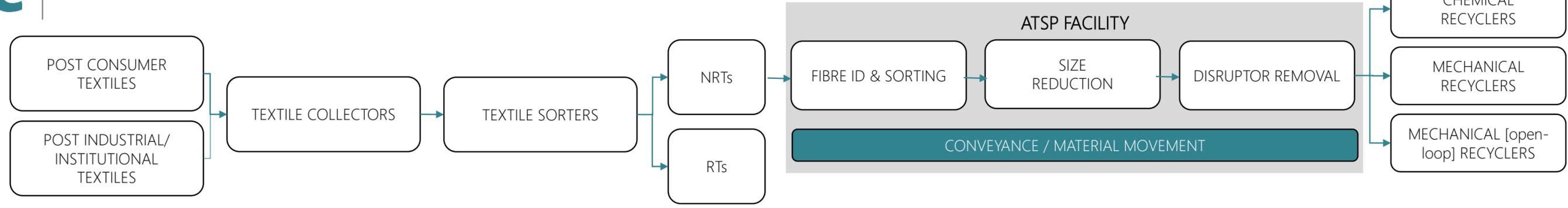
## TECHNOLOGY PROVIDERS

- Believe market needs efficient manual or automated scanning for high value re-wearable textiles.



## TEXTILE RECYCLERS

- Most recyclers have developed processes/performed small trials on homogenous post-industrial waste, rather than difficult post-consumer waste streams, but anticipate that in future approx. 70% of their feedstock to be from post-consumer waste



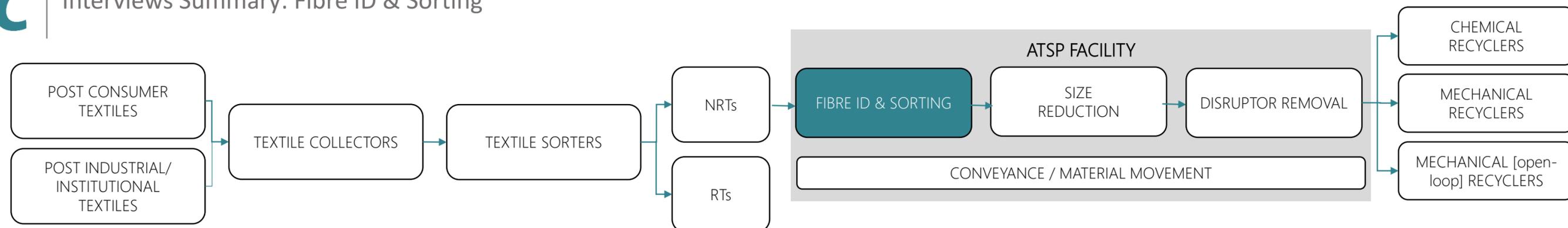
- Pneumatic processes and chute-feed considered useful for soft textiles rather than conveyor belts for overhead handling.

- Independently have heard that automatic and robotic feeding systems don't have the speed needed for the industry
- Best conveyancing systems they've seen in industry utilise dead space overhead or underneath to benefit from gravity and minimise overall footprint

- Valued the potential integration of PicVisa into facility for its ability to navigate 90-degree turns, addressing space constraints.
- FibreSort limited as it cannot accommodate 90-degree turns (at time of purchase consideration).
- Storage is a significant challenge for the end product because it takes time to accumulate sufficient bales to fulfil recycling customer orders.
- Challenges with textiles wrapping around traditional conveyors.
- Overlap on the conveyor belt is a challenge/problem- **\*\* reiterated by several collectors**
- Commends the Valvan roof conveyor for its efficiency, reducing labour by 100 people. Uses compressed air to unload items.
- Unimpressed with robotic arms due to slow speed, inaccuracy, and snagging issues; requires constant human monitoring due to variation in materials going through. Works mainly for standard items.
- Robotic arm feeding systems only useful if waste is already pre-segregated in to NRT only streams
- Have seen vertical bale breakers with hooks used for efficient singulation.
- Gravity trailer tipper at SatCol, using hydraulic lift, reduces manual effort from 15 hours to 20-30 minutes.

- The speed of feeding the sorting system and singulation of textiles is the biggest limiting factor/bottleneck - **\*\* reiterated by multiple suppliers**
  - Leading suppliers in textile equipment estimate that segregating to single items can be done 1 garment/sec – but very difficult to achieve
- Conveyor technology is the limiting factor in the size of garments which can be inputted.
- Some Fibre-ID suppliers provide conveyance as part of their overall package, others outsource to an integrator.
- Width of machines/conveyors used and types of valves/air nozzles used affects price – all can be changed/customisable.
- Non-singulated garments are detected through AI and rerouted.
- PellencST's Turbosorter stabilizes material on the belt by maintaining airflow speed equal to the belt, preventing smaller garments from tumbling

- Processes are designed to input entire bales (including any covering and strapping) - this necessitates these materials to meet fibre specifications.
- Some use pneumatic pumping and inclined arrangements for moving materials.
- Emphasised need for limited manual handling in their process.



## ACADEMIA

- Challenges with accurately detecting garments with special coatings, adhesives and surface treatments.
- Mechanical recyclers will want to know fibre length and diameter.
- Identifying multi-yarn, elastane, and particular types of dyed materials pose challenges; sophisticated scanning required for accuracy.
- Difficulty in determining chemical footprint (in production and in consumer use); poses challenges to downstream recyclers/ health & safety considerations.
- New developments in AI systems to ID & sort textiles with less expensive system than main market players – but not commercialised yet.
- Highlighted that colour is difficult to remove in recycling, especially when fixed into yarn.
- Technology to remove dyes would make it easier to achieve economies of scale on mono-colour feedstock, but at a huge chemical footprint cost.

## TRADE ASSOCIATION/ NGO

- Expressed interest in trialling Tomra tech integrated at the front and Valvan tech at the back of the process.
  - Appreciated the Tomra trommel system for effectively separating textiles and feeding them onto the conveyor.
- Aware that Valvan is eager to engage in discussions and enter the UK market.
- Recognize the limitation of NIR technology in handling clothing with multiple layers.
- Chem. recyclers' spec requirements for maximum weight % of trims/contaminant is often a commercial consideration for maximum yield, not a technical issue.
- Accuracy is crucial for recyclers; specifications often require IR spectroscopy for quality assurance.
- Collaborations occurring between textile mills/manufacturers and fib tech providers to validate readings and improve sorting accuracy.

## COLLECTORS & SORTERS

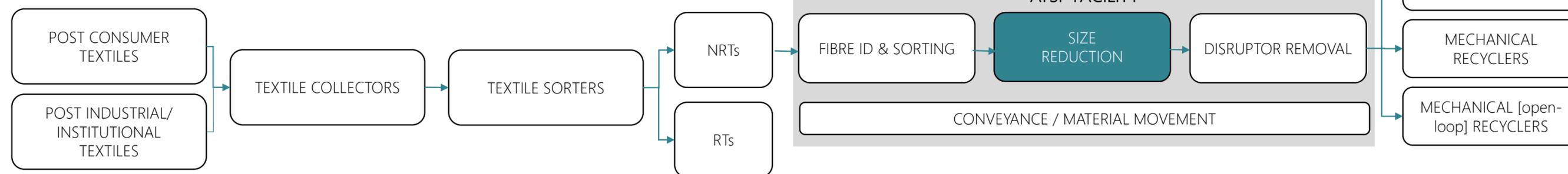
- Valued the potential integration of PicVisa into facility for its ability to navigate 90-degree turns, addressing space constraints.
- Appreciated PicVisa's capability to scan the entire garment, as opposed to a single isolated location of the garment.
- Want to have a tech that can sort all NRT that gets collected – not go into 'other'/generalisation bin.
- Desire to see a trial where all scanning technologies are compared against each other using same data sets e.g. ReFashion and Royal Fashion Museum have databases of fibre types.
- Multi-layer fabrics pose challenges for all systems in use.
- Challenges with detecting coarse vs. fine fibres and carrier/core-bound fibres.
- Black dyes, especially containing graphite, slows down detection.
- Konica Minolta acquired company with scanning technology and are developing their own automated textile conveyor system – are trialling with some collectors.

## TECHNOLOGY PROVIDERS

- Several providers started in general waste sorting and plastics recycling and have adapted their technologies for textiles.
- Black/dark materials are not a significant problem, especially as carbon blacks are rarely used in textiles.
- Colours and shiny fabrics, in general, do not pose issues.
- Have considered higher-tech and sophisticated spectroscopy scanners, but many are too expensive for commercial viability.
- Most accurate detection focused on polyester and cotton plus elastane blends – most applicable to industry.
- Problems in spectroscopy arise at 4-5m/s speed, but this speed is generally unnecessary – most run at 3 m/s.
- Limitations encountered with complex blends (3 or more fibre types), carbon black dye, multi-layers, wet textiles, core-spun fibres and elastane detection.
- Cotton recyclers see viscose as a contaminant as it has a synthetic fibre structure, so fibre ID technology needs to be able to differentiate.

## TEXTILE RECYCLERS

- Every chemical recycler has slightly different requirements on fibre blend ratios.
  - Some can accept small amounts of elastane, others cannot accept any
- Each individual textile garment does not have to meet specification – each bale has to have an average of what is in the spec.
- Different fabric structures (woven vs knitted) affect chemical processing and how much waste is generated.
- Quality of feedstock from NIR automatic sorting systems is excellent – no failures reported.
- Quality is worse from manual sorted suppliers- even those who claim to use handheld scanners for verification.
- Some recyclers have to verify new supplier feedstock with lab tests- stated that NIR scanned info for bales is not accurate enough.



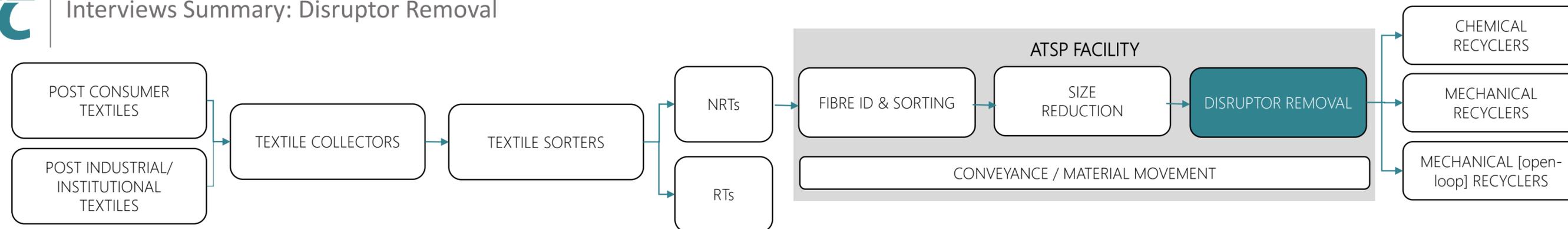
- Mech. recycling of low-quality material results in disintegration into dust.
  - Impressive mechanical recycling set-up seen at SOEX, but saw challenges in managing large bags of dust.
- There is less twist in knitted yarns, so they are easier to untwist and recover fibres for mech. recycling
- Re: disruptor removal and size reduction: *"The supply (of sorted, clean, size-reduced feedstock) is more than the demand, so they want to stick with that they are comfortable with. As soon as the competition will come, they will have to find ways to deal with that."*
  - reiterated by discussions with leading recyclers who have made the decision to invest in size reduction and disruptor removal themselves.

- Difficulties in size reduction techniques which retain fibre integrity limits the opportunities for mechanical recycling - most yarns must be used with at least 80% virgin fibres to achieve same performance.
- Highlighted that size reduction/ shredding should be carried out at a central place – too difficult to individual collectors/sorters to take on themselves.
- More and more chemical recyclers are accepting full garments rather than specifying feedstock be supplied to certain size spec.
- Think that recyclers would be willing to pay more if the quality re: size spec is right, but could face supply competition from other recyclers accepting full garments.

- Enquiring into purchasing shredding equipment to add value – but size of capital investment is daunting.
- Previously both mech. and chem. recyclers were very picky about feedstock specs, but now opening up to accept something more feasible to be produced with post-consumer waste.
- Would like to see fibre-opening technologies that can retain fibre integrity for mech. recycling so materials can be closed-loop/not down-cycled.
- Highlighted would like to see size reduction done by recyclers for business efficiency, collectors/sorters only willing to invest when ROI is proven.

- Different requirements in size spec means different costs for machinery and throughput.
- Smaller cut requirements require higher costs to achieve – not commercially viable, recycling customers not willing to pay the excess.
- Expressed frustration with the challenge of meeting chemical recyclers' precise size needs, involving considerable trial and error during technology development.
- If higher volumes and higher demand, size reduction machinery could be made more efficient and economical.
- Challenge in post-consumer waste is tuning and continuous maintenance of cutting blades for different materials.
- Service contracts and ability to maintain blades and equipment most important – particularly with handling all different variations of post-consumer textiles.
- Most common failure modes with shredders are knives cutting and breaking, requiring re-welding.

- While some recyclers are willing to conduct size reduction to some extent themselves, it is still unclear which way the market will go- it is expected that recyclers will expect the market to provide efficiencies in the pre-processing steps via ATSPs, similar to the PET bottle-to textile supply chain
- Each recyclers' process requires different 'optimum' swatch sizes – *"No [recyclers] seemed to want what the market has to offer."*
- Biggest challenge is achieving size spec at industrial scale.
- Concern with small swatches and dust generation and safety implications; need separation between size reduction and chemical plant operations.
- Concern/ongoing research with dust waste produced during size reductions- amongst different fabric structures.



- Dyes are considered serious disruptors, and research is ongoing for removing and recycling dyes – but no commercial equipment exists.
- Traces of copper and nickel could cause an explosion in certain chem. recycling processes.
- Challenges in disruptor removal with adhesives, threads, and labels.
- Research has been done to shred down to 50-60mm piece sizes; air separator can get out vast majority of contaminants.
- Have worked for many years on how to get a garment flat with robots/automation – has not been achieved yet.

- Disruptor removal has a greater impact on mech. recycling than chem., re: preserving fibre integrity.
- Laser removal preferred for mechanical recycling as it is the least invasive removal procedure.
- Vastly different methods needed for different recycling outputs- may require different facilities with different pre-processing steps
- More and more chemical recyclers are accepting full garments without any disruptor removal required.
- Yield loss from disruptor removal must be considered for potential ATSP and business model.
- Energy consumption comparison between different removal methods should be consideration for ATSP

- Emphasized disruptor removal as a crucial and emerging element in ATSP, acknowledged as the top challenge.
- Found TrimClean impressive but slow – far too expensive to put all NRT through.
- Wants to see trials on disruptor removal to improve efficiency and remove waste.
- Currently remove disruptors for mech. and chem. recyclers at small scale – not enough to be commercially efficient.
- Challenges in removing heavy plastics.
- Type and level of investment in disruptor removal to vary significantly dependent on output and recycler customer.
- Commercially ideal to work with recyclers who do the disruptor removal themselves.

- Have used over-band magnets to remove metals.
- Metal detection system can be used with tunnel with ejector flap and sensor array on conveyor belt, with eject conveyor belt air nozzles – there is IP on this 'material separation' technique able to be licensed out.
- Underneath camera can detect multi-layer fabric 'disruptors', but facility is set up so that these are filtered out from the process in the manual pre-sort.
- Challenge in post-consumer waste is tuning and continuous maintenance of cutting blades for different materials.
- Fibre-ID tech providers can do part of process, sorting out non-fabric components.
- Start-up company has developed technology to disassemble garments with 'dissolving' thread – can achieve max. of 10% waste.
- Investing in research into AI-assisted laser removal of disruptors.

#### Chemical recyclers:

- Disruptor removal is a commercial challenge, not a technical one – to get best yields.
- Can use pH modification and filtration systems to remove disruptor components during density/gravity-driven system processing.
- Fire retardants and certain dyes are considered disruptors in some chem. recycling processes and must be removed.
- More-established recyclers setting up capability to remove trims/disruptors themselves so they can obtain feedstock from a wider range of sources
  - Therefore, not willing to pay a 25% premium for trims being removed.
  - Interested in disruptor removal as an emerging technology area- if could be done in a central location and more efficiently than investing in themselves.