- TECHNOLOGY ASSESSMENT -

REDEFINING TEXTILE WASTE SORTING:

Impulses and findings for the future of next-gen sorting facilities

TEXAID

ITA Group International Centre for Sustainable Textiles

CETIA FROM GOODS TO MATERIALS

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IMPRINT

1 TEXAID Textilverwertungs-AG, Recycling Solutions, Steinhausen, Switzerland
| *Anna Pehrsson*

2 ITA Academy GmbH, Digital Manufacturing, Aachen, Germany
| *Gesine Köppe*

3 Institut für Textiltechnik gGmbH, Augsburg, Germany
| *Sebastian Geldhäuser, Amon Krichel, Prof. Dr.-Ing. Mesut Cetin*

4 Institut für Textiltechnik der RWTH Aachen University, Aachen, Germany
| *Florian Pohlmeyer, Kai Müller*

5 SAS CETIA, Recycling Solutions, Bidart, France
| *Julien Breton*

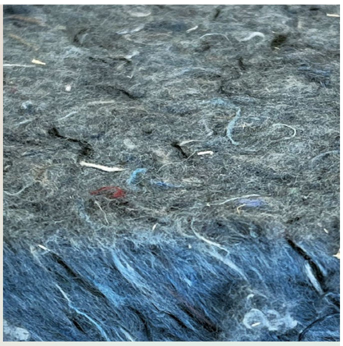
1 EXECUTIVE SUMMARY

Textiles play a fundamental role in our society, providing us with essential commodities such as clothing, footwear and home textiles. Once textiles are in use, they become unwearable or unusable after some time, leading to the generation of high amounts of textile waste in the world, which at some point end up in landfills or incinerators. Therefore, it is essential to collect and sort textile waste according to the waste hierarchy to allow for the best utilization to circumvent environmental pollution and conserve and reuse resources. Until now, textile sorting for reuse and recycling has been labor-intensive and not accurate enough for recyclers, making it expensive and creating quality issues for recycling. The Transform Textile Waste into Feedstock (TTWiF) project carried out a technology assessment (TA) to assess the best available sorting techniques and processes. Furthermore, it conceptualized and developed a highly automated and scalable textile sorting solution that addresses the critical challenges in textile recycling. The results from the TA show potential developments that would benefit textile companies and recyclers, through aspects such as:

- Faster and better quality recycled textiles
- Higher throughput of sorted textiles
- Reduced costs for textile recycling
- Increased profitability and sustainability for the textile and apparel industries

This white paper will take a deep dive into the method used and the findings from the technology assessment. The sorting system evaluated, which has identified bottlenecks and possibilities for sorting textile waste, has the potential to revolutionize the textile recycling industry and make it possible to achieve a more circular textile economy.





1.1 PROBLEM STATEMENT

European textile consumption is the fourth largest contributor to environmental pollution and climate change, following food production, housing, and mobility (European Environment Agency, 2019). The problem of waste in Europe is significant, with 7 to 7.5 million tons of gross textile waste generated currently (McKinsey & Company, 2022). According to McKinsey & Company, 2022, at a certain point textile products become non-reusable waste, and it becomes necessary to recycle them into usable materials. Fiber-to-fiber recycling is critical, as it can help turn waste into value. However, the value chain for textile recycling is not yet fully developed, and only 30-35% of the discarded textile waste is collected. Out of the collected waste, 15-20% is sorted at scale by mid and larger-sized sorting facilities in the European Union, as McKinsey, 2022 noted.

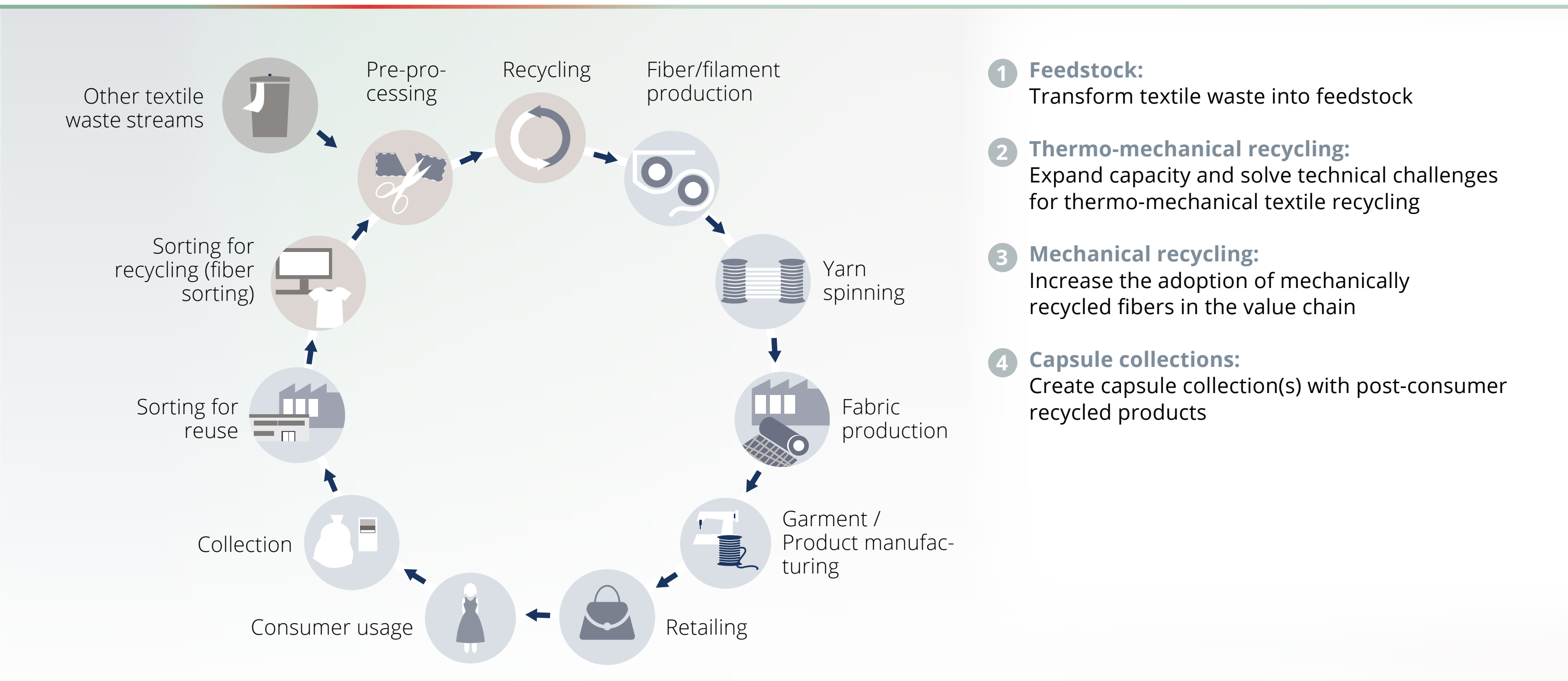


Figure 1: Four major gaps in the value chain which the ReHubs Initiative by Euratex identified. (EURATEX, 2022)

By 2025, all European Union member states are obliged to collect textile waste separately, according to the European Union Law (Directorate-General for Environment, 2022). This will increase the quantity of textile waste collected, however, the quality of the collected items may decrease since the textiles that are currently being incinerated will also be collected. As a result, a higher percentage of the collected textile waste will need to be recycled. To create a circular textile loop, the recycled material will have to be sorted by many parameters such as composition and material type. Currently, the sorting process is primarily manual and not automated.

To meet future demands on the amount of waste that needs to be collected and sorted, as well as the demand on recycling feedstock, it is necessary to match the availability and create cost efficiency. Sorting capacities with larger scale and automation are necessary.

2 AIM OF THE PROJECT

The aim of the "Transform Textile Waste into Feedstock" (TTWiF) project, led by TEXAID, and initiated as part of the ReHubs Initiative by EURATEX, was to understand the state-of-the-art in sorting for reuse and recycling in Europe and how this could be scaled to meet future demands through a TA. The TA aimed to identify state-of-the-art technologies which are suitable to be implemented within a waste sorting facility (textile sorting) of the "next generation". The TA will be able to provide an overview of the best available techniques, systems, and technologies and blueprint on how the sorting process would be set up best, and how different technologies will be able to be integrated and connected.

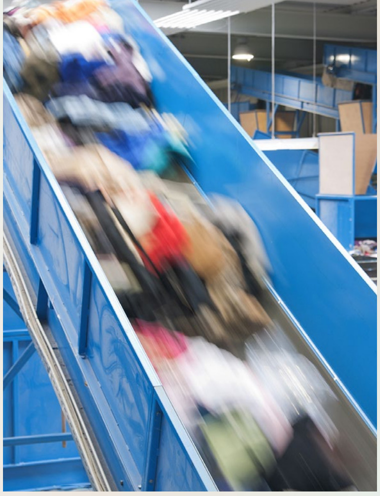
Three major segments have been identified to explore:

1. (Semi-)Automated sorting for reuse
2. Automated sorting for recycling qualities
3. Automated pre-processing for recycling

Within the TA, the technologies within each subfield were evaluated based on several criteria, such as: **technology readiness level (TRL), scalability, availability, speed, size, upgradability, modularity and integrability, environmental and economic performance.**
The objective of each segment of the TA was to provide a detailed overview and analysis of the technologies available and suitable for the respective segment.

2.1 (Semi-) Automated sorting for reuse

Sorting mixed clothes, shoes, and accessories for reuse and recycling is a labor-intensive task that is typically performed manually through several sorting steps. The goal of the process is to separate items into specific product and quality categories, which can result in over 300 different categories depending on the item's quality, condition, and type. To improve efficiency and accuracy, the sorting process needs to be automated and digitally enhanced. This would involve implementing automated handling and transportation technologies and sensor-based parameter detection. The system must recognize specific attributes such as product type, garment condition, size, brand, style, main material, color, textile construction, and trims. The system should also be capable of scanning garments using digital product passports (DPP) as well as those without any information tags.



2.2 (Semi-) Automated sorting for recycling qualities

Currently, the sorting of recycling qualities is carried out manually, relying merely on the feel of the material or analyzing the composition label (when still present and readable) to determine its condition. However, this method cannot guarantee the accuracy of the material composition of a batch going for recycling. The process becomes more complicated when the garment consists of a mixture of different fibers or is multilayered with various materials used. To enable fiber-to-fiber recycling, product and quality categories must be further sorted by fiber composition. Therefore, it is vital that the system sorts the products based on the complexity of the garment, scanning both the outside and inside, front, and back of a garment, and preferably recognizing trims.

2.3 (Semi-) Automated pre-processing for recycling

To achieve successful fiber-to-fiber sorting, the recycling qualities of products need to undergo pre-processing. This involves removing impurities such as trims and other components that might disrupt the recycling process. Trims can be cut off manually or using semi-automatic cutting tools. However, complex garments with multiple layers and trims pose a challenge and are usually sorted into downcycling or incineration fractions.

3 STAKEHOLDERS WITHIN THE PROJECT

TEXAID is a leading company in textile sorting in Europe with over 45 years of experience in collecting, sorting, repairing, reselling, and recycling textiles as well as shoes globally. The company collects around 80,000 tons of textiles annually and has a workforce of more than 1,200 employees across the group. TEXAID also operates over 80 owned and operated second-hand shops in Germany.

Several renowned companies such as Cure Technologies, Concordia, Decathlon, Inditex, Indorama, L'Atelier des Matières, Lenzing, Marchi & Fildi, Purfi, Södra, Worn Again have taken part in and supported the TTWIF project and TA with their expertise with the aim of promoting the development of scaled textile sorting in Europe.

The collaboration of clothing brands, sorters, recyclers, industry partners and scientific institutions (Figure 2) aims to enhance knowledge exchange, speed up innovation, and address real-world challenges.

This collaboration leverages diverse expertise, resources, and funding, fostering the development of practical solutions that benefit both academia and industry, ultimately advancing scientific understanding and driving technological progress.

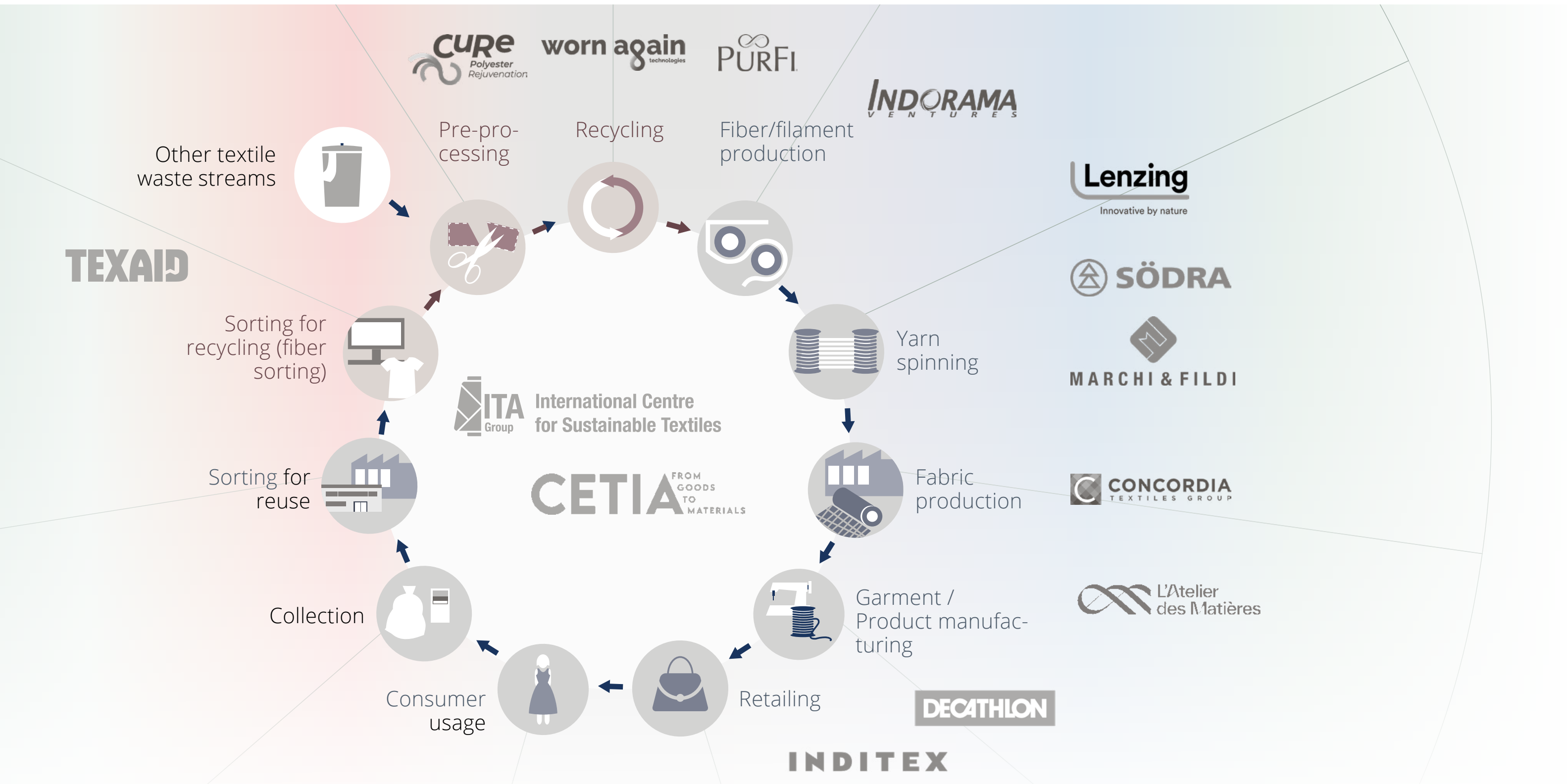


Figure 2: Stakeholders for circularity in the textile and apparel industry

The assessment of technologies for the project was commissioned to ITA Academy GmbH in collaboration with Institut für Textiltechnik Augsburg gGmbH, Institut für Textiltechnik of RWTH Aachen University (together representing ITA Group – International Centre for Sustainable Textiles), and SAS CETIA, France. The interdisciplinary team responsible for the technology assessment is focused on scrutinizing the current state-of-the-art processes and technologies.

The interdisciplinary consortium's remit was to bridge the gap between research, development, and industrial application. Since 2021, the ITA Group has partnered with TEXAID to collaborate on multiple projects, initiatives, and internal teams. This partnership has enabled all parties to develop their business capabilities, research expertise and to develop new partnerships, networks, and client relationships.

4 SOLUTION APPROACH

As mentioned in section 2, the TA has been divided into three segments, which are designed to function independently as standalone steps and distinct topics, while also integrating with each other for a cohesive process. The first layer of the TA provides a comprehensive overview, interconnecting various competencies and technologies, and emphasizing the integrability between the segments. To effectively sort garments, a promising approach was defined that maintains a holistic perspective, prevents duplicative efforts, and maximizes synergies among competences and technologies.

The following steps outline the recommended approach:

1. Establish general requirements and sorting criteria for recycling technologies.
2. Compile a list of best-available technologies on the market, adaptable to various process steps, conducting a technology assessment.
3. Carry out comprehensive tests for most promising technologies to elaborate the technology readiness level, and relevant key performance indicators (KPIs).
4. Employ a decision matrix for technology and supplier evaluation, incorporating prioritization and risk analysis.
5. Develop a comprehensive plan for a demo plant.
6. Conduct a gap analysis between the current state and desired outcomes, identifying areas for improvement and optimization in the recycling process.

5 KEY FINDINGS

To achieve the capabilities in automatic sorting for reuse and recycling, several technologies in transportation, preparation, feeding, detection, sorting, and logistics were analyzed. For the observation, current state-of-the-art machines, processes and software solutions were researched, tested, and evaluated aligning and incorporating automation, robotics, sensor technology, and artificial intelligence.

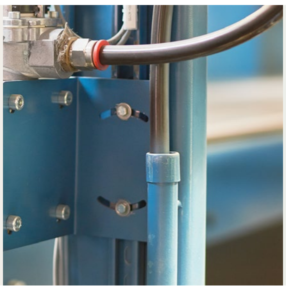
5.1 Requirements

During the research phase of the project, more than 160 requirements for technologies and feasibilities were collected and assessed in collaboration with the international consortium of recyclers, manufacturers, tech startups, and brands.

Addressing general requirements, the consortium defined that technologies must be able to be operated autonomously (without direct permanent personal intervention) and the technologies must not damage garments. When it comes to parameter detection, the consortium defined it as important that historical sensor and machine data must also be stored for all relevant processes in a central database for traceability.

Product and quality categories play a pivotal role in the context of recycling requirements. The suitability and the necessity for further sorting are based on fiber composition, as a fundamental step in achieving fiber-to-fiber recycling. A critical aspect of this process is the system's capability to sort products according to the complexity of the garment, involving comprehensive scanning of both the external and internal aspects, encompassing the back and front of each garment, and ideally, the recognition of trims.

For fiber-to-fiber recycling it is essential that the defined sorting categories maintain a tolerance level of no more than 5% accuracy, ensuring that the composition remains within the specified limits. For instance, if a category is designed at 90% cotton, the permissible tolerance is limited to a maximum of ± 5% for fiber-to-fiber recycling. Moreover, the process should be designed to facilitate color sorting as well. The aspiration is for over 90% of the recycling qualities to be sorted automatically, streamlining the overall recycling process. Furthermore, the system's extendibility is a significant requirement, allowing for potential upgrades or adaptations as recycling technologies and standards evolve. Lastly, the availability of the system until the end of 2023 is essential to meet project timelines and objectives, underscoring the need for timely implementation and integration into the recycling process.


5.2 Definition of recycling categories

At the start of the research project, a comprehensive survey was conducted, involving a diverse spectrum of companies representing the entire recycling process chain. This survey involved participants from different textile recycling sectors, with active participation by the entire project consortium. The survey's overarching objective was to elicit insights into the prerequisites associated with source materials, processing methodologies, and sector-specific requirements. The main aim of this survey was to discern the necessary specifications for recycling technologies, which are instrumental in establishing consistent and well-defined raw material streams. The survey's scope extended to encompassing both existing and prospective recycling technologies, with a focus on supporting open and closed loop recycling practices, thus contributing to the realization of a circular economy within the textile industry. To identify the most relevant recycling categories, a thorough analysis of mechanical, chemical, and thermomechanical recycling processes was carried out. Subsequently, a set of key performance indicators was derived from the survey findings, accentuating their paramount importance in the context of automated textile sorting. The performance metrics were subsequently ranked using pairwise comparison. This process was instrumental in establishing the significance of these metrics, enabling a systematic approach in the selection of technologies.

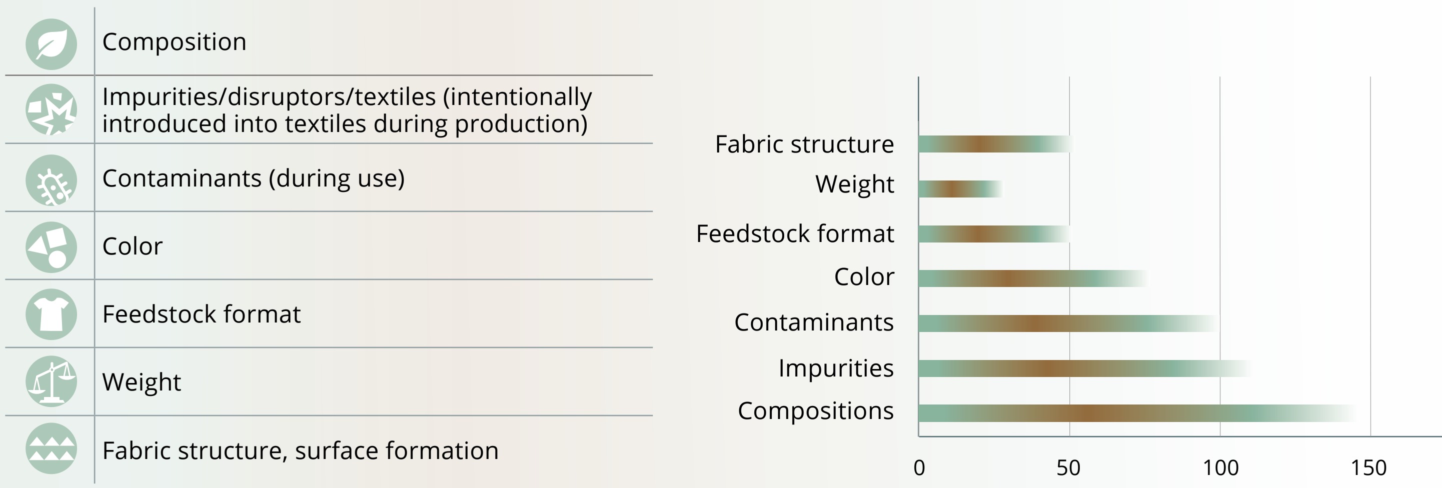


Figure 3: Importance of measurement criteria for recycling solutions

5.3 Technology selection

To ensure a reliable feedstock supply for circularity, as per the waste hierarchy (European Commission, 2023), a technology assessment was carried out. The assessment aimed to address the current shortcomings in sorting solutions for reuse, and to evaluate and train AI-based algorithms for pattern recognition and the non-destructive handling of garments. In addition, sorting categories for recycling scenarios were developed, and a training program was created for NIR, FTIR, and other sensors.

5.3.1 Pattern recognition for reuse solutions

A internal project task force for artificial intelligence (AI) solutions conducted a pairwise comparison to rank the performance metrics. This crucial process played a key role in determining the importance of these metrics, facilitating a systematic approach in the selection of technologies.

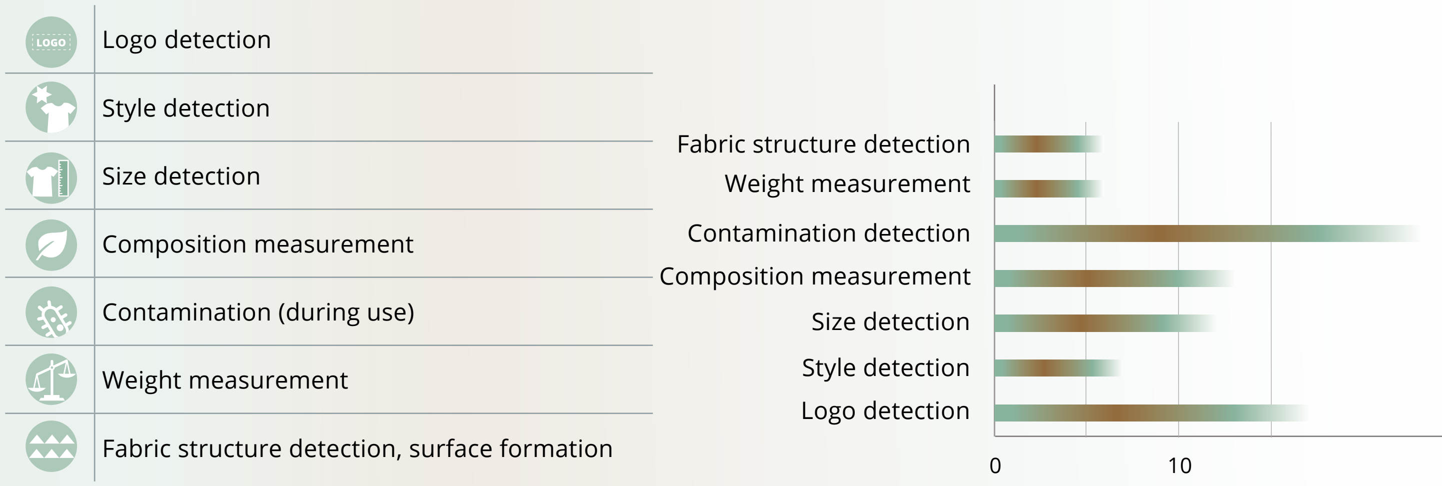


Figure 4: Importance of detection criteria for reuse solutions

5.3.2 TA for handling, reuse sorting and logistics solutions

During the evaluation process, various technologies like tray sorters, separation robots and garment-on-hanger (GOH) sortation systems were inspected and examined for feasibility, and implementation concepts were discussed with providers. The tray sorter was observed as an option for large volume operations, due to performance speed, flexibility, and modularity. The efficiency of tray sorters lies in their ability to handle a large volume of items rapidly, reducing manual labor, and increasing accuracy. However, many sorting solutions may face limitations in handling flexible, irregularly shaped items or items with varying dimensions. Other automation systems like automated folding systems and GOH transportation systems are already sufficiently implemented in textile manufacturing scenarios due to smaller variety and recurring fabric sizes, surfaces, and weight. But the existing technologies are reaching their limits in the sorting scenario with tremendous product variations. In further tests and expert interviews, the feasibility could not be proven.

5.3.3 TA for sorting for recycling solutions

Technical solutions were developed for each of the measurement criteria described in Figure 4. In the case of each identified solution, the underlying physical principles were documented and categorized first. Then, the solutions were assigned to the specific measurement tasks, further classified as individual sensors, measurement systems, or industrial sorting solutions. Measurement systems could be further subdivided into handheld sensors, laboratory equipment, and industrial systems.

In accordance with the requirements for an automated sorting system with high market readiness, only industrial individual solutions and complete sorting solutions were considered. Systems from six providers were subsequently put to the test within the scope of the project. Three different batches were utilized for the testing process (Figure 5).

Batch 0

- 409 samples with known composition, color, etc.
- State-of-the-art in material recognition

Batch 1

- Different kinds of whole garments
- State-of-the-art in handling and transportation

Batch 2

- Two batches of cut pieces
- State-of-the-art in impurity and trim detection

Figure 5.1: Overview of reference batches for technology assessment

The first batch drew upon the textile materials Library from Refashion, France, offering insights into the accuracy of material composition recognition (Refashion, 2021). This batch comprised 409 samples with known compositions certified through laboratory analyses. In addition, there was another batch composed of whole garments, representing a cross-section of the raw materials generated during the textile collection. The final batch consisted of cut textiles containing various contaminants and impurities.

Depending on the type of technology to be tested and the capacity available at the provider's testing centers, one or more batches were subjected to evaluation using these systems. Systems capable of capturing and sorting whole garments were tested with "Batch 0" and "Batch 1".

This testing process encompassed a qualitative assessment of material recognition and the system's ability to handle a diverse range of clothing items. The systems under consideration typically comprise a conveyor belt with an inspection unit positioned above it. They incorporate various technologies such as near-infrared sensors, cameras, and metal detectors. Located behind these units is a rejection mechanism, typically operated using compressed air.

photos: © CETIA

Figure 5.2: Test set up at SAS CETIA, France for testing Batch 0

The results from the system tests reveal that the requirements for material composition recognition are not entirely met. Initial qualitative pretests have already indicated that significant deviations, particularly in the case of material mixtures, are present. This is not an issue specific to a single provider but rather a widespread challenge due to the relatively recent application of near-infrared (NIR) technology to mixed textiles. On the other hand, there are no significant concerns with color recognition. As per the latest knowledge, the color cameras used can meet the requirements for sorting in recycling applications. Notably, the systems do not have the capability to capture the other five performance metrics.

Due to the significant number of unmeasured performance metrics, including impurities, contaminants, feedstock format, fabric structure, and weight, a two-step sorting stage is necessary for precise sorting, as required for fiber-to-fiber recycling.

1. **Sorting Step 1:** Multicategory sorting
2. **Sorting Step 2:** Binary sorting

Based on the decision for a two-step sorting procedure, each process was designed individually. Where the binary sorting can be considered a quality control step for recyclers to integrate at their facility to enable precision on the corresponding feedstock specification.

5.3.4 Elaboration of process flow for multiple category sorting for recycling

The textile sorting process begins with the delivery of mixed materials, which typically include various types of garments. These materials are fed into the initial stage of separation using a spiked lattice conveyor. The spiked lattice aids in breaking up clumps of materials and ensuring a more even distribution on the conveyor belt. The following separation unit employs a conveyor belt system with strategically placed sensors that detect different types of textiles based on their composition. The sensor-based composition detection technology is crucial in accurately identifying and classifying various textiles, allowing for precise sorting in the subsequent steps.

Pressure nozzles are strategically positioned along the conveyor belt, and they are activated based on the information provided by the composition sensors. These nozzles use controlled bursts of air pressure to divert specific types of textiles into designated chutes. The sorted textiles are compressed through a bale pressing mechanism into dense, manageable packages. Finally, the baled and sorted textiles are transported to the designated storage area or sent to recycling facilities.

5.3.5 Elaboration of process flow for binary category sorting for recycling

Throughout the course of the project, it was determined that a prior stage of textile cutting before re-evaluation with sensors offers distinct advantages. This cutting approach serves to enhance the purity of the materials, allowing for the removal of impurities and contaminants without the loss of all the garment material (Figure 6). For the cutting and subsequent fine sorting, two approaches were considered, primarily differing in the sequence of cutting and sorting processes. In the first strategy, impurities and contaminants must be identified first and then precisely separated from the rest of the material. In the prioritized second strategy, clothing items are randomly cut into smaller elements and then distributed on a conveyor belt for sensor-based detection (Figure 7). The ejection process, as commonly employed in plastic waste sorting, is accomplished using a compressed air bar, capable of accurately sorting small elements into binary categories.

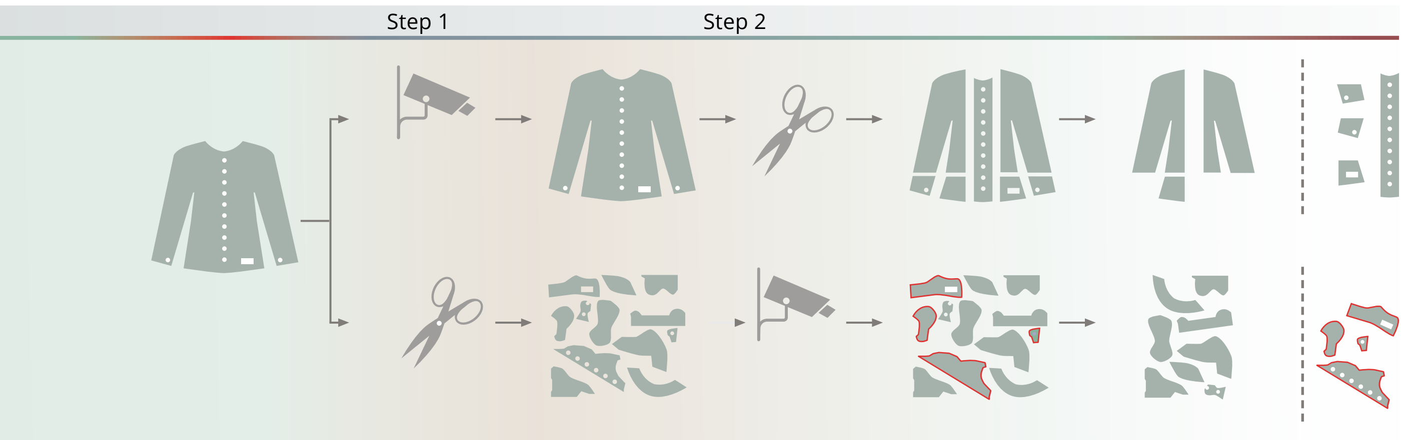


Figure 6: Pre-processing steps for impurity removal

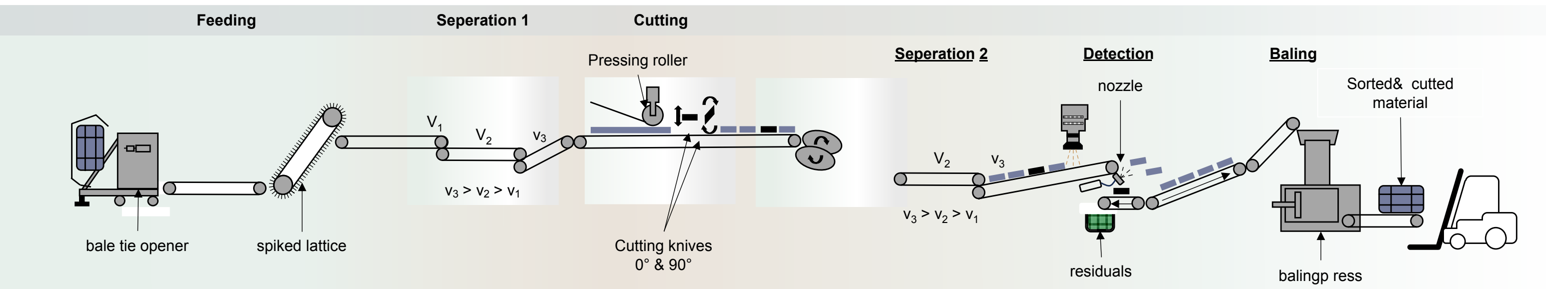


Figure 7: Process flow diagram for binary sorting for recycling

The tested systems for binary sorting, therefore, require a preceding cutting process, which allows for the rapid fragmentation of large quantities of textiles into approximately uniformly sized elements. This can be achieved, for example, by using two guillotine cutters arranged at a 90° offset. The cutting length can be accurately set by adjusting the conveyor speed. Subsequently, after an even distribution of textiles across the width of a conveyor belt, they undergo another round of sensor-based detection. In contrast to the first sorting step, a comprehensive inspection is essential in this stage, making point sensors unsuitable for the task.

The tests have revealed that metal contaminants can be easily detected and removed, even in very small quantities. On the other hand, plastic contaminants, patches like leather, or embroidery can only be recognized and separated if they are on the textile's surface. With the appropriate NIR hardware, it is even possible to detect polyester seams on cotton textiles. However, none of the systems tested had optical contamination detection implemented in them.

The binary sorting solution can be considered a quality control step for recyclers to integrate at their facility to enable precision on the corresponding feedstock specification and the option to enable the corresponding required feedstock format to be prepared before the recycling step.

5.4 CONCLUSION

To conclude the main challenge is that it is difficult to develop a process where different steps with different TRLs are combined throughout the process. Added to this, there is the complexity of the unevaluated area of textile waste sorting and several technologies not developed for the use case of textiles. Dealing with the complexity of textile waste is another issue, as textile waste is not standardized by comparison to other waste streams, where sorting for reuse is also not the case.

For the semi-automated sorting for reuse, the TRL is still very premature, and it will be challenging to fully automate this step in the future. Skilled operators will still be key when sorting textile waste according to the waste hierarchy. When it comes to the automated sorting for recycling, theoretical research and testing show that the sensors are not mature enough to sort as exactly and precisely as the recyclers need their feedstock to be.

There is a technology gap and two main points were found that will be important to develop further. Firstly, the databases behind the technologies and secondly the accuracy and precision of the scanning itself.

Pre-processing is also very specific and different depending on the use case and the specific recycler, which makes a standardized solution difficult. Therefore, the idea of two-step sorting for recycling could be a way to tackle the issue of quality control and pre-processing.

In general, the requirements vary considerably for the different use cases, the value chains, and stakeholders per use case, which makes the sorting and preprocessing for reuse and recycling more complex.

It was also found that from a technology point of view there is not only a lack of datasets lacking but also the need to digitalize the entire sorting process to unlock the potential of data in sorting in the future.

5.5 OUTLOOK

The collaborative project has revealed the current challenges in developing an innovative process with new technologies due to the unexplored field. Following the vision to shape the textile circularity in Europe and therefore to significantly reduce CO^2 emissions, TEXAID is committed to investing in an infrastructure of 50,000 tons of new sorting capacity in Europe using new technologies. For a spin-off project proposal to address the current gaps, TEXAID is inviting interested parties to expand the network and work together on innovations that will make the future more sustainable.

6 SOURCES

1. Directorate-General for Environment, E. C. (2022). Call for Evidence: Revision of the Waste Framework Directive. https://environment.ec.europa.eu/news/waste-framework-directive-revision-2022-02-14_en
2. EURATEX, European Apparel and Textile Confederation (2022). ReHubs - A joint initiative to circulate waste into value
3. European Commission. (2023). Waste Framework Directive. Retrieved from Waste Framework Directive: https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en
4. European Environment Agency. (2019). Private consumption: Textiles EU's fourth largest cause of environmental pressures after food, housing, transport. Retrieved from Private consumption: Textiles EU's fourth largest cause of environmental pressures after food, housing, transport: https://www.eea.europa.eu/highlights/private-consumption-textiles-eus-fourth-1
5. McKinsey&Company. (2022). Scaling textile recycling in Europe - turning waste into value. McKinsey Apparel, Fashion & Luxury Group.
6. Refashion. (2021). 2021 Activity report. Paris: Eco TLC. https://refashion.fr/pro/sites/default/files/rapportetude/Refashion%202021%20Activity%20Report.pdf

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CONTACT

TEXAID Textilverwertungs-AG
Militärstrasse 1 | CH-6467 Schattdorf
www.texaid.ch

Contact Recycling Solutions
Anna Pehrsson | recyclingsolutions@texaid.com

Contact Press
Frauke Kehl | pressestelle@texaid.de