AUTOMATIC-SORTING FOR CIRCULAR

ACT

FASHION & TEXTILES

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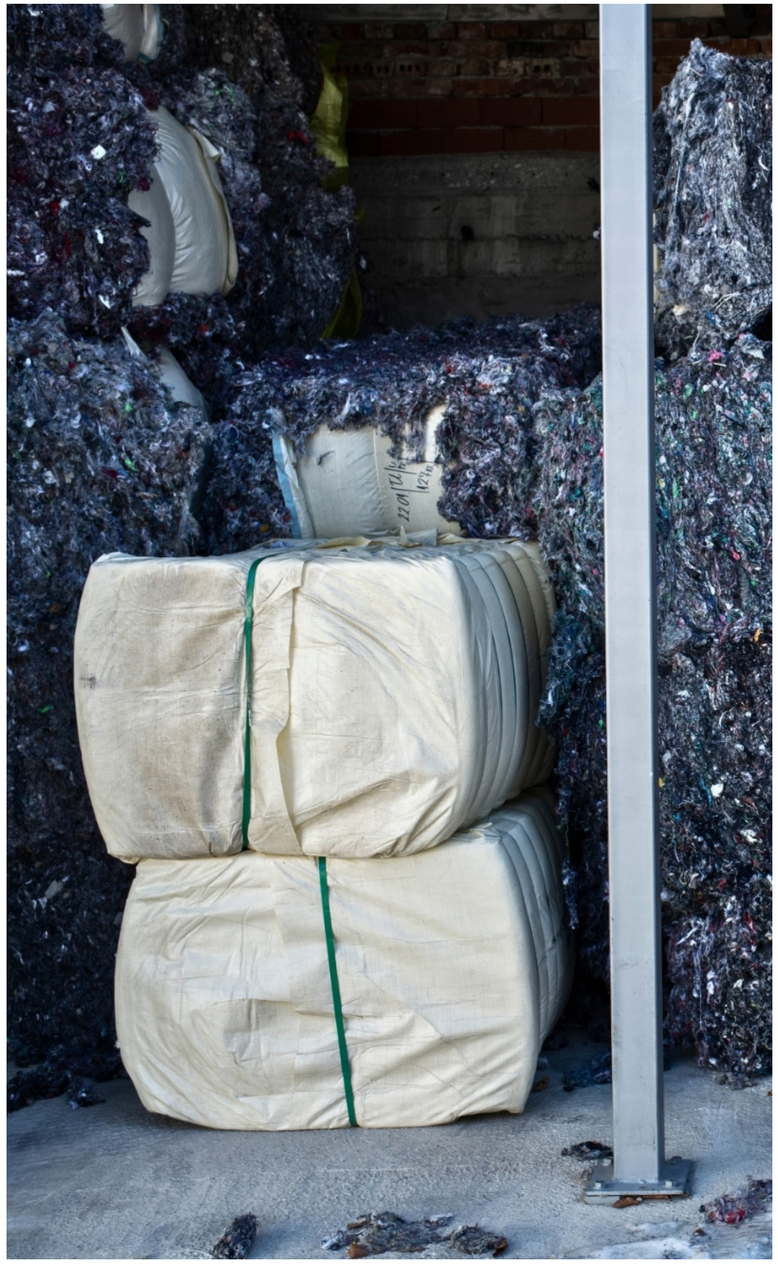
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Automatic-sorting for Circularity in Textiles

ACT UK Final report



ACT UK: UNLOCKING THE POTENTIAL OF TEXTILE WASTE

This report presents a comprehensive review of the ACT UK programme's activities and outcomes. It highlights how the project has generated valuable insights into one of the industry's most pressing challenges: how to convert the 744,000 tonnes of post-consumer textile waste discarded in the UK each year into new raw materials to support fibre-to-fibre recycling at scale.

The research explored in detail how automation can drive faster, more accurate sorting of non-rewearable textiles. It also demonstrated how brands, retailers and charities can increase public engagement and encourage more widespread participation in building a circular fashion system.

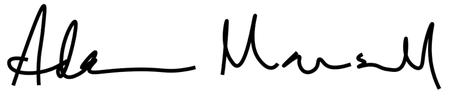
The consortium published detailed analysis of both the economic costs of inaction and the potential value of repurposing textile waste as a new resource. It also developed a blueprint for the site specification and engineering design of an Automated Textile Sorting Plant (ATSP), and successfully secured world-leading sorting technology, due to become operational in 2026.

In collaboration with UK recyclers, manufacturers and universities, the project produced fibre, yarns and finished products made from 100% post-consumer textile waste. The work confirmed that transforming waste into new raw material can stimulate growth in UK manufacturing. However, pilot trials also revealed technical challenges in using fully recycled fibres and yarns within traditional production systems.

Beyond advancing the technological potential of fibre-to-fibre recycling, the ACT UK project demonstrated the wider value of industry collaboration. It brought together the entire textile supply chain - from major retailers to local manufacturers, technology experts to recyclers - in a shared effort to address a global issue.

A fully circular fibre-to-fibre recycling infrastructure in the UK remains the long-term goal, but significant barriers remain. The final section of the report sets out the steps now needed - from government, industry and consumers - to implement an ATSP and move the UK's fashion and textile sector closer to a more sustainable future.

UKFT and the ACT UK consortium are committed to working with all stakeholders to take the next steps towards realising a national fibre-to-fibre recycling infrastructure. We invite industry, government and consumers to engage with the findings and collaborate in building the systems needed to transform textile waste into a valuable resource for the future.



Adam Mansell, CEO UKFT

> **The ACT UK project brought together the entire textile supply chain - from major retailers to local manufacturers, technology experts to recyclers - to tackle a global challenge with shared purpose.**

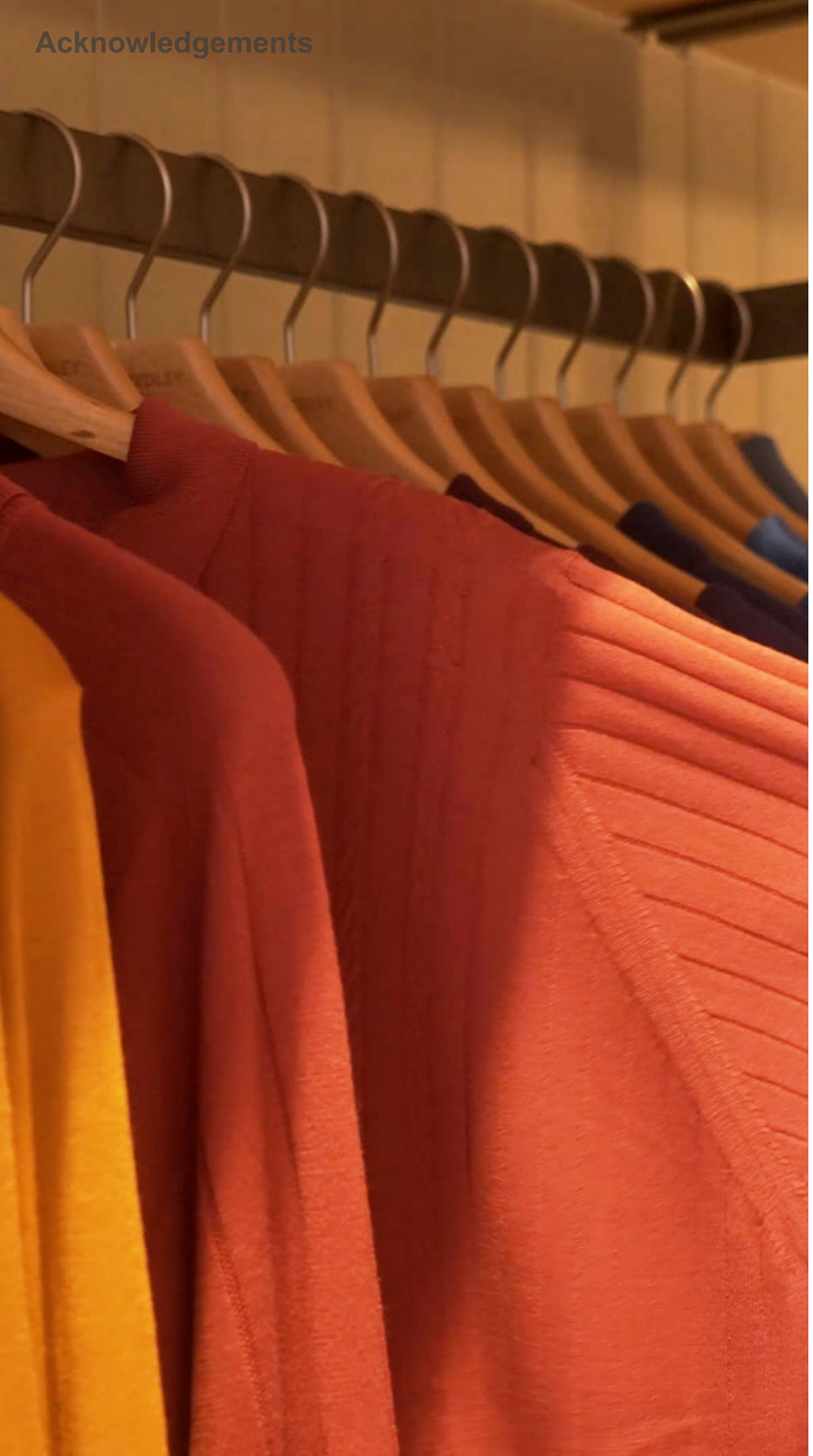
Table of contents

Acknowledgements	4
Chapter 1: Introduction	14
Chapter 2: Post-consumer textile collections and logistics	18
Chapter 3: Textile Sorting and pre-processing technology	45
Chapter4: Site selection and engineering design of an ATSP facility	103
Chapter 5: Textile recycling supply chain trials	143
Chapter 6: The business case for advanced textile sorting and pre-processing facilities	228
Chapter 7: The next phase of UK manufacturing	260
Chapter 8: Transitioning to a UK circular textiles ecosystem	277
Conclusion and priority recommendations	314
List of figures and tables	319
List of images	321
List of references	322



Acknowledgements

PROJECT CONSORTIUM



UK Fashion and Textile Association (UKFT)

UKFT is the largest network for fashion and textiles in the UK. As the industry's leading trade association and Sector Skills Body, we are committed to delivering sustainable growth for the entire UK fashion and textile supply chain.

We bring together brands, designers, manufacturers, suppliers, educators and retailers to promote their businesses and our industry, both in the UK and throughout the world. We offer practical advice and technical support to help member companies grow and trade internationally. We provide support to help businesses comply with UK and international regulations, offering guidance on areas including labelling, safety standards, sustainability, trade rules and Extended Producer Responsibility (EPR).

With a strong foundation in sustainability and innovation, UKFT continues to influence the direction of the circular economy through research and collaboration. Our work with reuse and recycling specialists is creating a connected, sector-wide network for sustainable change from fibre to final lifecycle.

Our President is HRH The Princess Royal.

Circle-8 Textile Ecosystems Ltd

The future of materials is not extraction. It's circulation. Circle-8 is advancing the new circular textiles industry by building the ecosystem and infrastructure to unlock textile-to-textile recycling. We are driving the design, build and commissioning of a network of automated textile sorting and pre-processing facilities to turn non-reusable textiles into feedstock for fibre-to-fibre recycling processes. Our end goal is to implement industrial-scale polymer recycling plants for textiles in the UK. We are growing the partnerships needed across the textiles value chain, working to divert the UK's estimated yearly 700,000 tonnes of non-reusable textiles away from export, landfill and incineration to make this circular future a reality.

Alex Begg Group

ALEX BEGG GROUP

Alex Begg Group is a Global Textile Manufacturer that designs and manufactures luxury cashmere knitwear, accessories and homeware for the modern lifestyle with mills in Ayr on the west coast of Scotland and Hawick, 'The Home of Cashmere', in the Scottish Borders. As well as crafting collections for their own brand, Begg x Co, they also work with the world's most prestigious fashion houses. With generations of expertise, Alex Begg Group is synonymous with quality, care and attention to detail.

For the UKFT ACT WP8 project trialling weaving 100% post-consumer recycled wool in a blanket, Alex Begg Group used Bureau Veritas to conduct chemical testing to check the product's compliance with current product restricted substances lists. However, it is important to note that chemical testing should take place on the feedstock material before any value adding activities are conducted. The reason for this is because the raw material in the trial was post-consumer material and chemical limits in products have changed over time, the testing should be completed at the beginning to ensure compliance.

Camira Fabrics

camira

Camira designs and manufactures textiles for every space and sector; from commercial and hospitality, to residential and public transport, including bus, coach and rail.

The company has always been a pioneer in sustainable textiles, introducing its first recycled fabrics in the 1990s, as well as innovating a new category of fabrics made from natural wool and plant fibres, such as nettles, flax and hemp.

A privately-owned UK textile group founded in 1974 under the name Camborne Fabrics, Camira's heritage goes back to 1783 through various acquisitions. Until a management buy-out in 2006, the company was a subsidiary of Interface, an international manufacturer of textile modular floor coverings, for almost ten years. Today, Camira has an annual turnover of around £85 million and employs more than 630 people. Its products are sold in approximately 75 countries and the business produces eight million metres per year.

Headquartered in the UK, the company has manufacturing facilities in the UK and Lithuania, offices and showrooms in Europe, North America, Australia and China and a global network of agents and distributors.

iinouiio

iinouiio

iinouiio, the brainchild of Dr. John Parkinson, is an acronym for "It is never over until it is over," and serves as Camira's circular textile recycling division. Founded in 2019 by Dr. Parkinson and his wife, Linda, whose family has deep roots in the 'shoddy and mungo trade,' iinouiio is the UK's leading wool recycler. With a wealth of knowledge in mechanical recycling methods that date back to the 1800s, the company has pioneered the revival of the 'shoddy' process—a technique that reuses wool garments to create new yarn and fabric. This method, once widespread, had fallen into disuse with the rise of synthetic fibers like polyester in the late twentieth century.

In 2021, iinouiio received funding from the Waste Resources Action Programme (WRAP) to expand its operations with a new textile recycling facility. A year later, in 2022, iinouiio was acquired by the Camira Group, enabling it to provide high-value recycling services for both wool and cashmere. This acquisition also enhanced Camira's own recycling capabilities, allowing the company to repurpose its own yarn, fabric stocks, and wool waste streams.

One of the most exciting innovations from the iinouiio-Camira partnership is ReSKU 2.0. This new fabric has an impressive 79% recycled content—66% recycled wool and 13% recycled polyamide—sourced from the company's own manufacturing waste and blended with 21% renewable flax.

IBM

IBM Consulting, as the sole global consultancy within a leading technology corporation, leverages advanced AI and a science-driven strategy to deliver substantial, impactful results. They collaborate closely with clients, guiding them through advisory, design, construction, and operational phases of business innovation. This partnership aims at creating enduring value and tangible results.

IBM boasts a robust presence in the retail sector, serving 80% of the world's premier Consumer Goods and Retail corporations. These businesses rely on IBM's consulting expertise and technology to propel their operations effectively.

A significant aspect of IBM Consulting's work involves addressing sustainability challenges faced by their retail clients. They utilize technology, especially AI, to address various facets of sustainability. These include managing Scope 3 emissions and supply chain origin, ensuring regulatory compliance, enhancing supply chain visibility, promoting Green IT practices, and facilitating the transition towards renewable energy sources. By integrating cutting-edge technological solutions into sustainability strategies, IBM Consulting helps its retail clients navigate environmental complexities and foster a greener future for the industry.

Marks and Spencer (M&S)

M&S is a leading British retailer bringing exceptional quality, great value food, clothing and homeware to millions of customers around the world.

The Manufacturing Technology Centre (MTC)

MTC transforms how products are designed, made and built so that they can be produced on a commercial scale - more sustainably, effectively and safely. Since 2010, our independent research and technology organisation has delivered pioneering solutions to help overhaul industries spanning Aerospace, Defence & Security, Power & Energy, Built Environments, Space, Agriculture, and Food & Drink. Always in collaboration. Always with purpose.

We are proud to be part of the High Value Manufacturing Catapult, established by and working in partnership with Innovate UK.

Oxfam

Oxfam is a global community of people who believe in a kinder and radically better world, where everyone has the power to thrive not just survive. We believe that together we can overcome poverty by fighting the injustices and inequalities that fuel it and create a more equal future.

Every day, Oxfam helps thousands of communities around the world work their own way out of poverty. In 2023/24, Oxfam worked with 475 partner organisations and helped reach 9.25 million people through Oxfam's humanitarian work.

Across the UK, Oxfam has more than 500 shops, with over 20,000 volunteers, who help make a difference every day. By buying and donating through Oxfam shops and online, you can help to protect our planet, while helping raise vital funds to tackle poverty and injustice around the globe.

Reskinned

Reskinned are an ACT UK partner and lead organisation for ACT UK Work Package 2: Innovating Post-use Textiles Collection Methods and Logistics. The Reskinned team worked closely with the UKFT and ACT UK partners to manage and deliver the trials.

Reskinned delivers a simple-to-implement, zero-risk circular solution that encompasses takeback, resale/reuse and recycling. They offer everything all in one place to deliver a truly sustainable solution.

All of this is supported with 'end to end' programme data to back up sustainability comms, ensuring transparency and delivering valuable product and customer insights to their Brand Partners.

Salvation Army Trading Company Limited (SATCoL)

Salvation Army Trading Company Ltd (SATCoL) is the trading arm of The Salvation Army in the UK and Republic of Ireland. SATCoL promotes the reuse and recycling of donated clothing and other household items at its 250 charity stores, via a nationwide network of around 9,000 clothing and shoe collection banks and from the retail-led takeback collection schemes it supports.

Each year, SATCoL collects over 65,000 tonnes of textiles and through the reuse and recycling of textiles and other items collected, prevents over 450,000 tonnes of greenhouse gases from entering the atmosphere.

With the support of the British public, SATCoL has donated millions of pounds to The Salvation Army to help its work with vulnerable people in the UK (over £100 million has been donated in the last ten years).

SATCoL operates the UK's only automated textile sorting line, FibersortTM, which identifies and sorts second-hand textiles by fibre type and is the first step in textile-to-textile recycling. SATCoL also operates Project Re:claimTM - a textile recycling venture with circularity specialist Project Plan B which recycles polyester clothing and textiles.

As an ACT UK partner already operating an automated fibre sorting line and a recycling process SATCoL played a central role in the project, providing samples to project partners for recycling. In addition to collaborating with the consortium partners, SATCoL worked closely with the Project Re:claim team, Leeds University and Fibre Extrusion Technology on recycling and market development trials for several types of post-consumer textiles.

Shred Station

Shred Station is the world's largest independent shredding company. With offices and depots across the UK, the company offers mobile and off-site shredding and recycling services to businesses and individuals across the four nations. Starting with just a single shredding truck in 2008, the business now operates from several large depots and a fleet of over 100 eco-friendly vehicles for both on-site and off-site shredding.

The business has grown and evolved over its existence and now provides a vast service offering for destruction and recycling - not just for paper but also for textiles, media, and products. Sustainability and minimising environmental impacts are core values to the business. Shred Station is proud to be a lifetime Carbon Neutral certified company that works to provide the best possible solutions, commercially and environmentally, to customers across its entire range of services.

Tesco

Tesco was built to be a champion for customers, serving them every day with affordable, healthy and sustainable food. Our commitment to our customers extends beyond our stores, and into every community we serve – in the UK, Republic of Ireland (ROI), Slovakia, the Czech Republic and Hungary. We invest in communities to help them thrive, through supporting schools and children's groups, food banks and other good causes.

In challenging times, our purpose has guided every part of the Group, from Booker and One Stop to Tesco Mobile and dunnhumby. Serving our customers, communities and planet a little better every day is what we do.

Textile Recycling Association (TRA)

We are the UK's trade association for collectors, sorters, processors and exporters of used clothing and textiles.

The main objectives of this Association are:

- To represent the interests of its members internationally, nationally and locally.
- To be a major force in creating a favourable climate within which merchants can operate to advantage.
- To strengthen the economic opportunities for all our members by promoting all forms of textile recycling and the second hand clothing/shoe recycling industry.
- To highlight the major environmental, social and economic benefits that the industry brings both here in the UK and in other parts of the world.
- To promote best practice in the industry.

Textile Recycling International (TRI)

Textile Recycling International is the largest textile recycling company in the UK specializing in sustainable textile recycling solutions. Committed to reducing textile waste and promoting environmental responsibility, the company offers efficient and eco-friendly services for businesses and individuals to recycle unwanted clothing, fabrics, and footwear. With a focus on innovation and sustainability, Textile Recycling International helps clients contribute to a circular economy by transforming textile waste into reusable resources. Their services support environmental goals, reduce landfill dependency, and foster a greener future for the fashion and textile industries.

The University of Huddersfield (UoH)

The University of Huddersfield is made up of a diverse community of almost 20,000 people from all walks of life.

Excellence:
The University of Huddersfield was awarded an outstanding Gold rating in all three aspects of the Teaching Excellence Framework (TEF) 2023. We were the only university in Yorkshire and the Humber and the North West to achieve Gold ratings in all three aspects of the TEF among those announced in September 2023.

The apprenticeship provision at the University of Huddersfield has been graded as OUTSTANDING. This is the highest possible grade that Ofsted can award, and Huddersfield is only the second university to be awarded Ofsted's outstanding rating for its apprenticeship provision in the last four years.

Our global stature is growing, as we were ranked top in the UK in the global Times Higher Education Young University Rankings 2024, a ranking that lists the world's best universities 50 years old and younger.

Our staff rank in the top 3 in England for the proportion who hold doctorates, have higher degrees, and hold teaching qualifications (HESA 2024).

Impact:
The University of Huddersfield is ranked 2nd highest in the world for Reduced Inequalities in the Times Higher Education Impact Rankings for 2024.

Three quarters of our research was classed as world leading and internationally excellent in the 2021 Research Excellence Framework (REF).

The University of Leeds (UoL)

The University of Leeds is one of the largest universities in the UK. We're part of the Russell Group of research-intensive universities and are renowned globally for the quality of our research and teaching.

The School of Design at the University of Leeds is an interdisciplinary School bringing together expertise from a range of design and technology specialisms. Creation and innovation are at the heart of both the teaching and research aims, and as a School, it develops new design ideas and provide solutions to issues faced in industry and society. The school has 150 years heritage in textile education and research. Launched in 2021, the Leeds Institute of Textiles and Colour (LITAC) brings together multi-disciplinary academic expertise in design, technology, science, and engineering. The institute, based in the School of Design at the University of Leeds, works collaboratively with partners globally to tackle important research challenges across textiles, colour, and fashion.

LITAC is built on a history of 150 years of textile teaching and research, working together with industry, charities, and non-governmental organisations (NGOs) – including some of the world's most well-known organisations and brands. As a collaborative research institute, LITAC works with partners to create new understanding, knowledge and solutions that address the needs of industry, society, and the environment. LITAC develops new materials, processes, manufacturing methods, digital tools, and technology, and informs decision-making.

Worn Again

Worn Again is the catalyst of a true circular economy for textiles, believing that the only way forward is through better, profitable recycling processes. Worn Again has led the textile recycling technology industry for years with a dedicated team of innovators, moving the industry in a new direction in partnership with retailers, manufacturers, and innovators who share Worn Again's commitment to sustainable materials—and sustainable business growth.

Worn Again's innovative chemical recycling process reclaims virgin-quality products and returns them to the supply chain. Its scalable process—developed through investment, research, and dedication—allows textile manufacturers to separate and decontaminate PET resin and cellulose from end-of-life textiles. Worn Again enables plant operators to become an essential part of the textile industry's future, producing superior materials for manufacturers across multiple industries and becoming a solution for an economically fractured part of the textiles supply chain.

With reliable access to reclaimed, virgin-quality synthetic and natural materials, manufacturers can authentically offer high-quality, sustainably made options to their retail buyers. Worn Again guides its partners into the future with a profitable business built around large-scale textile recycling. Everyone, from manufacturers to consumers, will be able to contribute to reducing waste. Within a truly circular economy, everyone helps protect the planet from the mistakes of the past.

Waste and Resources Action Programme (WRAP)

WRAP is a global environmental action NGO catalysing policy makers, businesses and individuals to transform the systems that create our food, textiles and manufactured products. Together these account for nearly 50% of global greenhouse emissions. Our goal is to enable the world to transition from the old take-make-dispose model of production to more sustainable approaches that will radically reduce waste and carbon emissions from everyday products. To do so we examine sustainability challenges through the lens of people's day-to-day lives and create solutions that can transform entire systems to benefit the planet, nature and people.

Our work includes: UK Plastics Pact, Courtauld Commitment 2030, Textiles 2030 and the campaigns Love Food Hate Waste and Recycle Now. We run Food Waste Action Week and Recycle Week.



PROJECT EXTERNAL PARTNERS

Accelerating Circularity

Accelerating Circularity is an action-oriented nonprofit focused on textile-to-textile recycling at commercial scale through a collaborative, stakeholder-led approach. Our mission is to build circular systems that turn used textiles into new raw materials.

Circle Economy

Circle Economy are a global impact organisation with an international team of passionate experts based in Amsterdam. They empower businesses, cities and nations with practical and scalable solutions to put the circular economy into action. Their vision is an economic system that ensures the planet and all people can thrive. To avoid climate breakdown, their goal is to double global circularity by 2032.

Greenstory

Green Story is a leading sustainability intelligence solution exclusively crafted for the apparel, accessories and textiles industry. Anchored in data excellence and empowered by a team of world renowned experts, Green Story drives sustainability transformation by delivering precise insights into a product's environmental footprint.

Henham Copywriting Ltd

Henham
Copywriting | Editing | Content

Henham Copywriting is an independent copywriting and editorial agency that provides organisations, businesses, and agencies with compelling words that bring copy to life, build brands, and engage audiences. From whitepapers to technical writing and from customer success stories to C-suite thought leadership, Henham works across a variety of industries, including sustainability, the circular economy, business, content marketing, energy, and public sector.

Jones Lang LaSalle

JLL

JLL (Jones Lang LaSalle) is a global commercial real estate services company with a significant presence in the UK. As a leading player in the UK property market, JLL offers a comprehensive range of services to clients across various sectors, with core services including Property and Asset Management, Leasing and Letting, Capital Markets, Valuation and Advisory Services, Project and Development Services, and Research and Consulting.

A key strength of JLL in the UK is its dedicated industrial tenant representation team. This specialised group focusses on securing advantageous deals and terms for occupiers seeking to acquire industrial properties. The team's expertise ensures that clients obtain optimal conditions and locations for their industrial real estate needs, whether they're expanding operations, relocating, or establishing new facilities.

TOMRA Recycling Sorting

TOMRA

TOMRA Recycling Sorting designs and manufactures sensor-based sorting technologies for the global recycling and waste management industry to transform resource recovery and create value in waste. The company was the first to develop advanced waste and metals sorting applications using high capacity near infrared (NIR) technology to extract the most value from resources and keep materials in a loop of use and reuse. To date, around 10,000 systems have been installed in 100 countries worldwide. TOMRA Recycling is a division of TOMRA Group. TOMRA was founded on an innovation in 1972 that began with the design, manufacture and sale of reverse vending machines (RVMs) for automated collection of used beverage containers. Today, TOMRA is leading the resource revolution to transform how the planet's resources are obtained, used and reused to enable a world without waste. The company's other business divisions are TOMRA Food and TOMRA Collection. TOMRA has approximately 105,000 installations in over 100 markets worldwide and had total revenues of about 14.8 billion NOK in 2023. The Group employs 5,000 people globally and is publicly listed on the Oslo Stock Exchange. The company headquarters are in Asker, Norway.

Chapter 1:

Introduction

The UK’s fashion and textile industry’s circular transition



The UK fashion and textile industry stands at a pivotal moment. It is facing the increasingly pressing environmental challenge of textile waste. Every year, the UK discards 744,000[1] tonnes of non-reusable textiles (NRT), which are currently being incinerated, sent to landfill, or exported. Additionally, globally, on average, less than 1%[2] of material used to produce clothing is recycled into new fibres, a figure that was replicated globally in 2023[3].

This presents a significant opportunity to scale a textile-to-textile recycling supply chain in the UK, to close the loop on post-consumer NRT textile waste, and to create a more sustainable future for the UK fashion and textile industry. A future where NRTs are recycled back into textiles or alternative products, and, ultimately, the UK is delivering considerably more socio-economic value from NRTs.

While the industry has established processes to recycle fibres into new garments or other applications, there is gathering momentum to scale commercially viable closed-loop fibre-to-fibre (F2F) recycling. In Europe, McKinsey forecasts[4] that textile-to-textile recycling could reach 18-26% of gross textile waste by 2030, creating 15,000 new green jobs across the supply chain and abating 4 million tonnes of carbon emissions. Globally, innovative solutions are being developed across mechanical, thermochemical, thermomechanical, and chemical recycling methods to successfully turn textile waste into new fibres for use in new products, creating a circular solution to NRTs.

However, this is only possible in the UK if textile-to-textile recycling capacity is increased and investment and innovation accelerated. ACT UK wants to close the loop by moving away from exporting or manually sorting NRTs and transitioning to cost-effective and sustainable automatic sorting. This transition is critical because automated sorting and pre-processing deliver consistent feedstock at scale, and consistent feedstock is needed to support recycling solutions and technologies.

ACT UK OBJECTIVES

The ACT UK project was established in 2023 by the UK Fashion and Textile Association (UKFT) in response to Innovate UK's call for organisations to apply for a share of funding to develop and demonstrate closed-loop recycling for the fashion and textile sector at scale. ACT UK is part of a broader Circular Fashion Programme supported by UK Research and Innovation (UKRI), and brought together a consortium of recycling technologies, manufacturers, textile collectors and sorters, academia, industry associations, technologists, brands, and retailers. The Innovate UK call outlined that the project must demonstrate it would increase the proportion of post-consumer fashion and textiles that are retained in a closed-loop system, increase the market value of processed post-consumer fashion and textiles, and reduce the proportion of post-consumer fashion and textiles which is sent to landfill, destroyed, or exported.

The ACT UK project's ultimate aim was to prepare the UK market for the transition to textile circularity by establishing an innovative Advanced Textile Sorting and Pre-processing (ATSP) facility. Currently, manual sorting is too costly and time-consuming to be commercially viable. The ATSP facility would take in NRTs, automatically sort them at scale and speed, and deliver this as feedstock for F2F recyclers.

ACT UK consortium member Circle-8 has calculated that there is the potential feedstock for building 12 ATSP facilities at 50,000 tonnes per year in the UK, as well as multiple industrial-scale textile-to-textile recycling plants.

To achieve this, ACT UK's key objectives were:

- Create a world-class, state-of-the-art blueprint for an ATSP facility, integrating the latest technologies
- Provide the economic incentivisation of regional material recycling over the export of NRT in lower-cost labour regions or to landfill/incineration
- Leverage the consortium roles, knowledge, and innovation to drive the UK's transition from linear to circular textiles
- Cement the UK as a global leader in innovation and textiles circularity, creating new markets, jobs, and overseas direct investment opportunities

ACT UK CONSORTIUM

ACT UK's project unites expertise across the fashion and textile industry. From retailers and charities to technology companies and universities, the ACT UK consortium is using its varied skills, experience, knowledge, and commitment to innovation to power the transformation from a linear industry to a fully circular industry.

By building on sorting solutions in other countries across Europe, the project explored how technology can help to overcome the current challenges of automated sorting and create an efficient, sustainable, and cost-effective framework for the UK to become a leader in textile recycling processes.

ACT UK's steering committee comprises members from:

UKFT, Alex Begg, Camira, Circle-8, IBM Consulting UK, Manufacturing Technology Centre (MTC), Marks & Spencer, New Look, Oxfam, Reskinned, Salvation Army Trading Company, Shred Station, Tesco, Textile Recycling Association, Textile Recycling International, University of Huddersfield, University of Leeds, Waste and Resources Action Programme (WRAP), Worn Again Technologies

STRATEGIC IMPACT OF AUTOMATIC SORTING

By creating a state-of-the-art ATSP facility blueprint, ACT UK's long-term vision is to secure the UK's place as a global leader in circular fashion and textile recycling and innovation. This will:

- **Affect change:** Enable businesses and government to measure, report, and achieve net-zero targets
- **Improve environmental impact:** Divert NRTs away from municipal landfill, incineration, and/or export and into materials recycling processes
- **Drive economic growth:** Turn waste into resources by scaling up emerging recycling methods that will enable old textiles to become new textile raw materials for the global marketplace
- **Generate employment:** Create jobs in the UK's textile sector, including new, regional green jobs, which will have significant spillovers into regional education and social inclusion
- **Increase exports and investment:** Become an international showcase for a circular ecosystem by demonstrating real-world environmental and economic benefits of regional infrastructure evolution

ACT UK is working to achieve these outcomes by focusing on three key project areas:

Post-consumer textile (PCT) collection and logistics: How do we collect and capture discarded textiles before they end up as landfill or at the incinerator? To empower consumers to bring NRTs into the loop again, ACT UK has launched textile collection trials in collaboration with both project partners and external organisations. These trials are part of a broader effort to gather insights on optimising PCT collections and improving the management of NRTs for a more sustainable textile economy.

State-of-the-art technology development: How do we overcome the sorting and pre-processing of textiles at a large scale? ACT UK has undertaken a market review of existing and emerging technologies for advanced textile identification, conveyance methods, and pre-processing technologies. The findings will inform the development and design of a blueprint for the ATSP facility.

Circular textiles ecosystem: How do we prove the viability of recycling NRTs and closing the loop in textile production? The transformation to a circular ecosystem won't be achieved in isolation, so in addition to developing the ATSP facility blueprint, the project provides proof of concept for a circular textiles ecosystem in the UK. ACT UK has undertaken recycling supply chain trials and explored the business case for transitioning to an economically viable circular textiles ecosystem.





REPORT STRUCTURE

This report sets out the steps ACT UK is taking to create a blueprint for achieving automatic sorting. It will cover the opportunities and challenges and report on the key outcomes, as well as the next steps.

The report breaks down the three key project areas above into seven work packages, which will be covered in the following chapters:

Chapter 2: Post-consumer textile collections and logistics
Exploring PCT collection trials, including car park and postal collections, and gathering insights into overcoming existing collection challenges.

Chapter 3: Textile sorting and pre-processing technology
Exploring the technology needed for ATSP facilities to work at scale, from analysing existing solutions to identifying new solutions.

Chapter 4: Site selection and engineering design of an ATSP facility
Exploring the process of selecting a site for the first ATSP facility from multiple proposals, and examining how the engineering process and facility design can maximise efficiency and scalability.

Chapter 5: Textile recycling supply chain trials
Exploring circularity trials of cotton, wool, and polyester and evaluating the recycling supply chain to prove that NRTs and PCTs can successfully be processed into new fibres through F2F recycling systems.

Chapter 6: The business case for ATSP facilities
Exploring current and future scenarios of NRT flow in the UK and the feasibility and impact of an ecosystem of ATSP facilities across the UK.

Chapter 7: The next phase of UK manufacturing
Exploring the role UK manufacturing must play to unlock and scale a workable domestic textile recycling ecosystem, and examining how the manufacturing of recycled yarn can become a crucial link in the supply chain.

Chapter 8: Transitioning to a UK circular textiles ecosystem
Exploring the viability of an ATSP network that supplies and feeds F2F recycling, detailing the challenges, enablers, and opportunities inherent in this systemic shift.

The report will set out all key findings, conclusions, and recommendations from each work package and the project as a whole, and look ahead to the next phase for UK manufacturing.

Chapter 2:

Post-consumer textile collections and logistics

Exploring innovative approaches to collections and sorting



CONTENTS

Introduction
- Current market challenges
- The future of textile collections
- Current innovation in collections
- Reusable vs non-reusable post-consumer textiles
- UK citizen pre-sorting collection trials
- Trials in brief and summary of key findings
- ACT UK innovation roundtable

Methodology: Trials
- Methods and aims: Citizen pre-sorting trials
- Methods and aims: External industry trials

Results: Trials
- Results: Citizen pre-sorting trials
- Results: External industry trials

Discussion
- Post-trial recommendations
- Roundtable recommendations
- Tesco survey recommendations
- Full recommendations

1. INTRODUCTION

The process of collecting textiles discarded by the public plays a vital role in the UK fashion and textile industry's supply chain, and, done more effectively, can be crucial to promoting circularity. This is because the reuse and recycling stage of the supply chain is typically initiated when clothing and home textiles are discarded. Therefore, a significant economic and environmental opportunity exists to reduce the volume of discarded textiles sent to end-of-life destinations, such as landfill and incineration, and instead prioritise pushing post-consumer textiles (PCT) up the resource hierarchy.

However, the PCT collections landscape must be reimagined if circularity is to be achieved. The industry must strive for a collections process that embraces innovative solutions such as AI, reverse logistics, citizen pre-sort, and regional hubs that are hosted and collectively run by existing facilities. Collections should also play a key role in engaging with the public and shifting their disposal behaviour, and collectors should be bolstered by strong and constructive partnerships with brands and retailers that reflect producer responsibility.

Under this scenario, significant progress can be made in transitioning to a circular ecosystem. However, we must first explore the viability of such a scenario. Therefore, this chapter investigates innovative approaches to PCT collection and logistics, highlighting practices that deviate from traditional methods and the use of technology in this area. It also presents the methods and results from pre-sort trials conducted by ACT UK consortium members and external partners.

This chapter concludes by highlighting key recommendations and transformative opportunities identified in the pre-sort trials. These recommendations aim to optimise collection processes, divert end-of-life routes, and ultimately support the development of a circular textiles ecosystem.

1.1. Current market challenges

The UK has a well-established collections infrastructure capable of taking in large volumes of textiles, with charities as the primary donation route for collected PCT.

However, the majority of collections (469,000 tonnes[5]) are also handled by collectors and sorters as materials move down the supply chain. Historically, collectors and sorters could rely on the quality of textiles and strong business partnerships to sell reusable textiles (RT) profitably. However, the landscape has changed. They now face significant challenges:

- Increased volumes of low-resale value textiles, with lower resale value principally due to:
  - Oversupply caused by greater competition in used clothing trade in export countries
  - High volumes of fast and cheap fashion
  - Devaluation of currency in export countries
- Increased operational costs
- Continued lack of policy and capital investment
- Growing public concern over clothing exports

These challenges have prompted warnings from UK businesses and trade bodies, such as the Textile Recycling Association, about the potential collapse of the used clothing trade[6]. This concern is shared by many countries with high levels of consumption.

1.2. The future of textile collections

Innovation and agility are crucial for the used clothing trade to survive and advance circularity in the fashion and textile industry.

The sector has primarily focused on fibre-to-fibre (F2F) recycling, and there is a growing emphasis on automated sorting to provide affordable F2F feedstock. However, smarter and more efficient collection systems and a rise in responsible citizen disposal habits are essential if the process is to be commercially viable at scale.

Therefore, there is an opportunity to:

- Optimise current PCT collection practices for reuse and recycling
- Divert textiles from end-of-life, transforming them into valuable resources

1.3. Current innovation in collections

Innovative solutions are essential to optimise current PCT collection practices. While efforts to modernise practices remain nascent, solutions are being explored in the UK and globally.

1.3.1. UK innovations:
Responding to market challenges, a handful of UK organisations have shifted from business-as-usual collections towards more innovative models to increase volumes, efficiencies, and financial viability. Innovations have primarily focused on:

Citizen communication campaigns
Local authorities and NGOs have run campaigns using established methods and various communication channels to reach the public. These campaigns encouraged people to donate unwanted textiles instead of throwing them away with household waste.

Utilisation of reverse logistics
As part of take-back schemes by brands and retailers, reverse logistics – the process of moving goods from their usual final destination back up the supply chain – has been deployed between distribution centres and delivery in-store/postal.

1.3.2. Global innovations:
There is greater variety in collections innovations worldwide, stemming predominantly from industry consortium projects such as CISUTAC and Siptex. In Europe, innovation is being driven by the need to prepare for incoming European Union (EU) policy, notably the introduction of separate textiles collections.

Artificial intelligence (AI)
AI is increasingly being used to optimise collections. AI can improve logistics by calculating efficient routes that reduce travel distances, and it can also identify the best locations for collection points to minimise contamination and maximise volume. Additionally, research is underway to use AI to identify and sort RT from NRT, potentially automating a significant part of the sorting process.

Citizen pre-sort trials
The separation of reusable (RT) and non-reusable textiles (NRT) is now established in Denmark. Additionally, a region in Norway successfully trialled citizen RT/NRT pre-sort at doorstep, bring bank, and waste collection. See 1.4 below for RT and NRT definitions.

1.4. Reusable vs non-reusable post-consumer textiles

It is important to note here the difference between textiles that can currently be recycled and reused (RT) and textiles that cannot currently be recycled and reused (NRT).

In April 2024, WRAP published Textiles Reuse and Recycling Definitions[7], which included industry definitions for post-consumer textiles:

Post-consumer textiles reusable in current state (RT): Post-consumer textiles that have been used by a consumer and ready to be discarded but are still reusable in their current form or with minimal repair.

Post-consumer textiles non-reusable in current state (NRT): Post-consumer textiles that are not reusable for their intended purpose. These textiles need to be collected, sorted, and treated in line with the waste hierarchy, prioritising remanufacture and recycling over energy recovery or landfill and incineration.

A ScienceDirect study found that only 77.2%[8] of textiles sorted at a central sorting centre in Europe were reusable, a figure it reports is decreasing across Europe. This is leaving vast amounts of textile waste that, currently, cannot be reused. This presents an opportunity to create solutions that enable the industry to better recycle and remanufacture textiles that are not reusable in their current state.

1.5. UK citizen pre-sorting collection trials

The ACT UK project aims to create a blueprint and catalyse the development of an Automated Textile Sorting and Pre-processing (ATSP) facility in the UK to provide quality feedstock for textiles recycling at scale.

To support the business case for an ATSP network, citizen pre-sorting trials were identified as a means to explore the challenges and opportunities of reimagining and enhancing collection processes.

The trials, which were conducted by ACT UK consortium members and external partners, aimed to determine if the public can effectively sort textiles into RT and NRT categories before collection. This pre-sorting must meet the required standards to provide a direct and efficient NRT stream to ATSP facilities, eliminating the need for manual sorting by commercial operators.

Next, we take a look at the six trials.

1.6. Trials in brief and summary of key findings

The six trials focused on four key collection types: bring banks, postal collection, postal take-back, and in-store collection. Section 2 details each trial's methodology, and section 3 contains the results.

Trial: Tesco x Salvation Army
Collection type: Bring bank

Trial: M&S x Oxfam
Collection type: Postal collection

Trial: Reskinned
Collection type: Postal take-back

Trial: Kirklees Council x Textile Recycling International
Collection type: Bring bank

Trial: Dunelm x Salvation Army
Collection type: Postal take-back

Trial: Crisis
Collection type: In-store collection

While section 3 provides a comprehensive analysis of each trial and sections 4.1 and 4.4 set out detailed systems-level opportunities and recommendations, this is a summary of the key findings from the trials combined:

Public appetite for NRT disposal: Feedback gathered from surveys and notes left in sorting bags showed that citizens overwhelmingly supported the trials, primarily motivated by environmental concerns. Communication campaigns across various media channels also contributed to high levels of public engagement and participation.

Increased collections volumes: Most trials saw a noticeable increase in textile donations compared to control sites. This benefits the entire textile value chain by moving towards a circular ecosystem and demonstrates the potential to divert NRT from landfill and incineration.

Trials fall short of a direct NRT stream: Overall, citizens did not separate NRT from RT to the levels needed for a direct stream to ATSP facilities. However, the trials showed promising signs that accuracy could be improved.

Building an NRT market: A clear market demand for recycled content and financial viability for NRT is needed to enable effective collections interventions. Ultimately, building a NRT market will require systems-level change.

1.7. ACT UK innovation roundtable

To complement the trials, Reskinned led an ACT UK roundtable, titled Managing the Mountain. The roundtable brought together industry experts and thought leaders to explore ways innovative ways to improve the current textiles collections system.

Key findings and recommendations from the roundtable have been collated in section 4.2.

2. METHODOLOGY: TRIALS

Here is a closer look at the aims, objectives, and methods of each of the six trials.

2.1 Methods and aims: Citizen pre-sorting trials

There were four citizen pre-sorting trial partnerships.

Trial: Tesco x Salvation Army

Collection type: Bring bank

Trial aim:
To increase the overall quantity and quality of clothing and home textiles collected.

Trial objectives:
- Positive feedback/reaction to the new service
- Increase volumes (by weight) of textiles collected by 10%
- Increase overall volume of RT collected
- Increase overall volume of NRT collected
- Evidence of behavioural change during the trial, e.g. a positive direction regarding pre-separation of RT and NRT



Image 1: SATCoL trial bring banks, Tesco carpark

Trial background and methods:
Building on a long-established partnership between Tesco and Salvation Army Trading Company Limited (SATCoL), this trial was planned to last six months across a sample of Tesco carparks, as well as local authority HWRCs, in the east of England.

At each location, existing textiles bring banks were replaced by separate RT and NRT banks for the duration of the trial. Information was provided on the bring banks to inform the public of what types of items, and in what conditions, they could be deposited.

To raise the profile of the trial, a mix of targeted local communications was used: regional press releases, articles, social media and local media publications, Facebook marketing, and print media.

As well as the 20 trial sites, there were an additional 20 control sites located nearby. These control sites followed SATCoL's standard 'clothing & shoes' branding and were also monitored and tracked to see if media campaigns impacted them.

Each month, the volumes of collected items were recorded at all 40 sites. Additionally, a sample was taken from the total volume of RT and NRT collected at the trial sites. This sample was graded and analysed by SATCoL staff based on the condition and products received.

At trial close, a questionnaire was available to donors via a survey board poster and QR code. Closing interviews were conducted with SATCoL staff to gain qualitative insights.

Trial: M&S x Oxfam

Collection type: Postal collection

Trial aim:
To establish how successful customers were at pre-sorting their textiles into RT and NRT.

Trial objectives:
To capture metrics on:

- Number of bags requested
- Volume of textiles donated
- Number of bags received (target 2,100 bags)
- Positive feedback/reaction to the service

Trial background and methods:
Marks & Spencer and Oxfam have worked together since 2012 to give customers a simple way to donate unwanted clothes in M&S stores. This ACT UK trial aimed to evolve the existing donation scheme to include postal collection so that customers could donate regardless of their proximity to an M&S store.

Customers could request a postal donation bag via the Oxfam website, and the bag contained information on how to differentiate between RT and NRT. Items deemed RT were placed in the main bag, while items deemed NRT were placed in a separate bag inside the main bag. Customers were directed to return the bags via courier to Oxfam's facility for sorting.

Due to trial budget restrictions, a finite number of bags (7,000) were produced, with the potential for further bag production depending on interest levels. Each month, records were taken on the number of bags requested, sent out, and returned, and how many included an internal NRT bag. Bags were then weighed to calculate donated volumes and sorted by Oxfam staff.

Awareness of the trial was raised through an article in The Guardian containing a website link to order the postal collection bag.

At trial close, participants were asked to complete an online survey to gather opinions on their experience. Closing interviews were conducted with Oxfam staff to gain qualitative insights.



Image 2: M&S x Oxfam sorting information

Trial: Reskinned

Collection type: Postal take-back

Trial aim:
To understand citizens' ability to pre-sort their unwanted clothing into RT and NRT at home.

Trial objectives:
- How successfully citizens can define the faults attributed to NRT
- Achieve 500 sign-ups within six weeks of launch

Trial background and methods:
Reskinned operates a take-back programme with fashion brands, where the customer sends their unwanted garments to Reskinned. In return, the customer receives a voucher to spend on the fashion brands' website.

For the trial, which was planned to last three months, Reskinned customers could sign up for the trial via a dedicated page on Reskinned's website. There, customers could specify the item, categorise between RT and NRT, and in the case of NRT, choose what fault it had.

Customers could then send these items via courier, free of charge, to Reskinned's sorting facility. Upon receiving and confirming the contents, the customers would receive the voucher.

At the sorting facility, the items were checked to establish if they met the categorisation designated and the fault described.

Each month, data was collected on the number of sign-ups, garments received, volumes of RT and NRT collected, and amounts of NRT in each subcategory. Reskinned staff were responsible for calculating the customer pre-sort. To drive participation, the trial was shared via social media campaigns and Reskinned's mailing list.

Closing interviews were conducted with Reskinned staff to gather qualitative insights.

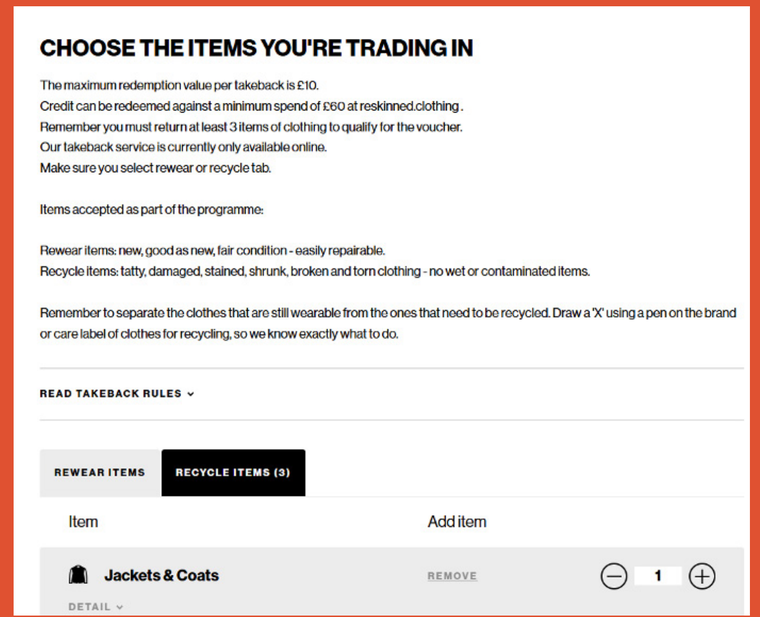


Image 3: Reskinned donation page, specifying either 'Rewear' or 'Recycle'

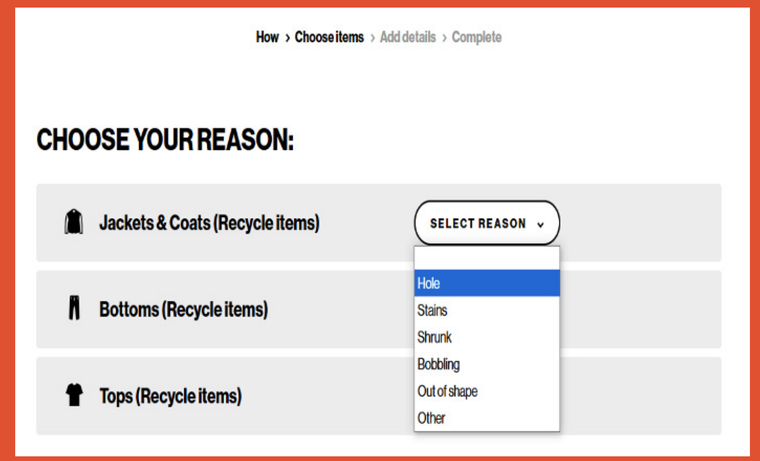


Image 4: Reskinned items specification page allowing the subcategorisation of NRT items

Trial: Kirklees Council x Textile Recycling International

Collection type: Bring bank

Trial aim:
To establish how successful residents were at pre-sorting textiles into RT and NRT.

Trial objectives (set by TRI):
- 25% increase in overall volume of collections
- 20% pre-sorting accuracy

Trial background and methods:
Kirklees Council wanted to participate in the trials as part of its textile collection strategy. Working in partnership with Textile Recycling International (TRI), 20 bring banks were placed at 10 sites throughout the local authority of Kirklees in West Yorkshire for a planned four-month trial.

The selected sites varied from existing locations to new locations, and were sometimes placed alongside other organisations' collections banks.

To raise awareness of the trial, information leaflets were posted through residents' doors, and there was a campaign across local media – both social and traditional – to spread the message. Information was also placed on the bring banks.

Each month, the collection volume and sorting accuracy were recorded, and data was compared to control sites from the previous year. Control sites were selected based on location and type to increase comparability in data.



Image 5: TRI bring banks



Methods and aims: External industry trials

Two of the six trials were conducted by organisations outside the ACT consortium.

Trial: Dunelm x Salvation Army

Collection type: Postal take-back

Trial aim:
To understand customers' ability to pre-sort RT from NRT via a postal service.

Trial objectives:
- Total of c.1,500 packages over the trial period
- Average 1kg per donation
- 80% accuracy in consumer pre-sorting

Trial background and methods:
Working with ACT consortia Salvation Army Trading Company Limited (SATCoL), for this trial Dunelm built on its current in-store textiles take-back scheme by providing customers with the option of donating unwanted homewares and clothing through a postal service.

The trial was planned for three months, during which Dunelm customers could access the service and log requests to donate textiles through its website. Information on pre-sorting was provided on Dunelm's website and shared via email once customers registered to donate. Donors were instructed to use their own bags, placing RT in one and using a second NRT bag within the first bag. Customers could take their bags to local courier drop-off points, from where they would be delivered to SATCoL, where bags were sorted.

Public awareness about the trial was spread via social media and other online media platforms, as well as through trade and consumer lifestyle publications. The trial's progress was monitored bi-weekly by Dunelm and SATCoL, with a view to driving further awareness if the desired progress wasn't being reached. Trial results were reported monthly across the trial period.

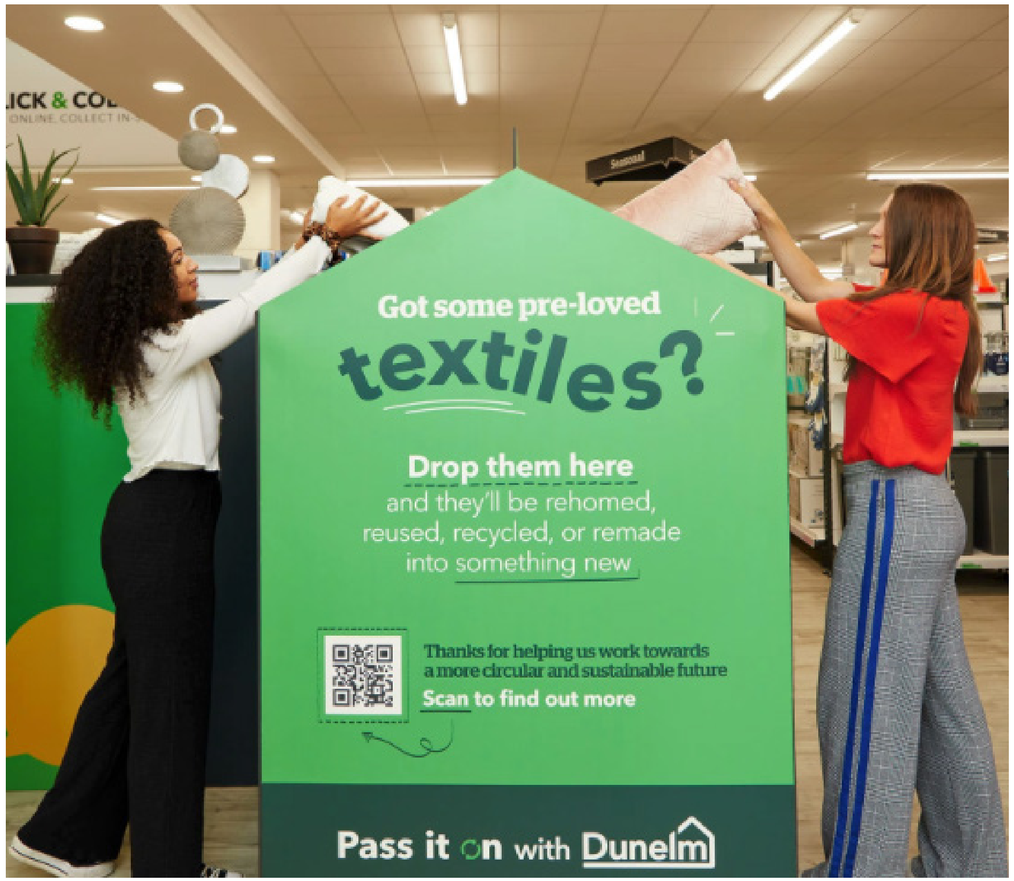


Image 6: Dunelm trial communication

Trial: Crisis

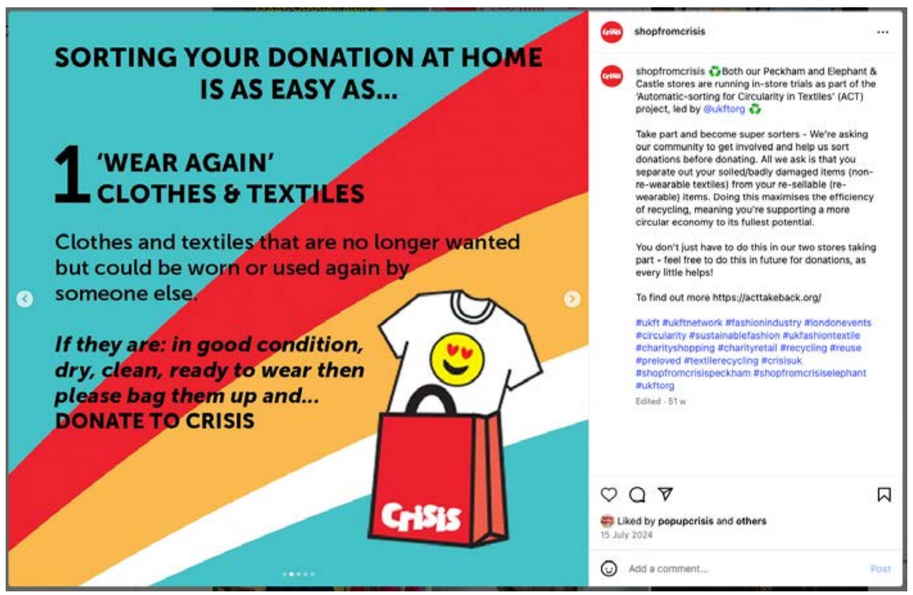
Collection type: In-store collection

Trial aim:
To understand customers' ability to pre-sort.

Trial objectives:
To increase total volumes collected.

Trial background and methods:
Using its two stores in London – Elephant & Castle and Peckham – Crisis encouraged its customers to pre-sort donations prior to dropping them off in-store. Crisis store staff then recorded items deemed as RT and NRT.

The trial was planned for two months, and communication on the trial and how to pre-sort was shared via Crisis' Facebook and Instagram platforms, as well as in-store leaflets.



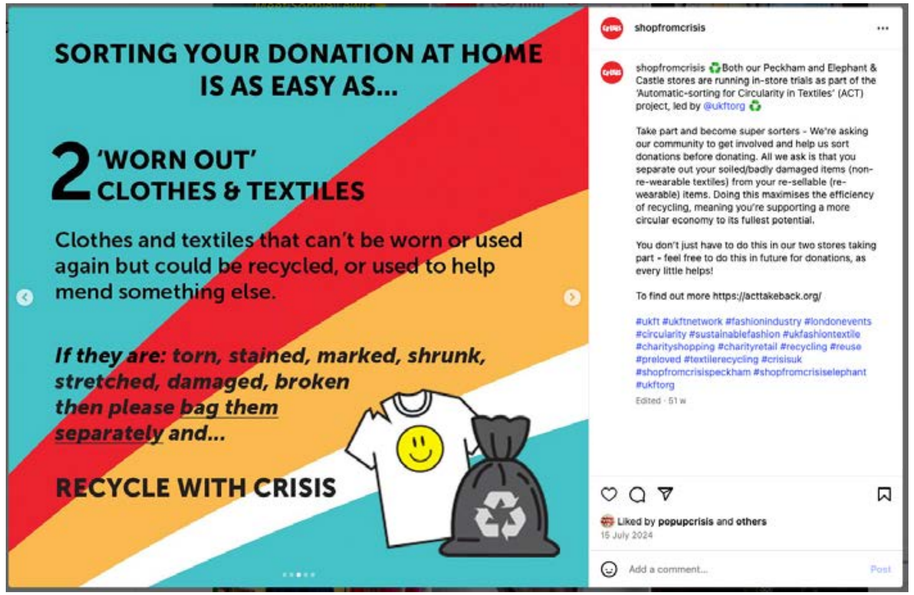


Image 7: Crisis Instagram reel defining RT and NRT

3. RESULTS: TRIALS

Below is an overview of the outcomes from each partnership trial. It should be noted that the trials have been evaluated and analysed independently, with no comparative analysis conducted. This is due to the differences between donation methods, trial duration, geographic location, and differences in receiving and sorting textiles collected.

3.1. Results: Citizen pre-sorting trials

Trial: Tesco x Salvation Army
Collection type: Bring bank

Campaign awareness:
SATCoL deployed its trial bring banks earlier than expected, which enabled data to be gathered for eight months (February-September 2024) rather than the originally intended six months.

The trial's communication campaign ran from April to September 2024 and reached a potential 132 million views. Yahoo News and MSN covered the trial, which contributed the largest reach.

Fashion retailer New Look also raised awareness by supporting the trial by sharing information with its customers via email in September.

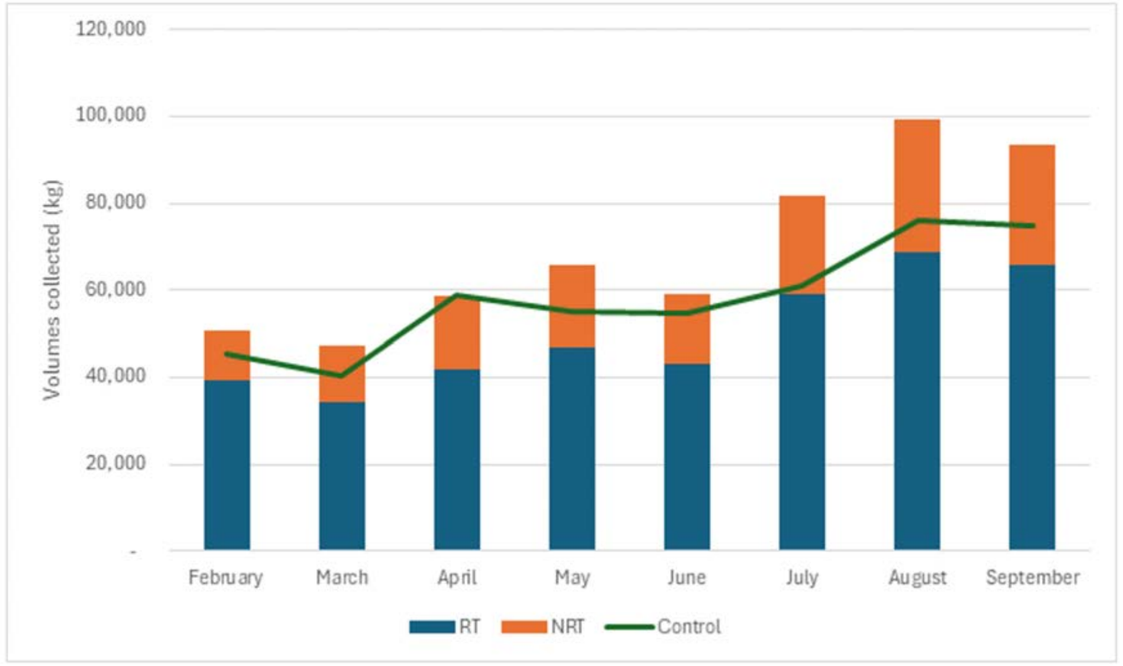


Figure 1: Total textile volumes collected

Figure 1 shows that while the communication campaign was running from April to September, the combined total volumes of RT and NRT collected were generally greater than that collected from the control sites, with the exception of April. The average difference between the sites during this period was 17%. However, it should be noted that when using a statistical t-test, the difference between sites was not statistically significant (p-value 0.15) over the six-month communication period.

However, volumes increased as the communication campaign built across the last three months (July, August, September). The average difference between the sites also increased in the final three months, ranging between 20-25%. Running a t-test on these months alone shows that the difference is statistically significant (p-value 0.04). This could suggest that as the trial progressed and volumes collected increased, so too did the difference in RT and NRT between the trial and control sites.

Volumes collected:
Figure 1 also shows that over the course of the trial, both the trial and control sites increased in the volumes collected. However, without analysing a full calendar year it is difficult to establish the significance of this. Interviews with SATCoL employees highlighted that where comparisons of year-on-year collection data and equivalent sites outside the east of England trial area were available, there was an additional 25% increase in volumes collected in the region targeted by the trial's communication campaign.

When we compare Figures 2, 3, and 4, which show the monthly volumes totals and percentage changes for RT, NRT and control banks, a similar pattern is clear across all graphs. Overall, there is a positive correlation with a coefficient of 0.91, 0.92, and 0.90 for RT, NRT, and the control, respectively. There is an increase in volumes collected as the trial goes on, but there is no significant difference in the percentage proportions between the three categories during the trial period. As there is minimal difference in the collection data compared by time and location, other than a positive boost that can be expected when running a new collection trial, it can only be assumed that the reason for the increased volumes collected at the trial sites is due to the ability to also donate NRT.

Even though having an NRT bank at a location increased the volumes of textiles collected, the data indicates that citizens donating the textiles were unable, overall, to successfully pre-sort these into the desired categories.

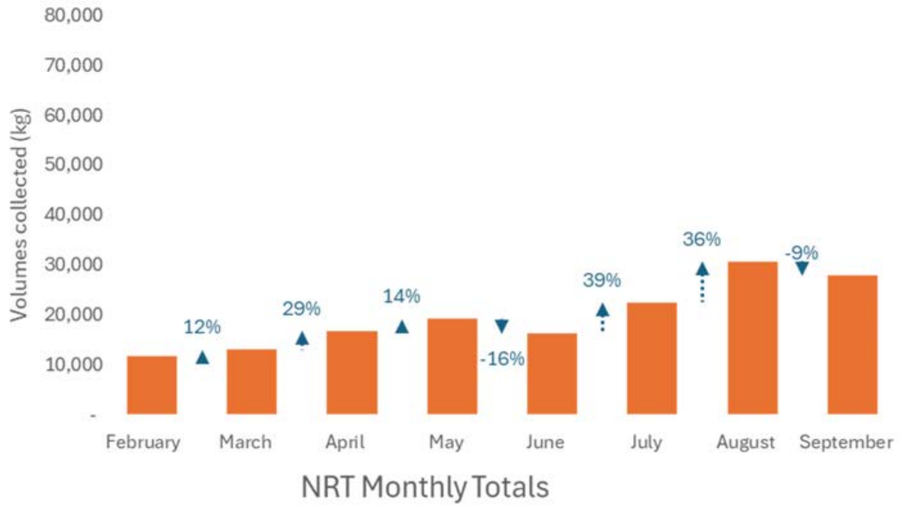


Figure 2: Monthly volume and percentage change of total NRT collections

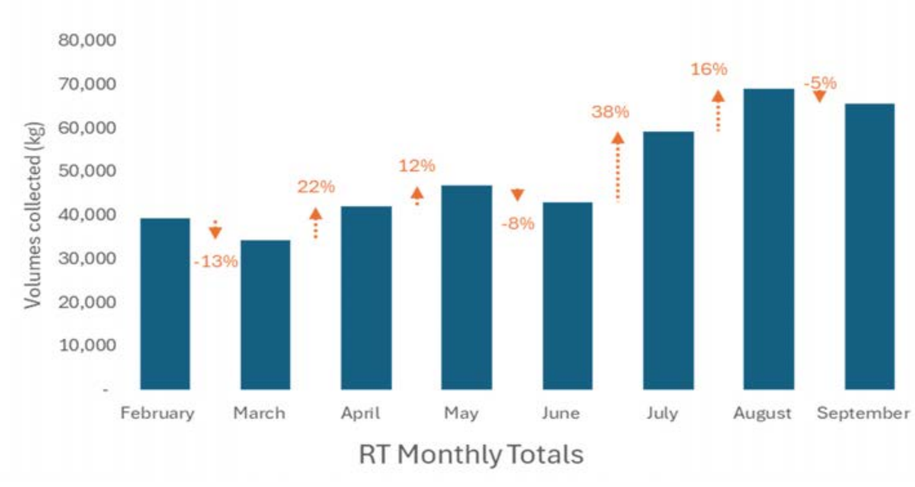


Figure 3: Monthly volume and percentage change of total RT collections

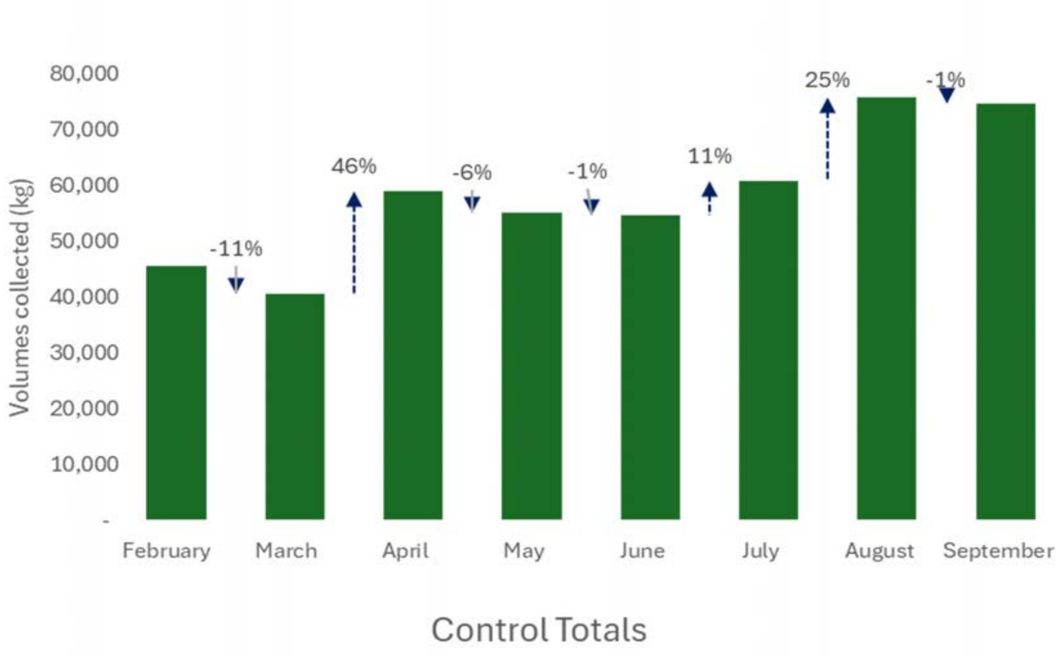


Figure 4: Monthly volume and percentage change of control site totals

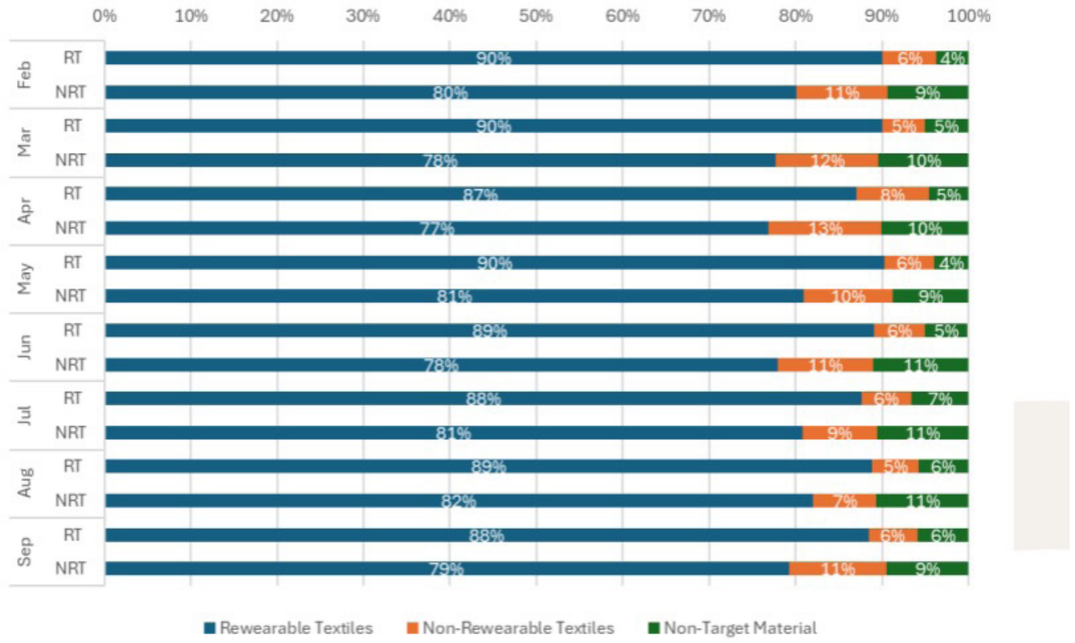


Figure 5: Tesco x SATCoL bring bank split post-sorting

Figure 5 shows the percentages of RT, NRT, and non-target material (NTM; covers materials not categorised as RT or NRT, such as shoes, accessories, household textiles, books, etc.) found within the RT and NRT bring banks each month. Here, RT comprised the largest proportion collected in both banks. A gradual increase in the percentage of NRT within the NRT bank over the course of the trial was not found. NRT levels ranged between 7-13% and were, on average, 3-5% more in the NRT banks than the RT banks.

Therefore, all or most donors were not learning to pre-sort their textiles over the course of the trial. The majority of donors tend to donate textiles occasionally, so it is not possible to conclude this would be the case over an extended period and/or when utilising different communications.

Although percentages of NRT are not high, results find there is consistently a larger percentage of NRT within the NRT bank, than within RT banks. Furthermore, SATCoL staff stated that when following their standard procedure for grading – A, B, and C grades – they found there was a greater proportion of A grade in the RT bank, and C in the NRT bank, with B being mixed between both. This suggests that citizens struggled to correctly identify the B grade. This information could be built upon to further educate people on correctly defining RT and NRT as donors currently have individual perceptions of RT and NRT.

Feedback and behaviours:
During the trial, Tesco and HWRC donors could access an online survey via a QR code from bring bank locations. By trial close, the survey had received 103 responses. Engaged repeat donors made up 65% of the sample. Overall, trial feedback was highly positive, with 96% of respondents liking the new service. Ease of use was a key highlight, with 94% finding the sorting process easy, with users supporting an NRT route, rather than disposal.

98% of respondents stated they pre-sorted textiles before donation, and 91% of these said they sorted at home. Interestingly, of the 9% who did not pre-sort their textiles, 80% said they placed all their items into the NRT bank. This could indicate why a large proportion of RT was found in NRT banks. This also gives insights into people's behaviour when they're required to categorise clothing and could be an area for further research, with scope to improve communication, motivation, and accessibility.

Conclusions:
Though Tesco and HWRC donors were not able to pre-sort their clothing into RT and NRT, there are positives to draw from the trial that can be built upon with further research. The objectives set for increasing total volumes collected of RT and NRT were met. Responses from donors via the SATCoL survey, as well as increased total volumes collected at trial sites over control sites, suggest that citizens view the trial positively and there is a strong interest in having an NRT service.

SATCoL intends to extend the trial for a further six months at Tesco and HWRC sites to assess impacts over an extended time period.

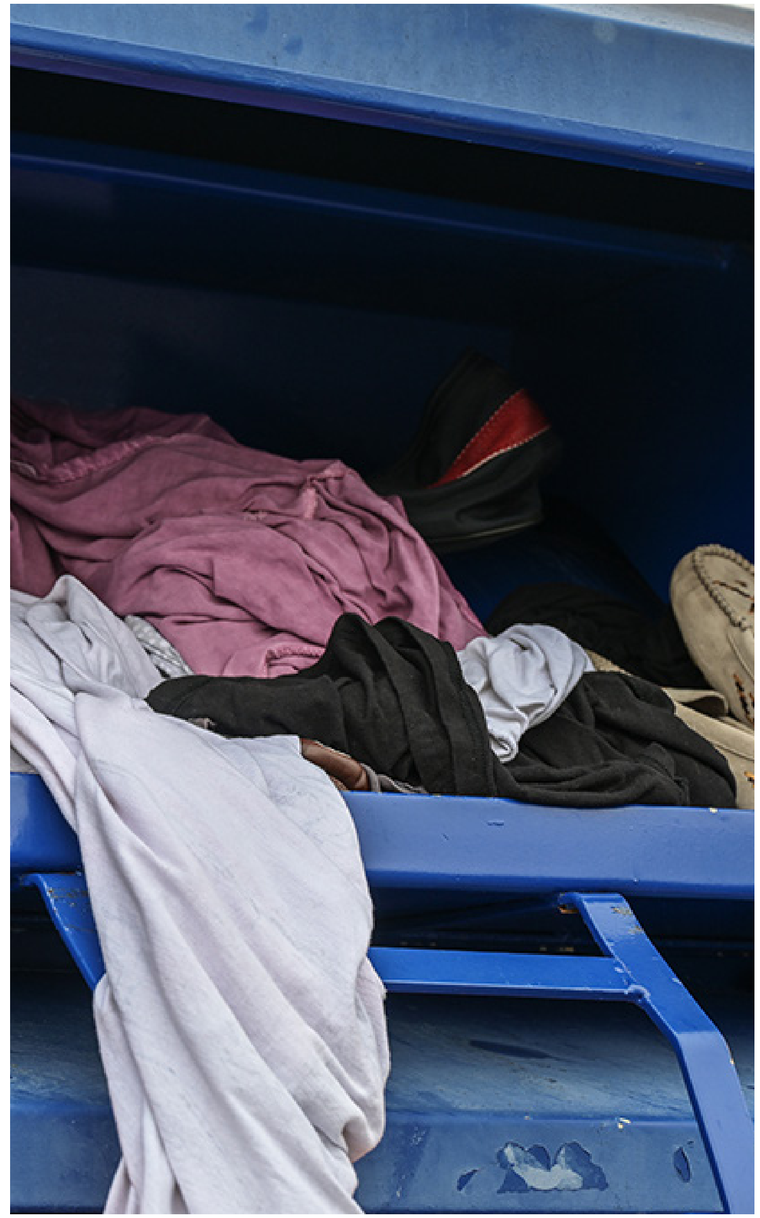
Trial: M&S x Oxfam

Collection type: Postal collection

Campaign awareness:
An article about the launch of the trial was published in print and online in The Guardian on April 22nd. Within nine days of publication, all 7,000 postal bags that Oxfam had printed for the trial had been requested. With more media coverage expected, including on BBC Radio 4 and BBC Breakfast, a decision was made to have a further 3,000 postal bags printed, totalling 10,000 postal bags.

Over the course of the three-month trial, there were 80 pieces of coverage across multiple national media channels, such as The Sun, The Mirror, and the BBC, with a combined potential reach of 734 million views.

Returned bags:
In total, 9,777 bags were requested throughout the trial, which was 140% of the original target. Participants had returned 2,460 bags by the end of the trial, exceeding the original target of 2,100. In total, the bags contained over seven tonnes of post-consumer textiles.



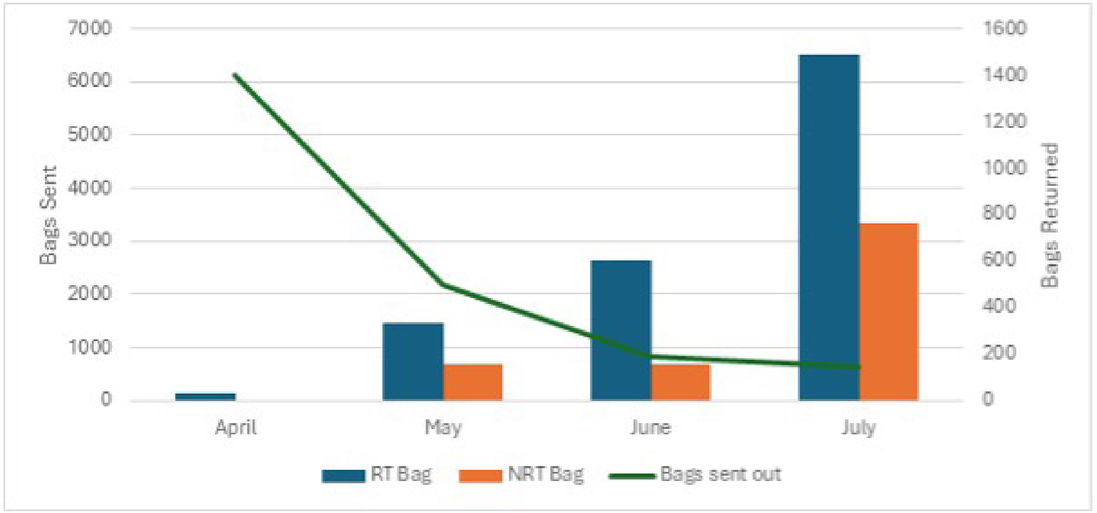


Figure 6: Bags sent versus bags returned

Figure 6 shows the decrease in the number of bags requested by customers over the trial period, against the increase in the number of bags returned, as well as the number of bags that also contained an internal NRT bag. The graph was typical of Oxfam's expectations within the three-month period. The average return rate for the trial was 25.2%, in line with baseline results. Of the bags returned, 44% of them contained an internal NRT bag, showing significant engagement in the trial.

Figure 7 shows that when combining the average weight from the RT and NRT bags, in each month of the trial there was a greater total volume compared to the baseline. Across the trial, there is an average increase of 46% of textiles collected per bag when the option to include NRT is available.

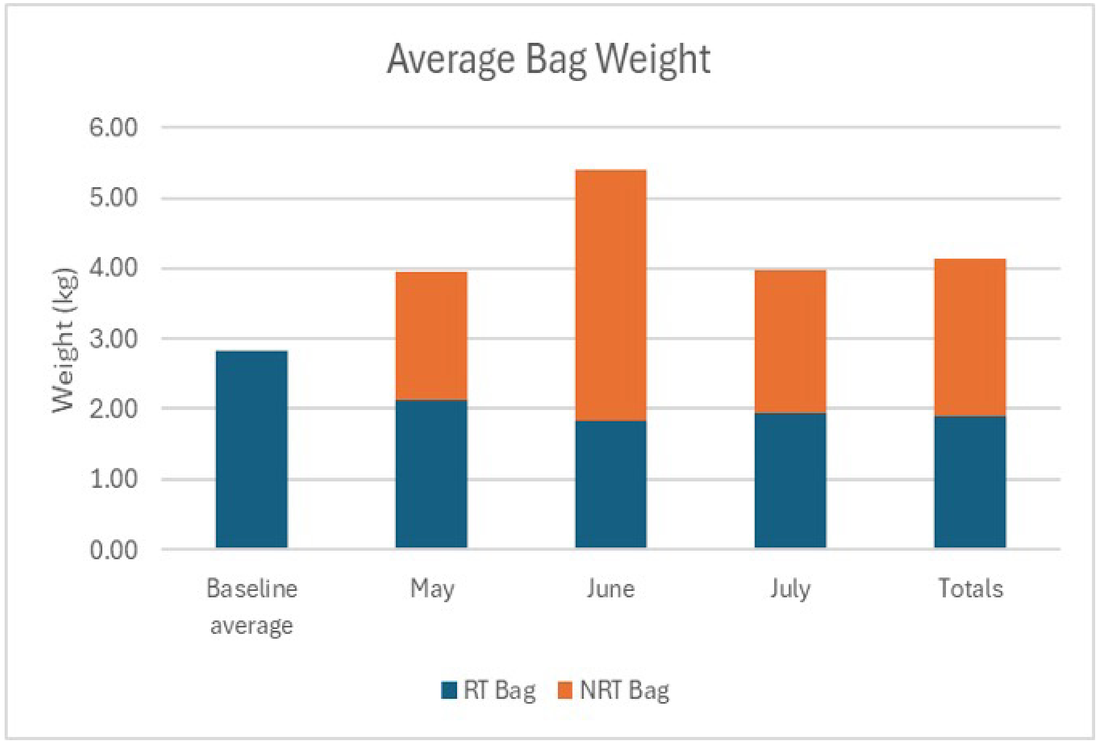


Figure 7: Average postal donation

Pre-sorting accuracy:
After weighing donations, Oxfam staff sorted textiles into RT, NRT and NTM categories to assess the accuracy of citizen pre-sort. Figure 8 displays the percentage splits for each month compared to a baseline. A large percentage of NRT was found in both RT and NRT bags, with the percentage of NRT within NRTs growing over the trial period, accounting for 94% by trial close. There is also a marked increase in the amount of NRT compared to the baseline.

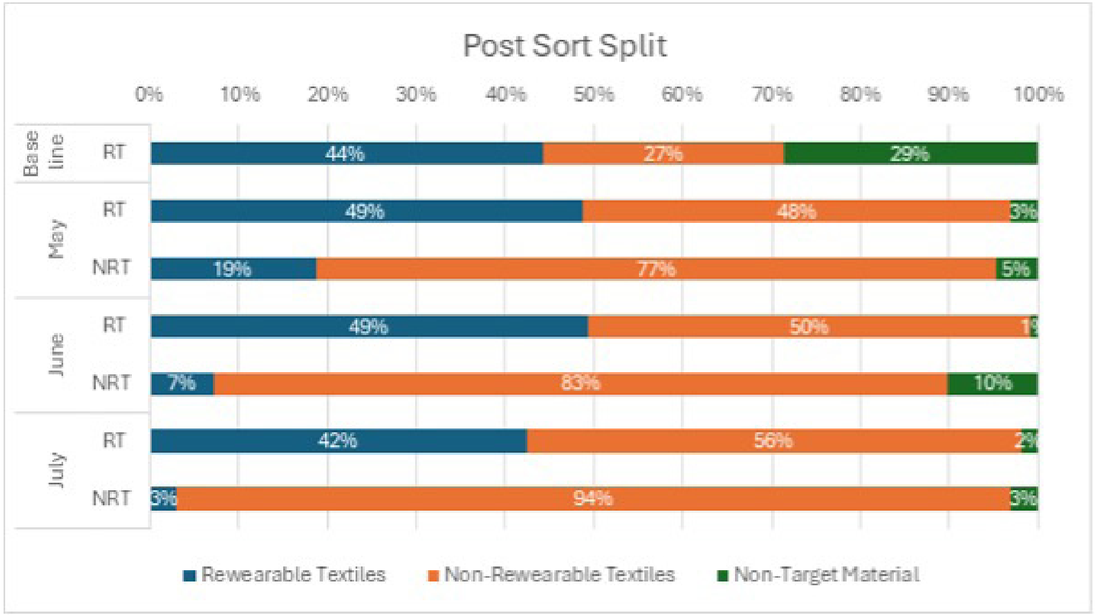


Figure 8: Post-sorting category splits

We can conclude that Figure 8 indicates that citizens can sort NRT correctly. However, when focusing on combined totals post-sorting, there are still large proportions of the RT in NRT bags – see Figure 9.

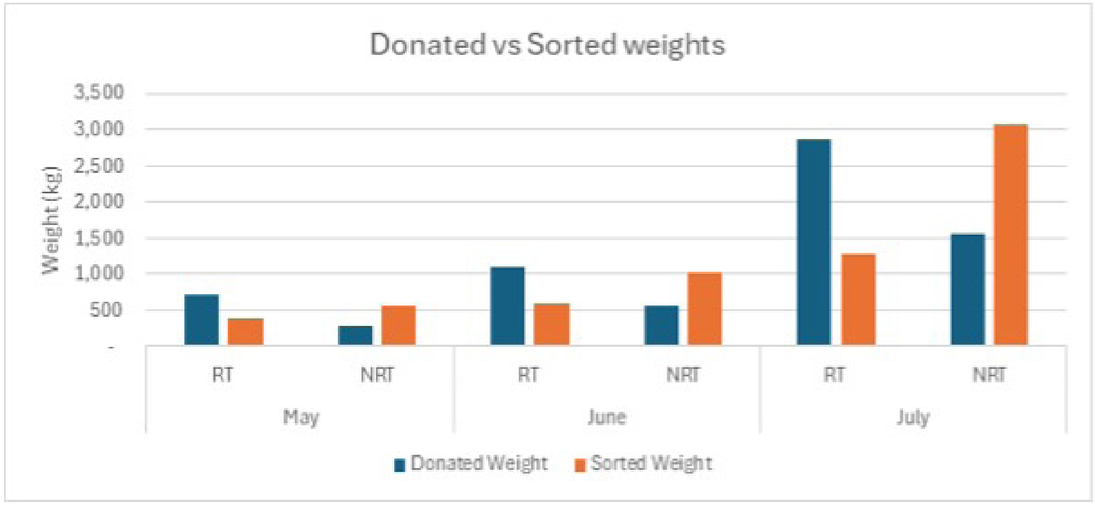


Figure 9: Comparison of donated weights and sorted weights

Feedback:
Approximately two months after the completion of the trial, Oxfam emailed participants for feedback. There were 344 responses in one week, revealing that:

- 94% found the site to order the bag easy to use
- 87% found the instructions that came with the bag on how to separate into wearable and unwearable easy to use
- 80% said that they had sorted their NRT items into a separate bag
- Of those that did sort before donating, the most common reason (44%) was that they were sending all one category of clothing (i.e. all RT or all NRT)
- 94% of respondents would use a scheme like this again if it were available

Trial: Reskinned
Collection type: Postal take-back

Campaign awareness:
Reskinned promoted its take-back programme to its customers and followers via email and social media, with a potential reach of 18,405 views. By Reskinned's measurement, engagement totalled 5.5%.

Received bags:
Reskinned received around 30 bags a month. This take-up was lower than expected, particularly when comparing it to a well-established partner brand that averages 380 take-back bags per month after running the scheme for four years. Despite this, each bag contained multiple items, and Reskinned received over 900 garments in total by the end of the trial.

There was an average 65% return rate from the initial point of the online take-back process to posting garments back to Reskinned. Additionally, the average number of items sent in each parcel during the trial was high when compared to the baseline – see Figure 10. This finding was also highlighted by Reskinned staff when interviewed, who stated that the average parcel size in the trial was greater than their usual take-back parcel volumes.

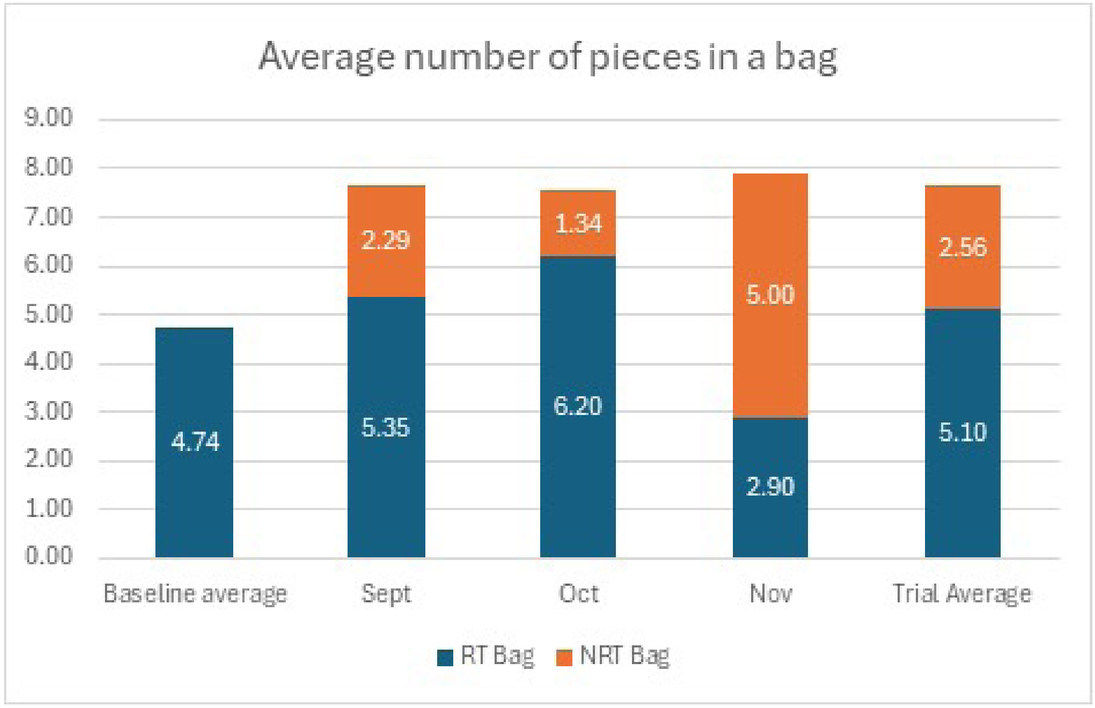


Figure 10: Reskinned average number of pieces per bag

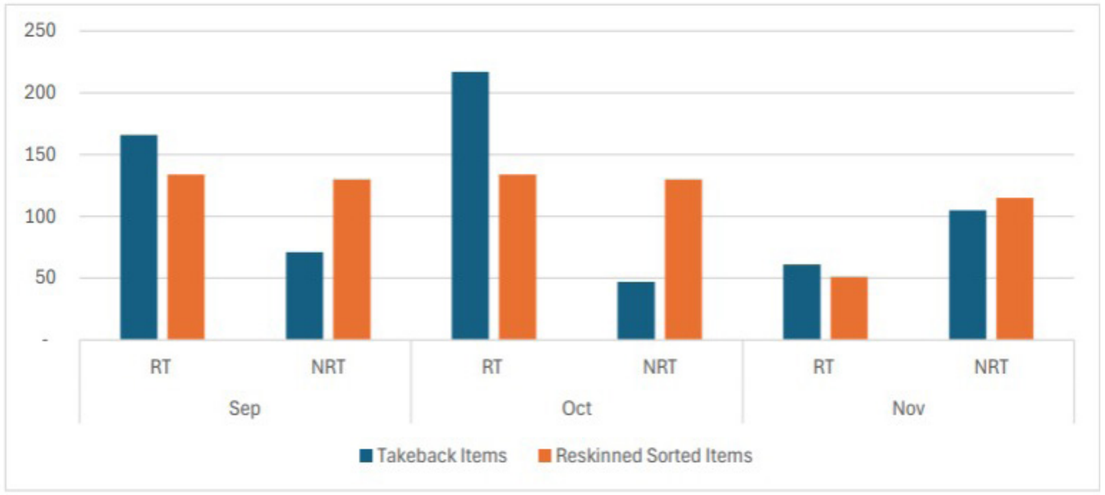


Figure 11: Reskinned take-back items compared to sorted items

Post-sorting accuracy:
Post-sorting accuracy of NRT, shown in Figure 12, appears high, averaging 91% across the trial. The average accuracy for RT was 72%, a slight improvement from the baseline. Figure 13 shows the amounts of RT and NRT received from customers compared to after it had been sorted by Reskinned. In the first two months, there is a noticeable difference between items categorised as RT/ NRT by customers and Reskinned staff. However, this difference shrinks in the final month. Despite this, RT accuracy levels would need to improve for citizen pre-sort to become the standard process at Reskinned.

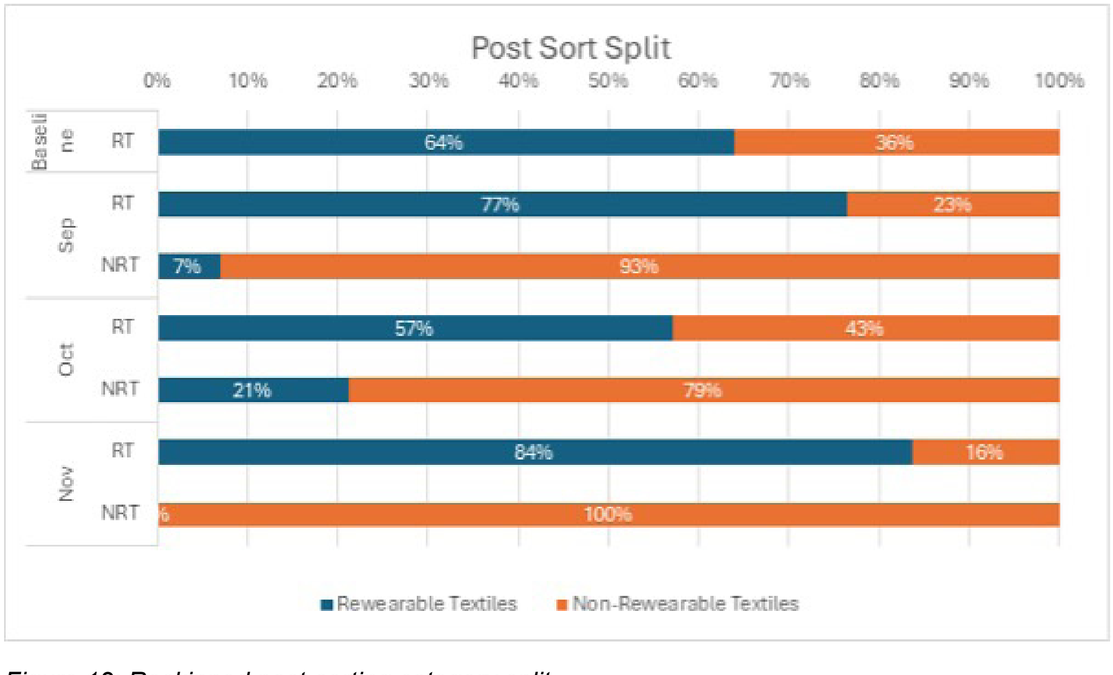


Figure 12: Reskinned post-sorting category split

Identifying subcategories:
Figure 13 presents totals for NRT subcategories. ‘Out of shape’ was the subcategory that customers most struggled to correctly identify. Faults such as ‘bobbled’ and ‘faded’ also had differences between pre-sort and sorted, with 28 and 27 items, respectively, being recategorised from RT. Although ‘stained’ had the largest number recategorised from RT (45), Reskinned staff only disagreed with two items returned by customers. An extended version of this trial would be highly beneficial to gain further insights into customer categorisation. This could help guide educational campaigns to help improve citizen pre-sorting.

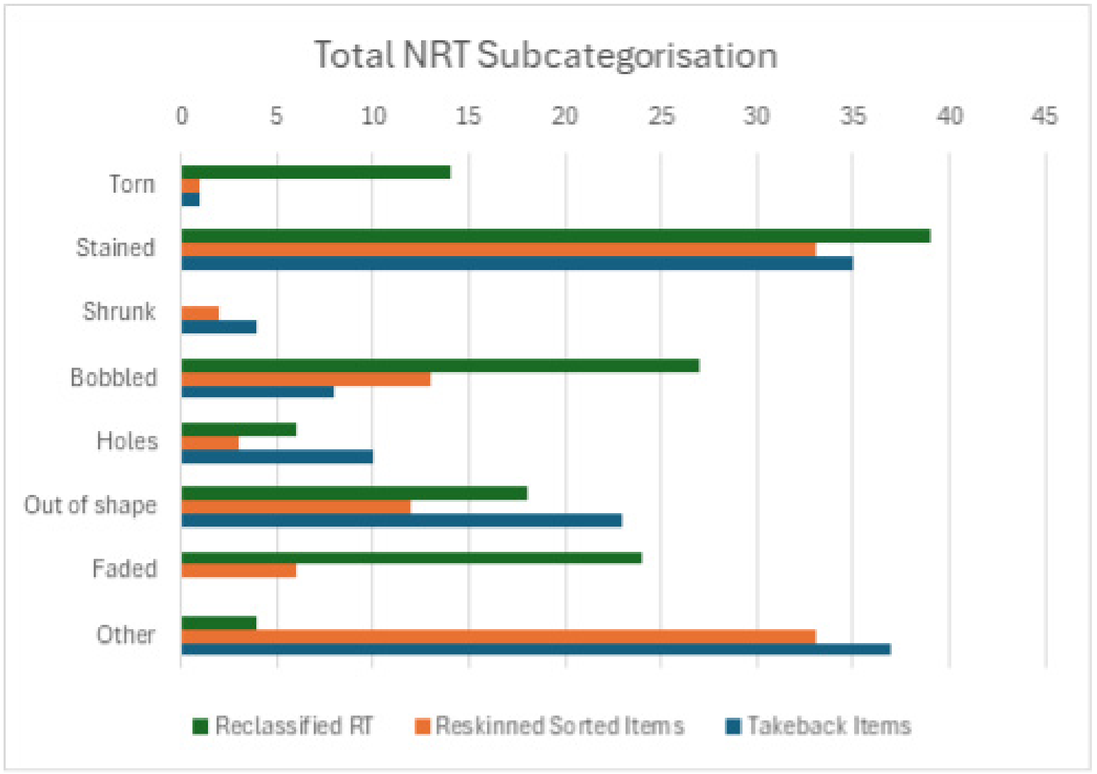


Figure 13: Reskinned NRT subcategorisation

Trial: Kirklees Council x Textile Recycling International
Collection type: Bring bank

Campaign awareness:
The Kirklees Council communications team issued a press release at the beginning of the trial in July. This was picked up by local newspapers and websites, and in September, it was covered online by the BBC. The total potential reach stood at 596 million views across the four-month trial.

Textiles collected:
Figure 14 shows the comparison between control site collection volumes from the previous year (2023), to the total RT and NRT from all project sites. During the trial, the trial locations struggled to collect significant levels of textiles at control sites. July had the largest difference between trial and control sites (248%), with four out of 10 RT banks failing to collect any textiles.

This disappointing outcome may be a result of competing with multiple textiles bring banks from other organisations at trial sites, as well as a lack of awareness of bank locations.

Despite this, there was a large increase in collections in October following the publication of the BBC article, with a difference of 32% against the previous month. Figure 15, Figure 16, and Figure 17 show the total volumes and percentage changes of RT, NRT, and control sites. Each month follows a similar trend, apart from October where there is an increase for both RT and NRT.

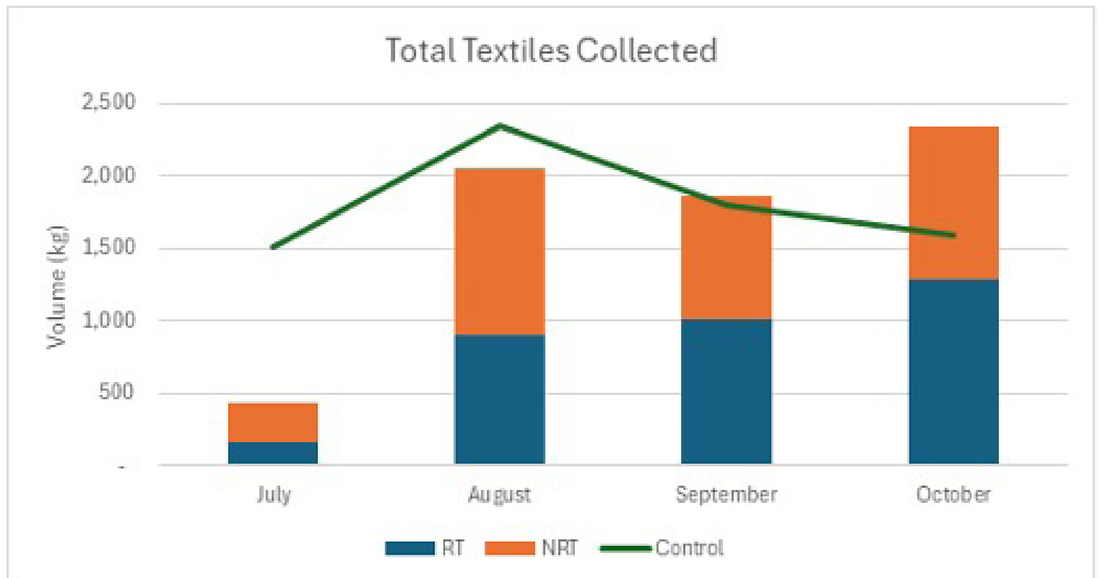


Figure 14: TRI RT and NRT collection volumes compared to control sites

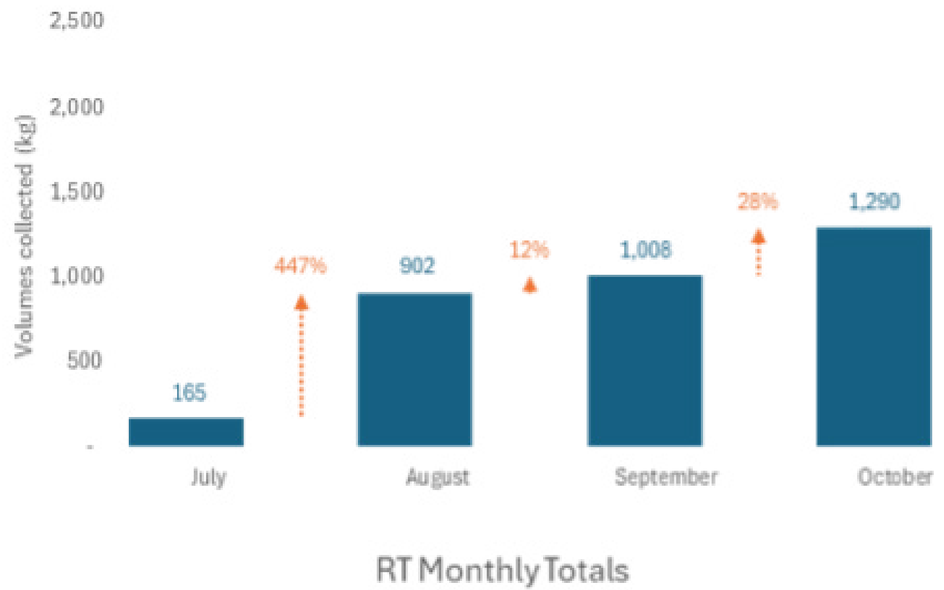


Figure 15: TRI monthly volume and percentage change of total RT collections

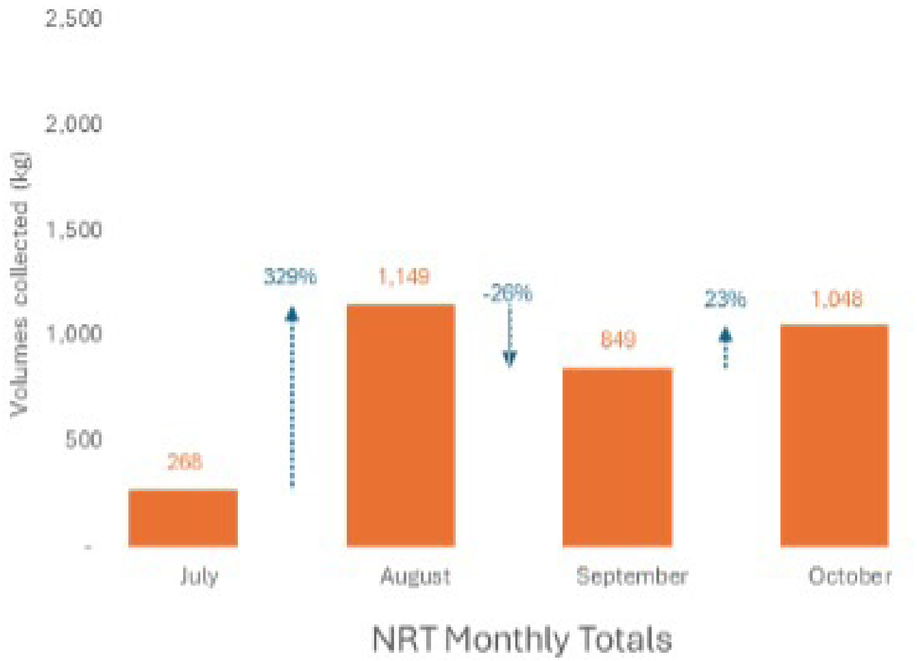


Figure 16: TRI monthly volume and percentage change of total NRT collections



Figure 17: TRI monthly volume and percentage change of control site collections

Trial sites:
Figure 18 shows the trial site locations. The larger circles indicate greater total volumes of RT collected, with the orange-ness of a circle reflecting larger NRT volumes collected. Figure 19 shows the locations of control sites, with larger circles indicating greater volumes collected over the same months (July-October) in 2023. There is only minor variation in size in Figure 18 and Figure 19, showing a consistency in RT collection across trial sites. The difference in colour in Figure 18 indicates that variation generally lies in the amount of NRT collected.

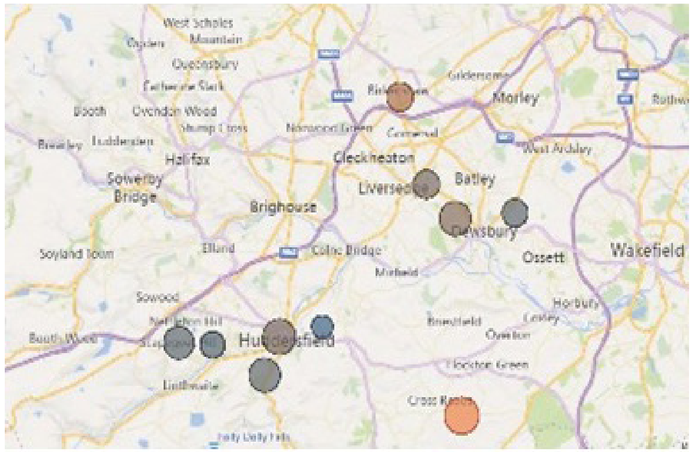


Figure 18: TRI trial site locations.

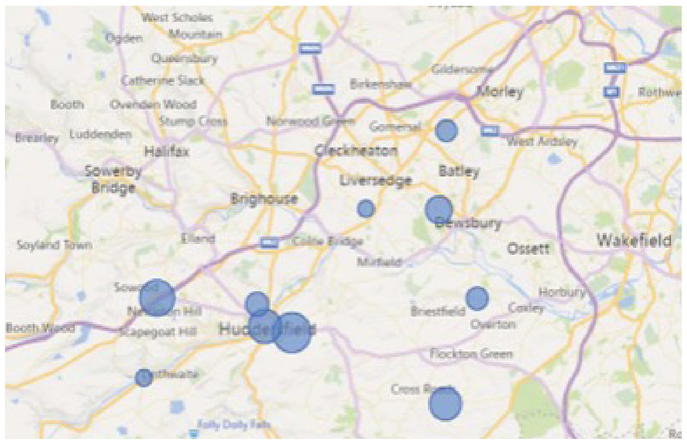


Figure 19: Control site locations

Pre-sorting accuracy:
Reviewing the post-sorting category splits found in Figure 20, there is little correlation between RT and NRT categorised by customers and professional sorters. Though there is a greater percentage of the correct category found in each bank every month, the constant fluctuation does not clearly demonstrate citizens were able to successfully pre-sort.

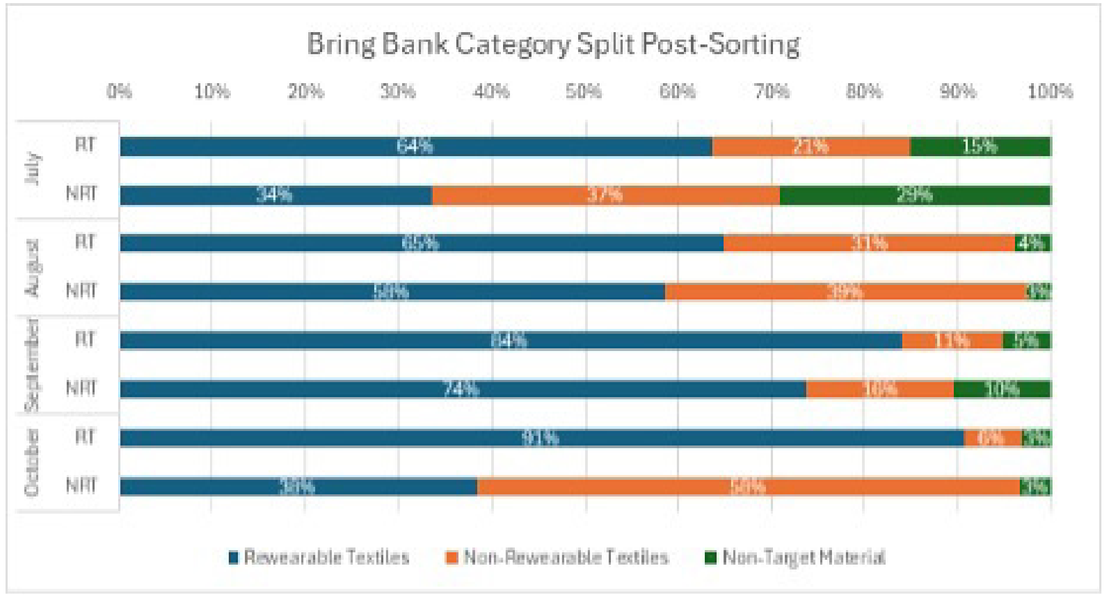


Figure 20: TRI post-sorting category splits

3.2. Results: External industry trials

Trial: Dunelm x Salvation Army
Collection type: Postal take-back

Campaign awareness:
Across the three-month postal trial, there were 16 pieces of coverage across a range of online and trade media, with a potential reach of 7.3 million views. This coverage resulted in a significant uplift in traffic to Dunelm's 'Pass It On' webpage, which hosted the trial service, both immediately after press coverage and throughout the three-month period.

Collected bags:
At 56%, the average return rate was high, with total donations broadly in line with expectations. However, of the 1,660 RT bags received, only 10 contained an internal NRT bag. This made it difficult to analyse customers' ability to pre-sort textiles, as it is unclear whether donors intended to send only RT donations, whether instructions were not followed correctly, or other possible reasons.

Reviewing post-sorting category splits of RT donations in Figure 21, the second largest proportion donated is NTM, which mainly contained synthetic duvets and pillows. In the last week of August, trial instructions were amended to reduce the volumes of NTM received. While this amendment seemed to have a positive impact in September with a reduction in the volumes of NMT received, the volumes of NTM received increased in October.

There are several possible reasons for the lower levels of engagement in pre-sorting RT and NRT. As Dunelm is a homewares retailer, customers may have been unable to post some items (RT or NRT) due to the size of the products. Additionally, customers may be more accustomed to identifying RT and NRT in clothing than in homeware products. Furthermore, unlike other trials, there were no physical instructions or bags sent to aid customers' ability to pre-sort. Instructions were provided online before registering to donate and via email once registered.

Dunelm and SATCoL intend to continue the online postal take-back service trial until March 2025, without requesting customers to pre-sort.

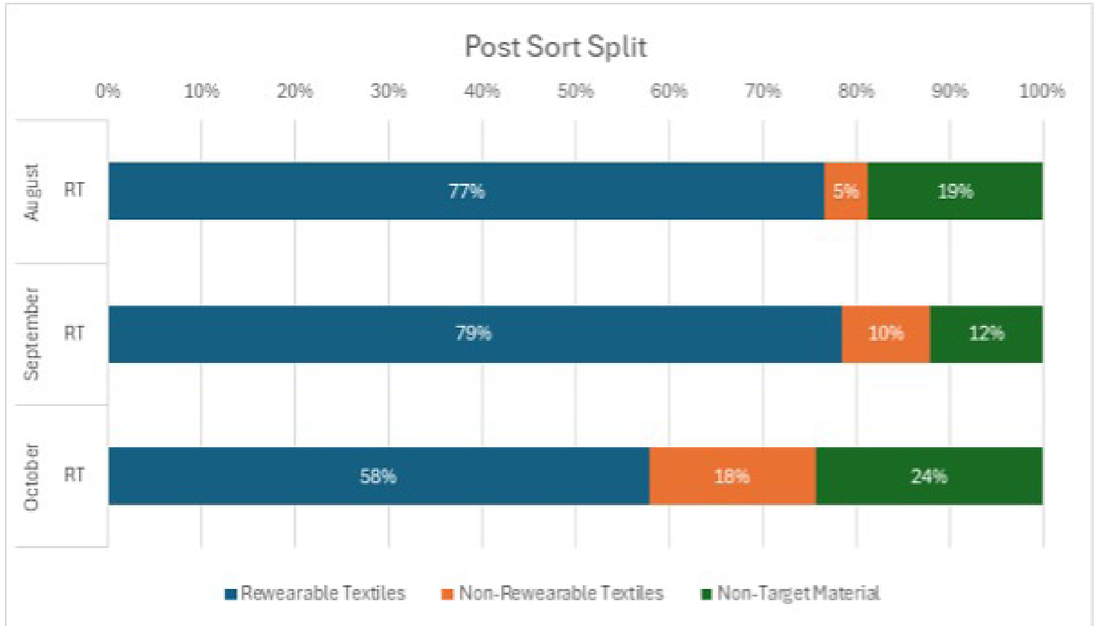


Figure 21: Dunelm post-sorting category splits

Conclusions:
Both Dunelm and SATCoL were pleased with the level of engagement from customers. Dunelm also reported a positive response from both retail trade and broader media, indicating an interest in this topic. Internally, colleagues at Dunelm also registered interest, with various departments requesting updates.

It was felt that a longer trial would have provided more opportunity to test different communication tools, such as video content, to help increase customers' understanding of pre-sorting.

The Dunelm team is keen to build upon the learnings from the trial with a specific focus on supporting the textile recycling sector through a closed-loop recycling system where Dunelm products can be recycled and the fibres used in new product collections.

Trial: Crisis
Collection type: In-store Collection

Pre-sorting accuracy:
Donations were given directly to in-store staff, who would record citizens' pre-sorting accuracy. This meant staff were managing the trial, as well as general duties, which led to discrepancies in volumes recorded between customer donations and Crisis sorting figures.

As a result, only post-sort totals were provided by in-store staff, and therefore, analysis of the customers' ability to pre-sort was not possible. Despite this, Figure 22 shows a large difference between baseline and trial RT and NRT splits. The reasons for this are unclear, but it could be due to NTM material.

To gain further insights, staff training and greater clarity are needed. Additional time to gather a representative baseline and more data from trial months would also provide a more accurate representation of customer categorisation.

Feedback and behaviours:
As the only in-store trial in the project, the Crisis trial was important for assessing the challenges and opportunities of in-store collections. The team running the trial found that while customers were pleased to have recycling options for their NRT, the process was difficult for the staff and volunteers. When customers donate clothing to a charity, they expect to drop, shop, and leave or drop and leave. Therefore, the extended interaction with the shop team related to the lifecycle of the donation was unexpected. Initially, the shop teams also felt uncomfortable when engaging customers in the conversation about what they were donating.

Because charity retail directly benefits from the income generated from the government Gift Aid scheme, staff would prioritise the standard conversation about Gift Aid over the new conversation about sorting. However, in the same way that the Gift Aid conversation is standard for the shop teams, a sorting conversation could also become standard. This would take additional training and time for paid staff, volunteers, customers, and the community to become familiar with the process.

Crisis would call for standardisation in sorting guidelines, as shop staff may currently sort differently depending on the NRT or rag collection partner (the term 'rag' is commonly used to describe NRT by charities). Crisis would also suggest that to scale pre-sorting, there would need to be further trials that tested technology as a means of reducing the burden on shop teams and customers.

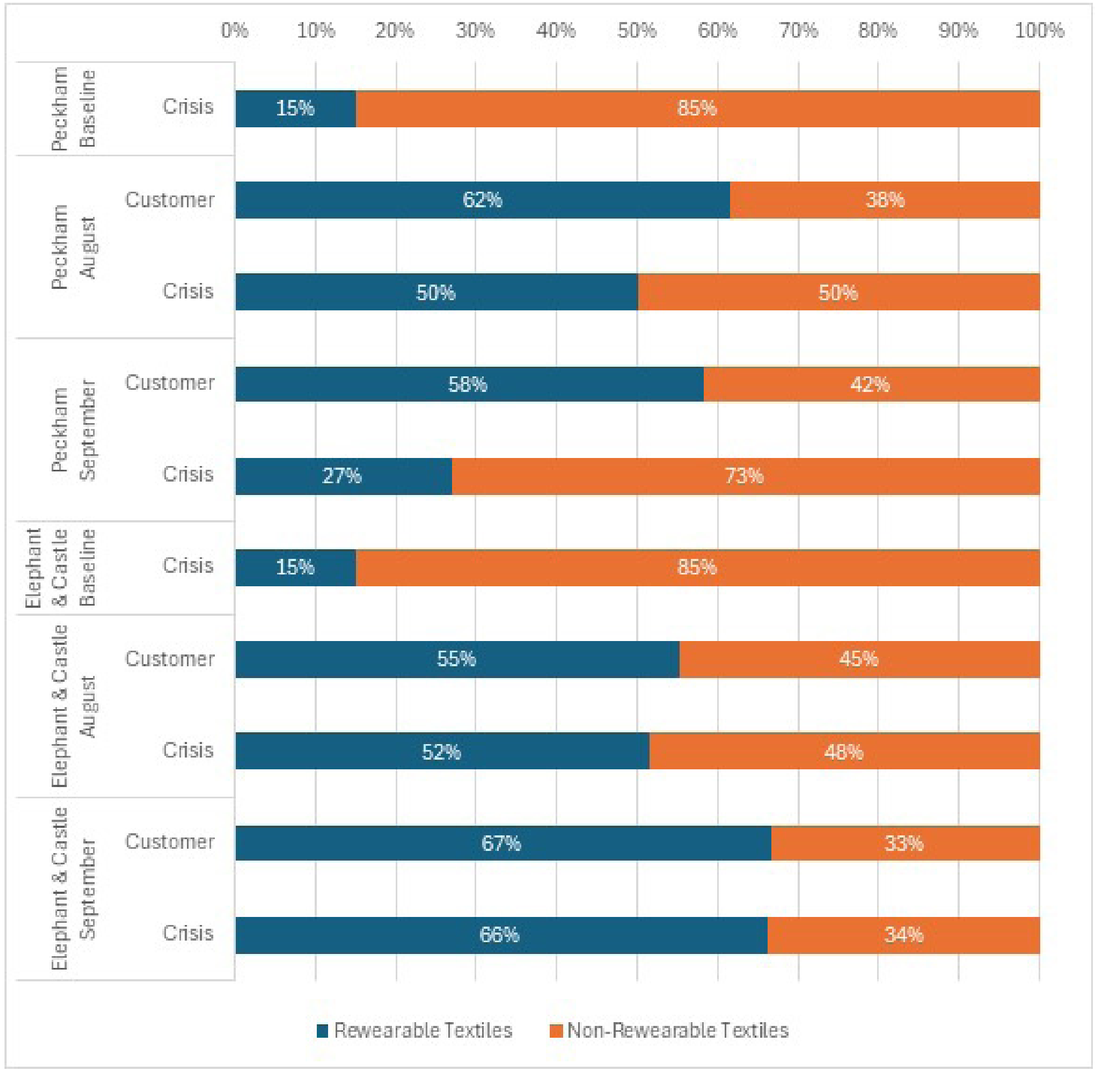


Figure 22: Crisis post-sort category splits

4. DISCUSSION

Below are four sets of recommendations:

- Post-trials recommendations
- Meeting the Mountain roundtable recommendations
- Tesco survey recommendations
- Full recommendations

4.1. Post-trial recommendations

Based on the trials increasing the total volumes collected, citizen appetite exists for NRT collection. However, trial participants fell short of delivering a dedicated NRT stream to ATSP facilities and onward markets. Therefore, to further test the effectiveness of citizen pre-sort, WRAP has set out recommendations for further trials and research:

4.1.1. Recommendation: Duration of trials

Utilise donation cycle: Trials should run across an annual donation cycle to gather insights on low/peak donation periods.

Extend trial duration: Longer trials will help to assess if citizen pre-sort can significantly reduce NRT in end-of-life across the various citizen segments.

Optimise communications: Extended trials could evaluate the effectiveness of communication campaigns on collected volumes and RT/NRT splits.

4.1.2. Recommendations: Collection type

Set up a trial of multiple collection methods and sort volumes post-collection: A designated business/partnership should lead this trial to enable the reliable comparison of different collection methods for citizen pre-sort, so the effectiveness of various methods can be better evaluated.

Organisations to avoid areas where other businesses run waste/resource streams: Bring banks should be isolated from competing banks to improve discard behaviour.

Provide training for sorting: A dedicated space for sorting should also be provided to optimise the simplicity and accuracy of each trial, particularly for in-store trials.

4.1.3. Recommendations: Grading

Analyse collected volumes by RT and NRT grades: This will deliver more granular results on citizen ability to categorise RT and NRT.

4.1.4. Recommendations: Communications

Conduct research on communications that best educate citizens on RT/NRT pre-sort accuracy: Public communications and media pick-up engaged citizens to action. Therefore, it is clear that strong communication is key to educating the public on best practices and plays a fundamental role in unlocking the knowledge barrier for citizen behaviour change.



4.2. Roundtable recommendations

Reskinned led an ACT UK roundtable, Managing the Mountain, in 2024. The event and subsequent meetings brought together industry experts and thought leaders to discuss the challenges facing post-consumer textile collectors and sorters and brainstorm solutions.

The results were four recommendations that will be put to the ACT UK Project Consortium to build towards during the last phases of ACT UK and beyond.

- **ATSP feeder hubs to reduce operating costs and climate impacts for sorters and collectors:** These hubs, potentially hosted by existing organisations, would sort unwanted PCT and ensure those suitable for reuse would be diverted accordingly. All NRT would be baled and sent to an ATSP facility to be prepared for recycling.

- **ACT UK taskforce to ensure Extended Producer Responsibility (EPR) policy is focused on the regeneration and support of the UK's textile recycling industry:** EPR has the potential to support textile collectors and sorters while we build a circular fashion industry in which PCT has a value that covers the cost of collecting and sorting. The ACT UK task force would represent textile recyclers and influence EPR policy to that end.

- **Design for recycling work to be amplified and made available beyond Textiles 2030 and the Circular Fashion Innovation Network:** Support is required to further engage designers at small-to-medium brands, as well as student and graduate designers. Once collections are ready for launch, brands should be supported to navigate greenwashing risk and aggressively promote these collections to customers in favour of less sustainable products.

- **Pre-research for a nationwide behaviour change campaign:** We need to more deeply understand citizen behaviour, specifically to redirect the 49%[9] of unwanted textiles that go in the household bin (residual waste). The findings would inform a UK-wide behaviour change campaign for textile disposal that would work in tandem with implementing the 'Simpler Recycling' reforms announced by the UK government in November 2024.

4.3. Tesco survey recommendations

Alongside ACT UK's trials and roundtable, Tesco surveyed over 600 customers to gather their thoughts on textiles collections. The main findings were:

- Majority of customers say they donate their unwanted clothes and home textiles
- Most customers donate unwanted clothes and textiles in a good condition to help those in need and declutter their home
- Customers feel encouraged to donate when reassured that it's for a good cause
- Prominent lack of awareness towards clothing recycling bins

As a result of the survey, Tesco has made the following recommendations:

- **Ensure convenience of service, as this impacts customers' decisions to donate**
- **Educate on acceptable donations**

4.4. Full recommendations

To advance collections and support stakeholders, systems-level change is required to build and maintain a market for NRT. To help achieve this, the following five key recommendations have been built through learnings from the trials and the Managing the Mountain roundtable led by Reskinned for ACT UK.

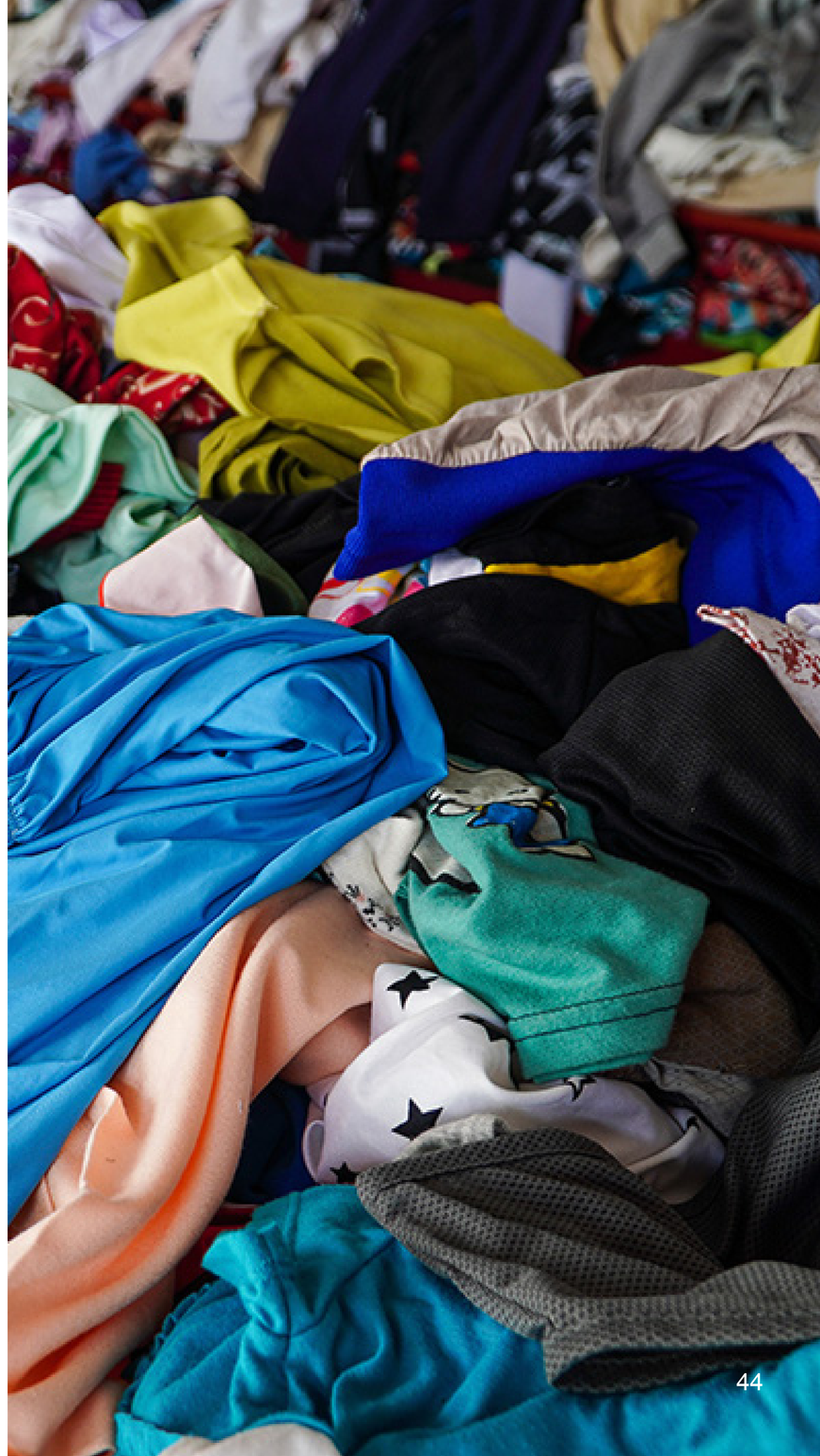
- **Divert end-of-life through research, interventions and citizen behaviour change:** 49% of all discarded textiles are placed in households' general bins. To achieve a circular textile ecosystem, this volume must be drastically reduced by redirecting NRT volumes to ATSP facilities and onward markets. Further research on disposal behaviours is needed to inform and design suitable collection interventions that drive impactful citizen behaviour, making positive behaviours the default. Engaging with citizens to understand and remove barriers is essential.

- **Standardise collections messaging across stakeholders:** Standardisation will relieve complexity and enable a greater understanding of discard methods among citizens. This will not only support positive citizen disposal routes but ensure consistent RT/NRT streams for reuse and recyclers.

- **Design for recyclability:** Brands and retailers have a responsibility to design for recyclability on product lines that are not produced for longevity. It is important to include brands in industry conversations to help educate staff on issues downstream and support the implementation of designing for recyclability. This should embed circularity as the norm and reduce complexities and costs for the reuse and recycling sector. WRAP's Textiles 2030 has developed a 'Design for Recycling Toolkit' due for release to the public in 2025.

- **Work with government to create textiles policy:** Government textiles policy is required to support collectors and wider stakeholders with key industry challenges. This includes influencing the direction of EPR funds to the sector and aligning an EPR to Digital Product Passports to facilitate efficient sorting and recycling. Minimum recycled content should also incentivise an NRT market by stimulating demand for PCT. See Chapter 8 'Transitioning to a UK Circular Textiles Ecosystem' for policy recommendations to support the textiles ecosystem.

- **Invest in textiles ecosystem infrastructure:** Green investors and grant mechanisms are crucial in supporting and de-risking innovation, as well as accelerating technology readiness levels for collections – alongside investing in automatic sorting and F2F recycling. Investors may seek to adopt a systems approach to investment, focusing on financing a holistic investment portfolio rather than individual projects. The government is also ideally situated to provide immediate grants and funding to relieve the critical pressure on the textiles sector.



Chapter 3:

Textile sorting and pre-processing technology

Evaluating current, emerging, and complementary technologies for an ATSP



CONTENTS

Introduction

- Condition of supply: Current feedstock landscape

Market review: Current technologies

- Conveyance and material handling processes and technologies
- Fibre identification and sorting technologies
- Size reduction technologies
- Disruptor removal technologies
- Conclusions and recommendations

Addressing the challenges: Emerging technologies review

- Conveyance: Emerging and complementary technologies
- Fibre identification and sorting: Emerging and complementary technologies
- Disruptor removal: Emerging and complementary technologies

Technology trials

- Gripper trials
- Fibre identification trials
- Disruptor removal trial: Shredding and air separation

Condition of supply: Phase 2

- Condition of supply: ATSP commercial viability key findings
- Condition of supply: Quality key findings
- Condition of supply: Technology key takeaways
- Condition of supply: Strategic key takeaways

Discussion

Appendix

1. INTRODUCTION

When evaluating whether an Advanced Textile Sorting and Pre-processing (ATSP) facility can operate at scale, it is crucial to assess both the technical capabilities and economic feasibility of the current and emerging technologies that will determine its performance and commercial success.

For an ATSP to work at scale, the right technologies will need to be in place across four key areas:

- **Conveyance:** The systems used to transport textiles through the different stages of production at the ATSP.
- **Fibre identification:** Textiles must be categorised based on their fibre composition to enable the ATSP to produce consistent, high-quality feedstock.
- **Size reduction:** Some textile recycling methods require garments to be pre-processed into smaller swatches.
- **Disruptor removal:** Disruptive items such as buttons and labels must be removed ahead of pre-processing.

This chapter, led by Innovate UK and the Manufacturing Technology Centre (MTC), explores these technologies through market reviews, interviews, and trials.

After setting out the standard technical and economical feedstock requirements for textile recyclers through a range of interviews with key stakeholders in section 1.1, this chapter builds a comprehensive market review into current technologies across the four key areas (section 2).

This market review revealed a number of challenges, with no one-size-fits-all solution for any of the four technology areas. Therefore, these challenges are explored in further detail in section 3 to evaluate how emerging and complementary technologies might offer potential solutions and further enhance future iterations of technologies for textile recycling. Based on these emerging and complementary technologies, a series of industry trials were carried out for robotic grippers, fibre identification equipment, and disruptor removal equipment to test their suitability for use at an ATSP. The results of these trials are covered in section 4.

The outcomes of the technology market review also emphasised the need for a deeper understanding of the ATSP's condition of supply. Therefore, section 5 seeks to establish consensus and guidelines for downstream feedstock requirements across recycling processes, strategy, equipment, quality, and commercial viability.

The structure of this chapter differs from the majority of other chapters in this report to allow for key takeaways and recommendations to be integrated throughout each section. The chapter concludes with a series of key findings in section 6.

1.2. Condition of supply: Current feedstock landscape

To help inform technology recommendations for a UK-based ATSP, it was important to first research the standard technical and economical feedstock requirements for textile recyclers.

For this research, a range of interviews were conducted among academia, industry associations and non-profits, collectors and sorters, technology and equipment providers, and textile recyclers. The interviewed recyclers encompassed a broad range of recycling techniques, technologies, and maturities, from lab-scale start-ups to long-established companies specialising in niche operations.

1.2.1. Types of textile-to-textile recycling

The collected data has been used to summarise the requirements by input fibre and recycling process types. The recycling process types are:

Mechanical
A type of recycling where materials are mechanically processed to recover and use the existing fibres in new textiles. This includes processes such as cutting, shredding, and flocking[10].

Thermomechanical
A type of recycling where heat and pressure are used to melt synthetic textiles to recover the polymers, which can be re-spun into new fibres[11].

Chemical
Any process that changes a polymer's chemical structure to produce substances that can be used as raw materials to manufacture new products. Chemical recycling is a broad term encompassing several recycling processes (gasification, pyrolysis, depolymerisation). Depending on the recycling methods, energy consumption, yield, and output can vary significantly; the reaction outputs include syngas, oils, monomers, polymers, and cellulose pulp. The recycling process produces substances that can be used as raw material to manufacture new material[12].

For further details about textile recycling processes, see section 1.3.2 of Chapter 7, The Next Phase of UK Manufacturing.

1.2.2. Overview of textile-to-textile marketplace

The list of global textile recyclers on the next page, taken from WRAP's Textiles Sorting and Recycling Database[13] and Manufacturing Technology Centre MTC research, isn't exhaustive and is subject to change. The research for this chapter took several months, during which time new companies were launched, and some companies that were interviewed sadly went out of business.

Textile recyclers operate across different business models:

- Some traditional yarn manufacturers and/or chemical companies have integrated recycled textiles alongside their virgin-input operations
- Some manufacturers specialise in breaking down used textiles into raw material for new fibres and/or yarns, to be sold into the supply chain
- Some companies license and/or sell their recycling technology or equipment

Textile-to-textile recycling: Shape of the Market

Mechanical

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WECYCLED®
TEXTIL SANTANDERINA SINCE 1923
MANTECO MANTELLASSI COMPAGNIA TESSILE
Vilarrasa Group
Tesma CASHMERE
GLAESER seit 1888 textil
purfi
Rifo
COMISTRA
Wolkat
CIRCULAR FASHION FOR ALL recover
NILTEXTILE
FdP FILATURES DU PARC
TEXCAR
VALÉRIUS
RE&UP
Sasia
RESTER

Thermo-mechanical

project re:claim
ANTEX
EarthProtex™
FULGAR
RE&UP
TEIJIN
UNIFI
NILTEXTILE

Chemical

Input: cotton-rich

CIRCULOSE®
SaXcell
sappi
INFINITED FIBER
EASTMAN
SÖDRA
Lenzing Innovative by nature
EVRNU®

Input: cotton & polyester

worn again technologies
irc
TEXTILECHANGE

Input: polyester

syre
matterr
CURE Polyester Rejuvenation
The LYCRA Company
CARBIOS
ambercycle
TEIJIN
grεn REDUCE, REUSE, RECYCLE

Input: polyamide (nylon)

epoch BIODESIGN
ECONYL® BY AQUAFIL
loopamid
RENYCLE® nylon after nylon
Let's write a new sustainable story
LONGWORTH

Overview of textile recycling marketplace: List not exhaustive, and subject to change. Over the course of a few months' research, new companies have been launched and some companies interviewed have gone bankrupt.

Textile recyclers operate in different business models- some traditional yarn manufacturers and/or chemical companies have integrated recycled textiles alongside their virgin-input operations, while others specialize in breaking down used textiles into raw material for new fibres and/or yarns, to be sold into the supply chain. Some companies license and/or sell their recycling technology or equipment.

1.2.3. The current state of feedstock

Due to varying levels of technological development in mechanical, thermomechanical, and chemical recycling, the requirements for feedstock differ. To examine the range of these requirements, Figure 23 illustrates the current textile recycling landscape's maturity, while Figure 24 offers an overview of the general requirements of the existing market players.

	Mechanical		Thermo-mechanical	Chemical			
	Wool	Cotton	Polyester	Cotton-rich	Cotton/ polyester blends	Polyester	Polyamide
Established feedstock supply	5	3	4	3	2	2	2
Established feedstock spec	5	4	3	4	3	3	3
Flexibility in feedstock fibre tolerances	2	2	3	1	3	4	4
Flexibility in feedstock input format	1	2	4	4	2	4	4
Established end customer	4	4	1	3	2	3	2
MRL	5	5	2	4	3	1	2
TRL	4	4	3	4	3	3	1
Current capacity	2	2	2	3	3	1	1
Future capacity	3	3	3	4	4	4	4

1	2	3	4	5
Not established/ very low/none	Slightly established/ low	Moderately established/ Medium	Well established/ High	Firmly established/ Very high

Figure 23: Current textile recycling landscape

	Fibre specification	Contaminants which MUST be removed	Contaminants would PREFER to be removed	Size input	Estimated TRL	Estimated capacity/ throughput
Mechanical - Cotton	Cotton-rich as possible		hard parts & trims	Shredded fibres	8-9	12K tonnes
	100% cotton	All hard parts, dyes (only accept white)		'palm-sized' swatches	8-9	2k tonnes
Mechanical - Wool	100% wool	Elastane, non-wool fibres	hard parts & trims	Shredded fibres	8-9	*not stated*
	100% wool	All hard parts, trims, buttons		Shredded/frayed fibres	8-9	*not stated*
Thermo-mechanical	100% polyester	Metals, organic/chemical soiling, high moisture, hard parts & trims		Shredded fibres	5-7	5k tonnes
Chemical – Cellulose/Cotton (only)	> 70% cotton <30% polyester	Prints (PVC), elastane, colours, trims, no other cellulosic fibres above 5%		Swatches, minimum 1mm	8-9	50k tonnes
	> 85% cotton	Placement prints (PVC)	hard parts & trims	Shredded fibres	1-4	"Thousands of tonnes"
	> 95% cotton	Seams, sulphur dye, metals	hard parts & trims	Full garments accepted	8-9	60k tonnes
	> 70% cotton			Full garments accepted	*No longer trading, (1-4 at time of interview)*	*No longer trading*
Chemical – Cotton/poly	≈ 70% polyester ≈ 30% cotton	More than 2% elastane	hard parts & trims	Swatches, 8mm x 8mm	5-7	50k tonnes
	Unknown % poly/cotton blend		hard parts & trims		5-7	≈50k-100k tonnes
Chemical – Polyester	≈ 90% polyester	Metals, colours	Plastic trims	Shredded fibres	1-4	250k tonnes
	> 90% polyester	More than 1% elastane	hard parts & trims	Shredded fibres	5-7	*not stated*
	≈ 95% polyester	Metals, plastic hard points		Swatches, 4 x 5cm	5-7	50k tonnes
	> 70% polyester	Buttons, zips, metals	Out-of-spec textile trims	Shredded fibres	5-7	40k tonnes
Chemical – Polyamide	> 70% nylon 66	Untested still	hard parts & trims	Ideally pre-shredded	1-4	Hundreds of tonnes
	> 80% nylon 6	Metals	Out-of-spec textile trims	Shredded fibres	5-7	Hundreds of tonnes
	any % nylon 6	Metals	Plastic trims	Full garments accepted	8-9	*not stated*

Figure 24: General requirements of current market players

2. MARKET REVIEW: CURRENT TECHNOLOGIES

This section presents a market review of commercially available technologies for the four critical textile-to-textile recycling areas – conveyance, textile fibre identification, size reduction, and disruptor removal – to evaluate their suitability for an ATSP.

Each process has specific technology requirements, and these detailed requirements have been provided by ACT UK consortium member 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, outlining their strengths, weaknesses, and challenges.

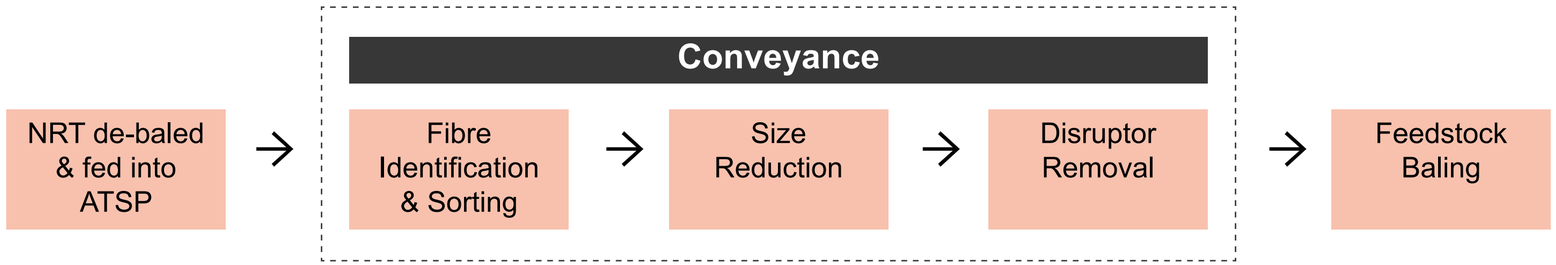


Figure 25: Scope of market review

2.1. Conveyance and material handling processes and technologies

Conveyance – the mechanical systems used to transport materials through the different stages of production – connects all processes across the ATSP facility.

Effective conveyance systems are critical for ensuring the reliability and efficiency of textile recycling processes. Conveyance directly influences facility throughput and establishes the operational parameters for fibre identification, disruptor removal, and size reduction technologies.

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

Figure 26: Technology requirements, conveyance

2.1.1. Conveyance equipment review

Horizontal conveyors:

The most relevant conveyor sub-types include belt and slat conveyors. Other horizontal conveyor types include roller and chain conveyors, but these are not effective for moving textiles.

Advantages:
- Industry standard. Easy to load and unload objects
- Easily adaptable to changes in production layout. Modifications can be made without major disruptions to the existing floor plan
- Versatile and capable of handling a wide range of materials/ garment lengths
- Generally easier to access and maintain. Repairs and routine maintenance tasks can be performed at ground level
- Generally lower initial cost compared to overhead conveyors
- More straightforward to integrate with existing workflows

Disadvantages:
- Low visual surface area of garments and risk of overlapping
- Textiles can potentially wrap around the conveyors and cause disruptions
- Positioned at floor level, which makes them easily accessible but takes up significant floor space
- Does not provide any garment control and relies on a separate feeding mechanism

Overhead conveyors:

Overhead conveyors are ideally suited for processes that require suspended product handling, such as paint lines, garment lines, and cooling or curing operations. However, due to their inherent operational complexities, the effectiveness of these conveyors in singulating and loading textiles with inconsistent form factors, such as bulk towels and bedsheets, remains unproven.

Advantages:
- Mounted above the working area, optimising floor space and reducing overall footprint
- Increased visual surface area of the garment for following processes, potentially enabling more efficiencies
- Individually hung garments
- Less risk of mechanical disruption and tangles.

Disadvantages:
- May require more careful integration due to the need for a stable and properly designed overhead support system
- May require specialised equipment or access platforms for maintenance
- More complex installation process and higher initial cost due to the need for overhead support structures
- Requires additional safety measures to prevent falling objects
- Hanging and loading items can be complex.
- Untested technology for inconsistent form factors

Pneumatic conveyors:

Pneumatic conveyors use air pressure or vacuum to transport materials through pipelines. They typically handle particulates, so the form factor of the garments should be considered when evaluating pneumatics. Additionally, a pneumatic conveyor may not efficiently handle larger garments. Consequently, size reduction may be necessary to enable this method to be used.

Advantages:
- Flexible routing, enabling an optimised floor layout
- Dust-free operation, promoting a cleaner working environment, which may be a consideration when working with fibres
- High throughput
- Gentle material handling, which maintains the integrity of the material during transport
- No risk of entanglement

Disadvantages:
- High energy consumption, contributing to higher operational costs
- Distance limitations, which impact the layout of the facility
- Noise generation
- High upfront cost
- Limit on size of garments

2.1.2. Handling and sorting

In an ASTP, textiles are transferred to and from equipment at multiple points, including bin-picking, conveyor loading, and general material transfer. A potential solution for individual control of garments is robotic pick-and-place using grippers. Different gripper types are used for grasping and manipulating workpieces, with the most common being vacuum grippers, mechanical grippers, and soft grippers.

A comparative analysis of various gripper types, including needle grippers (designed specifically for textiles), is presented in Figure 27, outlining their strengths and weaknesses in textile handling. Several additional gripper designs are available on the market to address specific requirements, and there exists an opportunity to develop a customised hybrid gripper solution optimised for textile sorting operations within the ATSP facility. See section 4.1 for the results of the gripper trials.

Getting a Grasp of Grippers [2]

	Vacuum Grippers	Mechanical Grippers	Soft Grippers	Needle Grippers
				
Manipulation Method	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.
Surface Compatibility	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.
Precision	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.
Complexity of Setup	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.
Maintenance	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.

Figure 27: Analysis of gripper types

2.1.3. Conveyance: Summary of findings

Technology limitations:

Feeding mechanism: Precise control over the textile feeding mechanism onto conveyors is crucial for optimising downstream processes because accurate garment singulation has been identified as a significant bottleneck in automated fibre identification.

Input method: Selecting a conveyance method that affords more control over the input method of the garments could significantly increase the facility's throughput efficiency.

Floor conveyors:

Industry standard: Floor conveyors offer a versatile, cost-effective, and simple solution for transporting textiles.

Increasing throughput: Floor conveyors are an expandable option for increasing the ATSP facility's throughput from 25,000 to 50,000 metric tonnes.

Size issues: Because they have a large footprint, floor conveyors may face difficulty if the facility's layout becomes complex. In busy layouts, there is potential for interference or congestion.

Maintenance challenges: There are known issues related to maintenance, such as chain stretch and the potential for entanglement with textiles, which became evident during some of the site visits conducted for this project.

Overhead conveyors:

Space-friendly: Overhead conveyors offer efficient use of space and a potentially smaller overall footprint. They also suit cornering, as garments would be attached via fixed runners.

Surface area: Overhead conveyors provide more visible surface area for later processes, such as identifying and removing disruptors.

Limited agility: Once installed, overhead conveyors have limited flexibility for layout changes and require a higher initial investment than floor conveyors.

Loading challenges: There are no automated solutions for loading garments from bulk bales onto an overhead conveyor.
Limit on size of garments

Pneumatic conveyors:

Smaller operations: Pneumatic conveyors typically operate with particulates and small-sized material.

Transportation issues: Pneumatic conveyors may not be suitable for transporting whole garments but could offer a solution that optimises the use of space via intricate routing of piping after the textiles have gone through the size reduction process.

Decreased footprint: The piping could enable increased floor space utilisation, reducing the ATSP's overall footprint.

Future opportunities and recommendations

Available floor space, flexibility requirements, expansion capability, garment presentation, and budget constraints are the top conveyance equipment 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 for material unloading, should be explored further.

2.2. Fibre identification and sorting technologies

Non-reusable textiles (NRTs) are collected in mixed collection bins, which currently also include reusable textiles (RTs). However, ATSPs will require all RTs to be sorted and removed either before or upon arrival at the facility. To enable the ATSP to produce consistent, high-quality feedstock, the mixed textiles must be categorised into aggregate bins based on their fibre composition and, if necessary, their colour.

Technology Requirement	
Detectable Fabrics *(In any blend combination)*	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

Figure 28: Technology requirements, fibre identification and sorting



2.2.1. Fibre identification and sorting equipment review

This section analyses the advantages and disadvantages of four products used for fibre identification and sorting, which all use near-infrared (NIR) sensors and pneumatic sorting. All products are proven, commercially viable options.

Tomra Autosort NIR VS:

Sensor deck applications: Hyperspectral linear scanner for fibre identification; hyperspectral imaging for colour identification

Machine learning: Classification based on the spectral input

Advantages:
- Sorting solution proven in other waste industries
- Autosort used in another high throughput textile facility (Siptex in Sweden)
- Tomra claims it can detect elastane blends (even 1% elastane in cotton)
- Highest throughput of the main solution providers
- Hyperspectral line scanner gathers large datasets per garment

Disadvantages:
- Could be limited to the manufacturer's technology; difficult to add external modules or request nonstandard changes
- Near-infrared (NIR) spectroscopy might not work correctly for fibre blends of three or more
- Carbon black dye (see section 3.2.3) affects the scanning results
- Multiple machines needed to categorise different textile fibres (1-2 blends per machine)
- Materials cannot overlap for scanning



Image 8: Tomra Autosort NIR VS



Image 9: Pellenc ST Mistral Connect

Pellenc ST Mistral Connect:

Sensor deck applications: Hyperspectral linear scanner for fibre identification; hyperspectral imaging for colour identification; RGB camera to be added

Machine learning: Classification based on the spectral input

Advantages:
- The solution can handle 15 types of blends, and depending on the market demand, it can be expanded to include more blends
- New development utilises mid-infrared (MIR) to combat the challenge of carbon black dye (see section 3.2.3)
- Relatively high throughput of the machine
- Multi-channel conveyer stream available, allowing one machine to detect more fibre blends categories

Disadvantages:
- NIR spectroscopy might not work correctly for fibre blends of three or more
- Multiple machines needed to detect a higher number of textile fibres (only a few blends per machine)
- Materials cannot overlap for scanning

Valvan Fibresort:

Sensor deck applications: Hyperspectral linear scanner for fibre identification; RGB camera for colour identification

Machine learning: Convolutional neural network, classification based on the spectral input

Advantages:
- Flexible solution, with manufacturer support in the design process
- Customisable number of fibre and colour categories
- Many fabric blend types sorted/detected using one scanner (up to 50 types)
- Additional system for wet material detection
- Solely dedicated to textiles development

Disadvantages:
- NIR might not work correctly for fibre blends of three or more
- Each fabric needs to be singulated before scanning
- Carbon black dye (see section 3.2.3) affects the scanning results
- Relatively low throughput for the machine
- Elastane blends in cotton are difficult to be detected



Image 10: Valvan Fibresort

Picvisa Ecosort Textil Optical Sorter:

Sensor deck applications: Hyperspectral linear scanner for fibre identification; RGB camera for colour and shape identification

Machine learning: Convolutional neural network, classification based on the spectral input

Advantages:
- Flexible solution, with the manufacturer able to adjust the design to fit customers' requirements
- Customisable number of fibre and colour categories
- Many fabric blend types sorted/detected using one scanner (up to 70 types)
- Several solutions are available for sorting, such as Ecosort and Ecoclip
- Established manufacturer in the waste sorting industry

Disadvantages:
- Each fabric needs to be separated before scanning
- Carbon black dye (see section 3.2.3) affects the scanning results
- Relatively low throughput for the machine
- Feeding the garments onto the conveyor is the bottleneck of the system

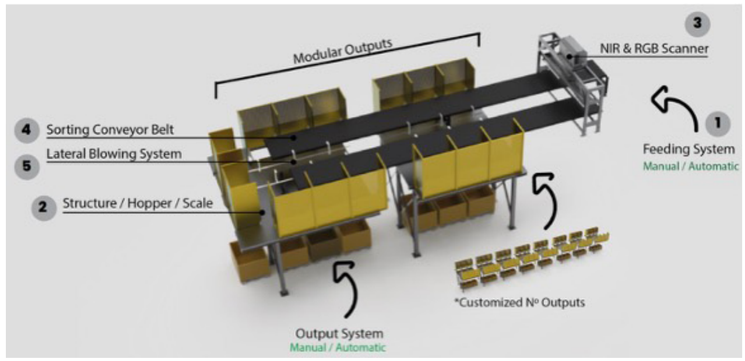


Image 11: Picvisa Ecosort Textil Optical Sorter'

The primary distinction between the Autosort/Mistral Connect and the Fibresort/Ecosort lies in the sorting mechanism after the fibres have been identified. Autosort/Mistral Connect provide only three output bins, whereas Fibresort/Ecosort feature a more scalable mechanism. See Figure 29 for further details.

Fibre Identification and Sorting

Summary Table				AUTOSORT *Tomra*		Fibresort *Valvan*		Mistral Connect *PellencST*		ECOSORT *Picvisa*	
	Criteria			Specification		Specification		Specification		Specification	
Measures	Lower Limit	Acceptable	Upper Limit								
Detectable Fabrics (Listed on slide 22)		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 *per complete line, inc. feeding*		TBC		Approx. £301k	

Legend
Suitable
Potentially Suitable
Not Suitable

Disclaimer: 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.

Figure 29: Fibre identification and sorting equipment summary table

2.2.2. Fibre identification and sorting: Findings summary

Technology limitations:

Throughput challenges: 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, the overall throughput will increase.

Data dependent: The accuracy of the sorting system relies on the validity and size of the data library in use as a reference.

Variety of options: Numerous hand scanner options are available that are viable for quality control and auditing.

Tomra Autosort NIR VS / Pellenc ST Mistral Connect:

Recycling experience: The ballistic separator sorting technique (see section 2.4.1) used by the Autosort and Mistral Connect has been introduced to the textiles market from municipal recycling applications.

Categorising challenges: They offer a high throughput but are limited in the number of categories that each machine can sort. This means 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.

Valvan Fibresort / Picvisa Ecosort Textil Optical Sorter:

Scalable options: They provide a more compact design with enhanced scalability if additional categorisation bins are necessary (by extending the output conveyor). This could mean a potentially higher initial price point, but it might represent a more future-proof choice. If more categorisation bins are needed with the Autosort or Mistral Connect, whole machines and additional floor space will be required.

Throughout challenge: These systems have a slower throughput and would require a minimum of two separate lines to meet the ATSP's requirement. Again, the limiting factor on throughput is the system's singulation and feeding mechanism.

Future opportunities and recommendations

No single technology on the market satisfies all ATSP requirements, and 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 it would be *"open to collaboration with other companies."*

While no single fibre identification and sorting system is specifically tailored to meet the needs of the ATSP, of all the technology on the market that was reviewed, Tomra's Autosort and Valvan's Fibresort systems were the closest-fit suitable options for an ATSP.

2.3. Size reduction technologies

Mechanical recycling and certain chemical textile recycling methods necessitate that garments be pre-processed into larger cut or filleted pieces, or cut into smaller swatches. The feedstock requirements vary among recycling methods; mechanical recycling demands the preservation of long fibre lengths, whereas chemical recycling requires small cut swatches, which can be more easily fed through high-volume hoppers before being broken down chemically.

While discussions with industry figures highlighted that size-reduction technologies exist, none are tailored for producing feedstock for textile recyclers. Please note that MTC had some difficulty obtaining information for some size-reduction technologies due to the lack of understanding around feedstock size requirements for chemical recyclers. However, many technology providers believe they can configure their systems to match the physical feedstock specification if it is provided.

Technology	Requirement
Chemical Recyclers	Short Fibre Lengths, No individual Fibres8mm² to 80mm²
Mechanical Recyclers	Individual, Long Fibre Lengths TBD
Metric Tonnes per Hour	12+
Garments Per Second (Initial Target)*	Approx. 4

Figure 30: Technology requirements, size reduction

2.3.1. Size reduction equipment review

Shredder:

Similar to paper shredding, a single shaft or dual shaft 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.

Advantages:
- One of the highest throughputs out of available technologies, but information unavailable for textiles
- Shaft shredders tend to be easier to maintain
- Versatile, capable of handling a variety of fabrics, including woven and knitted

Disadvantages:
- Produces irregular output lengths with ragged edges and loose fibres
- Limited precision, only allowing control over the maximum reduction size of the textile
- Large amounts of loose fibres or textile ‘dust’



Image 12: Twin-shaft shredder, Proshed 800

Guillotine cutter:

A guillotine relies on a scissor effect between a fixed blade and a second reciprocating blade edge, usually attached to a connecting rod and flywheel. The distance between blades determines the output material size.

Advantages:
- Precise cutting, with good control of output sizes
- Minimised fraying due to sharp cuts
- Versatile, capable of handling a variety of fabrics, including woven and knitted
- Produces minimal textile ‘dust’ compared to alternative processes

Disadvantages:
- Typically, a lower throughput compared to other continuous size reduction operations

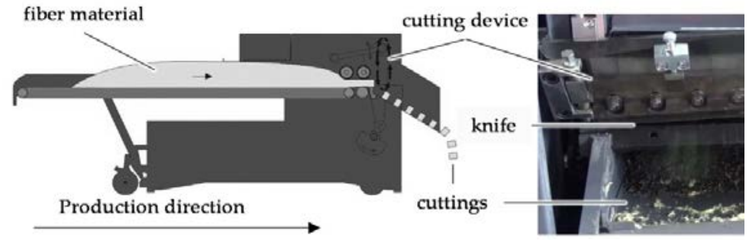


Image 13: Schematic of guillotine cutting

Rotative cutting machine:

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

Advantages:
- High throughput capabilities due to high-speed rotative cutters
- Capable of handling a broad range of materials
- Precision cutting

Disadvantages:
- High initial cost
- Complex setup and maintenance, dependent on setup
- Large footprint



Image 14: TRM rotative cutting machine

Tearing machine:

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

Advantages:
- Often has a higher throughput compared to cutting or guillotine machines
- Aids in retaining fibre length for recycling

Disadvantages:
- Cannot perform precise cuts or produce specific sizing of fabrics, ‘swatches’
- The process produces loose fibres and textile ‘dust’, requiring PPE for operators or posing a long-term hazard
- Not suitable for all fabric types
- Large footprint

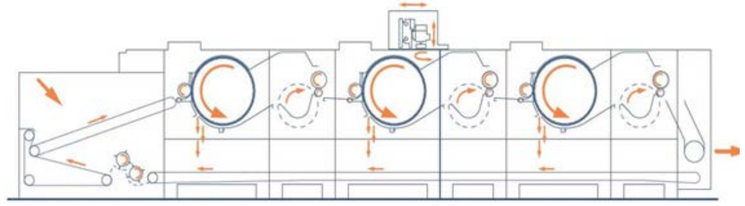


Figure 31: Tearing machine schematic



Size Reducton

Summary Table				MGC Guillotine *Dellorco & Villani*		N45 Guillotine *Pierret*		WGA Guillotine *WIPA*		TRM 1000 RCM *Dellorco & Villani*		Starcut *Andritz*		Mondial M/1900 *Dellorco & Villani*		Procut 1900 *Wagner-Shredder*		VAZ1600 *Vecoplan*	
	Criteria			Specification		Specification		Specification		Specification		Specification		Specification		Specification		Specification	
Measures	**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	

Disclaimer: 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	
Potentially Suitable	
Not Suitable	

Figure 32: Size reduction equipment summary table

2.3.2. Size reduction: Summary of findings

Feedstock requirements:

Lack of information: 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 technology providers with a detailed specification. Technology providers have stated that if the output specification was clear, they could configure machinery to create the desired output.

Cutting vs shredding:

Control and throughput: The guillotine cutting systems offer the most control over the swatch output size, which is critical for some chemical recyclers. They also offer moderate throughput that can be bolstered by 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 and safety:

Reducing risk: Consideration must be given to the particulates and irritants that these systems will produce, and whether a production line using multiple systems should be contained within barriers to contain dust and loose fibres, which can pose a fire hazard and a long-term respiratory risk to operators in close proximity for extended periods of time.

Protective equipment: PPE can mitigate some of the operator's risk via respirators.

Future opportunities and recommendations

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

2.4 Disruptor removal technologies

Disruptor removal is an important step in textile recycling that focuses on removing hard trims (such as buttons, zippers, and rivets) and soft trims (such as labels, tags, and decorative fabric) from the textiles before reprocessing.

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

Figure 33: Technology requirements, disruptor removal

2.4.1. Disrupter removal equipment review

Ballistic separators:

The technology behind ballistic separators, which are commonly used for sorting municipal waste such as bottles, glass, and metals ahead of recycling, has been adapted for use in textile recycling. Utilising a similar sensor deck as fibre identification and including an additional electromagnetic sensor, the system can identify and separate disruptors. This technique requires the textile garments to be pre-cut into swatches of approximately 100mm x 100mm.

Advantages:
- Technique proven in multiple recycling industries
- Emerging in the textile recycling market and has good scope for development
- Metal and plastic disruptors can both be removed

Disadvantages:
- Difficulty seeing both sides of the swatch. How the swatch falls onto the conveyor will determine if the disruptor is seen by the sensor deck or not
- Requires pre-processing of garments (size reduction)
- Textiles are cut into swatches, and if a disruptor is present, the whole swatch is rejected, which results in a low material yield

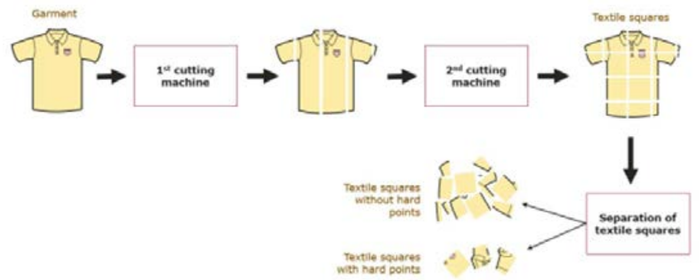


Figure 34: Size reduction for ballistic operators

Garnetting/tearing:

Garnetting machines combine mechanical and air-based separation methods to create individual strands of fibres that can be collected and processed into recycled textiles. This technique can remove disruptors from textiles during the tearing process but requires the machine to be built specifically for this purpose, with multiple separation stages such as magnets and air separation via density.

Advantages:
- Mechanical process not reliant on vision or machine detection technology
- Metal and plastic disruptors can both be removed
- Capable of handling large volumes (200T/day)
- Already being used on an industrial scale
- Most developed disruptor removal technology for textiles to date

Disadvantages:
- Lack of control over the disruptor removal process
- Output of the process is likely not suitable for chemical recycling
- Requires pre-processing of garments (size reduction)
- Requires fine-tuning to get an optimised system
- Cannot differentiate some disruptors, such as logos, tags or alternate fibres

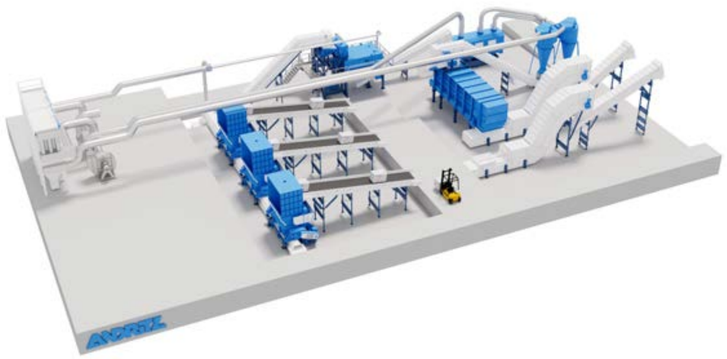


Figure 35: Exemplary textile waste conditioning system'

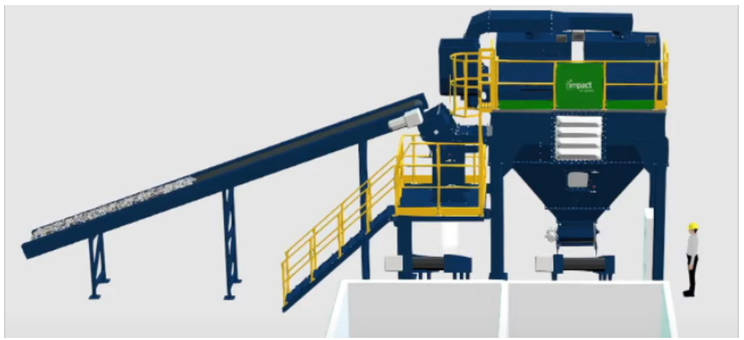


Image 16: Zigzag Air Classifier, provided by trial partner Impact Air Systems

Density-based air suspension:

Density-based air separators utilise air flow to separate materials based on their density and aerodynamic properties. This is achieved by cascading the mixed in-feed material through an air stream that travels upwards inside a zigzag-shaped enclosure. For this system to be applicable for disruptor removal, the textiles must be cut or shredded into smaller material to efficiently separate the materials.

Advantages:
- Mechanical process not reliant on vision or machine detection technology
- Metal and plastic disruptors can both be removed
- Can handle a wide range of fibres
- Process parameters, such as air velocity and feed rates, can be adjusted to achieve specific specifications

Disadvantages:
- Lack of control over the disruptor removal process
- Requires pre-processing of garments (size reduction)
- Requires fine-tuning to get an optimised system
- Doesn't deal well with a variety of input material



Size Reducton

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: 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.

Figure 36: Disruptor removal equipment summary table

2.4.2. Disruptor removal: Summary of findings

Ballistic separation:

Requires pre-processing: Ballistic separation technology has good potential for disruptor removal but relies heavily on pre-processing the textiles to create suitable swatches for detecting the disruptors.

Uniformity across companies: Valvan, Tomra, and Picvisa technologies all use the ballistic separation technique that has been used successfully in other waste recycling industries. There is little difference in the technologies being implemented by these companies, with the key distinguishing factor being their throughputs, which generally correlate with the companies' experience in other recycling industries.

Ballistic separation limitations:

Yield challenges: Material yield is a significant problem with ballistic separators, as any swatch with a disruptor present is rejected, taking a percentage of the textile with it.

Missed garments: There are also limitations with the presentation of the swatches on the conveyor belt, with some of the disruptors hidden from the sensor deck and 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 this report.

Garnetting/air separation:

Limited data: Other disruptor removal techniques, such as garneting using air-based separation, have less information about their function, throughput, technology and processes being used for disruptor removal.

Future opportunities and recommendations

Removing disruptors is a crucial step in purifying feedstock for recycling. Therefore, emerging technologies that use different removal methods will be a vital area for further research to enhance material yield and feedstock quality.

2.5. Market review conclusions and recommendations

Having reviewed the commercially available technologies for conveyance, fibre identification, size reduction, and disruptor removal, it is clear there is no one-size-fits-all solution for any technology area. Each area has challenges that require further research and development.

Therefore, a future ATSP should integrate a combination of commercially available technologies and further-developed emerging technologies, depending on the nature of the ATSP's output customers.

2.5.1. Conveyance recommendations

- Horizontal belt conveyors, with their proven industry track record, are recommended for ATSP implementation in floor and overhead configurations, dependent on available space.
- Pneumatic conveyors could be used in an ATSP after textiles have been size-reduced to control dust and fire risks and optimise space.

2.5.2. Fibre identification recommendations

- Tomra's and Valvan's equipment have been identified as the most viable candidates for this ATSP.
- The decision on which system to procure should be based on a detailed capacity and simulation of an ATSP.

2.5.3. Size reduction recommendations

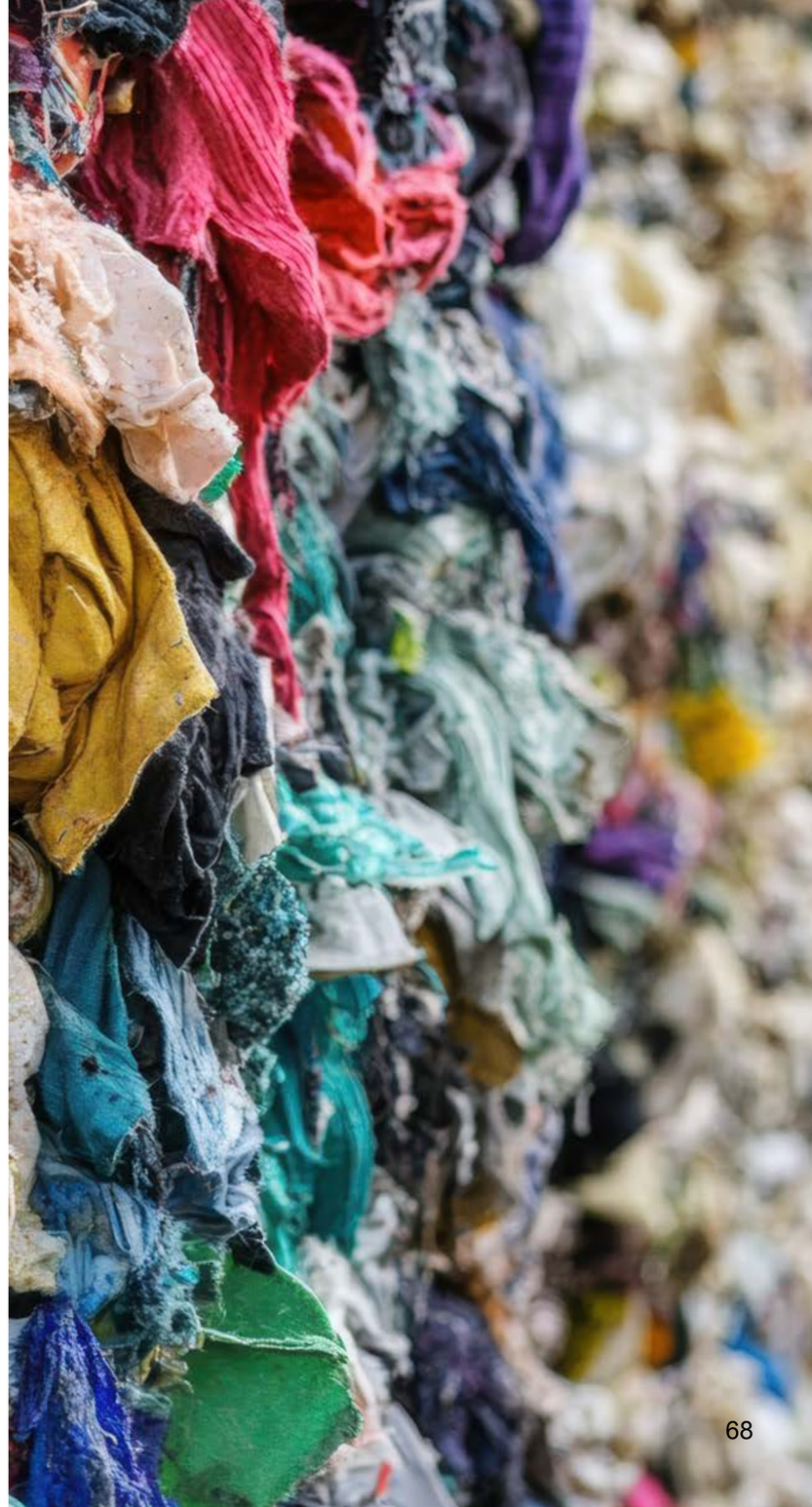
- A rotating-shaft shredder would be most appropriate to provide feedstock for recyclers who require a partially size-reduced rough cut, as it can achieve the highest throughput.
- To provide feedstock for recyclers who have very specific requirements of their optimum swatch size, a guillotine-type cutter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

2.5.4. Disruptor removal recommendations

- More development is required because no commercially available disrupter removal technology is entirely suitable for an ATSP at present.
- Garnetting/air separation disruptor removal could be utilised where textiles can be accurately pre-sorted into streams where the types of disruptors are known.

2.5.5. Equipment morphology recommendations

- Bottlenecks may form when considering potential equipment combinations (see Figures 37 and 38). In design, bottlenecks can be overcome by introducing buffers and/or increasing the number of equipment/processing lines.
- The systems engineering aspect of the facility design should not be understated. Therefore, design studies and simulations of equipment combinations under various operational scenarios should be completed 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

Figure 37: Fibre ID to size reduction

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

Figure 38: Size reduction to disruptor removal

3. ADDRESSING THE CHALLENGES: EMERGING TECHNOLOGIES REVIEW

In the previous section, the technologies currently available for conveyance, fibre identification and sorting, size reduction, and disruptor removal were evaluated against the ATSP's requirements. During this process, several challenges were highlighted across the technology areas.

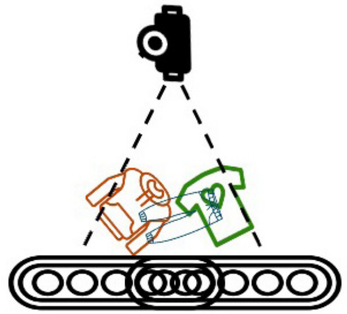
This section aims to address these challenges by researching complementary and emerging technologies that may improve the efficiency of existing equipment or inspire alternative developments.

3.1. Conveyance: Emerging and complementary technolog

3.1.1. Challenge: Material feeding and conveyance

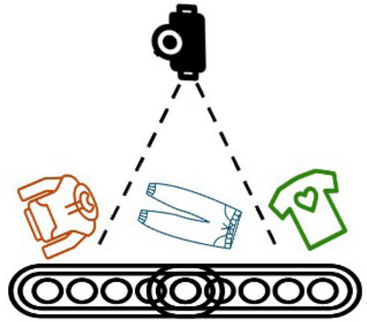
Common challenges faced by all material movement and conveyance technologies for garments in automated sorting and pre-processing applications are:

Overlapping/garment presentation



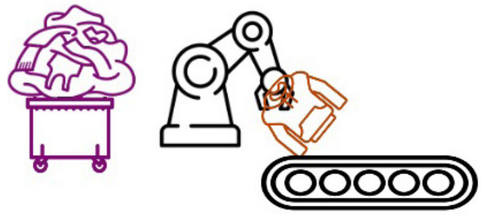
When garments are input into conveyance systems from tightly packed bales, they are naturally overlapped and folded onto themselves. This makes it difficult for automatic fibre sorting and detection of trims to be carried out accurately. To overcome this, garment singulation needs to take place.

Garment singulation

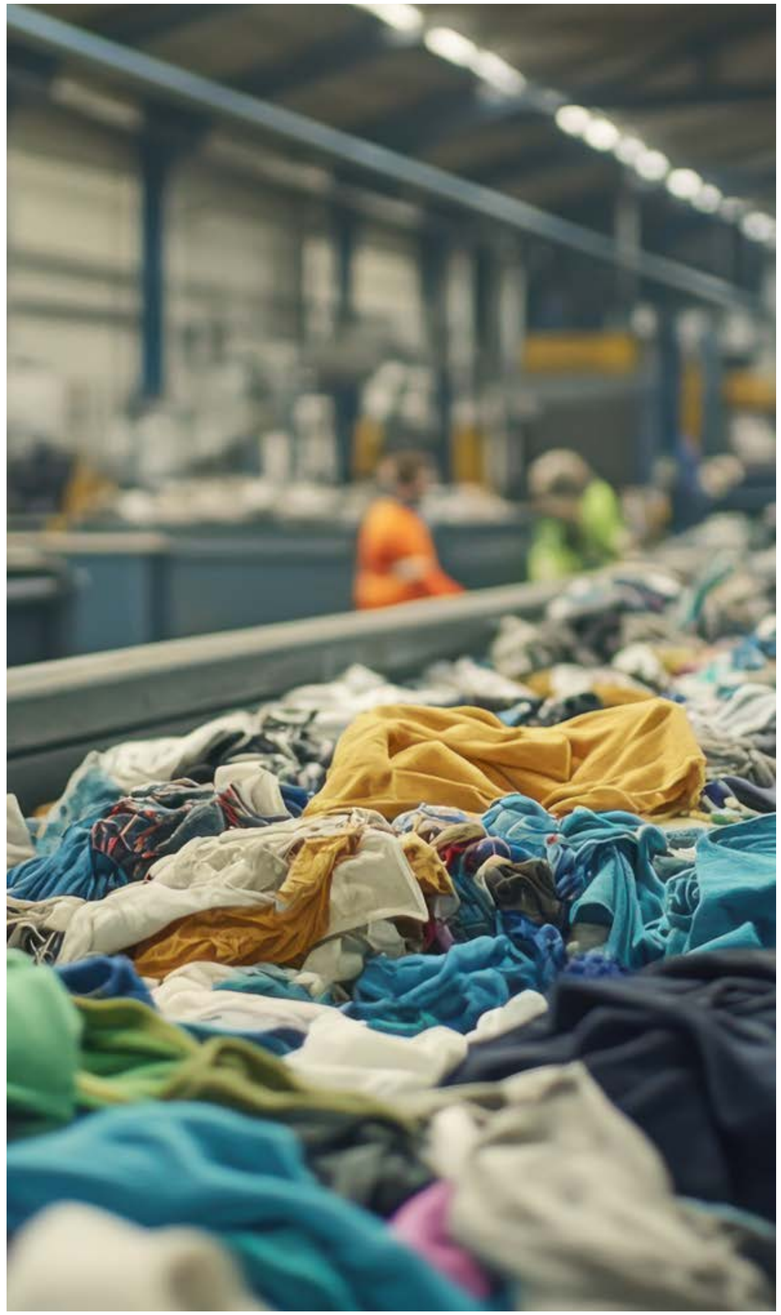


Instead of manually inputting individual garments onto a conveyor, an automated solution is necessary to facilitate garment singulation as swiftly as possible. This can be accomplished with a series of bale-breaker systems featuring spikes or through robotic arm 'pick and place' feeding.

Robotic feeding: Double picks and missed picks



Robotic feeding, integrated with machine vision to direct the robotic arm in picking up individual garments, can effectively singulate garments with minimal human intervention. Errors occur when the robot's gripping end effectors inadvertently pick up more than one garment at a time or fail to grab a garment if it is not effectively gripped during the picking action.



3.1.2. Challenge: Material feeding and garment singulation

Textiles are expected to be delivered to the ATSP primarily in large bales of mixed-fibre garments. Opening and pulling the tightly packed bales apart into smaller, more manageable pieces is essential for subsequent processes.

Mechanical bale breaker/auto-feeding:
Bale breakers can operate in several ways, including spiked rollers, rotating beaters or fluted drums that penetrate the bale and begin to separate the garments into smaller batches for further processing. Further singulation of garments is possible, but these systems have a limit to the control of individual garment positioning, so overlapping cannot be fully eliminated.

Robotic pick and place:
Robotic feeding offers an additional solution for garment handling with enhanced accuracy, efficiency, and flexibility. However, it has limited throughput potential and may encounter operational errors through missed picks, where no textile is engaged by the robotic gripper, and occasional double picks, where multiple garments are engaged in the gripper. Opportunities exist to integrate robotic picking and placing with fibre-ID sensors, enabling singulation and sorting to occur in a single step.

Additionally, selecting the right end effector for textile recycling can reduce the likelihood of missed picks and double picks, streamlining the feeding process by effectively grasping and manipulating textiles while reducing the need for complex programming. A range of grippers could be applicable for this application. Among all possible gripper types, three have been identified by the MTC for comparison testing with different textiles – see Figure 27 in section 2.1.2.

3.1.3. Complementary technology and further research: Garment flattening

A key challenge in automating textile processing is the tendency of textiles to cluster upon themselves, which makes it difficult for machines and sensors to analyse garments accurately. Therefore, garment flattening is a crucial preliminary step in automating precise textile processes, as ensuring the entire garment is accessible to sensors and automation systems optimises RT vs NRT classification and facilitates precise disruptor removal.

However, flattening is one of the most challenging tasks to automate on an industrial scale. Below are some potential avenues for further exploration based on current research efforts and other avenues of mechanical investigation.

Pneumatic and mechanical devices:
A potential solution could be to develop a system that employs pneumatics and mechanical devices to flatten garments for processing. For example, a press or a series of pneumatic air pressure chambers could be utilised to manipulate the garment into a sufficiently flat state for pre-processing before disruptor detection and removal.

Robotic manipulation:
A robotic system could utilise dual-arm manipulation to introduce a flattening step into the process. A combination of manipulation techniques and the use of gravity monitored by a vision system can flatten garments successfully.

Robotic manipulation and pneumatics:
A hybrid approach could employ dual-arm manipulation and pneumatics to optimise the flattening step. This would enhance the flattening speed without strictly relying on gravity and manipulation techniques.

3.1.4. Conveyance challenges and technology: Findings summary

Challenge identified from market survey:

- Controlled feeding and singulation of textile items onto conveyors.
- Emerging technology that could address this challenge: Automated bale breaking and controlled conveyance systems.
- Estimated Technology Readiness Level (TRL) status: 7-9
- Recommendations/what happens next: Bale breaking and auto-feeding should be trialled in conjunction with emerging robotic feeding technologies to find the optimum solution for meeting an ATSP's throughput requirements.

Challenge identified from market survey:

- Overlapping of multiple garments when put through automated scanning systems.
- Emerging technology that could address this challenge: Integrating fibre-ID with robotic picking and placing.
- Estimated TRL status: 4-6
- Recommendations/what happens next: Develop and trial emerging technology to establish the capabilities and limitations, such as speed and accuracy, of such systems.

Challenge identified from market survey:

- Accuracy and reliability in robotic pick-and-place systems for highly variable post-consumer textiles.
- Emerging technology that could address this challenge: Robotic handling of high-variation textiles; bespoke grippers for textile feeding systems.
- Estimated TRL status: 7-9
- Recommendations/what happens next: Gripper-textile compatibility trials to establish the most suitable end-effector design.

Challenge identified from market survey:

- Garment presentation/visibility of whole garments impeding downstream (and upstream) ATSP processes.
- Emerging technology that could address this challenge: Automated garment flattening.
- Estimated TRL status: 1-3
- Recommendations/what happens next: Develop robotic and pneumatic automated manipulation of garments.



3.2 Fibre identification and sorting: Emerging and complementary technologies

3.2.1. Challenge: Overlapping of garments during scanning

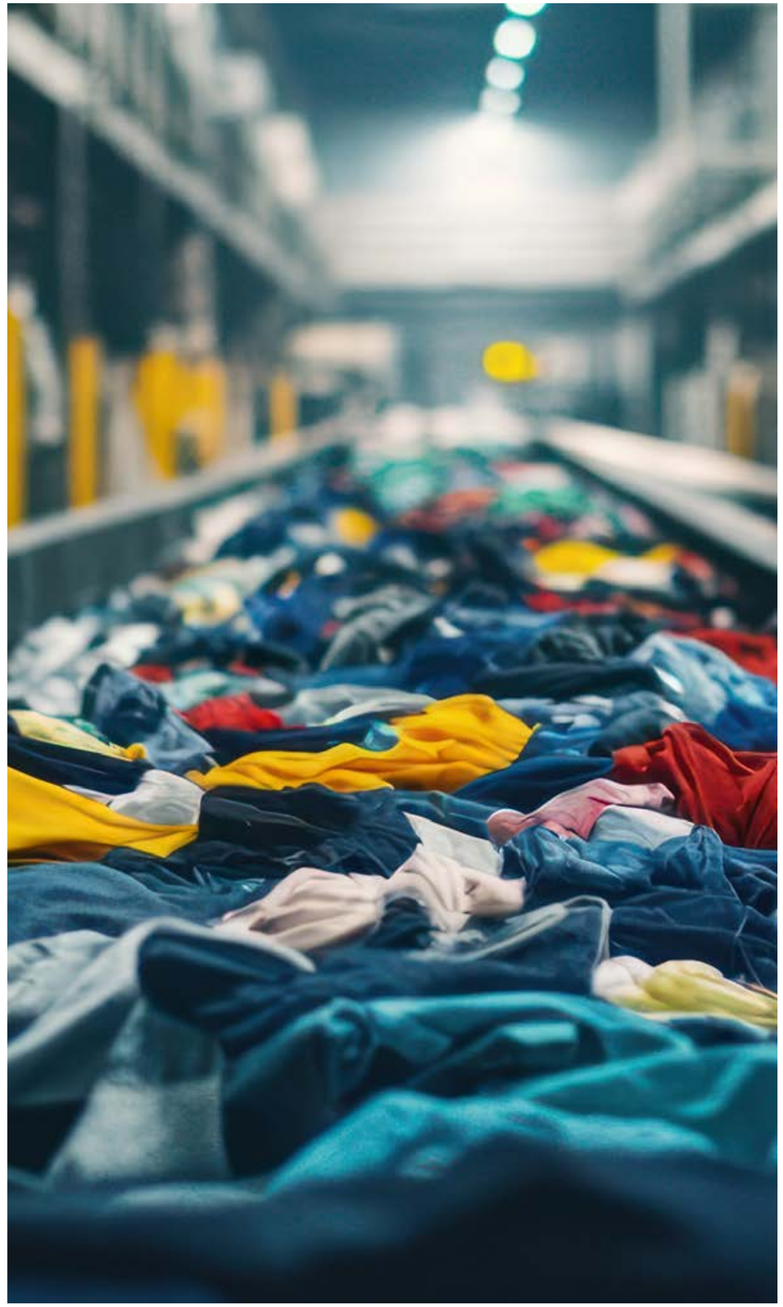
When garments overlap prior to fibre identification and sorting, it can lead to several problems. Firstly, the detected fibre type might be based solely on one of the garments. For example, if the scanner is located above the conveyor, the top garment could be the only detected fibre type. This limitation arises because the currently employed technologies for fibre identification, such as NIR, lack the ability to penetrate textiles, limiting identification to what is visible on the surface.

Another challenge is that overlapping may cause errors during the sorting process, as two garments might be incorrectly sorted into the same classification bin due to their proximity. If the garments possess differing fibre compositions, this will diminish the batch's purity. Furthermore, scanning systems that measure from multiple points on a garment, rather than from a single data point, may mistakenly identify multiple garments as one. The spectrum utilised for garment classification is obtained as an average from all collected data points, which can lead to misidentification of fibre composition if garments are not singulated when scanning, causing sorting errors.

Fundamentally, when overlapping occurs, the accuracy of the sorting system declines, compromising the purity of the final sorting batch. However, there are potential solutions to this:

Singulation of garments at the feeding stage:
Controlling the singulation of garments during the material feeding stage is currently the most robust method for eliminating garment overlap in the downstream processes, particularly fibre identification and sorting.

Detection and intervention of overlapping garments:
Using the current RGB camera systems and combining them with more sophisticated algorithms enables the exact shape of the garment to be detected. This could be used to identify when overlapping occurs and classify different garments' fibre composition during overlapping. However, it would still require an additional precise automated sorting solution, such as robotic pick-and-place, to mitigate sorting errors.



3.2.2. Challenge: Multi-layer fibre identification

Multi-layer garments make up approximately 9%[14] of all clothing in recycling streams and are textiles made of two or more layers of fibre material. Just as with overlapping garments, current classification methods cannot penetrate through garments and analyse multiple fibre compositions. This makes the identification of multi-layer garments extremely difficult, and at the time of writing, no method exists.

Identifying multi-layer garments is essential for maintaining batch purity for an ATSP. This responsibility currently lies with pre-sorting facilities such as the Salvation Army Trading Company Ltd, which relies on a skilled workforce to identify and pre-sort garments based on various criteria, including RT, NRT, and multi-layer textiles.

Some technologies are capable of penetrating through the layers, and these have been evaluated for their effectiveness in identifying distinct layers:

Backscatter X-ray:
This technique detects the radiation that is reflected from the target object and is more suited to shallow image capture when compared to traditional X-ray that relies on the transmission of X-rays through the object. Initial tests conducted at the MTC did not clearly distinguish between the layers, thought to be due to the low density of the fabric layers. This demonstrates that it is not suitable for multi-layer fibre identification.

Terahertz 3D imaging:
Terahertz waves sit between infrared and microwaves on the electromagnetic spectrum. This non-contact technology was explored for its high penetrative qualities (compared to infrared) while being safer than X-rays. This method can identify and measure multi-layer thicknesses for applications such as coats of paint. Initial discussions with technology developer and provider Optikan indicated that its scanner cannot detect multi-layers in textiles, again due to the low density and similarity of the materials.

Due to the current lack of solutions, a possible mitigation is to cut garments into smaller swatches to separate layers. If there are no joins or bonding connecting the layers, when cut into small pieces, the layers will naturally separate, reducing them to single-layer materials for processing. However, along joins or other bonded layers, they will not be able to separate.

Some sorting systems are compatible with a high volume of small swatches, and this same size-reduction approach is also used for classifying and removing disruptors. Cutting the garments before fibre identification can reduce the risk to batch purity from multi-layer garments by allowing individual layers to be classified and sorted. However, turning one garment into multiple swatches will increase the throughput demand of the aggregate sorting system.

This mitigation introduces an additional challenge where the multi-layer swatches, still connected by joins or bonding, will not be able to be accurately identified and sorted, posing a risk to batch purity. While this may reduce the batch purity, the overall weight percentage of the sorting error will likely be less than when compared to an entire multi-layer garment.

One further consideration is that the size of the swatches would affect the length of the recycled fibres, likely limiting the feedstock to chemical recyclers, as mechanical recyclers require long fibre lengths.

3.2.3. Challenge: Carbon black dye identification

A known issue among sorting system providers is the effect carbon black dye, a pigment derived from black soot, has on identification results. Carbon black dye is used in some black and dark grey garments, increasing energy absorption into the material and affecting NIR measurements.

Technology providers confirmed that carbon black dye can pose challenges for the fibre identification process, though they are encountering carbon black dyes less frequently and, consequently, are spending less time addressing this issue.

Nonetheless, solutions are still required:

Mid-infrared (MIR) spectroscopy:
MIR spectroscopy covers wavelengths from around 2500nm to 25,000nm[15]. This wavelength enables the detection of carbon black dye. Technology provider Pellenc ST has developed a prototype solution incorporating MIR for such detection.

Contact sensing: Triboelectric sensor (TES) by Sony:
A potential alternative fibre identification technique was identified through the market review (section 2). Sony is developing a contact sensor that measures the electric charge-transfer characteristics of materials. Just as each fibre type possesses measurable spectroscopic characteristics, each fibre type also has triboelectric charge-transfer characteristics that can be measured and classified. This technique has yet to be tested for carbon black dye detection, but a collaboration between the MTC and Sony will seek to explore this specific classification further.

Further development of the textiles database:
Although carbon black dye cannot be detected directly using NIR, its effect on specific fibres, if consistent, may be quantifiable. For instance, it is hypothesised that cotton with carbon black dye produces a distinctive pattern, differing from other fibres both with and without the dye. If this is the case, incorporating additional textiles with carbon black dye into the dataset used for training and tuning the detection model could facilitate the classification of materials containing carbon black dyes. A comprehensive study indicates that advanced algorithms can overcome, to some extent, the effect of this dye on NIR. Further research into this solution could eliminate the carbon black dye challenge while utilising equipment already available in sorting solutions.

3.2.4. Challenge: Multi-layer fibre identification

Elastane, also known as spandex or Lycra, is a synthetic fibre that is known for its exceptional elastic properties[16]. Elastane can be incorporated into garments in two ways:

- Elastane can be wound around the yarn in a blend or fed in as a separate material. In this scenario, parts of the elastane should be visible when using such techniques as NIR.
- The elastane could be in the core of the constituent yarn, which would mostly remain hidden from view. In this case, its effect on the spectrum might not be significant enough for detection[17], making its identification more challenging or impossible.

Possible solutions to this challenge include:

Incorporating more textiles with cotton/elastane blends in the training dataset:
Current sorting machines utilise the same NIR technology, with some producers claiming the ability to detect elastane. Similar to carbon black dyes, it may be feasible that integrating more samples containing elastane into the detection model would facilitate the reliable identification of blends with elastane. This solution would require testing across various elastane incorporation formats to determine whether elastane can be detected both as a distinct material and as part of the core yarn.

Contact sensing: Triboelectric sensor (TES) by Sony:
As mentioned in section 3.2.3, this technology is based on different sensing principles than current identification technologies. As the TES is still in development, it has not been tested for the detection of elastane. Due to its direct contact detection, it could potentially detect changes in the material's electric charge-transfer characteristics due to the presence of elastane, even in the yarn's core.

3.2.5. Challenge: Fabric structure identification

Technology provider Valvan has underscored the importance of identifying and classifying textiles based on their fabric structure, whether woven, knitted, or non-woven, as a key area for future development. This type of identification has not been thoroughly explored and has not yet been incorporated into an automatic sorting process.

There are also notable differences among various fabric structures, such as yarn count and yarn twist type. Typically, woven yarns exhibit more twist, while knitted yarns have less. This distinction makes it considerably easier to untwist and recover fibres from knitted yarns, suggesting that sorting them could be advantageous for mechanical recycling feedstock.

Although the quantification of yarn count and yarn twist type by the sorting system is less critical, it would be advantageous to determine if these factors could influence the outcomes when designing a fibre identification model. Additionally, including a range of structures in the dataset may enhance the overall properties of the identification model.

Further investigation into the requirements of textile recyclers is needed to justify additional research in textile structure identification. Nevertheless, potential solutions to this challenge include:

1D/2D imaging systems or 3D imaging systems:
Line scanners or area scanners could be employed to capture images of the visible fabric structure at the surface of the material, while laser or volume scanners could be utilised to acquire volumetric images of the visible fabric structure. Both solutions, when combined with machine learning techniques, can then classify the fabric structure as knitted or woven, provided there is a sufficient training dataset. However, due to the large variations in yarn counts used in textiles, either high-resolution cameras must be utilised to obtain clear images of the denser fabric structures, or smaller fields of view may be required. In most instances, the fabric structure remains consistent across the entire fabric. Consequently, sampling a smaller area with a lower-resolution camera could be a more cost-effective alternative.

Gelsight tactile sensor:
When pressed against a surface, the Gelsight sensor generates a height map that can be treated and analysed as an image. The technology provider has developed a database containing 40 classes of tactile textures, including fabrics, and Gelsight claims the system can accurately categorise materials from this database. If not already included, characteristics distinguishing knitted from woven fabrics could be added to the database.

Texture recognition from tactile images and vision:
Some academic research has been conducted in the field of combined camera-tactile sensors: “A new fusion method named ‘Deep Maximum Covariance Analysis’ aims to learn a joint latent space for sharing features through vision and tactile sensing”[18]. Initial results of the algorithm show recognition performance of greater than 90%.

3.2.6. Fibre identification and sorting challenges and technology: Findings summary

Based on feedback from textile recyclers, the most critical factor is receiving highly accurate, fibre-sorted feedstock that precisely meets their specification tolerances.

Challenge identified from market survey:

- Multi-layer textiles.
- Emerging technology that could address this challenge: No emerging technologies were identified as suitable for the challenge. Mitigation efforts are prioritised for the initial operation of an ATSP.
- Recommendations/what happens next: As almost 10% of textile products are multi-layered, a focused effort needs to be made to mitigate problems in the recycling process from multi-layer textiles.

Challenge identified from market survey:

- Carbon black dye and elastane identification.
- Emerging technology that could address this challenge: Contact sensor; MIR spectroscopy; machine learning models.
- Estimated TRL status: Contact sensor 1-3; MIR spectroscopy 7-9; machine learning models 7-9.
- Recommendations/what happens next: Trials to verify contact sensor capabilities, and build a database with relevant carbon black and elastane yarn structures to train machine learning models.

Challenge identified from market survey:

- Fabric structure identification.
- Emerging technology that could address this challenge: Gelsight tactile sensor; advanced machine learning.
- Estimated TRL status: Gelsight tactile sensor 7-9; advanced machine learning 4-6.
- Recommendations/what happens next: More thorough research to quantify fabric structure needs for downstream recycling processes to determine most important properties to classify (e.g. yarn twist).

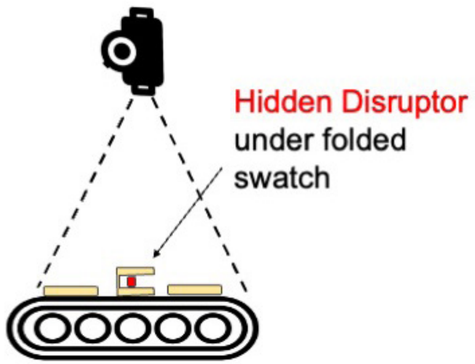
Challenge identified from market survey:

- Verification of fibre-id system’s accuracy claims.
- Recommendations/what happens next: Create an open-source lab-verified database to act as a baseline for comparing different fibre-ID technologies.

3.3. Disruptor removal: Emerging and complementary technologies

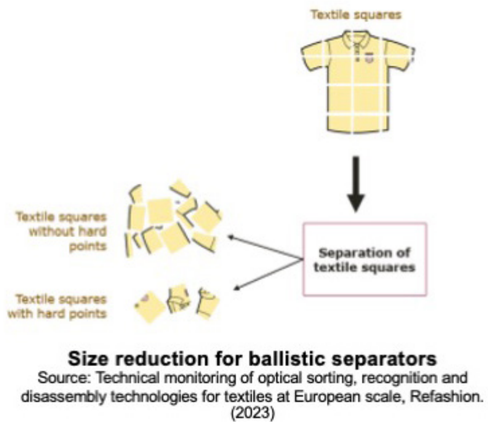
3.3.1. Challenge: Disruptor detection and removal

Detection of hidden disruptors



Current disruptor detection solutions rely on the disruptor being visible to the camera for identification and classification. However, the natural tendency of textiles to bundle and fold onto themselves can conceal disruptors from the camera, which may result in missing disruptors or inefficiencies in the process. This requires multiple cycles of the same batch to confirm that no disruptors are present.

Localised disruptor

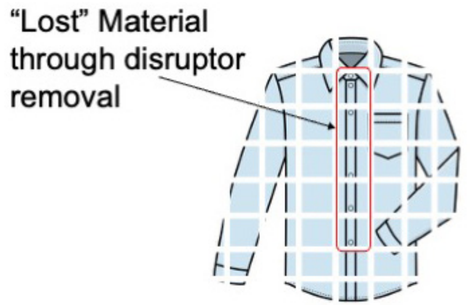


Size reduction for ballistic separators

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

At the time of writing, there are no market-ready solutions that provide localised disruptor removal. Ballistic separators, which are commonly used in other recycling sectors, require textiles to be pre-processed into small swatches for disruptor removal. Swatches containing a disruptor are ejected into a separate aggregate bin, away from other swatches.

Material yield



As ballistic separators for disruptor removal depend on smaller swatches for detection and removal, there is an inherent yield loss of textiles from this process. Since textile recyclers already operate on fine margins, it is crucial that any material loss during the process is minimised to make the process financially viable.

3.3.2. Potential technologies: Disruptor detection

Multiple RGB cameras:
When synchronised and positioned strategically, multiple RGB cameras provide enhanced depth perception and spatial awareness. Their combined capabilities facilitate accurate colour capture and spatial mapping for a broad spectrum of imaging tasks across a range of industries. Multiple cameras enable the garment to be viewed from multiple angles, thereby increasing the likelihood of disruptor detection.

Terahertz:
Terahertz waves are particularly effective at penetrating the surfaces of objects during scanning. If integrated with a machine learning model, this technology could be employed to identify disruptors on garments.

X-ray backscatter:
X-ray backscatter is a technique that involves the scattering of X-rays by materials. The scattered radiation is detected and analysed to provide information about the composition and structure of the target object. It is commonly used in security screening applications to detect concealed objects or substances.

3.3.3. Potential technologies: Localised disruptor

Robotic cutting system:
For any localised disruptor removal to be feasible, garments must be presented to the system so that the entire garment is accessible by the removal method, such as robotic garment manipulation.

A robotic cutting system that uses machine vision and complex path generation models to create cutting trajectories can facilitate the localised removal of disruptors while minimising material loss.

Existing cutting technologies, including laser and ultrasonic cutters (see benefits and drawbacks below), can be used on a robot or CNC machine, which dictates the movement of machinery and tools in factories. It would utilise algorithms such as the Travelling Salesman Problem, which seeks the shortest possible route to visit every point in a given set of locations exactly once, to efficiently remove disruptors from garments. Other cutting techniques, such as conventional knife blades, either lack the necessary precision or require additional technologies to maintain tension on the garment.

It is unlikely that a single system of this kind would be capable of performing this task at the throughput rate that the ATSP requires, so multiple lines would likely be needed. This would incur large investment and floor space requirements that may render the solution financially unviable.

Laser cutting benefits:
- High levels of accuracy and motion versatility allow for the creation of complex shapes and designs.
- It can cut a wide range of materials, making it suitable for various industries and applications, including textiles.
- It is faster than traditional cutting methods, enabling rapid part production, making it a good fit for industrial automation.

Laser cutting drawbacks:
- Set-up can be expensive, requiring an investment in equipment, training, and maintenance
- While laser cutting is versatile, certain materials may emit toxic fumes.
- Poses risks of fire, eye damage, and exposure to hazardous fumes if safety precautions are not followed diligently.

Ultrasonic cutting benefits:
- Offers high levels of precision, making it useful for cutting complex shapes and delicate materials
- Produces minimal heat, reducing the risk of material deformation or melting.
- It can be used on a wide range of materials, including textiles, making it a quite versatile tool across various industries.

Ultrasonic cutting drawbacks:
- It can have a relatively high initial cost, including the purchase of ultrasonic generators and specialised cutting tools.
- Less effective for cutting through thicker materials compared to other cutting methods.
- Requires regular maintenance and upkeep to ensure optimal performance, including blade sharpening or replacement. Also, periodic calibration of equipment settings is needed.

3.3.4. Disruptor detection and removal challenges and technology: Findings summary

Challenge identified from market survey:
- Detecting hidden disruptors.
- Emerging technology that could address this challenge: Multiple RGB cameras; Terahertz scanner; X-ray backscatter.
- Estimated TRL status: Multiple RGB cameras 7-9; Terahertz scanner 4-6; X-ray backscatter 7-9
- Recommendations/what happens next: Penetrative sensing technology can improve efficiencies of current disruptor removal processes, although some development is still required for moving objects at industrial speeds.

Challenge identified from market survey:
- Material yield loss and localised disruptor removal.
- Emerging technology that could address this challenge: Localised disruptor removal
- Estimated TRL status: 1-3
- Recommendations/what happens next: Localised disruptor removal is unlikely to be a direct replacement for current equipment in an ATSP. However, utilising these techniques throughout the textile recycling landscape (i.e. collectors and sorters) could reduce the demand on an ATSP.

Localised disruptor removal continues to present a challenging area for technological development within pre-processing, largely due to the variability and material handling difficulties of post-consumer textiles products. The advancement of supporting technologies capable of consistently manipulating garments to expose key features is necessary for enabling the precise analysis of garments and facilitating the removal of their disruptors.

Further trials are recommended to compare the energy consumption and yields generated from existing technologies (ballistic separation, air separation), alongside a cost-benefit analysis to determine if the potential improvements in material yield from localised disruptor removal justify the investment in development.

4. TECHNOLOGY TRIALS

Based on both the market review (section 2) and emerging technologies review (section 3), trials were conducted across various technologies to thoroughly assess and explore their viability for use in an ASTP.

- The three key trial areas were:
- Gripper trials
- Fibre identification trials
- Disruptor trials

4.1. Gripper trials

The aim of the gripper trials was to identify the most suitable end-effector for textile handling that could be used for material transfer within an ASTP. However, these often experience missed picks or double picks, making it essential to determine the correct end-effector to reduce or eliminate these issues for efficient operation. Additionally, gripper strength was tested to evaluate the likelihood of garment slippage.

The trials were conducted using the following technology and equipment:

Finger gripper trials:
For the finger tripper trials, a Franka Emika Panda collaborative robot was paired with the Franka Hand.

- The robot's programming was done using Desk, a web-based software for programming and operating Panda.
- The pick points and moves were programmed via the manual guiding mode.
- Force and torque tolerances were modified to allow the arm to dig into the pile of clothes without detecting a collision.
- Different finger widths were tested (ranging from 0 to 80 mm), and 35 mm was selected as it provided a good balance between missed and double picks.

Vacuum gripper trials:
For the vacuum trials, Universal Robots' UR10 was coupled with a Schmalz vacuum gripper.

- Programming was done using the teach pendant.
- Four different vacuum tips of different sizes were tested to determine which worked best for the textile use case.
- An industrial vacuum was also tested for a best-case scenario for suction-based grippers.

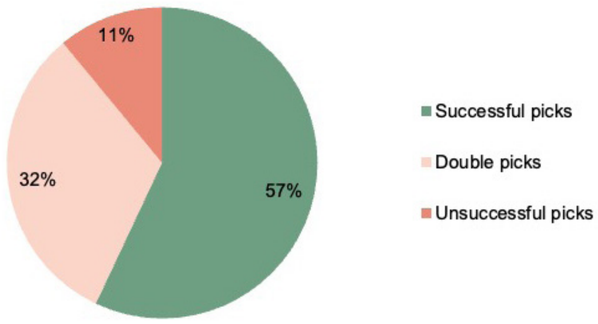
Needle gripper trials:
For the needle gripper trials, a custom mount was designed and 3D printed to enable the Schmalz needle gripper to attach to the Franka Emika.

- Unlike the previous two trials, the gripper was controlled independently of the robot arm using an SDI control box from Schmalz.
- The programming was again done via Desk, and the programme from the finger gripper trials was modified to adapt to the external gripper control with the SDI box.
- Different needle strokes were tested (ranging from 0mm to 10mm), and 6.6mm was selected as it provided a good balance between missed and double picks.

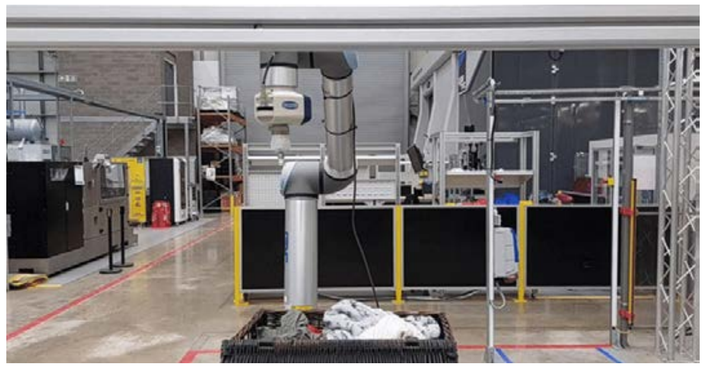
4.1.1. Gripper trial 1: Successful pick comparison:

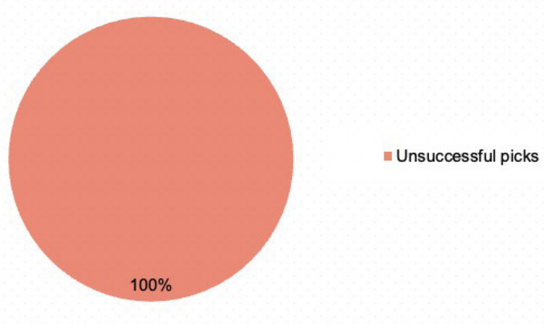
Finger Gripper





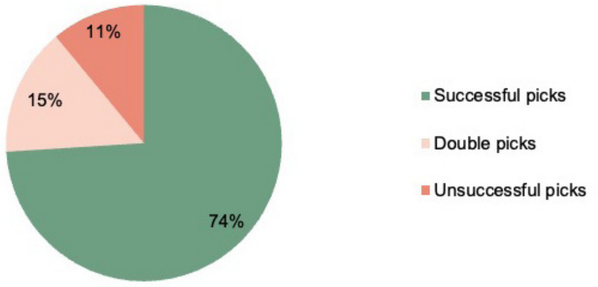
Vacuum Gripper





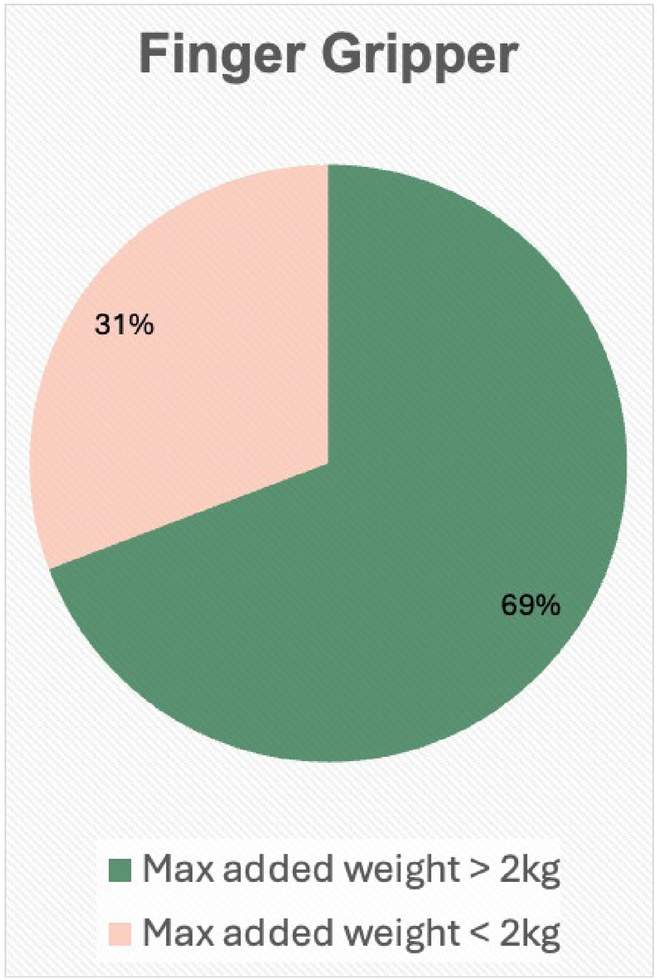
Needle Gripper

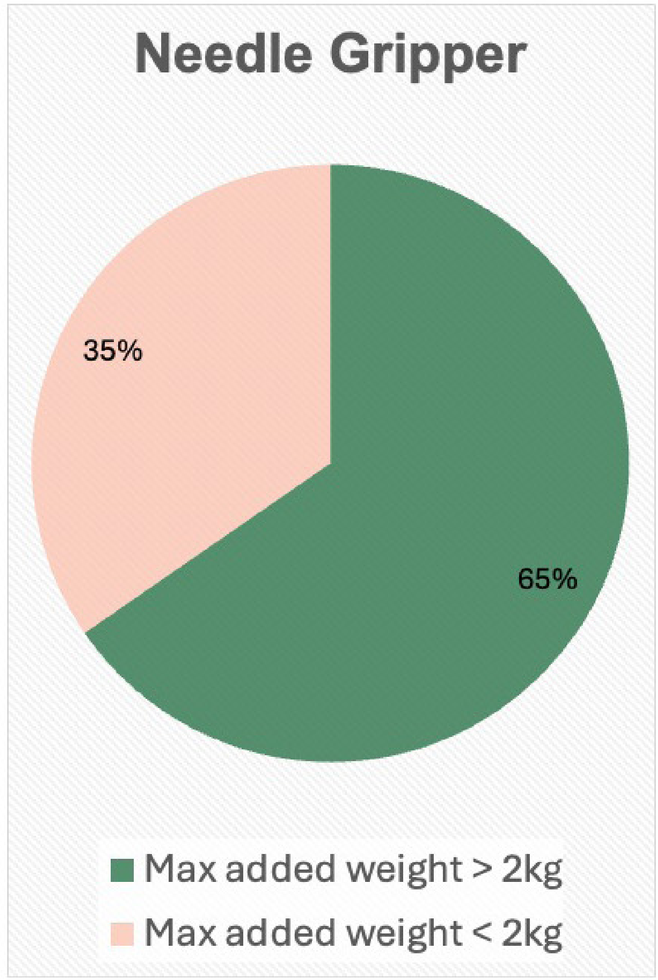




4.1.2. Gripper trial 2: Grip strength comparison:

The ratio of instances when an item did not slip out after an additional 2kg weight was added is shown below:





General key takeaways:

- The ratio of slips was roughly consistent across both gripper types.
- The weight did not seem to matter as much. Once a piece of cloth was properly gripped, it was highly unlikely to slip out.
- Some clothing items were more susceptible to slippage than others, but most slips were due to poor or marginal picks for both grippers rather than variations in the material characteristics of the items themselves.

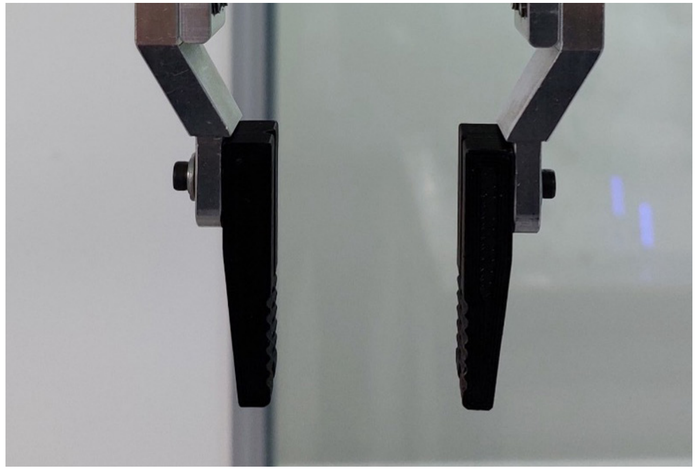
Finger gripper vs needle gripper key takeaways:

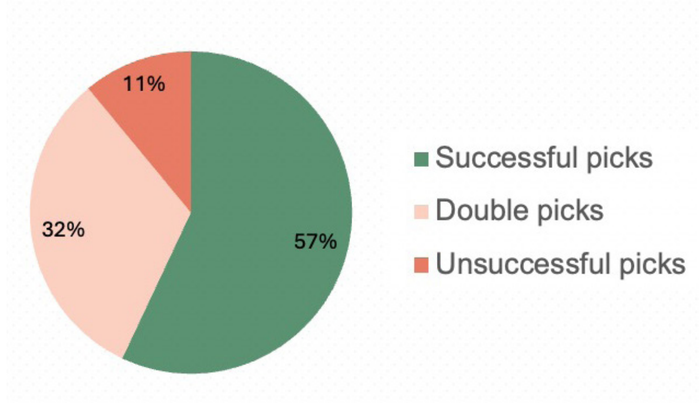
- Items were not damaged in any way when handled by the finger gripper. However, the needle gripper pierced the items, causing puncture holes.
- The slipping of items was caused by inadequate or marginal picks for both grippers. Slippage occurred when the item wasn't gripped properly by the fingers of the finger gripper or when multiple needles were not engaged by the needle gripper.
- The needle gripper's needle extension affected the security of the grip. A higher extension made double picks more likely but provided very secure grips.
- The needle gripper was better at picking up thinner and smaller items than the finger gripper.

4.1.3. Additional trial 1: Finger design comparison

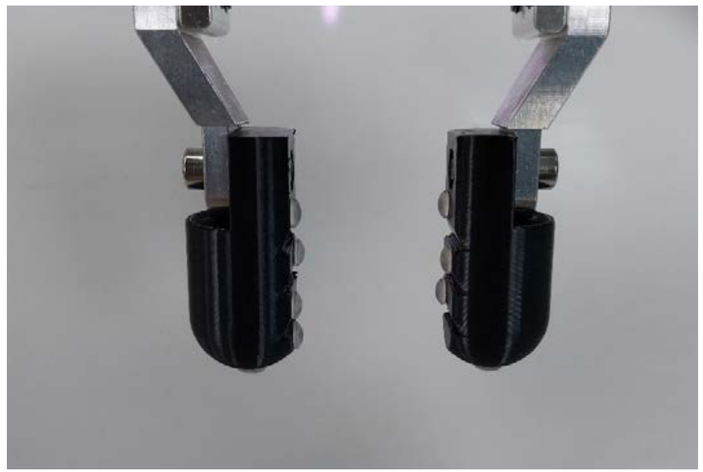
Gripper trial 1 (section 4.1.1) was repeated with new finger designs, and the results were compared to assess whether the finger design significantly affects the number of missed and double picks.

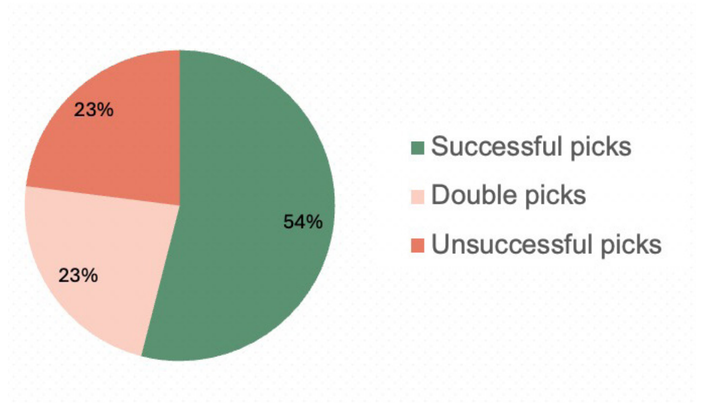
Original



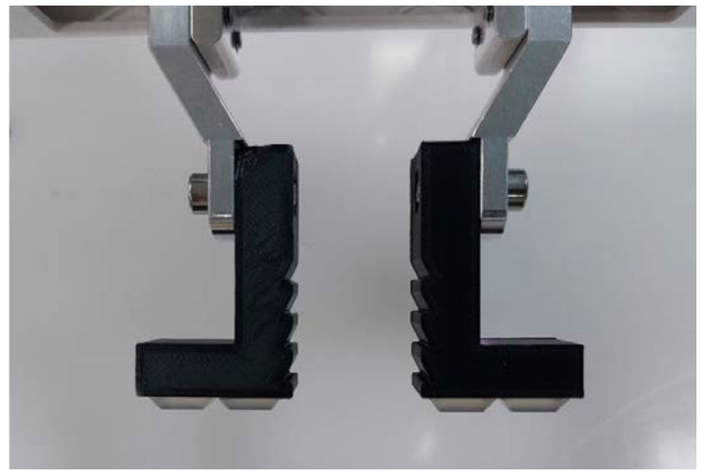


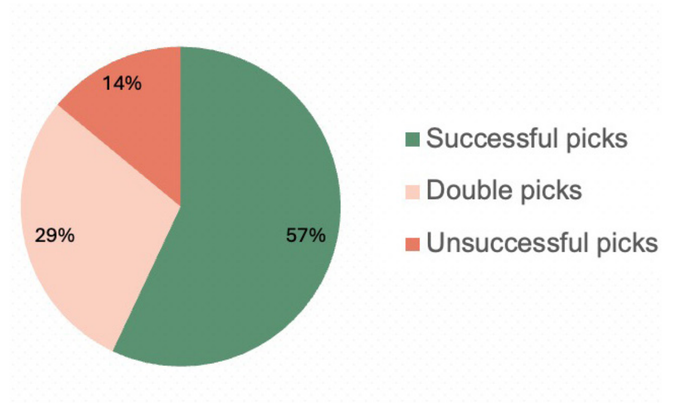
Rounded





L-Shape





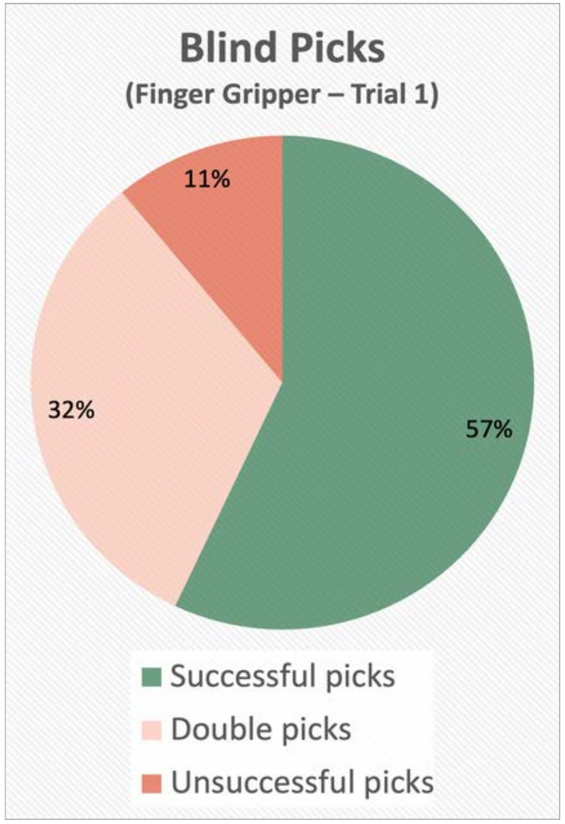
Key takeaways:

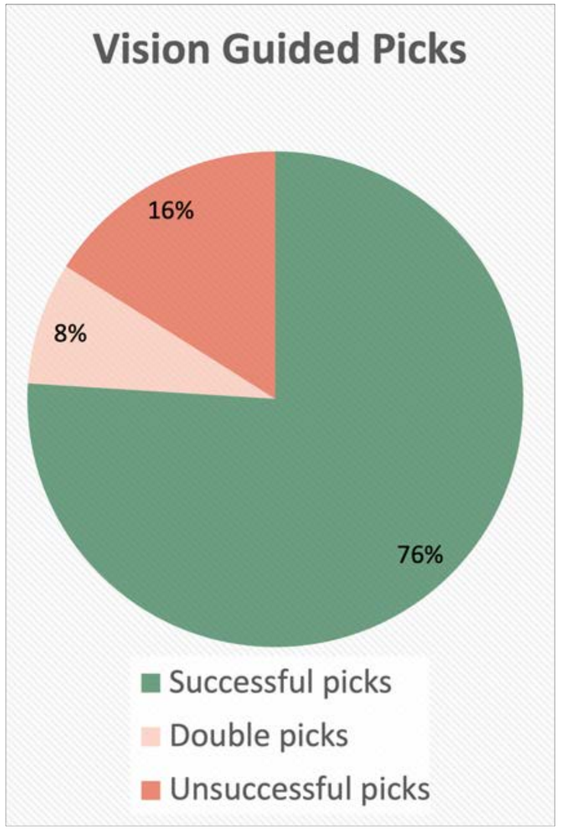
- There was little to no difference in the number of successful picks between different finger designs.
- Both missed and double picks resulted from poor pick positions. Given that the pick position and orientation remained constant throughout these trials, those figures were not significantly impacted.

4.1.4. Additional trial 2: Vision system trials

An Intel RealSense D435 Depth Sensing Camera was integrated with the Franka hand system to inform the picks. The expectation was that, using a relatively simple peak detection algorithm, the gripper would identify the location of a clothing item and attempt a pick at that location instead of blindly picking at a pre-recorded position.







4.2. Fibre identification trials

To enable an ATSP to produce consistent, high-quality feedstock, mixed textiles must be categorised into aggregate bins based on their fibre composition and, if required, their colour. The market review (section 2) has shown that fibre identification solutions utilise a few key technologies to accurately categorise and sort textiles by their material composition: NIR spectroscopy, RGB cameras, and machine learning.

Therefore, the objective of these trials was to identify the constituent materials and composition of the fibres using various sensors while reviewing their strengths and limitations. Additionally, the trials examined the known challenges of identifying black textiles and samples containing elastane.

Four different technologies were selected to investigate their advantages and limitations for use in an ATSP:

Hyperspectral system:
Hyperspectral imaging is a technique used to collect and process information across the electromagnetic spectrum to obtain the spectrum for each pixel in an image[19].

Short-wave infrared (SWIR) camera system:
SWIR covers the shorter wavelength end of NIR, ranging from 700nm to 1700nm, the infrared region closest to the visible spectrum[20].

Matoha FabriTell:
A small, pre-programmed desktop unit utilising NIR spectroscopy for fibre identification.

Sony triboelectric sensor:
Sony is developing a technology that measures the output voltages versus time. This will enable the creation of a triboelectric signature for each material in the sensing geometry, with potential use cases for fibre identification[21].

The following pages cover the results of these trials. For the methodology of each trial, please see Appendix.

4.2.1. Hyperspectral system trial summary

Key takeaways:

- The developed system can achieve high precision in fibre identification, comparable to industrial solutions. However, the precision of fibre identification significantly declines for black-dyed samples due to the dye's masking effect. Nevertheless, black dye samples and areas can be detected using hyperspectral technology with relatively high accuracy.

- The detection of elastane appears to be moderate to good, with some false positives noted. Since the contribution of elastane was only up to 10%, the error was smaller, resulting in high precision. The model was tested to classify elastane contribution into three categories. Its accuracy was about 64.9%. Further preprocessing of the input training data could potentially enhance elastane detection.

- Including a large number of training samples is crucial for the AI detection model's robustness. Therefore, increasing the number and variety of training samples could further enhance the model's performance.

- While the precision of fibre identification decreases with certain black dyes, the system remains capable of identifying these regions or samples. This ability not only facilitates the distinction between textile pieces containing carbon black dyes, but also, in instances where the black pattern does not cover the entire visible textile, enables the system to locate areas where the spectral signal is readable and identify the fibre from those areas.

4.2.2. SWIR camera system trial summary

Key takeaways:

- The images captured by the SWIR camera are influenced by the physical location of the light sources and the resultant light spread across the image, the intensity of the light sources, and the camera exposure time setting.
- This means that any output parameters calculated from the images to identify textile materials would only apply to the specific setup of the SWIR camera system. To ensure that the analysis and comparison parameters are transferable, the calculated parameter values should be independent of the SWIR camera system setup.
- A method for effectively normalising the SWIR camera images was tested. This involved eliminating the effects of the system setup on the final calculated comparison metrics. This method identified a parameter that remained constant under varying system setup conditions. This provided a universal metric that could be used to identify textile materials, regardless of the system's physical setup. This method was used to reliably identify and classify cotton and polyester samples.

A detailed description of the proposed methodologies for using SWIR camera data to identify cotton and polyester is currently under review for submission to the Journal of Imaging for publication.

4.2.3. Matoha FabriTell trial summary

Key takeaways:

- Four textile materials were tested: cotton-rich polyester, polyester-rich cotton, cotton-rich with elastane, and polyester-rich with elastane.
- Matoha's device's output varied when testing a single layer compared to multiple layers of the same textile sample, particularly with thinner samples. Consequently, tests were conducted on both single layers and samples folded into four layers. The following results are based on samples folded into four layers, as this provided a closer approximation of the percentages of the constituent materials.
- In seven samples (15%), none of the constituent materials could be identified.
- The system failed to detect elastane in 19 of the 20 samples containing it, resulting in a 95% error rate for elastane detection.
- In 50% of the 46 samples, one or several of the results below were observed:
  - None of the constituent materials could be identified.
  - Only one constituent material could be identified, while the other could not.
  - One constituent material was identified correctly, but the other was identified incorrectly.
- In samples with large areas containing carbon black dye, the system failed to identify the constituent materials.
- Matoha's device is easy to use and manually operated for low-volume applications. However, it is not suitable for identifying elastane in textiles or for use with thin fabrics. Such fabrics must be folded to create a thicker layer and then placed on the device's sensing window.

4.2.4. Sony triboelectric sensor trial summary

Key takeaways:

- The tests conducted on the triboelectric sensor demonstrated high accuracy in classifying samples according to the specific textile piece from which they originated.
- Follow-up work has shown that this technology has the potential to help identify specific fibre IDs.
- A greater number of verified samples is needed to further confirm the system's accuracy. However, these initial observations are promising and suggest that the sensor has some capability to distinguish between different fibre types.
- The initial tests showed that this technology was not affected by the carbon black dye, but more data is needed to confirm this observation.
- The sensor could potentially support vision-based fibre identification technologies, such as hyper-spectroscopy.
- The technology could potentially be used to capture data from moving objects or within a gripper system through a tapping action. However, as a low-technology readiness system, several challenges need to be addressed:
  - The system was sensitive to different tensions within the textile material. Therefore, attachments with specific pulling forces are needed to ensure measurement consistency.
  - The relative velocity of the materials between which the triboelectric effect is observed influences the charge value: greater velocity results in higher charge. Consistent data sampling is currently required to obtain reliable results.
  - Conductive fibres affect the results, reducing or preventing triboelectric charging.
  - More research is needed to assess if other external conditions affect the measured data and to what extent.

4.2.5. Fibre identification trials: General overview

	Suitability for moving items	Suitability for static items	Accuracy	Spectrum of detectable materials	Throughout	Cost	Use Cases for ATSP
Hyperspectral System	✓	High	High	High (Can be used to detect a wide spectrum of materials depending on its trained model)	High (Refer to Appendix A for further information)	High (£50,000)	Providing an industrial flexible detection system over a moving conveyor. Due to relatively high resolution of this system extensive areas of the test piece can be scanned.
SWIR Camera System	X	✓	High	Low (Best for binary classification of specifc material)	Medium (Refer to Appendix A for further information)	Medium (£7,000)	Providing an industrial detection system, where a binary output for the detected material is required. Sich as inspection of laudary receieved from a hospital, where the items are expected to be from cotton. The system inspect extensive regions of the test pieces.
Matoha Fabritell	X	✓	Medium	High (Can be used to detect a wide spectrum of materials depending on its trained model)	Low (Refer to Appendix A for further information)	Low (£3,500)	This system us ideally suited for manual inspection. The system may also be adapted to be placed within robot grippers. The system covers only a small finite region of the test pices.
Sony Tribo Electric Sensor	✓	✓	-	-	Low (Refer to Appendix A for further information)	-	This is a low TRL system still under development. It is shown to be able to capture data from moving objects as well as within a gripper system by a tapping action (closing/ opening the tripper).

4.3. Disruptor removal trial: Shredding and air separation

Research into disrupter removal has revealed that size input is the most variable feedstock requirement across different recycling technologies. Many recyclers' size specifications are a direct result of their disruptor removal processes. Furthermore, the disruptor removal process determines the maximum permissible size in the reduction process.

In general, chemical recyclers are more adaptable with size input and can accept smaller sizes, while mechanical recyclers require larger swatches to maintain fibre lengths, ensuring their outputs retain value.

The trials were set up to:

- Determine the accuracy and yield of air-based gravity separation on different input fibre types and sizes.
- Develop the settings for different fibre types and input sizes, looking for opportunities for overlap where possible.
- Identify if mechanical limits exist within equipment settings for three input sizes to develop an understanding of how suitable the technology is for handling various textile fibre types and input sizes.

Full results and analysis from these trials can be found in two MTC reports, 'Pre-Processing Trials: Shredding + Air-based Density Separation' and 'Pre-Processing Trials: Guillotine + Valvan Trimclean Disruptor Removal'.

4.3.1. Post-shredding stage

To ensure the air-separation system operates efficiently, samples of whole garments needed to be shredded into smaller sizes for classification. Various screens were used when shredding to regulate the maximum permissible size of the samples. There exists a balance between shredding the textile material to make it "light" and easy to separate and over-processing, which results in disruptors being fragmented into lighter pieces.

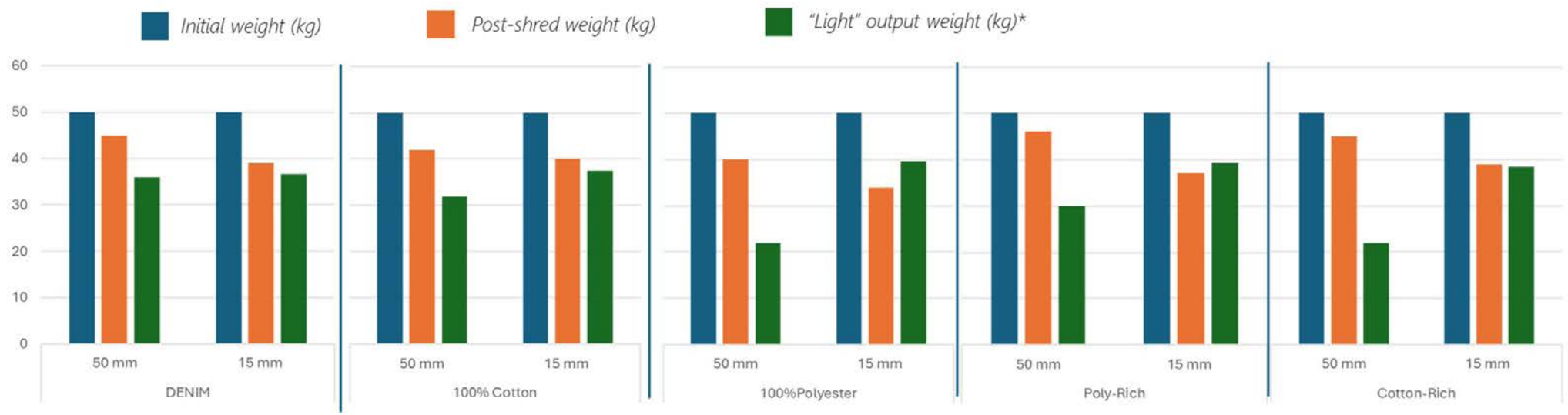
No screen:
No screen was not a suitable option, as the absence of a screen meant the fabric was pulled through the shredder and was only partially torn, rather than shredded. This resulted in disruptors remaining on garments and the fabrics being unsuitable for air separation.

50mm screen:
The 50mm shred screen was identified by the equipment provider Impact Air Systems as the optimal balance of size without over-processing the disruptors.

15mm screen:
The 15mm screen produced a finer result, as expected. However, the finer screen also increases the likelihood of disruptors being shredded into smaller, lighter pieces, which would be harder to separate based on density.



4.3.2. Yield loss results: 50mm screen vs 15mm screen



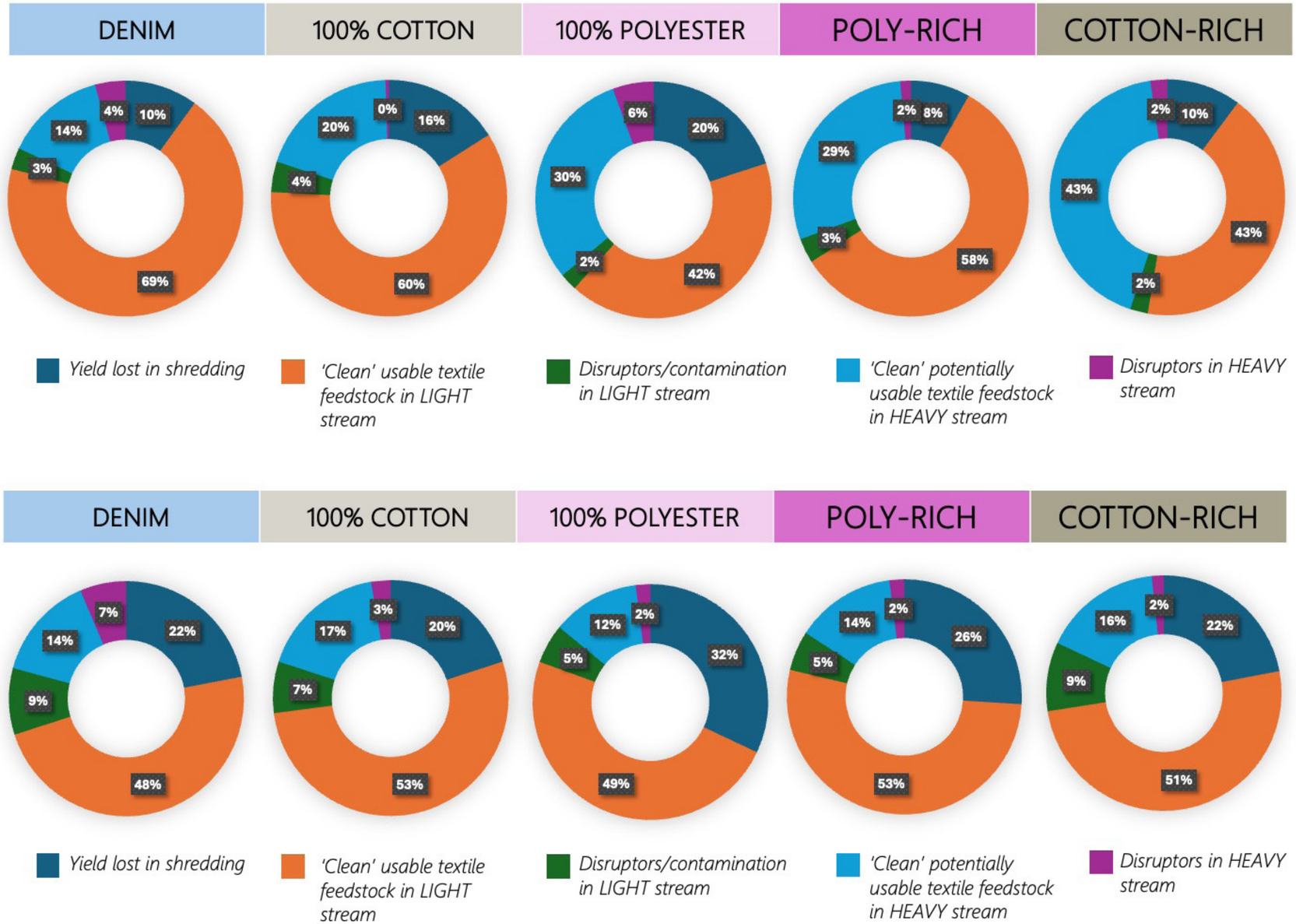
TOTAL yield loss from original 50 kg batch *

	DENIM	100% COTTON	100% POLYESTER	POLY-RICH	COTTON-RICH
[50 mm]	28%	36%	56%	40%	56%
[15 mm]	43%	40%	46%	42%	40%

** NOTE: As the 15mm air separation trials used a smaller input weight than the total kg available after the shredding stage, the yield loss calculations have been deduced as a percentage of the total input quantity.*

In addition to the yield loss from each process stage, it is also important to consider the clean textile “lost” to the heavy/disruptor stream, which could, in theory, be used as textile feedstock.

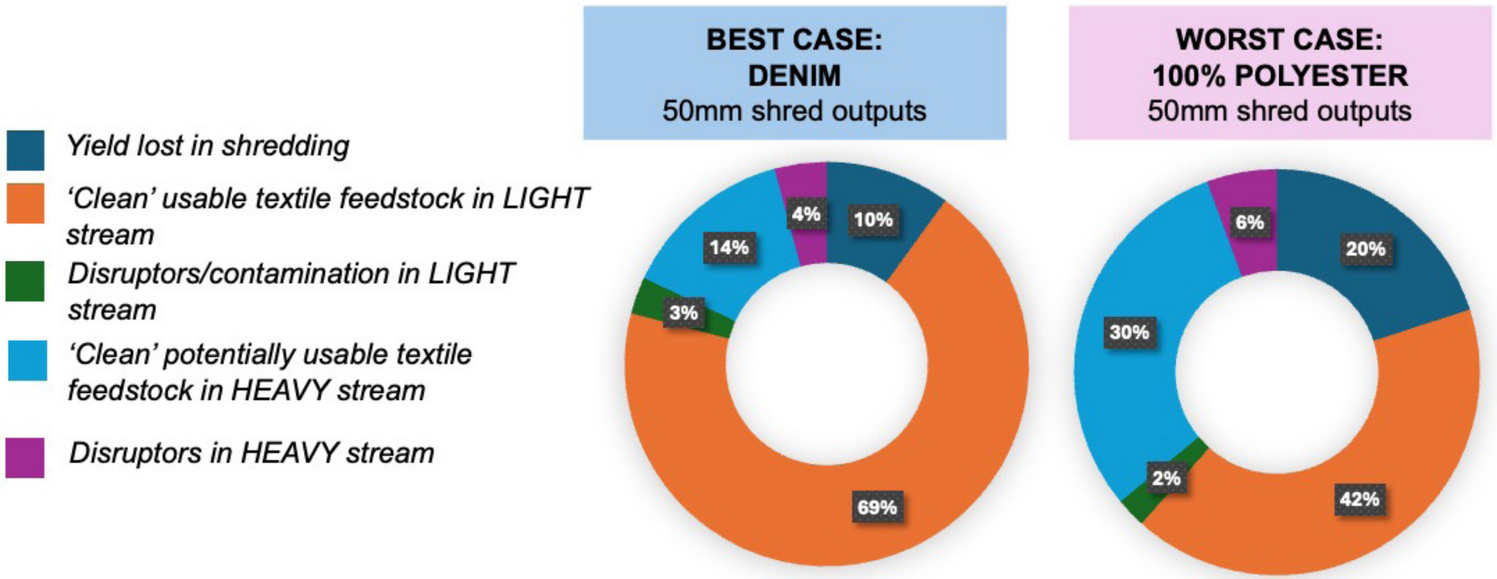
A breakdown of the contents of each 50mm batch and 15mm batch are below:



4.3.3. Yield loss results in relation to an ATSP

When taking into account the contamination of usable outputs, the amount of clean textile output generated in the ‘clean/ light’ stream of the air separation process was, at best, 69% and, at worst, 42%.

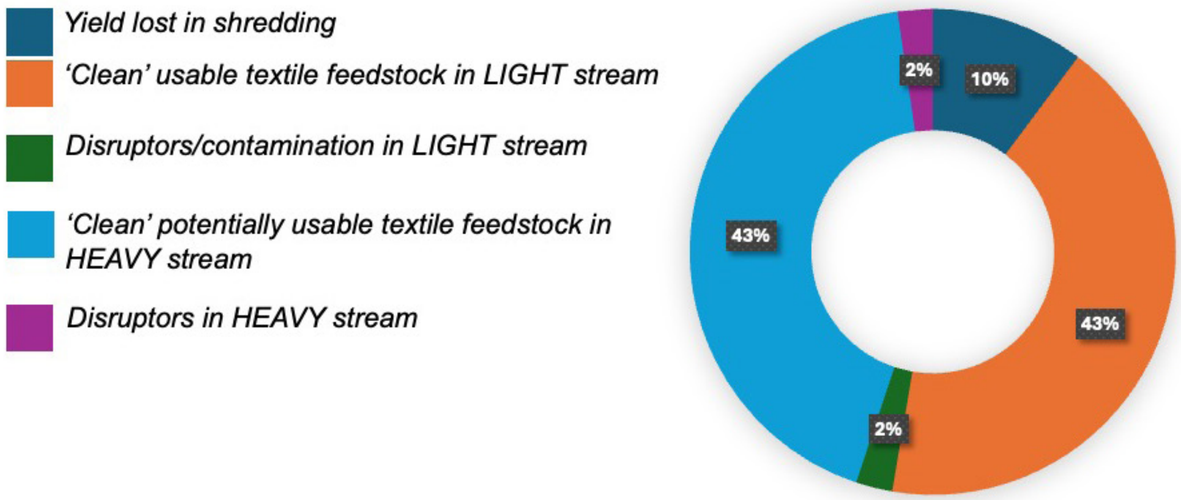
In both scenarios, additional potential yield is lost from clean textiles that could be recycled in the heavy stream. Such a level of yield loss would likely not be financially viable in an ATSP where fine margins are already associated with textile recycling.



It was noted from the trial results that a large quantity of the ‘heavy’ outputs were clean textile pieces that were not separated from the heavy disruptors during the aeration process. This issue was more prevalent in certain fibre types (cotton-polyester blends and polyester) and was particularly pronounced in the 50mm shredded batches.

In the case of 50mm cotton-rich cotton-polyester blends, equal amounts of clean textile were found in both the light/clean output stream and the heavy output stream.

WORST-CASE:
COTTON-RICH
50 mm shred outputs



If replicated at scale, these results could pose challenges for textile collectors, sorters, and ATSP operators if over 50% of their fibre-sorted fractions cannot be used as feedstock or sold to a recycler. This would necessitate storage or finding alternative off-takers.

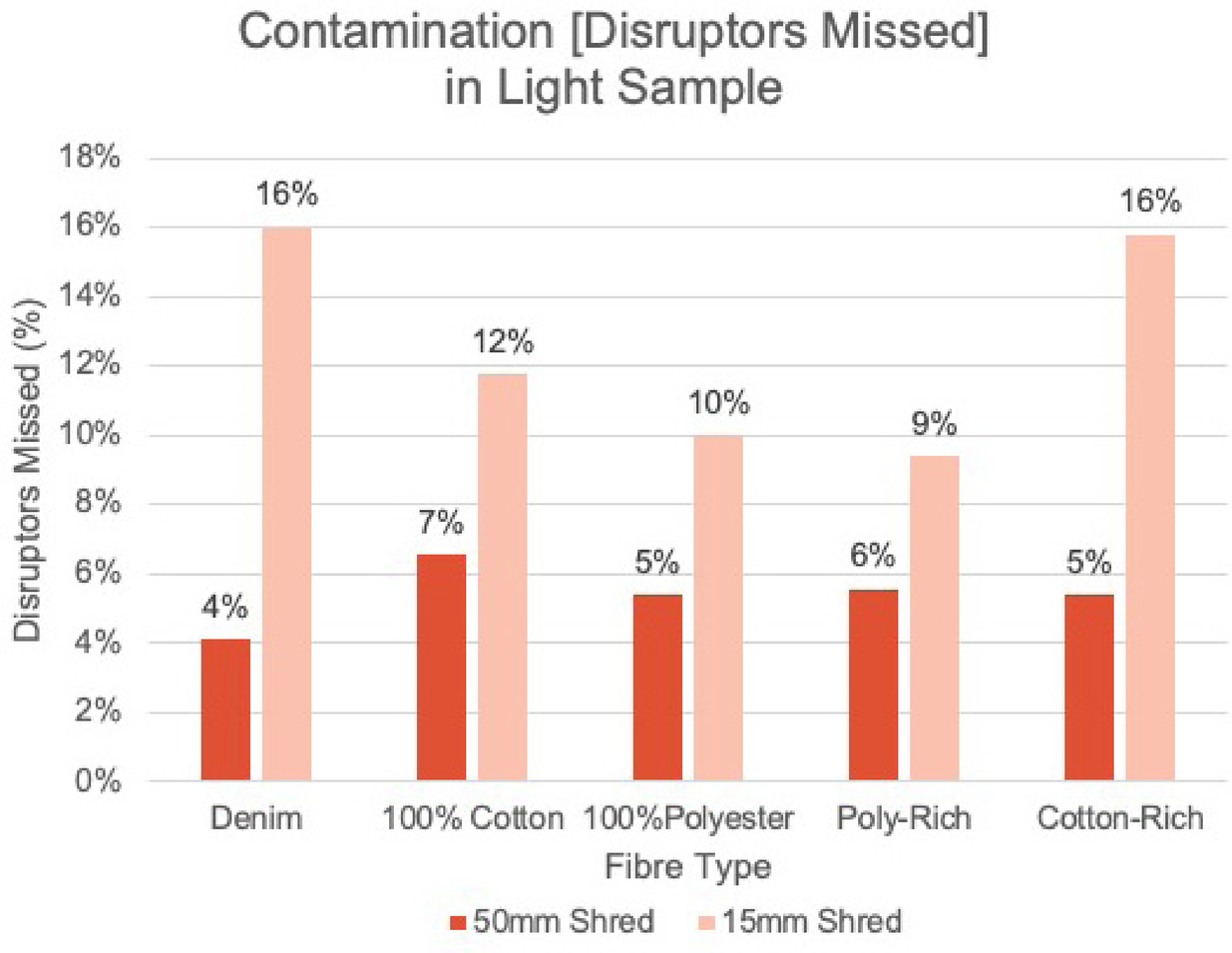


4.3.4. Results in relation to recyclers' condition of supply requirements

The outputs from air separation technology do not meet the requirements of more established recycling technologies, such as mechanical and thermomechanical processes, which have stricter feedstock specifications and lower tolerance for disruptors.

Emerging chemical recycling technologies assert a higher tolerance for elastane and other fibre contamination. Therefore, the outputs from this process could be suitable potential feedstock.

Type of Recycling:	Estimated TRL of recycling technology:	MAXIMUM disruptor process tolerance
Mechanical	8-9	0%
Thermo-mechanical	8-9	3%
Chemical – Cellulose/cotton-rich	5-7	5%
Chemical – Cotton/Polyester	5-7	10%
Chemical - Polyester	5-7	TBD – not quantified in interviews
Chemical - Polyamide	5-7	TBD – not quantified in interviews



4.3.5. Disruptor removal: Valvan Trimclean trial

This trial aimed to assess the effectiveness of Valvan's Trimclean technology in removing disruptors from sorted textile feedstock.

Sorted feedstock was initially reduced in size using a guillotine cutting machine to approximately 5cm x 5cm swatches. Initial visual assessments found that contamination (i.e., swatches containing disruptors entering the 'clean' output category) was very minimal and lower than that measured in the shredding and air separation processes trials.

However, measured data from this trial was not available at the time of submission (February 27, 2025). Full results with measured quantities of yield loss and contamination will be available in the report titled: Pre-Processing Trials: Guillotine + Valvan Trimclean Disruptor Removal, published in March 2025.

5. CONDITION OF SUPPLY: PHASE 2

The market review (section 2) emphasised the need for a deeper understanding of the condition of supply, with several key takeaways to consider for phase 2.

Due to scale, supplying feedstock to fibre-to-fibre recyclers faces significant commercial viability challenges. A primary technological hurdle is achieving high throughput, encompassing the need for high-volume, bulk processing. Furthermore, the availability of substantial quantities of PCT waste is essential to driving prices down to levels that ensure commercial viability throughout the downstream supply chain. Finally, sorters must consider adequate storage space to accumulate and organise sufficient quantities of desired feedstock specifications for selling to customers

Some consensus exists among feedstock specifications for certain recycling processes, but other recycling technologies that utilise PCT as a feedstock are still in their infancy and lack established processes. Several recyclers have expressed a desire to adapt their processes to accept more disruptors and contaminants from post-consumer NRT, though more established recyclers maintain stricter feedstock specifications. Many recyclers indicated they would be willing to pay an ATSP for feedstock that has already been sorted and pre-processed to their requirements. However, most do not yet have an established pricing model to quantify precisely how much more they would be willing to pay.

Equipment or process steps in an ATSP must be flexible, or waste streams (and potential customers) must be targeted. Size input is the most varied feedstock requirement, while the disruptor removal process dictates the maximum permissible size in the size reduction process. In general, chemical recyclers are more flexible regarding size input and can accept smaller sizes inputs, while mechanical recyclers require larger swatches to maintain fibre lengths, ensuring their outputs hold value. For mass volume, specific equipment can be targeted at designated waste streams and customers.

The next sections explore key findings across commercial viability, quality, technology, and strategy.

5.1. Condition of supply: ATSP commercial viability key takeaways

Increase flexibility: Developing a flexible sorting facility to deliver multiple and more accurate feedstocks will stimulate market growth.

Route to market: Mapping the value chain from collection to recycling will highlight the most profitable route to market and focus technology investment.

Reduce waste and cost: Sorting to fibre level will minimise waste and the associated disposal costs.

Utilise open loop: Developing open-loop recycling streams will initially provide revenue streams until fibre-to-fibre recycling is implemented more widely.

5.2. Condition of supply: Quality key takeaways

Raise standards: Standards in textile recycling exist at a product/material level to certify recycled content. However, there are no codified or consistent certifications or standards for the quality of inputs at earlier stages in the recycling supply chain.

Introduce validation: Currently, there are no accepted validation mechanisms to ensure that the feedstock produced after sorting and pre-processing meets recyclers' or customers' specifications.

Certifying feedstock: In an ideal future state, an ATSP could issue a certificate of conformity certifying that its feedstock meets an industry-agreed standard. This would enable recyclers to confidently accept feedstock quality rather than adding value to further sorting and conducting repeated trial-and-error experiments.

Standardise industry terms: There is a lack of common language and standardisation among players in the value chain, from textile collectors and sorters to yarn spinners, weavers, and knitters. For example, different terms exist for the same or similar feedstock criteria, and different terms exist for the same or similar processes.

5.3. Condition of supply: Technology key takeaways

Standardise technology requirements: The advancement of sorting and pre-processing technologies is hindered by the uncertainty in the textile recycling market, which encompasses various specifications, standards, and requirements from individual recyclers.

Upfront investment is challenging: Investing upfront in commercially available sorting and pre-processing technologies is risky when the market is volatile. There is no guaranteed path to the market or selling price.

Opportunities are restricted: The limitations within current commercially available sorting systems and technologies will limit the commercial opportunities that can be exploited with the feedstock generated.

Investment needed to improve quality: To develop higher quality standards, there is a need for investment across the whole value chain to enable the delivery of feedstocks that meet specific customer levels of quality.

More valuable feedstock: Further opportunities exist for technology to be developed to sort and refine textile waste at a smaller fibre or swatch level, making it more valuable as a feedstock for recyclers. This could help to minimise generated waste and recover the maximum targeted fibres, as well as improve the quality of feedstock, as contaminants are removed more precisely from finer inputs.

5.4. Condition of supply: Strategic key takeaways

Work collaboratively: The industry has a fragmented approach to dealing with the textile circularity problem, with collectors, sorters, recyclers, manufacturers, and brands all operating individually rather than collaboratively. Therefore, introducing standards and legislation should give confidence to stakeholders to invest more resources into the adoption of recycled textile feedstock. Additionally, different organisations undertaking distinct processes often operate in silos and lack strategic alignment. This lack of collaboration across the supply chain leads to inefficiencies and increased costs within the value chain.

Distribute investment fairly: To enable and encourage the development of commercial opportunities, continued coordinated, significant, focused, and controlled investment distributed fairly through the supply chain is needed.

Mitigate risk: Vertically integrated textile recycling supply chains, which encompass the entire value chain, have proven to be an ideal business model that mitigates operational risk. This can be attained by organising, partnering, and controlling collection points; establishing operations and processes that align with commercial value; and developing markets for both closed-loop and open-loop customers, thereby minimising waste and related disposal costs.

To summarise, as the textile recycling industry expands, collaboration across the supply chain could enable pre-processing to be carried out at scale in one central location, enhancing quality, efficiency, and cost benefits. This ideal 'meet in the middle' location for both ATSP operations and the rest of the textile recycling supply chain will produce feedstock that benefits everyone's commercial interests.



6. DISCUSSION

Each section of this report – market review, emerging technologies, technology trials, and condition of supply – has its own set of key takeaways and recommendations. Below is a summary of these central findings:

Key finding 1: The textile recycling landscape is still developing, and there needs to be open communication between recyclers and technology providers to ensure their feedstock requirements are understood and that equipment can be configured appropriately.

Key finding 2: When selecting equipment for an ATSP with high throughput targets and multiple output streams, the chosen plant designer and systems integrator will be essential in designing the layout and combination of equipment to meet the facility's specifications.

Key finding 3: For material feeding and horizontal conveyance, automating item singulation and minimising the likelihood of garment overlap is critical to the efficient operation of an ATSP. Based on trials conducted, finger grippers paired with vision systems appear to be the method with the highest levels of control.

Key finding 4: Regarding size reduction, no technologies are versatile enough to produce optimal feedstock for the broad range of different fibre-to-fibre recycling processes.

Key finding 5: Localised disruptor removal requires developments in a number of key areas of robotics and machine learning. Although the throughput capacity of disruptor removal technology has been increasing rapidly, it remains unlikely to meet the requirements at an industrial scale due to significant yield loss and limited accuracy.

Key finding 6: Currently, there are no accepted validation mechanisms to ensure that the feedstock produced after sorting and pre-processing meets recyclers' or customers' specifications.

Key finding 7: In an ideal future state, an ATSP could issue a certificate of conformity certifying that its feedstock meets an industry-agreed standard. This would enable recyclers to confidently accept feedstock quality rather than adding value to further sorting and conducting repeated trial-and-error experiments.

APPENDIX

Hyperspectral system trial methodology

Fibre Identification Trials – Hyperspectral System Summary

The hyperspectral camera used in this trial is a Specim FX17. It has a sensitivity range of 900 to 1700nm, providing a spatial resolution of 640 pixels with 224 wavelength bands responses at each pixel.

The camera operates as a line scanner, requiring relative movement between the camera and the object to build a two-dimensional image. This system is ideal for industrial applications where the camera is fixed, and objects are placed on a moving conveyor system.

From each captured image, 100 patches were sampled, with each patch composed of 100 pixels. This method allows for the creation of a reliable hyperspectral signature (mean value) from these 100 pixels. As a result, 100 hyperspectral signatures were obtained for each image (for each textile material).

The algorithm developed for automatic sampling detected the edges of the material in the image and randomly sampled the patches within this region. Additionally, some materials were found to produce two different hyperspectral signatures, mainly due to the black dye (likely carbon black dye) used in certain regions of the textile piece. In such cases, the algorithm collected 100 samples for both signatures.



Image 17: Hyperspectral System

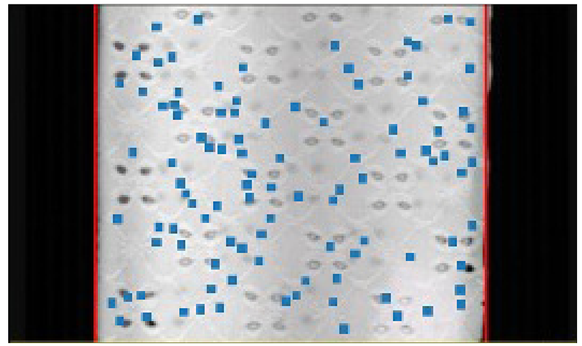


Image 18: Automatic collection of 100 spectral samples

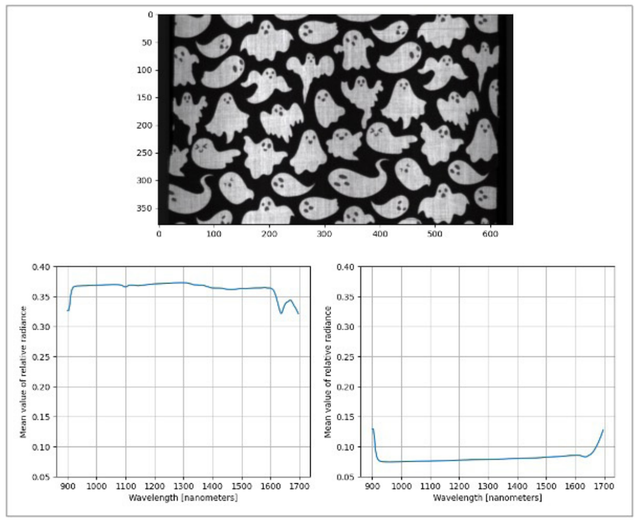


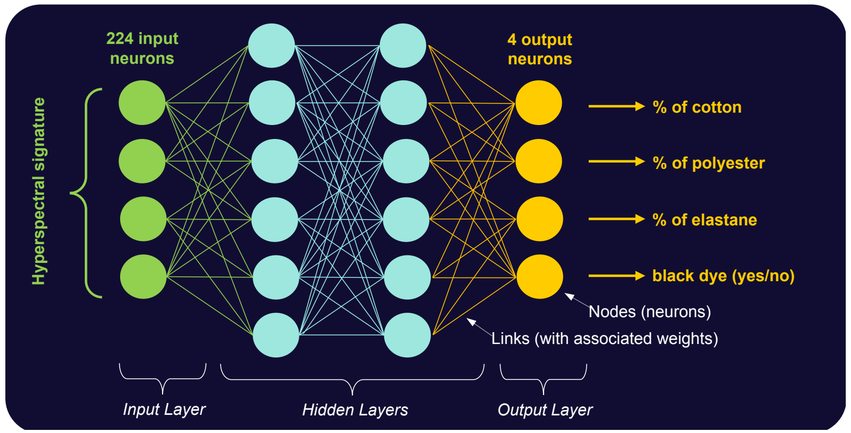
Image 19: Automatic collection of 100 spectral samples

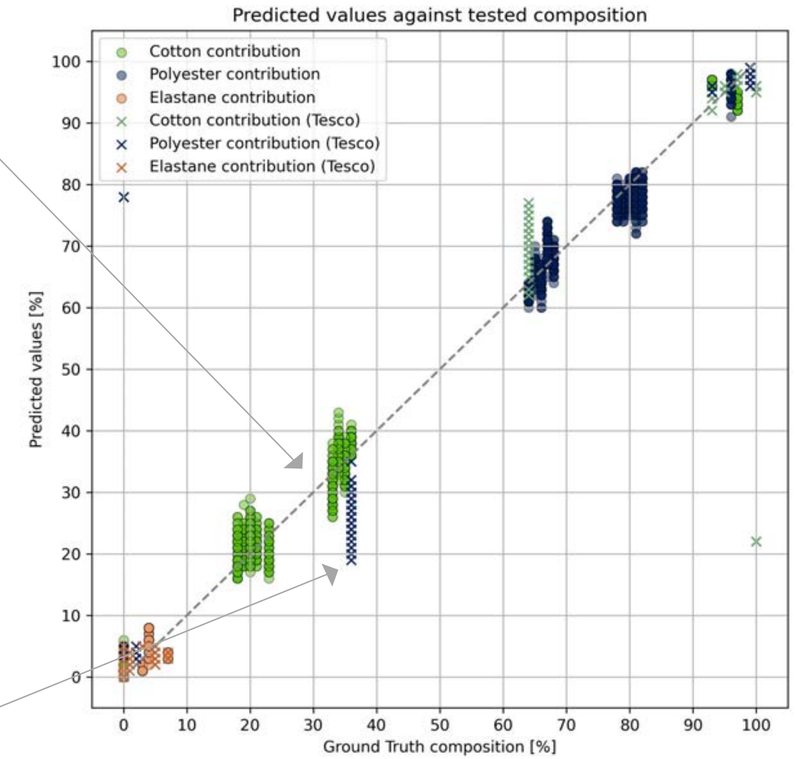
Fibre Identification Trials – Hyperspectral System Summary

Model Architecture: An Artificial Neural Network (ANN) model was trained to determine the fibre composition. The ANN model is comprised of layers of nodes (neurons), containing an input layer, one or more hidden layers and an output layer. The nodes are connected by the links with associated weights.[1] During the learning process, these weights are adjusted so that the output layer produces the desired outcome.

The results can be illustrated on the plot:

- The plot shows percentage of each tested constitute fibre type (e.g. 65% polyester, 35% cotton). Colours depict content of each fibre. This excludes the regions with carbon black dye.
- The perfect prediction corresponds to the diagonal line (shown in grey). The line marks the location where values of predictions match verified fibre composition.
- The points closer to this line correspond to more accurate prediction.
- The plot includes the results from the initial test set as well as additional data sampled from textile pieces provided by Tesco.





Collected data often forms vertical lines. This is because these points come form one textile piece with the same Ground Truth values (variations only in prediction).

SWIR camera system trial methodology

Fibre Identification Trials – SWIR Camera System

The experimental setup consists of a camera, lens, optical filter, and two halogen lamps.

The camera used is a Basler a2A1280-80gmSWIR, with a resolution of 1280 x 1024 pixels and a maximum frame rate of 80 frames per second. The camera sensor is sensitive to light wavelengths ranging from 400 nm to 1700 nm. Attached to the camera is a 12mm Computar M1218-APVSW lens.

Two 35W halogen lamps were used to illuminate the test pieces.

During the trials, several optical filters were used to allow only a narrow range of light wavelengths of interest to pass through the filter.

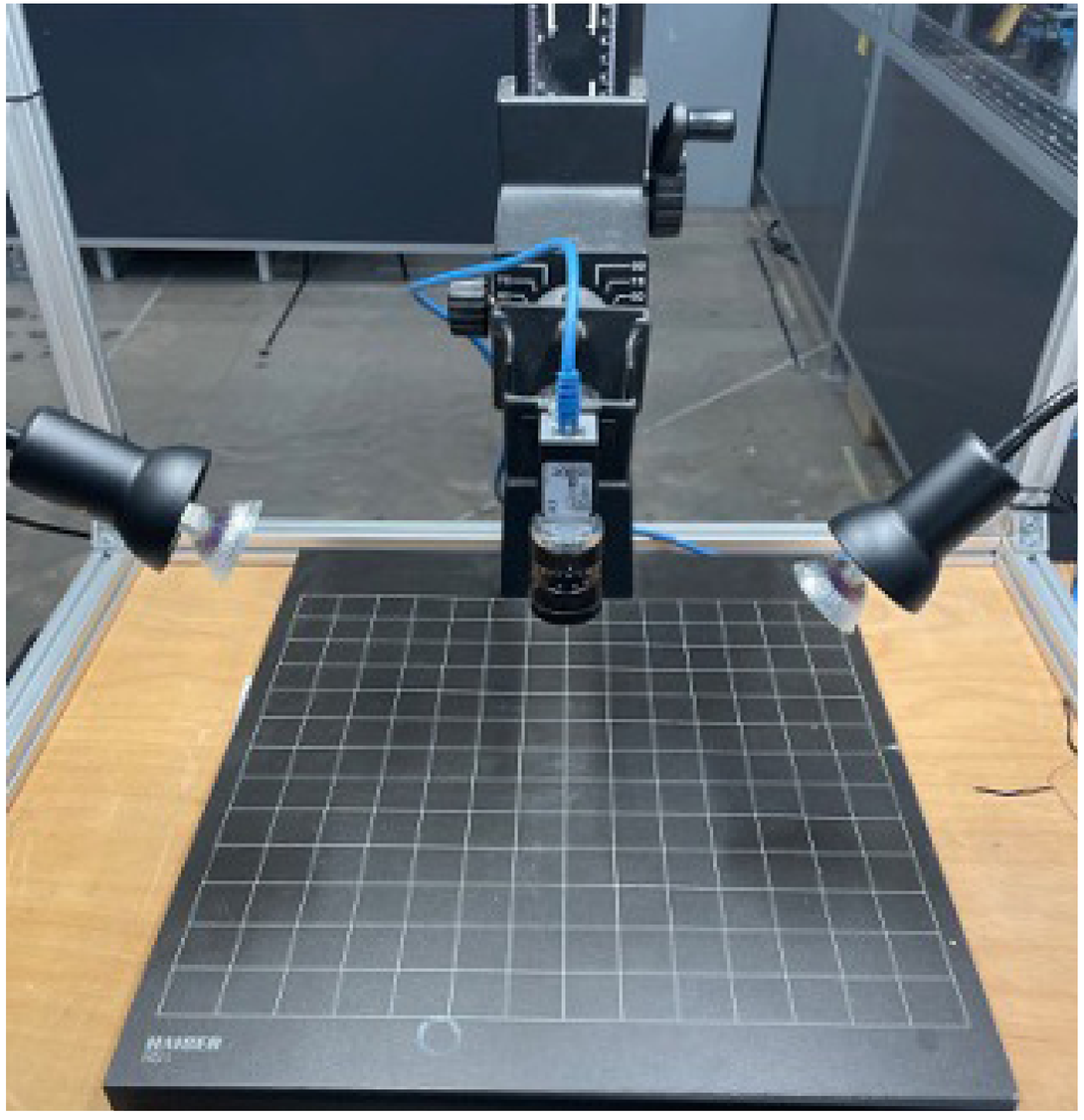


Image 20: SWIR Camera Setup

Fibre Identification Trials – SWIR Camera System

Several examples of textile samples are shown with their corresponding images captured by the SWIR camera.

A band-pass filter was attached to the SWIR camera's lens, allowing only a selected range of light wavelengths to pass through. As seen in the corresponding SWIR images, the color data in the range of 400 nm to 700 nm were filtered out.

In images (b) and (f), the carbon black dye appears as a deep black because very little light is reflected from the regions containing this dye. Thus, the SWIR camera can readily detect regions with carbon black dye.

Black carbon dye is widely used in dyeing textile fibres and printing patterns on textile materials. This poses challenges when using near-infrared technologies to identify textile materials. Black carbon dye absorbs most of the incident light in wavelengths below 1700 nm, functioning as a mask and preventing the system from detecting light reflected from the underlying textile materials. Therefore, the constituent materials of the fibre covered by the carbon black dye would not be identifiable using the NIR wavelength range.

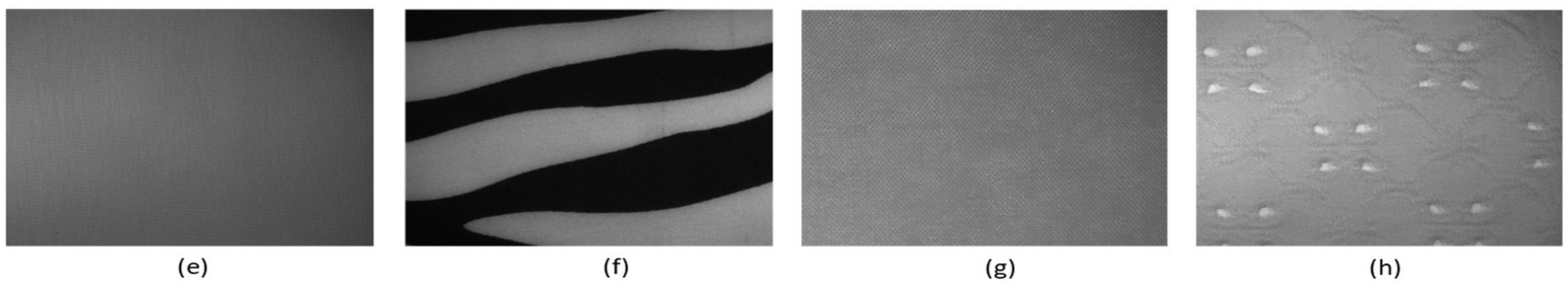
However, this masking characteristic makes the SWIR camera suitable for detecting the presence of carbon black dye.

In cases where the black dye is present in some regions of the material but does not cover it entirely, simple image processing techniques can be used to exclude the regions identified by the system as containing black carbon dye from the analysis. Subsequently, only the regions not containing carbon black dye can be analysed and material constituents of the fibre identified.



(a) (b) (c) (d)

Photographs of the samples



(e) (f) (g) (h)

Images captured by the SWIR camera of the corresponding samples above

Matoha FabriTell trial methodology

Fibre Identification Trials – Matoha FabriTell Summary

The Matoha FabriTell Desktop is a portable handheld device that uses NIR technology to classify the constituent materials of textiles. The device has a detection window where the textile sample is manually placed. A NIR light source shines light containing a range of wavelengths on the test piece, and the reflected light is detected by a NIR sensor.

The system includes a trained AI model used to classify the material under inspection. The reflected light responses to the various wavelengths, detected by the NIR sensor, are used as input to the AI model. A small LCD display on the handheld device shows the identified constituent materials in the sample and their percentages. If the model cannot classify the material, a message is displayed on the screen.

FabriTell is a self-contained device that does not require any additional setup. Simply place it on a workbench, turn it on, and it is ready for use.

Test sequence for data acquisition:
1. Switch on the device
2. Place the textile sample(single layer) on the detection window.
3. Read the display and record the results.
4. Fold the sample into 4 layers and place it over the detection window
5. Read the display and record the results.



Image 21: Matoha FabriTell Desktop

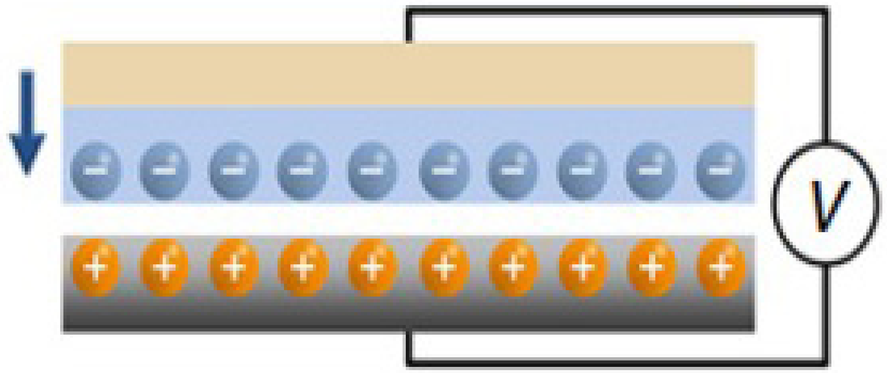
Sony triboelectric sensor trial methodology

Fibre Identification Trials – Sony Tribo-Electric Sensor Summary

Tribo-Electric Sensor (TES): The Tribo-Electric Sensor (TES) is being developed by SONY and utilizes the triboelectric effect to determine the material of an object. Tribocharging occurs when an electric charge is transferred between two objects upon contact or sliding. When two different materials come into contact, they exhibit specific preferences towards gaining a positive or negative charge. The first empirical studies listing materials in the triboelectric series were obtained in 1757.[1]

TES technology requires direct contact between the sensor and the object, which can be in the form of tapping or sliding. The sensor measures the output voltage changes over time, creating a tribo-electric signature for each material. Tests performed at the SONY laboratory show that data obtained by the sensor produced distinct data clusters for different fiber types such as polyester, cotton, viscose, wool, and linen.

This low Technology Readiness Level (TRL) technology has the potential to be used as a complementary system to identify fiber types where spectral methods fail or provide unclear results.



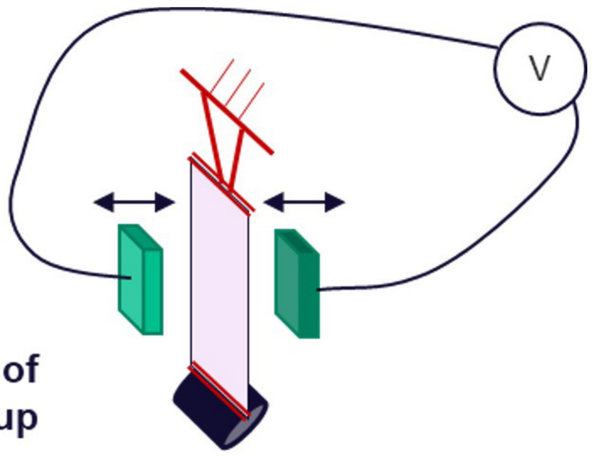
Fibre Identification Trials – Sony Tribo-Electric Sensor

An MTC employee observed and participated in the data collection process at SONY labs in Stuttgart.

Specific sizes of textile samples were required due to the system's attachment constraints. A total of 161 MTC samples were tested using the tribo-electric sensor. Three sample were excluded as they gave low or no signal (possible due to incorporated conductive fibre).

Methodology:

1. A prepared piece of material was vertically attached at the top and bottom in the testing system.
2. Automatic tapping was performed, with both sides of the material tapped by the electrode. One electrode was covered by an array of nonconductive materials to facilitate the tribo-electric effect.
3. The change in charge was recorded, with 100 taps performed on each material sample.



Simplified illustration of the experiment set up

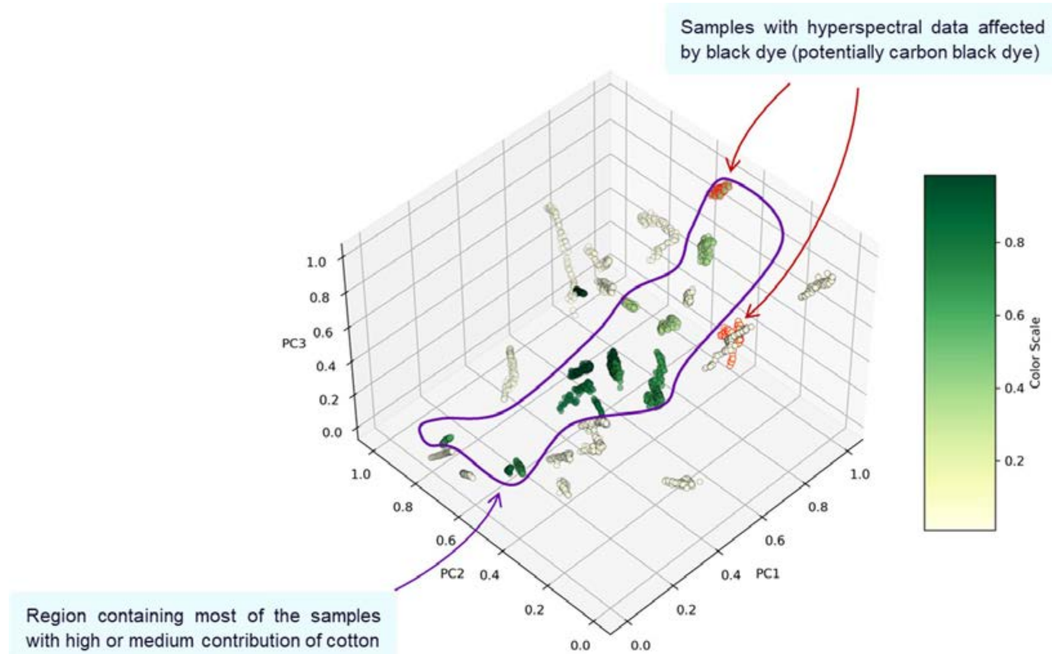
Fibre Identification Trials – Sony Tribo-Electric Sensor Summary

Clusters corresponding to textile samples:

- The plot on the right visualises the data in a 3D space.
- The data points obtained from the same textile piece clearly create clusters.
- The initial classification model tested by SONY assigns the data points into these clusters (corresponding to textile pieces).
- The model was trained on a higher number of textile samples (that were initially provided) and shown an accuracy of about 94%.

Fibre Identification:

- The colours of the plot on the right correspond to cotton contribution (green colour – higher %).
- As the textiles are only composed of two fibres (cotton and polyester) the yellow colour corresponds to high contribution of polyester.
- We can see that textiles with high percentage of cotton create visible central region which can be identified.
- Circles on the plot with red edges correspond to two textile samples with black dye that prevented correct hyperspectral analysis. They seem to be correctly positioned based on their fibre composition.



Three main principal components of the data from selected samples presented in the 3D space – % of cotton.

Chapter 4:

Site selection and engineering design of an ATSP facility

Aligning a cost-effective and replicable ATSP design with selecting an optimal location



CONTENTS

Introduction

ATSP engineering and operations

- ATSP design methodology
- Operations and engineering design
- ATSP capital and operating expenditures
- ATSP equipment purchase

ATSP site selection

- ATSP site scope
- ATSP site selection methodology
- ATSP site evaluation: Criteria and process
- AT market search and analysis
- Securing a preferred site

Discussion

- Findings and recommendations: Engineering and operations
- Findings and recommendations: Site selection

Appendix

- Appendix 1: ATSP Supply Specifications Guide
- Appendix 2: Civil works
- Appendix 3: Permits

1. INTRODUCTION

The aim of this work package was to establish a replicable engineering design for an Automated Textile Sorting and Pre-processing (ATSP) facility and to demonstrate its operational viability to enable investment for the development of full-scale ATSPs.

The scope included:

- Creating an ATSP engineering design process
- Identifying requirements for a large-scale ATSP site location and facilities
- Defining an ATSP facilities layout and scoping civil works
- Finding, securing, and preparing a site for an ATSP facility

Therefore, this chapter presents an overview of key considerations, methodologies, and findings for the conceptual engineering design phase and site selection for the first UK-based ATSP, operating at 25,000 tonnes per year (ktpa).

To illustrate the significant need for ATSPs, imagine that the first industrial-size polyester/cotton blend chemical recycling plant in the UK is commissioned in the next two to three years at a capacity of 50,000kpta. The plant will require a steady flow of fibre-sorted inputs, which are accurately sorted and pre-processed, with all disruptors, such as buttons, zips, metals, etc., removed. To be economically viable, these plants must operate 24/7 without disruption because having to shut down and restart during periods of poor feedstocks can cost hundreds of thousands of pounds.

Given that approximately a third of all non-reusable textiles (NRTs) will be suitable fibre compositions to go into this process, this means it will take the sorting of over 150,000 tonnes of textiles to meet the processing needs. This would require six ATSPs, each processing 25,000kpta.

These numbers highlight the chicken-and-egg challenge of transitioning from a linear materials supply chain to a circular one: how to attract investment in chemical recycling plants if there are too few ATSPs to supply continuous feedstock and, similarly, how to attract investment in building multiple ATSPs if there are too few chemical recycling plants.

Automated sorting is critical because manual sorting is costly. Furthermore, it is not possible to accurately separate textiles by fibre composition manually or by eye, which is why automated sorting and pre-processing for both mechanical and chemical recycling is needed. Simply, it's the missing link to enable fibre-to-fibre (F2F) recycling.

Circle-8 Textile Ecosystems, the company leading this work stream, was established to bridge the gap between today's linear post-consumer textiles (PCT) supply chain flows of materials and the future needs of F2F recyclers by turning NRTs into high-volume, high-quality feedstock for recycling by developing, owning, and operating ATSPs. Its ultimate aim is to operate the UK's first textile chemical recycling plant. Circle-8's role within this project was to initiate the design and development of an ATSP business model as part of an ecosystem of actors. The goal is to commission a 25,000 tonnes-per-year ATSP facility and create a standardised approach which is replicable by other ATSP operators and delivers for recyclers in a highly efficient and economical way. Beyond supplying chemical recycling, ATSP facilities would also be able to automatically sort for open-loop and mechanical recycling markets and sectors.

The facility design brings together multiple components and approaches to sorting and turning textiles into feedstock for recycling. This required a unique approach to connecting and building a commercial solution from existing market-ready solutions and technologies, often from other industries, to create the UK's first large-scale, fully automated ATSP.

Site selection and engineering design of an ATSP facility

Unlocking textiles circularity does not sit with a single company or a single part of the textiles supply chain. Instead, the whole industry needs to change its ambitions and ways of working together. Therefore, the ACT UK project provided a platform for collaborating with industry partners on multiple work packages relating to collection systems, manufacturing, and business case development while centring on the crucial missing link: the design and development of the UK's first industrial-scale ATSP focused solely on NRTs. By supporting this development phase, the ACT UK project seeks to de-risk the industry transition to automated sorting as a precursor to F2F recycling while bringing industry together to overcome key barriers through knowledge sharing and innovation.

The conceptual engineering design was developed during the ACT UK project, and the basic and detailed engineering will be completed during 2025. At this point, the full equipment order will be placed.

The research and work for this chapter was led by Circle-8, in collaboration with the Manufacturing Technology Centre (MTC) and UKFT. In April 2024, Circle-8 and TOMRA – a global technology leader in recycling solutions and the technology provider to the world's first fully-scaled automated textile sorting facility, SIPtex, in Malmo – announced a collaboration which included TOMRA carrying out a conceptual engineering design for a 25ktpa ATSP facility in parallel with but not part of the ACT UK project.

Additionally, Jones Lang LaSalle (JLL), a global commercial real estate services company, was also brought on board as a partner for the site search to utilise its expertise in analysing logistics networks, identifying suitable warehouse and distribution locations, and negotiating favourable lease terms.

Commercial confidentialities

It should be noted that the engineering design has been developed from assumptions about sourcing inputs, logistics, output products, etc, provided by Circle-8 that are commercially confidential. Equipment specifications, including lists of equipment (model, maker, cost), are also commercially confidential between the maker and the buyer. The conceptual engineering design developed by TOMRA, working closely with Circle-8, was undertaken with the intent of providing a foundation for developing future customised ATSP designs for other parties based on those parties' identified manufacturing and commercial objectives and as agreed commercially between interested parties and TOMRA.

The chapter starts by detailing the design and operational considerations for an ATSP facility in section 2. It explores the methodology behind the design, key operational factors such as inputs and outputs, and the engineering required to optimise the facility's capacity and performance. Section 3 then sets out the process of identifying, securing, and preparing a site for an ATSP facility. It outlines the methodology used for site selection – including defining requirements and evaluation criteria – and the subsequent market search, analysis, and negotiations that led to securing a preferred site.

The chapter closes with section 4, which outlines the key findings and recommendations, covering both design and site selection.



2. ATSP ENGINEERING AND OPERATIONS

This section explores the operational methodology, engineering design, capacity analysis, equipment requirements, and financial considerations for building a 25ktpa ATSP facility.

2.1. The ATSP facility

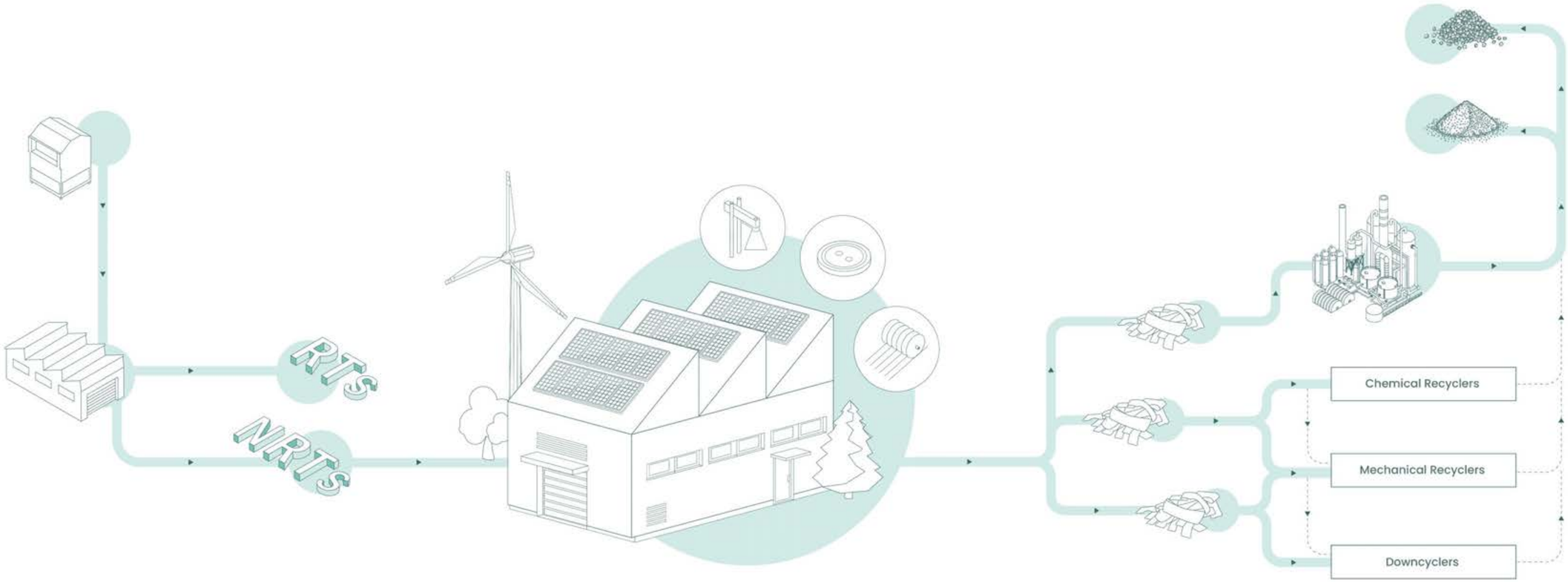


Figure 39: ATSP facility's place in the recycling ecosystem

Site selection and engineering design of an ATSP facility

An ATSP facility exists to sort and pre-process textiles into feedstock for recyclers, including mechanical and chemical processes. It can also produce feedstock for downcycling or open-loop markets.

The key ATSP processes and functionalities for both fibre-to-fibre and open-loop feedstock customer sectors include sorting, size reduction, and disruptor removal. Other steps and processes include:

- Unloading, de-baling, baling, and loading
- Conveyance equipment for materials transfer throughout the ATSP
- Limited work-in-progress inventory workspace, warehousing and management
- Product sample testing facility for quality control
- Chain of custody tracking as required

The project focused on an initial 25ktpa facility, with the aim of scaling up to 50ktpa as the mechanical and chemical recycling markets grow.

2.2. ATSP design methodology

Aim

- A 25ktonne per annum Automated Textiles sorting and Pre-Processing facility

Suppliers - Plant inputs

- Identify ATSP suppliers - post-consumer, pre-consumer, post-commercial etc
- Establish fibre characterisation for inputs
- Create scenarios created to understand processing required: form factor (whole garments vs linens, textile scraps etc), fibre compositions, level of disruptors, multi layers etc

Customers - Plant outputs

- Establish product specifications for existing and emerging fibre-to-fibre recycling companies and open-loop players
- Develop ATSP products based on customer sorting and pre-processing requirements

Design

- Design the process flow to handle the supply mix in terms of fibre compositions and end-markets identify products and markets which require pre-processing steps
- Use MTC capacity model and operations simulation model

Figure 40: ATSP engineering methodology

Site selection and engineering design of an ATSP facility

The conceptual design work – which creates the strategic foundation for turning a concept into reality – has been developed in parallel with and informed by market analysis to assess market growth potential, types of supply to the ATSP, products and volumes, and ATSP customer requirements.

This research set out to understand today's current collection and sorting business model, which was carried out in another ACT Project workstream, as well as in a separate feasibility study undertaken by Circle-8 and TOMRA Textiles, independent of the project. The research has been essential to inform key aspects of the facility and system design, helping to answer key design variable questions, such as:

- Type of equipment needed
- Price allowance of material inputs
- Processing cost barriers
- Market needs for a first industrial-scale ATSP

Fibre characterisation data from two reports was used as a reference for potential fibre compositions on incoming NRT volumes received into the ATSP[22]. A more detailed fibre composition formula was developed, combining assumptions around a certain percentage of inputs from post-consumer sources and post-commercial suppliers, the latter of which have less complicated fibre blend recipes.

An assessment of supplier types was made together with an analysis of the ramp-up phase for the ATSP, with an estimation of likely volumes per year. Once this was established, a supply approach was developed. This involved reaching out to potential suppliers to explore methods for NRT collection, handling, and logistics which might bring cost savings, efficiencies, and a standardised approach to incoming materials.

Product specifications for existing and emerging F2F recycling companies and processes, together with open-loop recycling companies (wipers, insulation, etc.), were established using existing resources, such as WRAP's Textiles Sorting and Recycling Database[23], Fashion for Good's Recycler Database[24], and research with potential buyers. Engineering design needed to be developed to ensure products from the ATSP meet customer pre-processing requirements.

Scenarios were developed to understand the implications of variations in incoming materials. There was a particular focus on exploring how they would be processed through automated sorting and entered into pre-processing steps, a stage which could vary significantly depending on end customers and markets. For example, when comparing post-consumer NRT with commercial or industrial NRT, the form factors of inputs (e.g. whole garments versus linens, textile scraps, etc.), fibre compositions, level of disruptors, and the existence of multi-layers were all variables which will affect system performance and costs.

Mathematical (capacity) and Discrete Event Simulation (operations) models were developed with the Modelling and Simulation team at MTC to evaluate equipment requirements to meet annual targets and assess the impacts of scaling up certain types and sources of materials, together with different operational parameters and flows of materials through the facility. This included analysing the feasibility of a pre-sort of rewearable textiles (RT) from NRT for all incoming materials and the order in which pre-processing steps are carried out.

The capacity model and analysis provided by MTC supported Circle-8 in understanding machine requirements and analysing key factors that would impact production. This was then explored further through an ATSP system modelled using MTC's Discrete Event Simulation (DES) modelling techniques. Key factors studied included:

- Garment source distribution
- Shift patterns
- Machine performance
- Sorting accuracy
- Yield loss
- Cleaning cycles
- Throughput targets
- Machine quantity

Using DES techniques, MTC supported Circle-8 by modelling various scenarios with different input combinations, including machine parameters, materials, and customer segments.

To evaluate equipment, multiple company visits were carried out, supported by a market overview study undertaken by MTC. These visits informed the ATSP conceptual design for bringing together fibre sorting technology, materials movement, and pre-processing steps under one roof.

Working iteratively with the TOMRA Textiles team, these methods were used to create a conceptual engineering design for a state-of-the-art ATSP facility with a capacity of 25,000ktpa. The design would be adaptable and incorporate continual improvements as technologies, equipment, and components continue to advance.

To commence the engineering design process, the first stage of the process was to agree on a specification sheet for the ATSP, which detailed:

- Plant inputs, which is explored in section 2.3.1
- ATSP products, which is explored in section 2.3.2
- Plant concept, which is explored in section 2.3.3
- Plant capacity and operations, which is explored in section 2.3.4

2.3. Operations and engineering design

2.3.1. Plant inputs

To agree on a specification sheet for the design, a significant amount of supply relationships development and design process modelling was required. This work was necessary to understand the types of materials likely to be received by the ATSP during its first one to three years of operation, ensuring alignment with the ATSP ramp-up and the arrival of commercial-scale chemical recycling.

The modelling would also determine whether a specific supply strategy for inputs was needed to support the most efficient and cost-effective design approach. Understanding the markets these materials would be selling into – open-loop, mechanical, and chemical recycling – was also relevant to the sourcing strategy and, consequently, the facility design.

To build the modelling, key questions were asked, including:

- What will the key fibre compositions – including mono fibre and blends – of incoming materials be, and in what proportions/percentages?
- What type of materials would be supplied to the ATSP, e.g. post-consumer/pre-consumer/post-commercial, with or without multi-layers, post-commercial?
- Will the ATSP offer to take mixed re-useable textiles (RT) together with NRTs, which would require a pre-sort line with manual labour, a greater footprint, and a sales team for the RT?
- What form factor and sizes will materials be in, and how would they arrive at the ATSP – whole garments, non-apparel textiles (e.g. sheets, pillowcases, curtains, fabric scraps, etc)? Would individual garments still be in packaging, have hang tags, or be on hangers?
- How would materials be received? In plastic bags, bales, etc?
- What kind of vehicles are delivering inputs? Vans, flatbed lorries, articulated trucks?

After answering questions such as these, analysing the cost implications of different material inputs on facility design, and consulting with potential suppliers, Circle-8 developed an ATSP Supply Specification Guide for materials inputs. This guide informed the equipment specification required at the facility's receiving end (for further reading about the guide, please see 'Appendix 1: Supply Specification Guide' in the Appendix).

Storage areas for the materials and the inbound delivery characteristics are also integral to the facility design. Therefore, key questions were asked to address these variables, including:

- What volumes of materials will arrive daily, and at what times?
- How will the materials be stored before entering the sorting process?
- At what stage does the quality check of inputs get carried out?
- What's the running time of processing one tonne of throughput?
- What's the availability of the processing plant (shutdowns, breaks, shift changes, etc.)?

After answering these questions, functional areas with specific space requirements could be identified and integrated into the facility design, including:

- An unloading zone and/or number of tipping points
- Traffic area for delivery vehicles
- Storage areas
- Installation area for loading unit with working radius
- Collision-free circulation areas for mobile chargers so that a continuous system is possible.
- Movement areas of vehicles with driving templates

2.3.2. ATSP products

ATSP products – or finished goods – are the output which is sold to customers. The main customer segments for the ATSP and the predominant fibre types (and blends) customers demand are:

Closed-loop: Non-reusable clothing and apparel transformed into feedstock for recycling into materials (fibre, polymer, etc.) used in making new clothing and apparel. This is for:

- Mechanical recyclers (wool, cotton, polyester, poly/cotton, higher-cotton/poly, and higher-poly/cotton)
- Chemical recyclers (cotton, polyester, and poly/cotton)

Open-loop: Non-reusable clothing and apparel transformed into feedstock for recycling into materials to make non-apparel products, such as:

- Higher-value open-loop products, which generally have more demanding specifications in terms of textile type composition, consistency, and performance qualities (thermal, soundproofing, waterproofing, tenacity, durability, comfort, etc.)
- Lower-value open-loop products (lower performance, lower purity, disposable, etc.), such as disposable industrial rags

Particular combinations of these variables yield key product composite attributes. Specifically, input supply volumes from the market, textile performance characteristics, appearance, aesthetic values, and sensory appeal attributes all contribute to a given product's market demand and, when considering available competing substitutes, its market value.

2.3.3. Plant concept

Working from the range of ATSP products and corresponding potential markets, a profile of each product's required processing, inputs, and production restrictions can be developed. These profiles also consider how the volumes and specifications may change during a ramp-up as the ATSP reaches full capacity.

The profiles are used to create a plant concept, which is the overall design and organisation of a production facility. It encompasses layout, processes, technologies, and infrastructure and aims to optimise efficiency, flexibility, and cost-effectiveness.

ATSP products are manufactured according to a number of variables, including:

- Form factor (whole garments or pre-processed into preferred shapes, thicknesses, etc.) via size reduction or other mechanical processing
- Fibre compositions
- Preferred size of textile pieces or swatches produced from NRT
- Disruptor removal requirements
- Colour sorting
- Construction of the inputs (woven, knits, felts, etc.)

The preferred sequencing for each product aims to achieve higher yields and greater quality in an efficient and effective manner that limits the downtime of processing flows and avoids the risks of cross-contamination between product streams. Alternative processing technologies, such as guillotines, shredding, cutters, and rotative cutters for size reduction, are compared for their production throughput for:

- Flexibility
- Consistency
- Wastage
- Energy and other resource consumption
- Maintenance
- Production labour requirements
- Downtime
- Consumables

Comparative product profitability is assessed based on the cost of goods sold, using cost allocations where necessary, input costs, and market pricing. This analysis is extended over the ATSP's ramp-up period into a steady-state phase in which customer demand across product segments may shift and then, possibly, stabilise. This provides snapshots of the optimum mix of production profiles over time, which may, in turn, influence design and layout.

Other plant concept aspects relating to customer segments to consider include:

- Estimation of the main product flows according to type, quantity, and volume
- Dimensioning of product transfers and product transport
- Design of press systems required for the packaging of products
- Dimensioning of product warehouses according to type, area, and volume

Considering process flows and relevant variables, a facility logic was developed to ensure design, layout, and technology integration are adaptable to evolving customer segments.

The engineering design of ATSP products must be closely aligned with the commercial model to meet customer requirements, ensure optimal pricing, and adapt to market changes throughout the initial and steady-state years.

2.3.4. Plant capacity and operations

Plant operations, which can be defined as transforming input materials into finished products, are central to the conceptual engineering design. To understand and establish the components of plant operations that would shape the design, a range of variables were brought together to be modelled and analysed, from production planning, quality control, and maintenance to safety, troubleshooting, and process/design improvements.

These analyses were undertaken by MTC, building and applying the two aforementioned analytical models of an ATSP: a capacity model and a DES model.

For both models, MTC consulted with Circle-8 on practical aspects and limitations of various facets enumerated in sections 2.3.1 to 2.3.3, which Circle-8 considered as part of the development of an ATSP conceptual design. Where possible and relevant, Circle-8 drew on prior experience with commercial recycling facility operations serving both the textile and other recycling sectors.

At the same time, Circle-8 and MTC worked closely to ensure that the key inputs, model logic, and assumptions used in the capacity and DES models were sufficient to effectively model the conceptual system and enable the model's analytical capabilities and insights while safeguarding commercial sensitivities.

Therefore, the analyses and results outlined further below, including but not limited to system throughput, electricity consumption, operating expenses, capacity utilisation, etc., should not be attributed to the likely performance or economics of an ATSP facility that Circle-8 intends to build and operate. Rather, Circle-8 and MTC focused on modelling a "generic" ATSP system to avoid infringing any commercial sensitivities. The modelling work was then demonstrated with an industrially relevant use case, enabling impact to be retained due to the modelling work being demonstrated with an industrially relevant use case.

ATSP Process flow

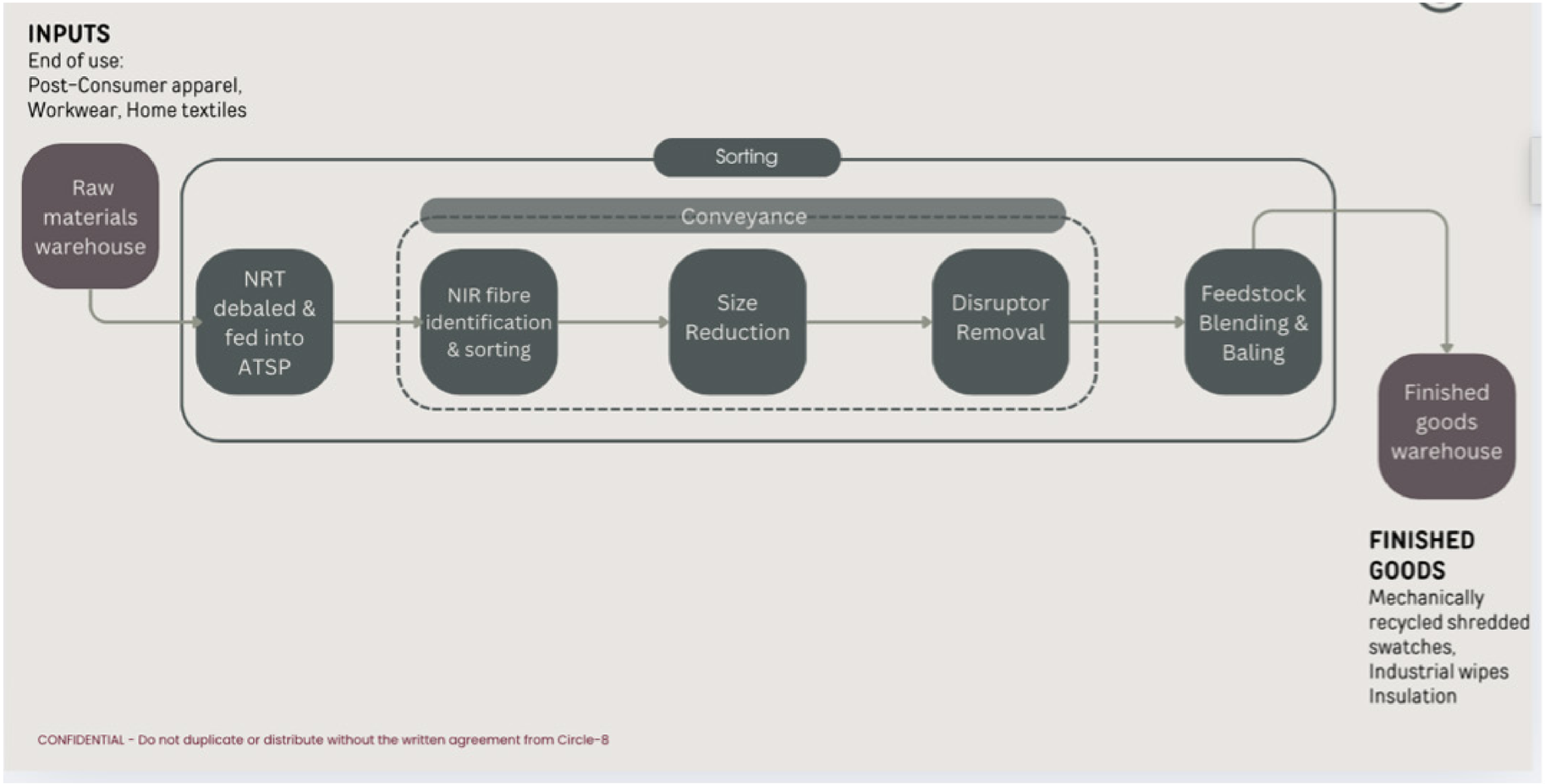


Figure 41: Overview of ATSP operations

Capacity study analysis

Notable acronyms and terms:

Acronym/term	Definition
Sorter Type 1	A sorting set-up that uses Near InfraRed spectroscopy to sort input material by textile composition
Sorter Type 2	A sorting set-up that sorts input material by textile composition and colour
B2B	Business-to-business
Baler	A machine that performs a baling process with a given input material
BQ-P-1	Business question 1
BQ-S-2	Business question 2
BQ-S-3	Business question 3
Size Reduction 1	A machine that reduces the size of input material to a chemical recycling specification
Size Reduction 2	A machine that reduces the size of input material to a mechanical recycling specification
Size Reduction 3	Shorthand for machine that reduces the size of input material
LabQC	A machine that performs quality inspections/control of a given input material

Scope of work

The capacity model, developed by MTC, was used to inform the design of the ATSP being developed for ACT. However, the data captured in the report was made generic due to commercial sensitivities. Key factors were assumed to significantly impact throughput and equipment quantities; therefore, the analysis, provided by MTC, explores the effect of changing:

- Yearly throughput targets
- Shift patterns
- Sourcing ratios
- Number of output bins in the Sorter Type 1 machine

The aim was to evaluate the equipment requirements to meet annual feedstock throughput targets in the proposed ATSP facility, excluding yield loss and sorting accuracy. Please note that the work completed in this project was indicative of a generic ATSP facility, with the purpose of demonstrating the modelling methodology used. However, business decision-making (i.e., machine procurement strategies) of a similar facility must be evaluated on a case-by-case basis.

Business questions and analysis

Analysis projects are driven at the highest level by a 'business question', which should inform both the insight required from the analysis and the approach taken. For a given business need, there can be a primary and several secondary business questions. A business question is a question, decision, or concern that a business or organisation seeks to resolve or address[25].

For the capacity study analysis performed by MTC, three key, primary business questions were considered for the capacity analysis, which are captured below with the analysis.

Question 1: How many machines are required to meet yearly feedstock throughput targets with specific sourcing strategies in the proposed ATSP facility?

In all scenarios studied, it appeared that the Sorter Type 2 machine is the machine type which requires the highest number of units to reach the throughput target because it has the slowest processing time.

In all scenarios modelled, no more than one unit appeared to be required for the following machine types:

- The Size Reduction 2 machine, which reduces the NRT material ready for mechanical recycling
- The Baler machine to compress the processed NRT material for handling and shipping
- The LabQC machine (quality inspection/control) for processing the NRT material

It appeared that the number of units required is sensitive to an increase in target throughput for the machine types seen in Figure 42. The Sorter Type 2 and Size Reduction 3 machines appear to be the most sensitive to this increase, showing the greatest change in quantity required when the target was increased.

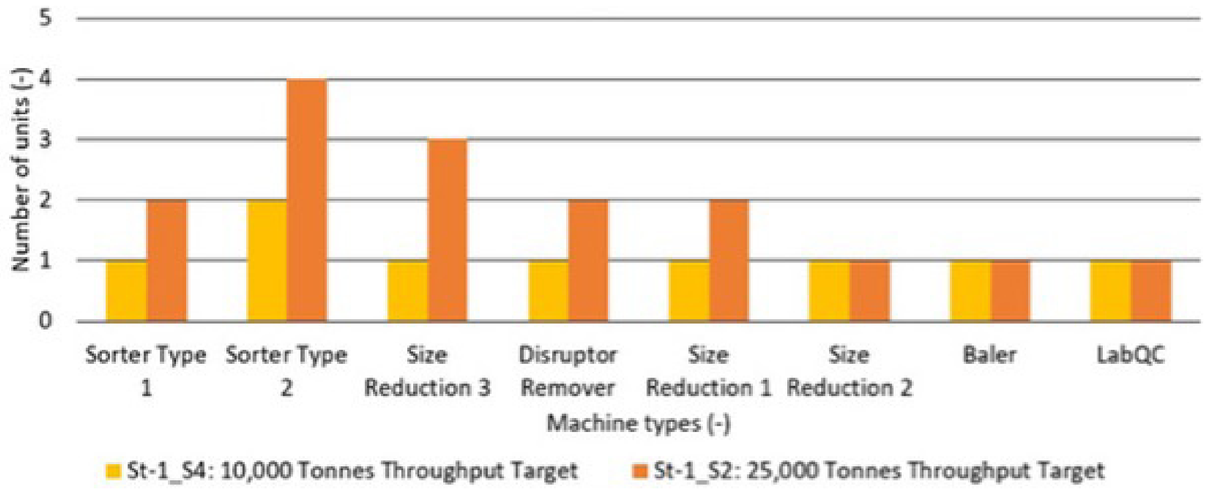


Figure 42: Effect of target throughput increase to number of units per machine type

Similarly, the number of units required seems to be sensitive to the input material proportion. The Sorter Type 2 and Size Reduction 1 machines appeared to be the most sensitive to a difference in input material proportion, as seen in Figure 43.

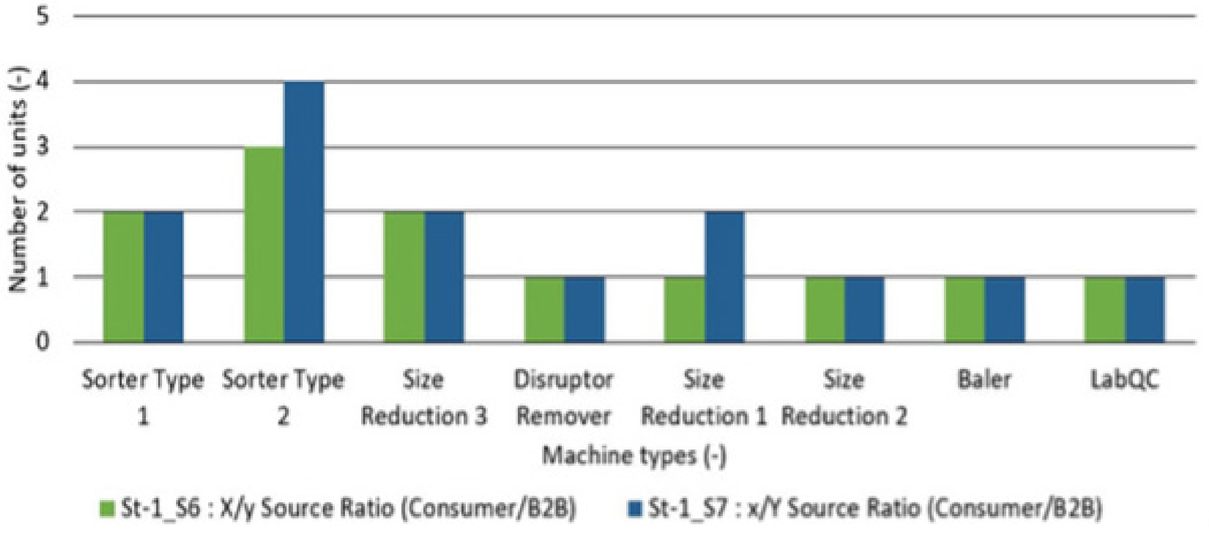


Figure 43: Effect of B2B ratio increase to number of units per machine type



Scenario-specific inputs:

Scenario	Shift pattern	Number of bins on Sorter Type 1	Source ratio (Consumer / B2B)	Throughput target
St-1_S2 and St-1_S4	3	N	x% / Y%	As seen in Figure 42
St-1_S6 and St-1_S7	2	N	X% / y%	14,400 tonnes

Question 2: How much energy is needed to run the machines in the proposed ATSP facility on a yearly basis?

In all the scenarios studied, the Sorter Type 2 machine type appeared to be the highest electricity consumer, contributing the most to electricity costs. Conversely, the LabQC machine type appeared to be the lowest electricity consumer, likely because it is only used on an intermittent basis, making it the lowest contributor to electricity costs. Additionally, when target throughput increases, all machine types increase their electricity consumption, as shown in Figure 44.

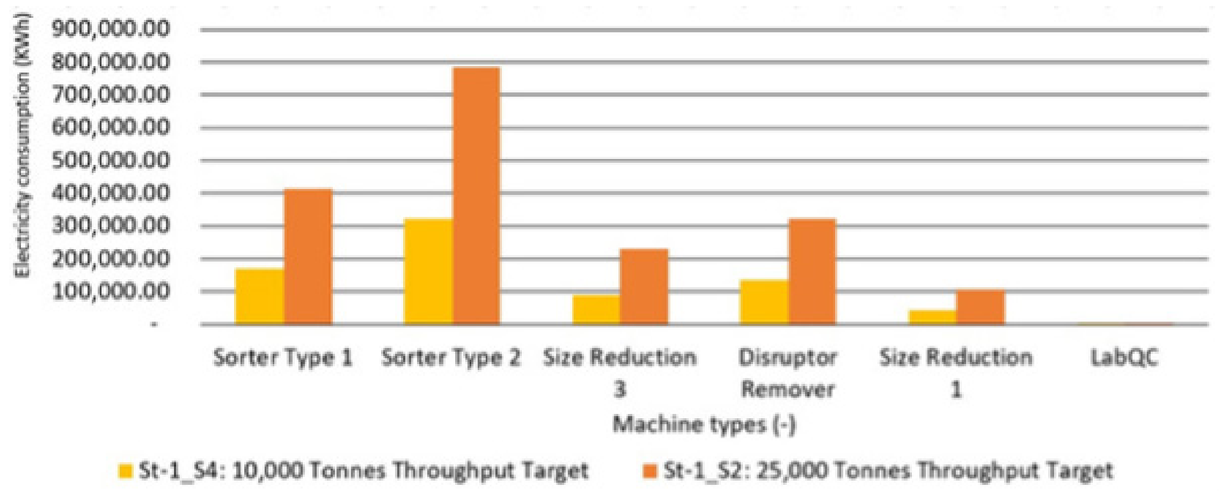


Figure 44: Effect of target throughput increase to machine electricity consumption

When the proportion of B2B input material increases, it appears that the following machine types increase their electricity consumption (as seen in Figure 45):

- Sorter Type 2 machine
- Size Reduction 1 machine

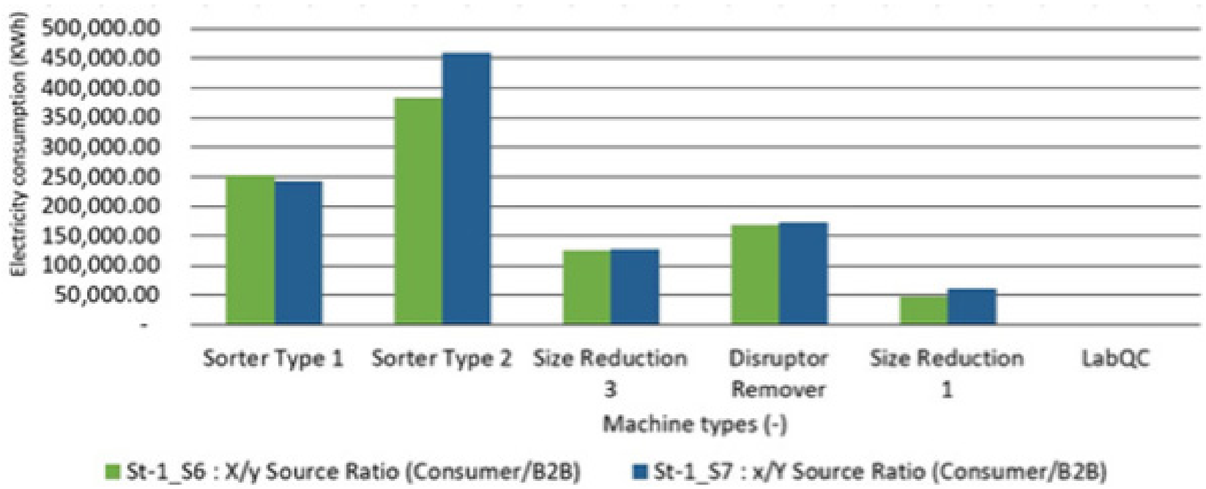


Figure 45: Effect of B2B ratio increase to machine electricity consumption

Scenario-specific inputs:

Scenario	Shift pattern	Number of bins on Sorter Type 1	Source ratio (Consumer / B2B)	Throughput target
St-1_S2 and St-1_S4	3	N	x% / Y%	As seen in Figure 41
St-1_S6 and St-1_S7	2	N	X% / y%	14,400 tonnes

Question 3: What is the working utilisation of the machines in the proposed ATSP facility on a yearly basis?

All utilisation outputs are based on an Overall Equipment Effectiveness (OEE) of 95%, which was factored into the analysis. In all scenarios studied, the LabQC machine appeared to be the machine type with the lowest working utilisation because it is only used intermittently.

When throughput increases, it appeared that all machine types increase their average working utilisation, as shown in Figure 46. The exception is the Size Reduction 3 machine, which has a lower average utilisation, indicating that the increased number of machines created a surplus of capacity.

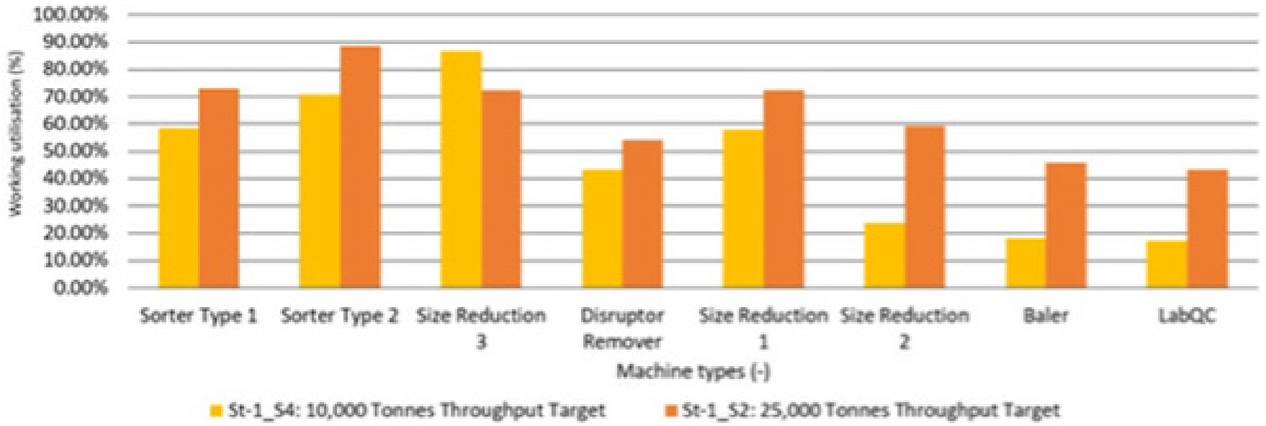


Figure 46: Effect of target throughput increase to machine working utilisation

When the proportion of B2B material increases, the Sorter Type 2 machine and the Size Reduction 1 machine appeared to increase their average working utilisation, as seen in Figure 47. Furthermore, the increase in the number of Sorter Type 2 and Size Reduction 1 machines appeared to create a surplus of capacity.

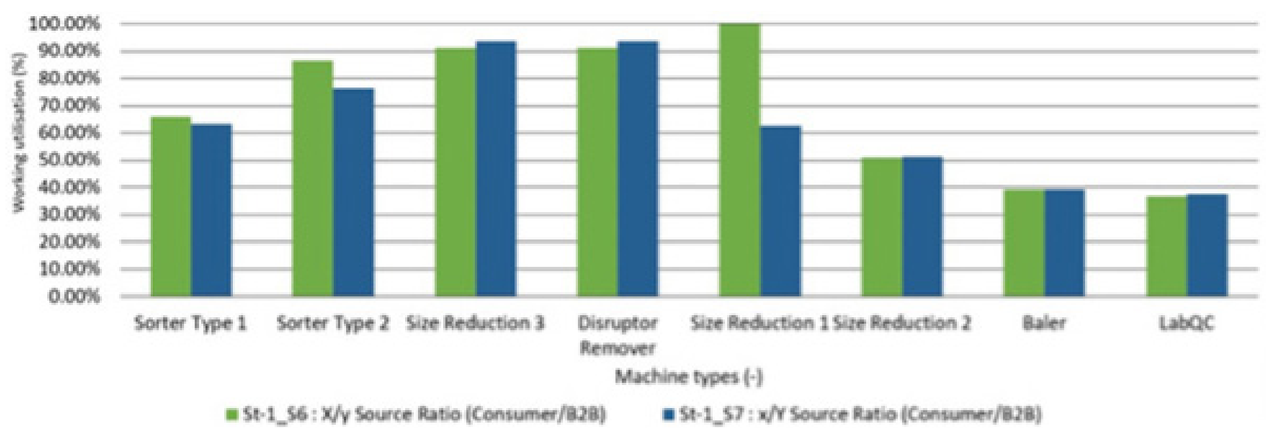


Figure 47: Effect of B2B ratio increase to machine working utilisation

Scenario-specific inputs:

Scenario	Shift pattern	Number of bins on Sorter Type 1	Source ratio (Consumer / B2B)	Throughput target
St-1_S2 and St-1_S4	3	N	x% / Y%	As seen in Figure 43
St-1_S6 and St-1_S7	2	N	X% / y%	14,400 tonnes

By addressing the three business questions, the capacity study indicated that:

- The number of units required for specific machine types increased as target throughput increased, which is an expected behaviour
- Electricity consumption behaves as expected, as consumption increased when the number of units increased
- When additional units were added to a machine type, a surplus of capacity was created for certain machine types, but not all. This indicates that more units may be required for certain machine types if spare capacity is required

However, the analysis did not manage to conclusively demonstrate the effect of different shift patterns and the number of bins in the Sorter Type 1 machine, as the effect of these factors could not be isolated during the capacity study.

Capacity study recommendations

Based on the analysis within the capacity study, MTC provided the following recommendations:

Recommendation: The number of units estimated within the capacity study should be used as a starting point for the upcoming (now complete) DES study.

Recommendation: Modelling efforts in the DES study should focus on the following assets, as they appeared to have the highest sensitivity to the factors studied:
- Sorter Type 1 machine
- Sorter Type 2 machine
- Size Reduction 3 machine
- Disruptor remover
- Size Reduction 1 machine

Recommendation: Simplifications may be suitable for the following machine types to help with simulation run time:
- Size Reduction 2 machine
- Baling machine
- LabQC machine

Recommendation: Use the lessons learnt and insights gained from the capacity study to demonstrate MTC's research approach, which is typical of Collaborative Research & Development projects.

Please note that the scope of work, assumptions, and input data are available from MTC.

ATSP discrete event simulation study

Background:
MTC designed a DES model, representing a generic ATSP system, to conduct analysis to understand the key factors impacting a generic ATSP system. This generic system approach was employed due to the sensitivity of Circle-8 data and commercial interest at the time of the project.

This DES model was designed and operated with consideration of various key factors which are assumed to significantly impact the production throughput of an ATSP system and, therefore, this analysis explores the effect of:

- Garment source distribution
- Shift pattern
- Machine profiles
- Accuracy and yield loss
- Machine cleaning time
- Throughput target

Similarly to the capacity study, the work completed in this project was indicative of a generic ATSP facility, with the purpose of demonstrating the modelling methodology used. However, business decision-making (e.g., machine procurement strategies) of a similar facility must be evaluated on a case-by-case basis.

Project aims:
- Analyse a generic ATSP system to understand the impact of key drivers on the system process and performance
- Demonstrate how modelling techniques can be utilised to analyse facility systems within the textile industry
- Highlight how MTC approaches this type of project as a typical example of their Collaborative Research & Development projects

Business questions:
The business questions relevant to, and guiding the approach of, the analysis of a generic ATSP system are:

Primary question:
- How sensitive are the system parameters on an ATSP system performance?

Secondary questions:
- What is the working utilisation of the machines for an ATSP system on a yearly basis?
- How much energy is needed to run the machines for an ATSP system on a yearly basis?
- What is the impact of machine cleaning time for the non-sorting machines?
- What is the maximum throughput that can be achieved with the proposed ATSP system?
- How many machines are required to meet yearly feedstock throughput targets for an ATSP system?

Methodology:
When planning, designing, and analysing a model, MTC employs a particular methodology during projects. A top-level summary of this methodology is included below:

Problem definition:
- Understand the business questions that would drive the analysis conducted
- Understand and recreate the system representation for a sorting process with help from project partners, especially Circle-8

Solution definition:
- Set the scope of modelling requirements
- Details of the model build
- Design and validation of modelling logic and system process

Analysis design:
- Identify studies focusing on specific areas to analyse
- Define a set of scenarios to run within each study

Solution build and validation:
- Modelling process and continuous validation of model
- Final testing to ensure the model is representative and delivers against requirements

Analysis:
- Determine the impact of changes to system performance and behaviour
- Complete sensitivity analysis to determine the most impactful factors
- Assess system performance against target KPIs (e.g. throughput)

Site selection and engineering design of an ATSP facility

Project approach: Model description:

- A baseline configuration consisting of a sorting and a non-sorting line was set to represent a generic ATSP facility
- The sorting line has four sorting locations in parallel
- The non-sorting line has two baler locations, two size-reduction locations, three disruptor removal locations, and one quality control location
- The system represents the flow of mixed materials and the relationship between the sorting and non-sorting processes that transform input material (i.e. recycled clothing) into output product (i.e. feedstock for new clothing) at the generic facility

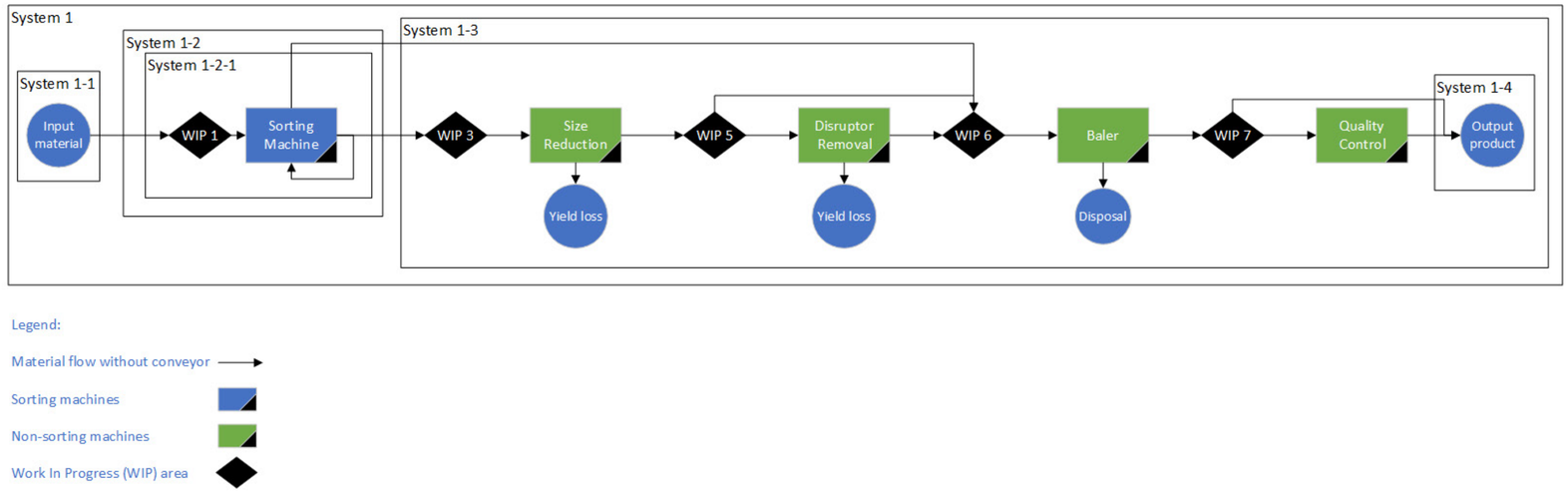
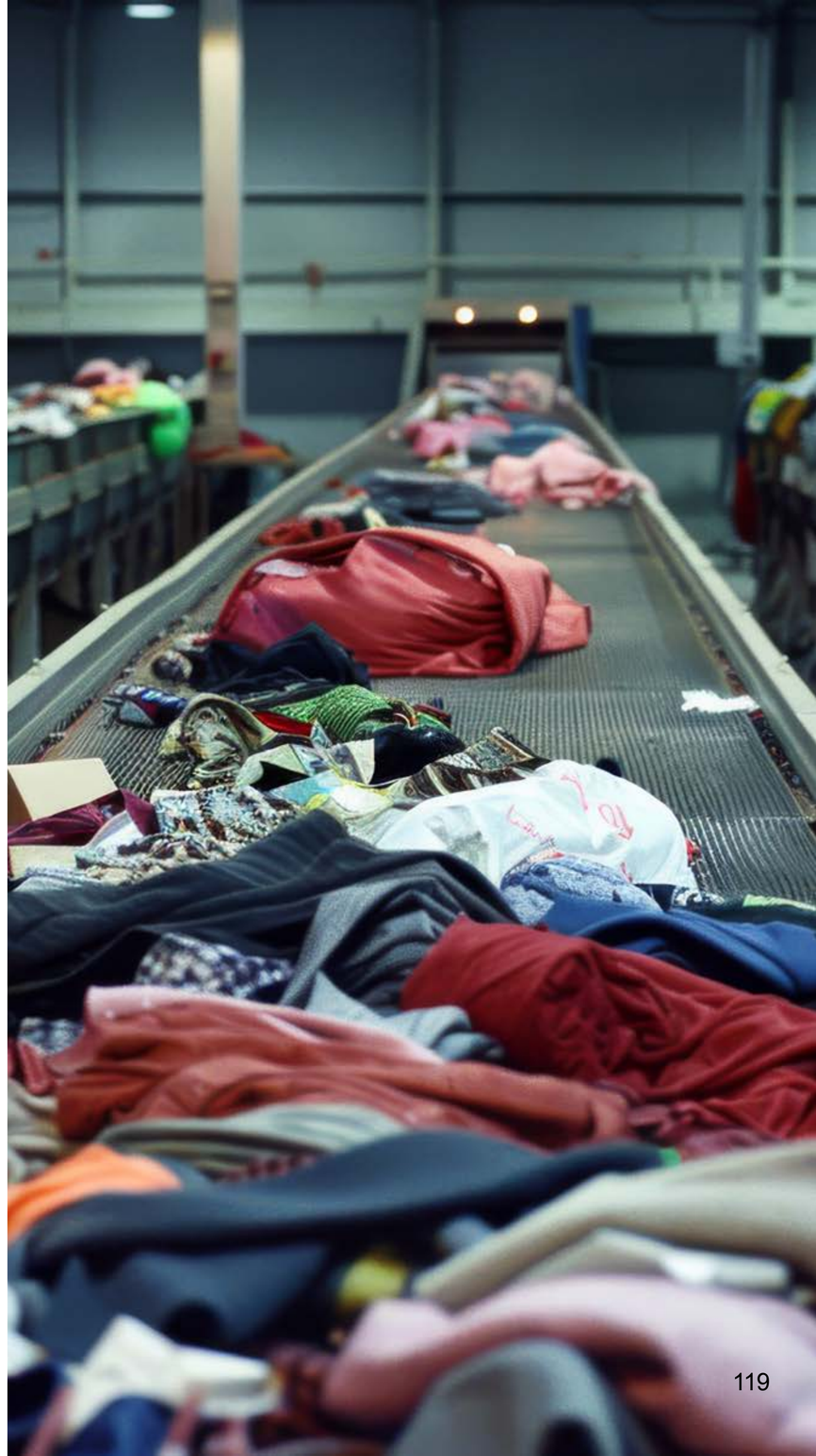


Figure 48: The 2D layout and flow of the generic system





Terminology	Definition
Yield Loss	The amount of material that is lost when it is processed by a machine
Sorting Accuracy	How accurate a machine is in sorting different material types correctly
Loss-To-Yield Ratio	Ratio between how much material was lost and how much was created into a final product
Product Purity	The percentage describing how pure a product is (100% purity means that no incorrect material was used to create the product)
Throughput	Amount of product created within a specified period of time
Cleaning Cycle Time	The amount of time required to clean a machine before it processes a material of a different type
Utilisation	The amount of time that a machine spends in a specific state
Energy Consumption	How much electricity has been used by a machine
Garment Source Distribution	Distribution of the input tonnage by source type (i.e., what percentage is from a consumer source)

Project approach: Analysis studies

The following studies were undertaken:

Study 1: Baseline capacity ROM equipment sensitivity
This was not a study run for this work package but a preliminary study using the mathematical modelling capacity model used in a previous work package. This is not a study from the DES model and is present for reference purposes only.

Study 2: Baseline DES ATSP system
A study to observe the production impact of a generic ATSP model when setting the garment source distribution, working time, system performance, process timings, and throughput target.

Study 3: Input garment distribution
A study to quantify the impact on system production when inputting different garment source distributions.

Study 4: Production working time
A study to quantify the impact on system production when changing the working time of the system by varying shift patterns.

Study 5: Machine profiles
A study to quantify the impact on system production when using a different machine profile with differing cycle times.

Study 6: Machine sorting accuracy and yield loss
A study to quantify the impact on system production when incorporating sorting accuracy and yield loss of some of the system machines.

Study 7: Cleaning process strategy
A study to quantify the impact on system production when varying machine cleaning times.

Study 8: Production throughput
A study to quantify the impact on maximum production throughput when removing system constraints.

Each of the above studies ran several scenarios to highlight the impact of system changes on overall performance. It is worth noting that study labels will follow the naming convention of “Study X.Y”, where X is the study number and Y is a sub-study looking at a particular configuration as part of the wider analysis for study X (shortened to St-X.Y).



Analysis of study 2: ATSP system performance

Baseline system performance:

- Fails to meet the throughput target of 12,500 tonnes per year and has a 14% yield loss (Figure 49)
- Has a total energy consumption of 635,934 kWh per year
- Equivalent cost of £146,265.00 per year
- Impurities vary widely across product types, ranging from 52% for the mechanical recycling (MechRE_100%) to 83% for incineration
- Two eight-hour shifts do not provide enough time to process the volume of material and meet the target throughput with the current system set-up
- The total cleaning time is equivalent to 14,471 hours or 603 days

Key findings:

- A large proportion of time is spent cleaning non-sorting machines, creating a bottleneck that cascades upstream (Figure 50)
- Baler machines contribute the most to sorting machines being underutilised (30%) because they have the highest percentage of cleaning activity

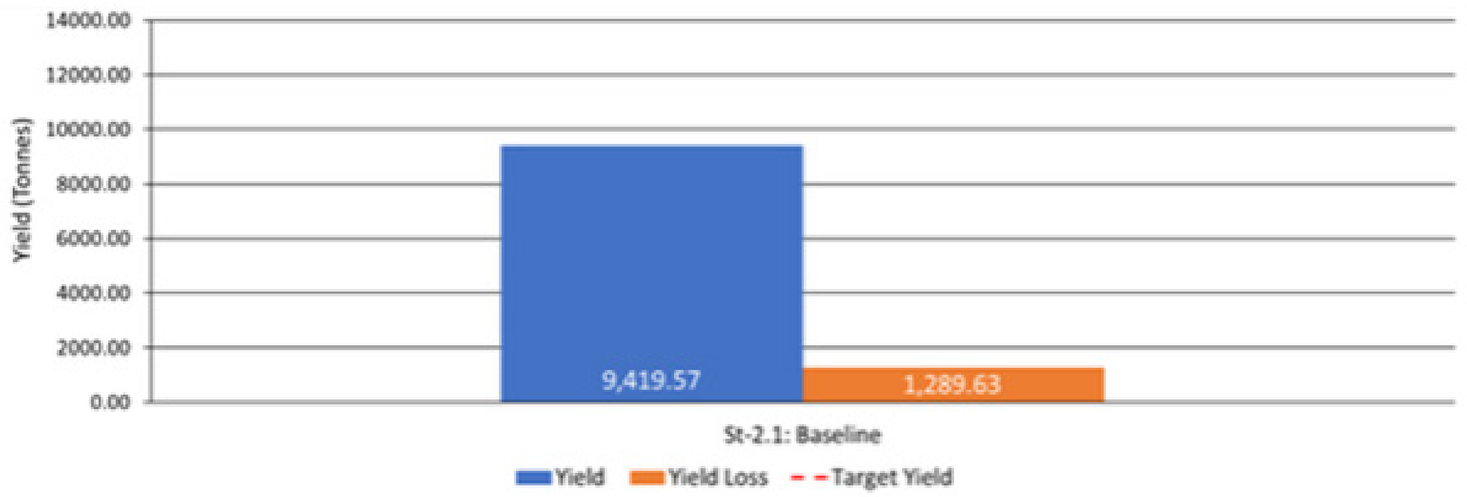


Figure 49: System yield profile for the baseline (S2.1)

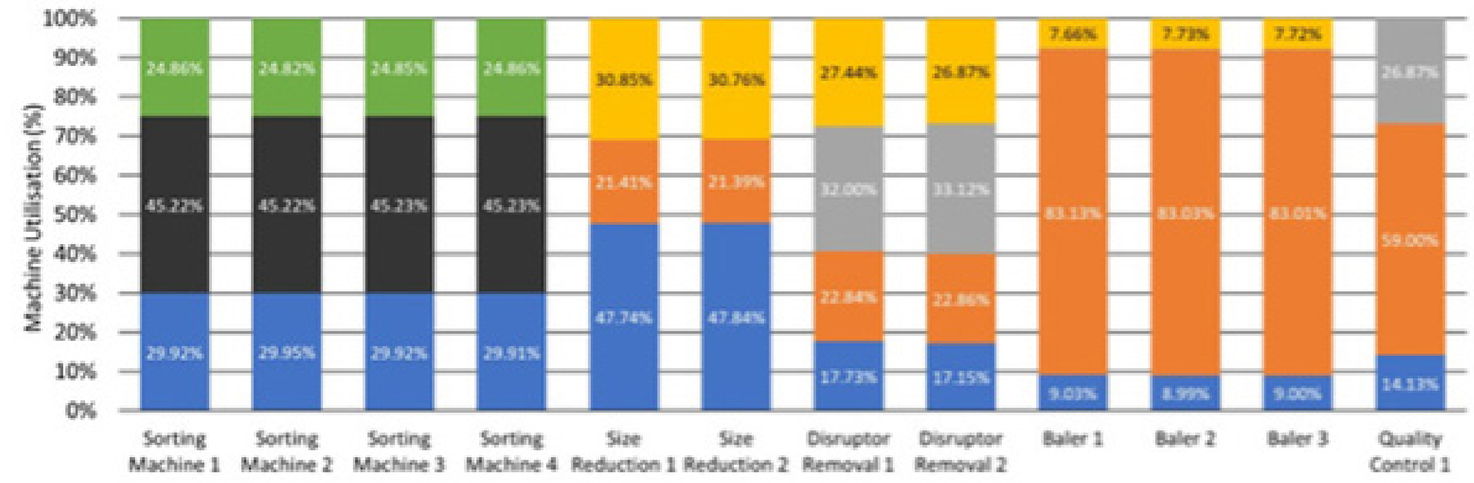


Figure 50: Individual machine utilisation profiles for the baseline (S2.1)

Analysis of study 3: Input garment distribution

The change in garment source distribution for the system made the following changes from baseline:

- The change in garment mix had no significant impact on performance (product yield) although the routing of garments differ
  - St-3.1 showed an insignificantly higher working, cleaning, and waiting time, with lower blockage time
  - St-3.2 showed an insignificantly lower working and cleaning time, with higher blockage and waiting time

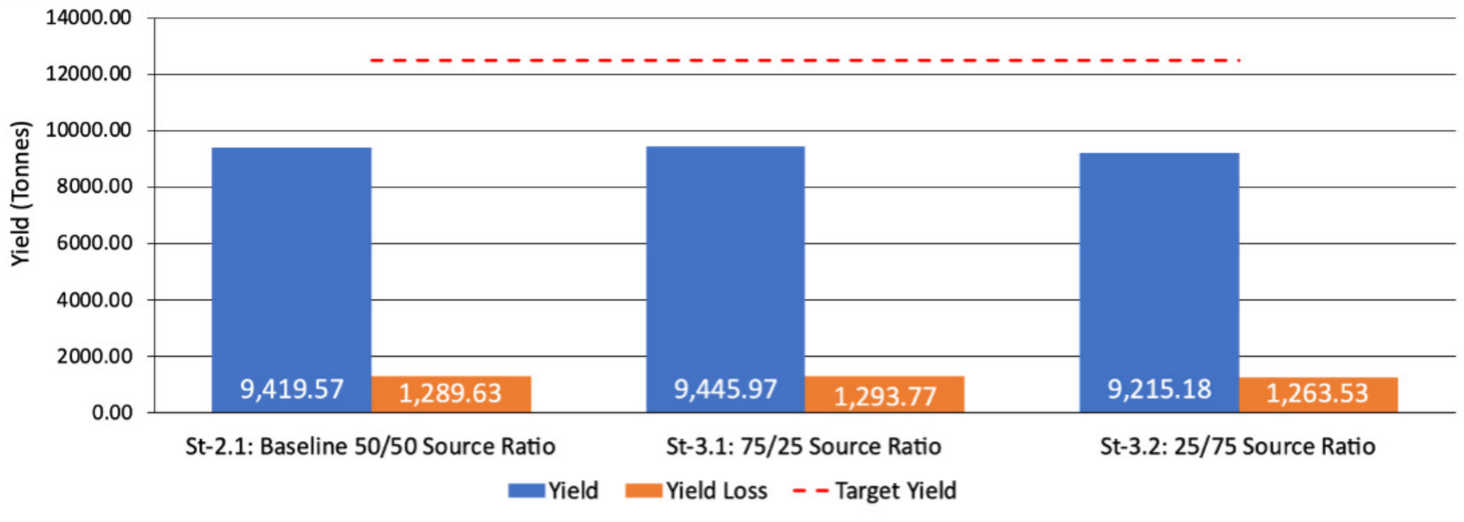


Figure 51: System yield profile for the baseline (S3.1 and S3.2)

Key findings:

- The issues with the bottleneck and performance against the target are not resolved with a different garment source distribution.



Analysis of study 4: Production working time

The change in working time for the system made the following changes from baseline:

St-4.1:

- Decreasing to one shift from two caused the total cost, cleaning time, and annual energy consumption to drop by ~50% (£73,911.74; 7289.58 hours; 321,355kWh)

St-4.2:

- Increasing to three shifts from two caused the total cost, cleaning time, and annual energy consumption to rise by ~33% to target throughput (£48,899.65; 4775.77 hours; 212,607kWh)
- The production target is met with three shifts (Figure 52), with the potential total production exceeding the target throughput

Key findings:

- The increase in shift hours per day is directly related to the increase in production throughput
- The increase in cleaning time observed when adding shifts is due to the system working longer and, therefore, requiring more cleaning processes
- The bottleneck issue caused by machine cleaning cycles was not resolved by varying shifts

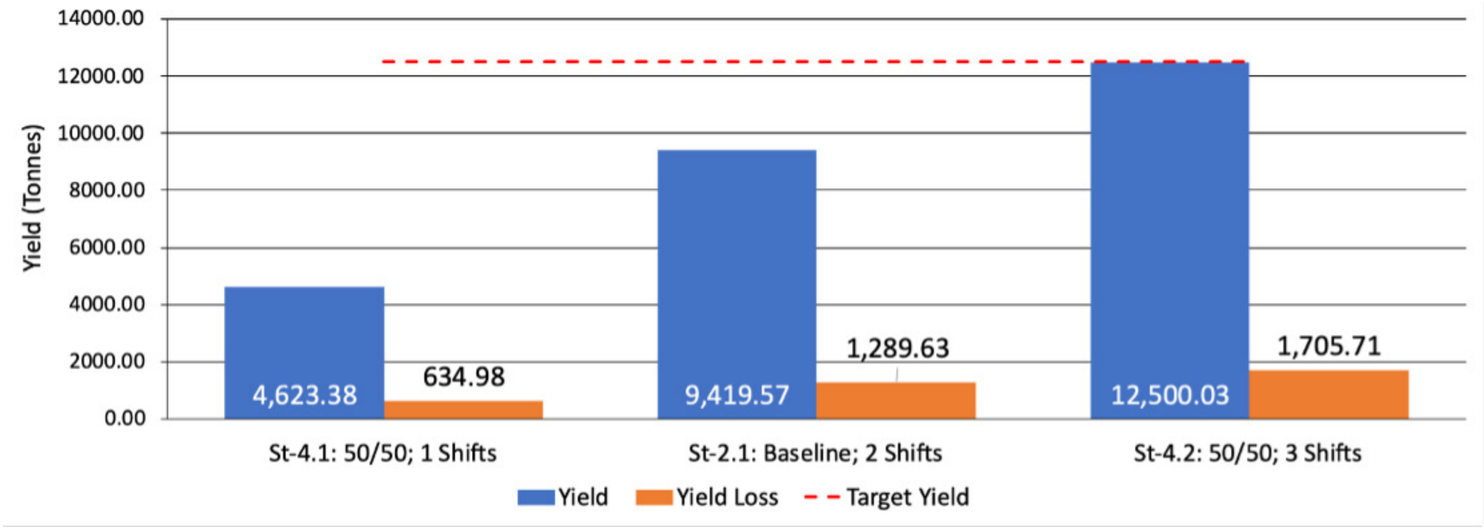


Figure 52: System yield profile for S4.1 and S4.2 compared to baseline

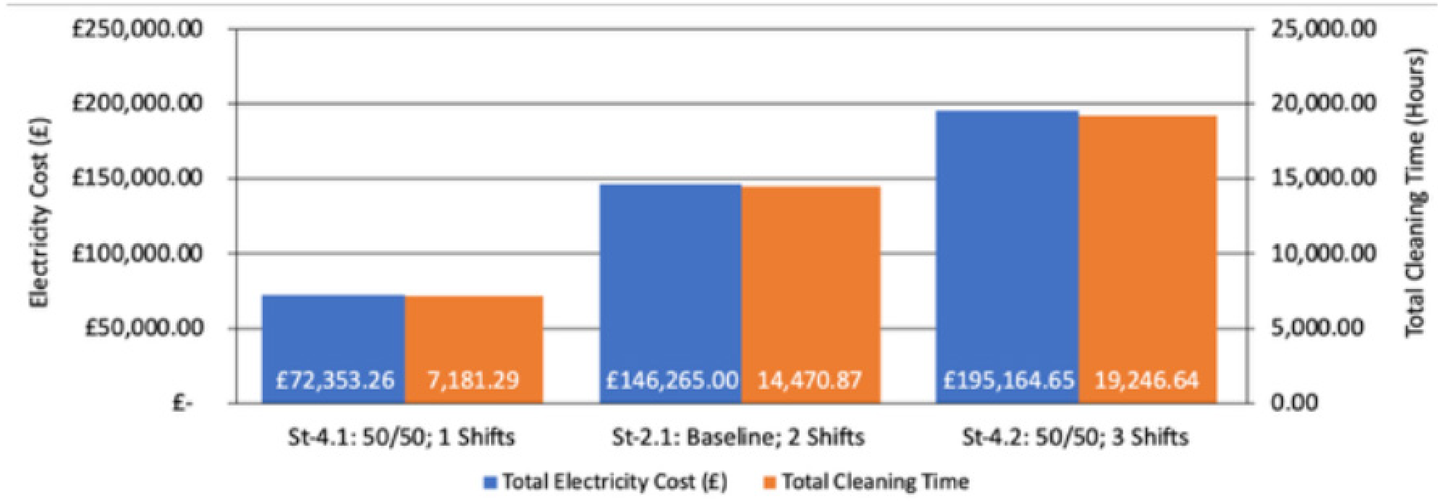


Figure 53: Total electricity cost and cleaning time for S4.1 & S4.2 compared to baseline

Analysis of study 5: Machine profiles

The change in the machine profile (machine profile X to Y) for the system made the following changes from the baseline:

St-5.2 (directly comparable to baseline):

- Yield only increased by 3.93% compared to the baseline (Figure 54), with a 10% yield loss (baseline 14%)
- Product purity for all product types, except incineration, increased by ~3% (Figure 55)
- Total energy consumption and cost per year increased by ~21% (133,375kWh; £30,676)
- The new machine profile reduced working utilisation for all machines

Key findings:

- An improved machine profile Y alone is not sufficient to resolve issues with the bottleneck and performance against the target
- Any differences in yield loss, product purity, energy consumption (yearly cost), and utilisation are solely due to improved machine profile Y performance

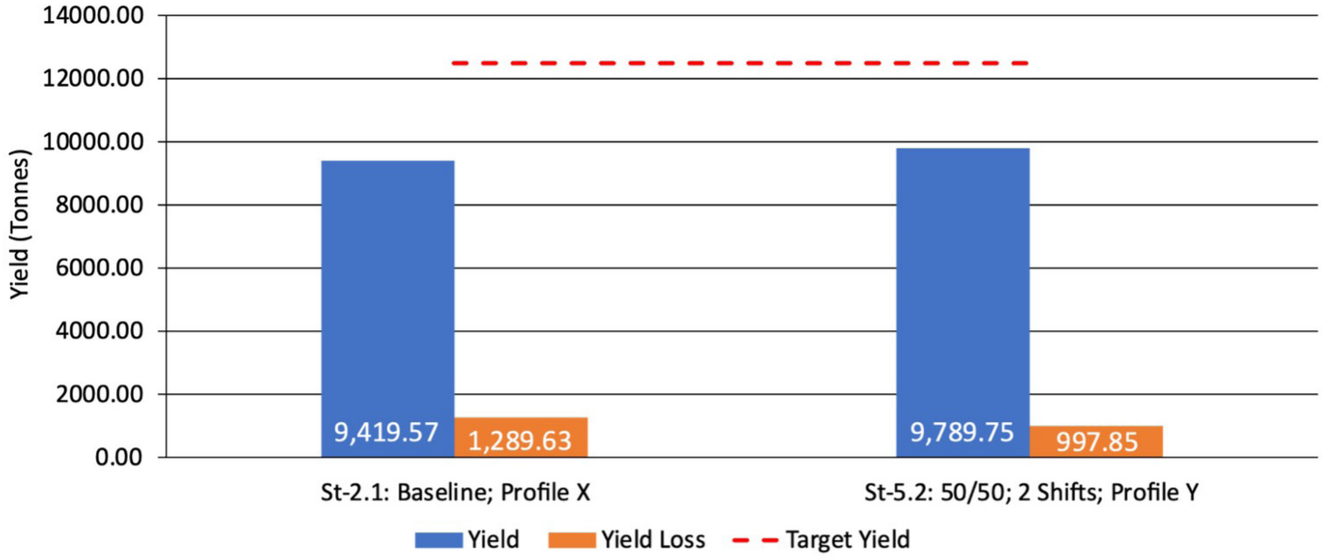


Figure 54: System yield profile for St-5.2 compared to baseline

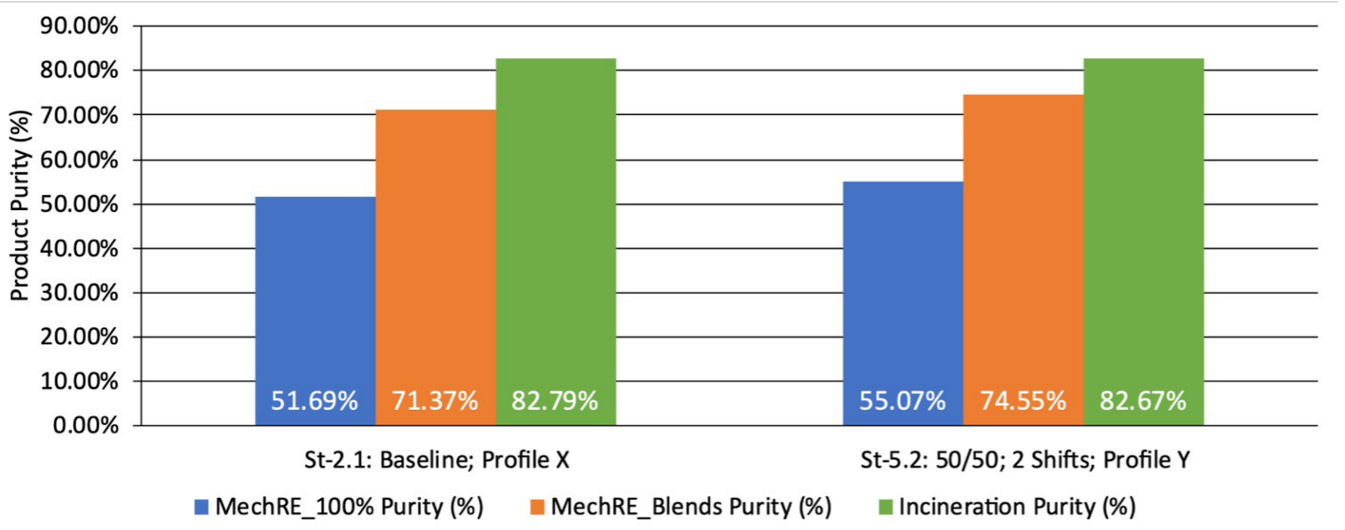


Figure 55: Product purity profile for S5.2 (2-shift, 50:50 blend) compared to baseline

Analysis of study 6: Machine sorting accuracy and yield loss

The change in sorting accuracy and yield loss for the system made the following changes from baseline:

- The yield loss and product purity output is almost proportional to the change in sorting accuracy and yield loss percentage (Figure 56)
  - St-6.1 both improving by ~3%
  - St-6.2 improving by ~7% and ~6% respectively
  - St-6.3 improving by ~9% and ~10% respectively
  - St-6.4 improving by ~11% and ~12% respectively
- There is a disproportionate impact on purity across product types.
  - Mechanically recycled cotton 100% change of 14.71%
  - Mechanically recycled blends (i.e. polycotton change of 12.35%)
  - Incineration change of 0%
- Any changes in utilisation profiles were negligible for all scenarios

Key findings:

- Improved accuracy and yield loss for non-sorting machines are not sufficient to resolve issues with the bottleneck and performance against the target
- The impact on product purity improvement comes from the variety of materials being processed (Figure 57)
  - Highest improvement from the mechanically recycled cotton 100% is from being sorted first with the largest quantity and variety of material
  - Lowest improvement from the incineration is from being sorted last with the smallest quantity and variety of material



Figure 56: System yield profile for study 6 compared to baseline

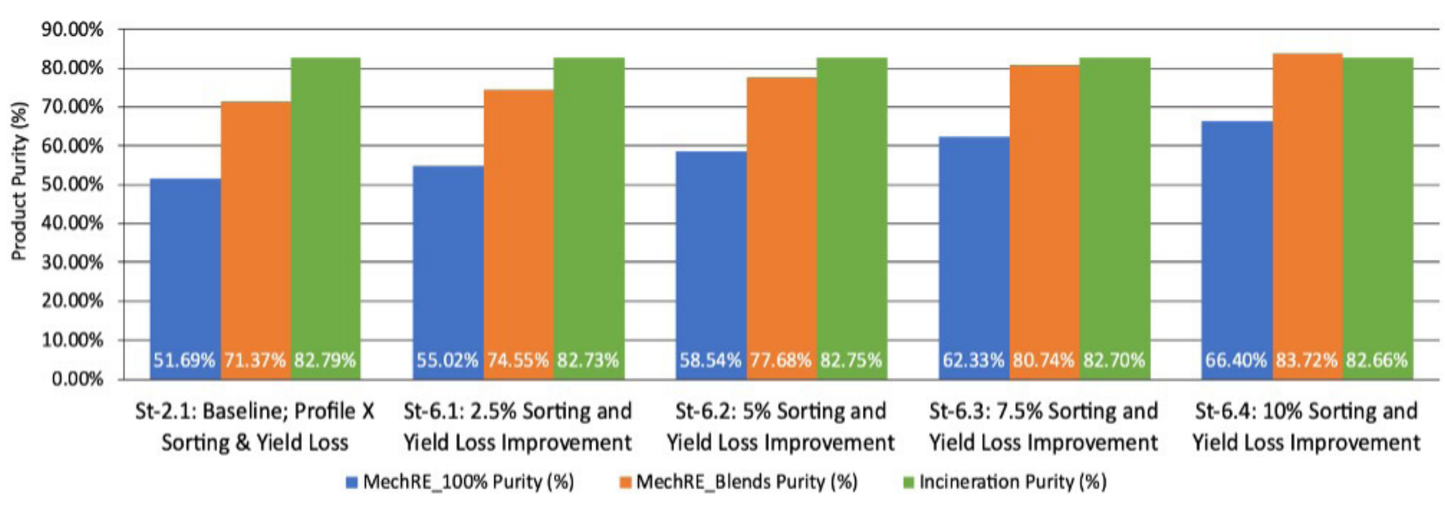


Figure 57: Product purity profile for S6.1 – S6.4 (2-shift, 50:50 blend) compared to baseline

Analysis of study 7: Cleaning process strategy

The change in cleaning times for the system made the following changes from baseline:

- St-7.1: System reached 99.29% of target throughput with 0% blocking
- St-7.2: System reached 99.28% of target throughput with 0.28% blocking
- St-7.3: System reached 94.19% of target throughput with 8.49% blocking
- St-7.4: System reached 84.82% of target throughput with 14.43% blocking
- Increasing cleaning cycle times higher than 7.5 minutes (St-7.2) limits the system production and thus limits the total cleaning time (Figure 58)
  - Blocked time appears in the system shown in St-7.3, St-7.4 and St-2.1 (Figure 59).

Key findings:

- Reduced cleaning cycle time is nearly sufficient to resolve issues with the bottleneck and performance against target (with a small shortfall)
- There is little increase in total yield when reducing cleaning time from 7.5 minutes to 5 minutes (Figure 58)
  - Cleaning time reduces, but yield stays the same
  - Although reducing the cleaning cycles impacts yield these shorter cycle times may be unrealistic for this type of system

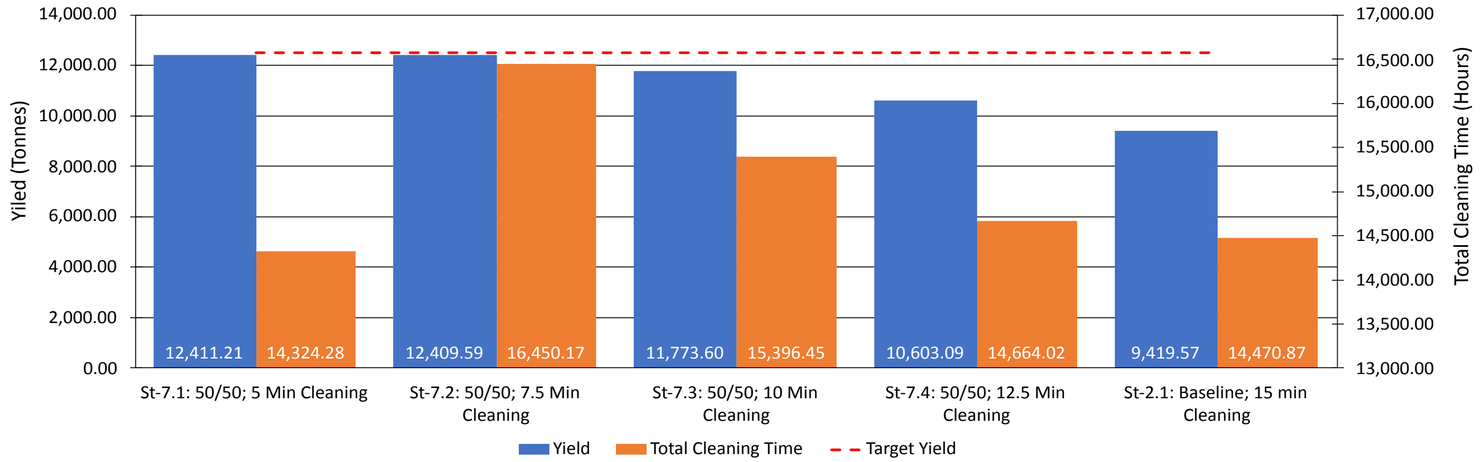


Figure 58: System yield and cleaning time values for study 7 compared to the baseline

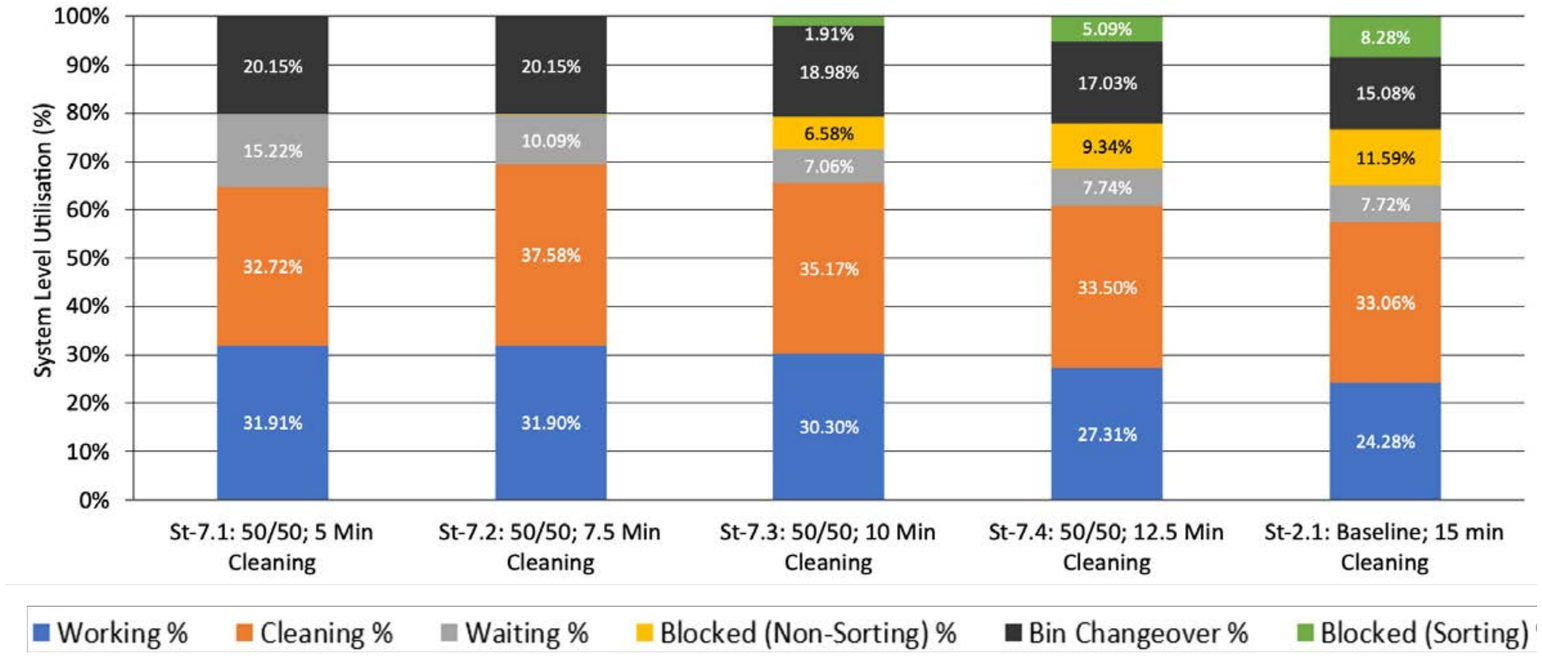


Figure 59: System level utilisation

Analysis of study 8: Production throughput

A change in target throughput (to 25,000 tonnes) with different constraints resulted in:

- St-8.1 to 8.4 (Figure 60): The increase of one shift has the most impact on maximum production throughput, from 9,789.75 (St-8.2) to 14,712 (St-8.4) tonnes per year (an increase of 50%)
- St-8.5 to 8.8 (Figure 61): The reduction in cleaning time has the most impact on maximum production throughput, from 16,478.44 (St-8.6) to 22,541 (St-8.8) tonnes per year (an increase of 37%)

Key findings:

- Maximum gains with system throughput can be achieved if:
  - Working time per year is increased by adding shifts
  - Cleaning cycle times are reduced
- Even reducing system constraints does not achieve the target throughput, which indicates that the number of machines in the system needs to be investigated

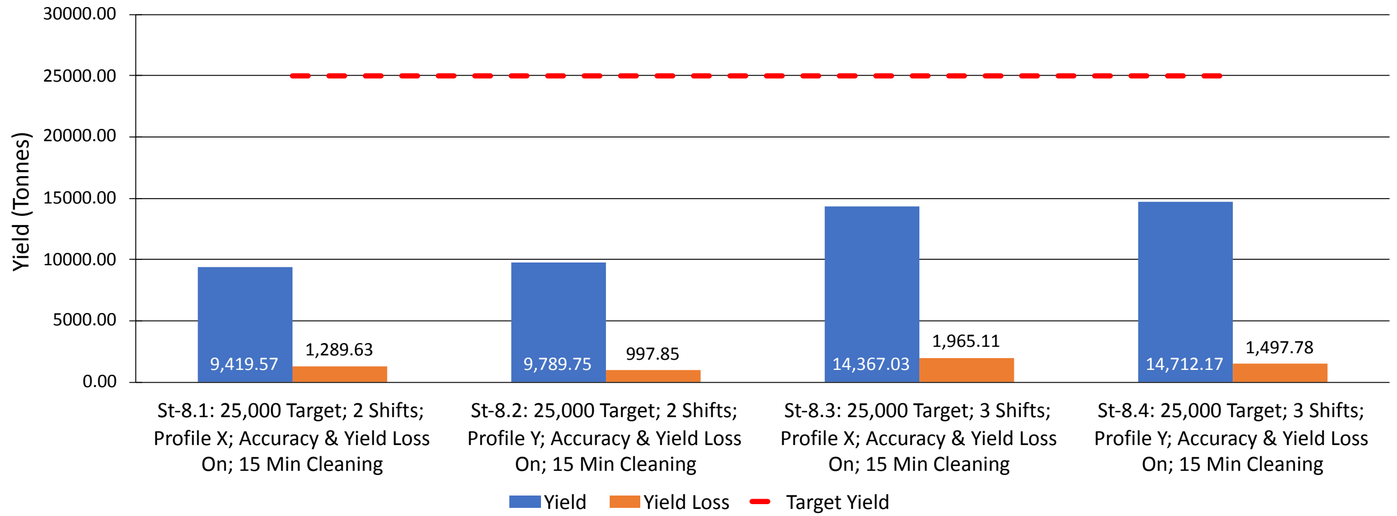


Figure 60: Maximum system yield profile for St8.1 - St8.4 (with constraints)

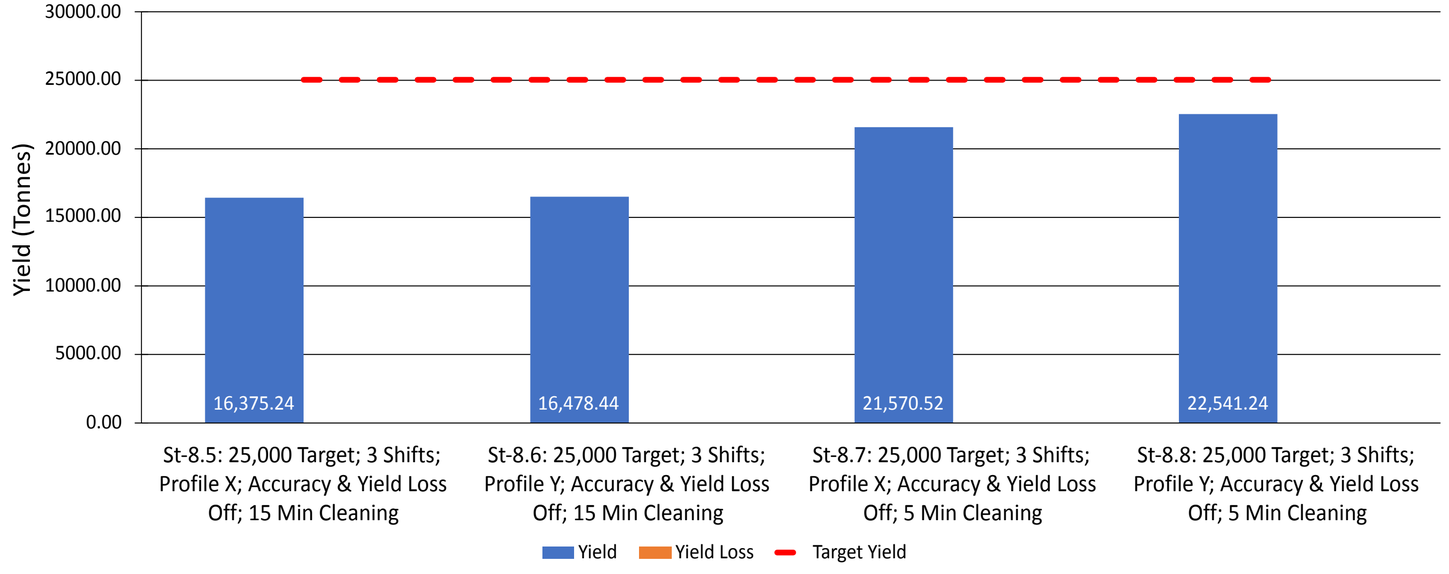


Figure 61: Maximum system yield for St8.5 – St8.8 (without constraints)

Further research

Below are MTC's recommendations for additional research areas.

Industrial analysis of a real system:
- This analysis can be adapted for use on an industrial ATSP system to better understand the practical impact of system options
- Evaluate the introduction of new technology and machinery to better identify the benefits of automation, control systems, and digital support

Investigate support functions for the ATSP system:
- Assess the requirement for material delivery and movement to support the chosen ATSP system set-up
- Identify the buffering and storage strategy required to manage incoming and outgoing stock levels and Work In Progress (WIP)
- Analyse the impact of multiskilling operators or different skill strategies on the production system performance

Generate additional outputs:
- Include other operational process and management KPIs specific to a business or tailored to individual businesses, in addition to the system statistics
- Conduct a 'what-if' analysis on current and future production scheduling and any planned ramp-up of facility capacity
- Conduct facility blueprinting of an ATSP set-up for further site expansion

Development of the digital environment:
- Carry out offline and live modelling experimentation for process improvement
- Explore integrated industrial control of the system for production demands
- Measure system performance for cost and time savings

Operations recommendations

Below are MTC's recommendations based on the DES analysis work package.

Recommendation: Assess variations in the machine quantities and configuration of the production line to determine the maximum achievable throughput, the machine utilisation, and the downtime.

Recommendation: Further assess the sensitivity of system improvements to understand the most effective impact of system performance and identify the limits of each change.

Recommendation: Explore the impact of the machine cleaning strategy on system performance and throughput. The system is sensitive to cleaning frequency and cleaning time. Therefore, a study that explores alternative scheduling options and strategies will determine the impact to overall system performance and production time.

Recommendation: Invest in additional machinery to increase future throughput and assess layout options for the system machines and support functions. This is necessary because the late addition of machines can disrupt production and compromise a working layout and support, especially when looking to increase capacity.



2.4. ATSP capital and operating expenditures

The conceptual engineering design for the ACT Project requires a capital investment of between £15million and £22million. This range reflects the potential for lower initial capital expenditure by implementing a simpler sorting system in the early years, as chemical recycling plants continue to industrialise.

At full capacity, an ATSP's total operating expenditures, encompassing cost of goods sold, overheads, and fixed expenses, range from £175 to £270 per metric tonne sold (please note that this structure has been established from a business case developed by Circle-8, independent of the ACT Project, which incorporates bespoke supply relationships, brand engagement, and other levers that support transitioning from a commodity-linear model to an economically resilient F2F circular and collaborative model).

The key components of these costs are:

- **Electricity:** This is dependent on the grid rate, the extent of sorting required, and the intensity and variety of pre-processing, which are tied to the nature and range of ATSP products made and sold.
- **Labour:** This includes labour required for pre-sorting, if applicable.
- **Transport:** This covers inbound NRT and outbound waste.
- **Waste disposal:** This primarily covers incineration, and is significantly influenced by the 'waste fraction' of the NRT inputs at the gate.
- **Site-related costs:** Such as leasing, servicing, and business rates.

These operating expenses are cost-effective in parallel with the increasing demand for commercial-scale the chemical and mechanical recycling of NRT, as well as open-loop product innovations for the more challenging NRT textile fractions. Where feasible, supply partnerships and revenue levers such as gate fees can be implemented to further reduce these costs, helping to overcome some of the financial challenges associated with PCT sorting and logistics.

A 25ktpa ATSP developed with these variables in mind can generate an attractive return based on commercial assumptions and partnerships.

2.5. ATSP equipment purchase

Outside of the ACT Project's scope, Circle-8 will develop the engineering from a conceptual design to detailed technical drawings, equipment specifications, and system supplier information. This will constitute the engineering package provided to an EPC (engineering, procurement, and construction) contractor, who will then generate the detailed engineering required for a full ATSP procurement order.

The ACT Project prioritised purchasing key ATSP equipment that could be immediately specified. Therefore, instead of an initial downpayment on the full 25ktpa equipment order (which requires further detailed engineering), a standalone single-line sorter was chosen. This sorter, already selected as part of the 25ktpa design, has an 8- to 10-month lead time. As a standalone unit, it will enable automated sorting upon delivery and commissioning. If the ATSP facility isn't ready to receive it upon delivery, a consortium partner will host the sorter at its existing site.

Once the ATSP's detailed engineering has been completed, Circle-8 will place a full order for the remaining equipment. When these are delivered to the site (expected by the end of the first quarter of 2026), the remaining ATSP components will be integrated with the single-line sorter. This will deliver an innovative, industrial-scale ATSP facility, integrating a range of equipment based on an engineering design.

It will be the first of its kind in the UK to include fibre sorting, pre-processing steps to remove disruptors, and size reduction.

3. ATSP SITE SELECTION

This section will focus on the process of finding, securing, and preparing a site for an ATSP facility.

3.1. ATSP site scope

The ACT Project supported the site selection and development by subcontracting property search and development experts. Following a procurement process, JLL, a global commercial real estate services company, was chosen as the consortium lead and Circle-8's property partner of choice.

JLL's scope of work was to collaborate closely with Circle-8 throughout the site selection process, with input from the wider ACT Project team on specific areas, ensuring the warehouse selection aligned with specific project needs and goals.

The scope of the site evaluation and selection process covered:

Site requirements and brief:
- Develop the specific site requirements
- Revise requirements in response to ATSP operations and engineering development

Site search:
- Circulate the site brief to interested stakeholders, including regional and local authorities
- Undertake the property market search

Site evaluation and shortlist:
- Develop a site evaluation assessment criterion for the ATSP based on the identified site requirements
- Conduct further research, including approaching potential sites, to ensure information is gathered
- Undertake a site evaluation to create a site shortlist to visit, with a minimum of six sites. This number of sites was chosen for several reasons:
  - To provide a meaningful comparison between each site
  - To effectively represent the range of available properties
  - To provide negotiation leverage with landlords
  - To encourage the thorough evaluation of each property
  - To allow for some properties to be eliminated during the process, while still leaving enough options to choose from
  - To allow for viable options to consider in the event of unforeseen issues arising with one or two properties
  - To ensure Circle-8 can feel confident that it has explored the market adequately
- Organise visits to shortlisted sites and provide real estate and supply chain advice
- Undertake any further research needed for shortlisted sites, including environmental factors (e.g., flood risks), transportation (e.g., what are the weight limits on nearby roads), and the labour market (e.g., what is the availability of workers with the skills needed for the operation)
- Conduct a supply chain and transportation analysis, incorporating the analysis of inputs and outputs from the ATSP, suppliers and customers, and stakeholder requirements
- Conduct CO2 analysis to understand and minimise the environmental carbon impact of transport to and from the chosen site
- Conduct labour market analysis to understand labour availability and cost
- Conduct a 10-year cost analysis to provide Circle-8 with all factors that contribute to the overall cost associated with leasing warehouse space

Site selection:
- Perform a detailed evaluation assessment on shortlisted sites, provide additional advice and support to consolidate views, and rank and agree on a shortlist of three sites with one preferred site
- Undertake site visits

Site development:
- Define a plan of action for the three shortlisted sites, identifying civil work requirements, permits, and certifications required (and associated costs). These are detailed in Appendix 2.

3.2. ATSP site selection methodology

To fulfil the scope, JLL worked with Circle-8 on the methodology outlined here.

JLL initiated the project with a kick-off session. This session was used to determine and discuss the existing sites that had been preliminarily shared with the project team from various local authorities. The session was also used to determine space requirements, location preferences, budget constraints, operational needs, and any other specific requirements.

To define the site requirements, input was provided from across several business areas. Key input was provided by Circle-8 and TOMRA, Circle-8's engineering partner, to understand the conceptual engineering design and operating requirements of the ATSP. Supply and sales leads developed by Circle-8, working with other project partners, also provided input to understand the location of suppliers/customers, the frequency of deliveries, the types of vehicles that would be used, etc.

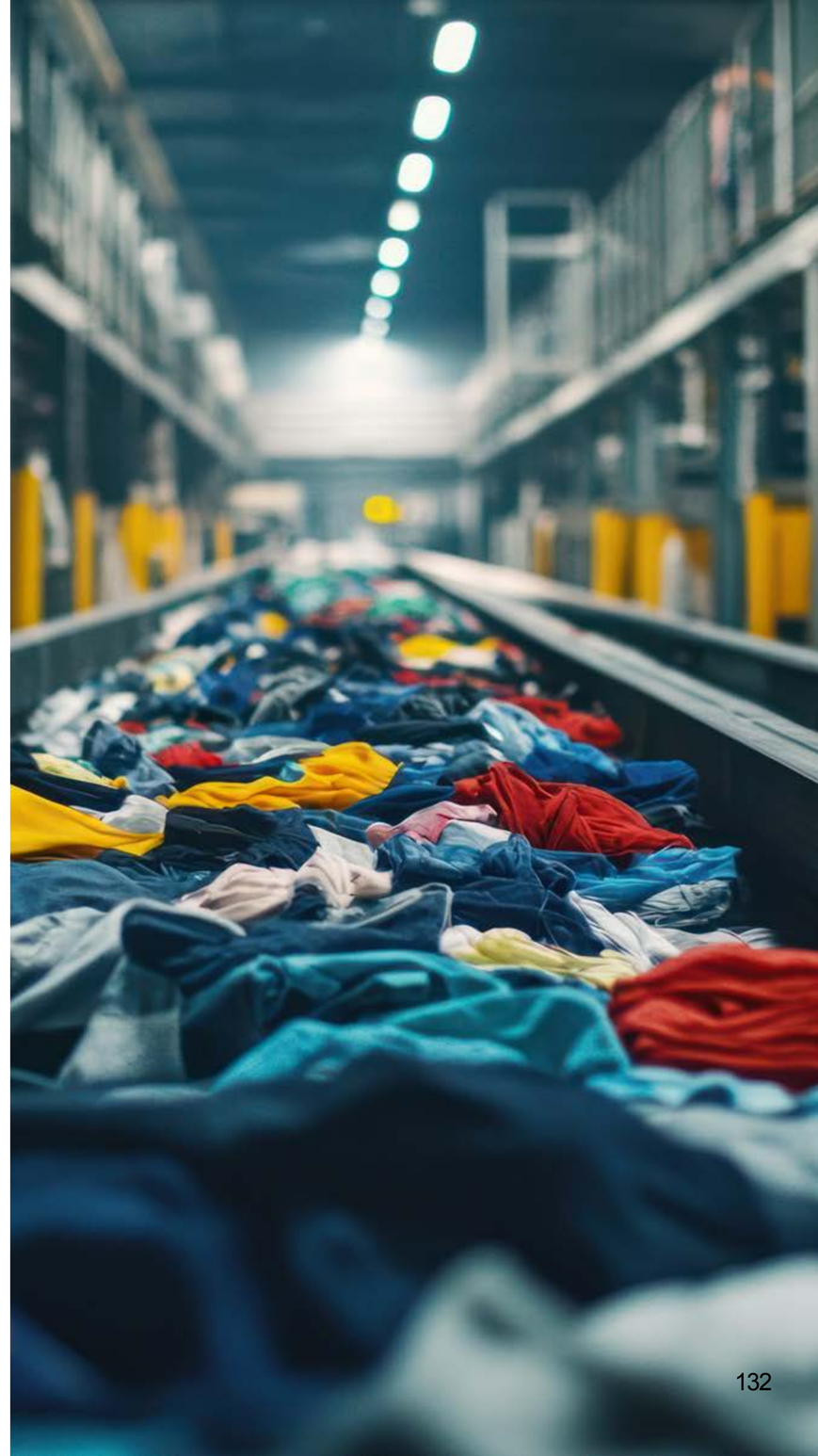
Following this input, site requirements were determined as follows:

B2 use – which is the classification for general industrial use – to meet ATSP operations: To operate the UK's first 25ktpa ATSP for NRTs.

- **Size:** The total combined land area of buildings, logistics, etc., is approximately 135,000 sqft. This is based on the conceptual engineering design, which includes the warehousing needed for a 25ktpa operation, provision for fire risk mitigation, and space considerations for logistics, car park, staff room, and yard.
- **Location:** Proximity to textile/apparel distribution centres, with access to rail freight considered an added benefit.
- Permits: 24/7 operations, T4 waste exemption (accounting for potential future textile regulation changes, expected 2026), industrial fire permit, industrial environmental permit, environmental impact assessments (please see 'Appendix 3: Permits' in the Appendix for further details on the required permits).
- **Utilities:** The current electric power assumption is 1.5 MW of installed capacity for water demand, discharge access, and access to renewable energy. This assumption is based on the usage of the plant technology, which in turn is based on one shift per day across eight hours, excluding Sundays and public holidays. There are no expected peaks or troughs in demand throughout the year.
- **Facilities:** Fitted or ability to fit sprinkler system, and staff welfare facilities.
- **Clear height:** 10 metres minimum to accommodate ATSP machinery and operations/process requirements.

Based on timelines and requirements, it was determined that an existing building would be the suitable option for the first ATSP. Future ATSPs will have more timescale flexibility and offer design, build, and tenure options.

Throughout the site search, discussions with Circle-8 and TOMRA, Circle-8's engineering partner, continued to ensure that requirements remained the same.



3.3. ATSP site evaluation: Criteria and process

Stage 1: Evaluate against essential selection criteria:

To remove unsuitable options, the Expression of Interests that were received and the database search by JLL were tested against the minimum essential selection criteria on a pass-or-fail basis. Those that passed were then scored against the evaluation criteria in Stage 2.

The essential selection criteria were developed by Circle-8 alongside JLL. JLL's input was invaluable, particularly its advice that the key factors of importance would be:

- Ensuring that B2 use is already in place because the process typically takes between 4-6 months for straightforward cases, but can extend to a year or more
- Understanding the building's height and the ATSP's power requirement would be essential to finding building availability. Therefore, both of these factors formed a key part of the conceptual design, particularly as a reduction in the power requirement would potentially open up significantly more building options

Following this evaluation, the essential criteria were refined to be:

- Ensure that the land and building meet footprint and height requirements
- Ensure that B2 use is already in place
- Ensure that the building and land meet the power requirement
- Ensure that the site's cost analysis meets the requirement for the price per square foot to be below £10, and that it also meets the deposit requirement

Stage 2: Evaluate against full criteria:

Expressions of Interest that passed the selection process would be considered against the subjective award criteria in the table below (Figure 62). Each factor was given a weighting rating according to its level of importance to support the assessment of different sites.

Full criteria	Importance
Access to renewable energy (Renewable energy – levels / %)	High
Existing building attributes/state/level of modifications needed and space for suitable expansion to 50ktpa and ancillary activities	Medium
Operational permits/certificates requirements and timeframes in the region and 24/7 operations approval	Medium
Location (supported by JLL transport analysis) • Near current collection/distribution of used and new textile product • Labour supply and cost/transport/cost of living • Near textiles/apparel sector/growth opportunities • Near other manufacturing support • Urban area or sources of collections • Road access/capacity suitable for lorry throughput • Access to rail • Access to ports • Proximity to freeport • Proximity to a potential site for future chemical recycling plant • Proximity to other stakeholders	High
Fit to broader synergies (proximity to other industries that could be part of ecosystem)	Med/low
Level of alignment and interest to key stakeholders	Low
Additional support (e.g., consultancy support, site feasibility, funding)	Low

Figure 62: Importance weighting of full criteria

Stage 3: Site visits

The shortlisted sites were visited in May and June 2024. This allowed the project team to refine its understanding of each site against the subjective criteria and to gain a better understanding of the building's location and surrounding environment.

Stage 4: Site decision

Before making a final decision, three factors were considered:

- A light touch risk assessment of each preferred site was undertaken
- The business case and financial model were aligned to each site location
- If required, a discussion with potential ATSP investors would be undertaken

Once this was done, there would be a final sign-off on a preferred primary site, plus second and third back-up options.

3.4. ATSP market search and analysis

Having developed the initial site requirements, a deck with the outline brief was created to attract the interest of potential stakeholders and landlords.

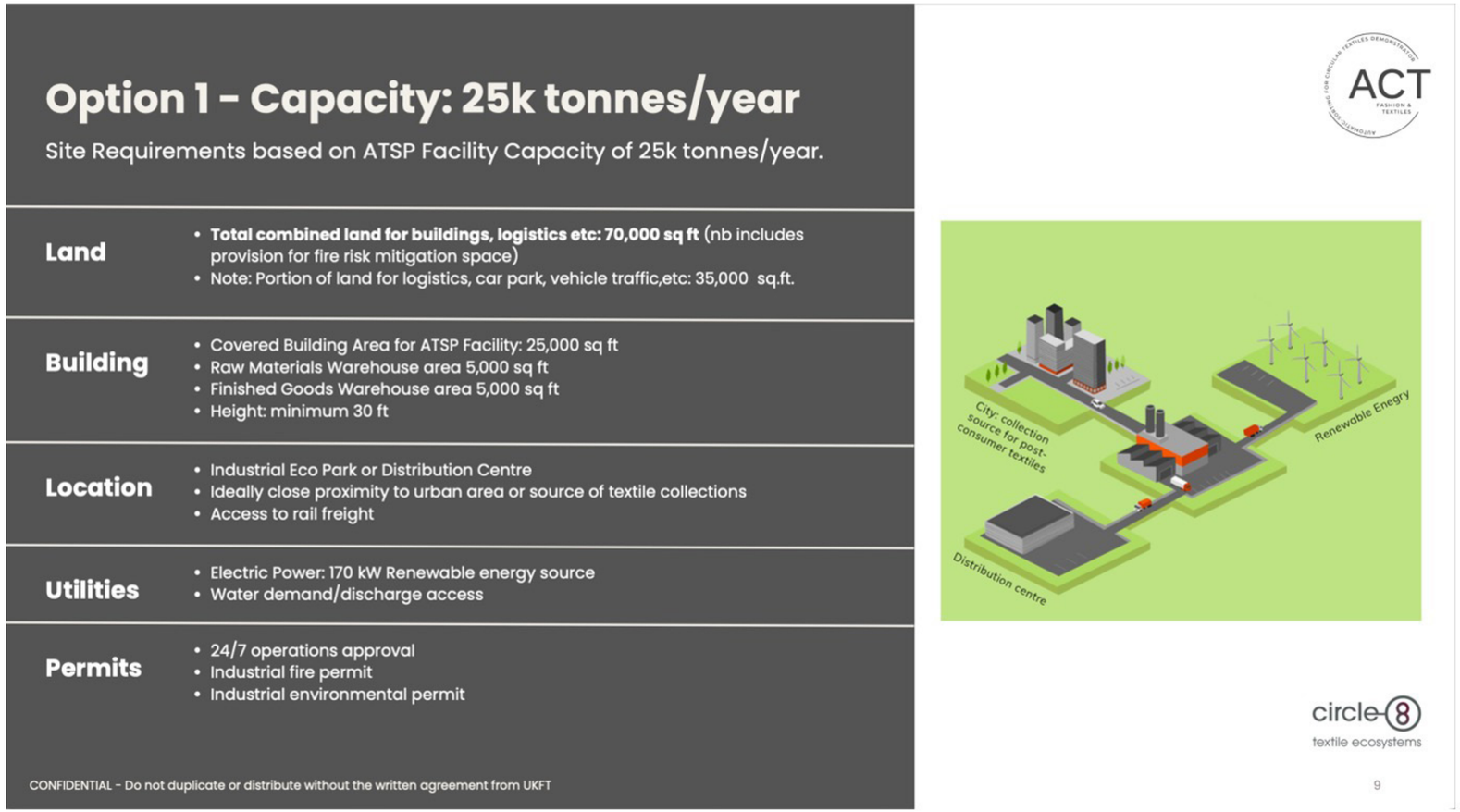


Figure 63: Expression of interest outline brief

4.3.1. Site search

As part of Circle-8's initial process, the outline brief was circulated publicly to local authority contacts across the ACT Project consortium. The authorities were invited to submit Expressions of Interest and, based on the site requirements, 11 responded with available property options.

Once JLL had been onboarded, it undertook a market search into further potential options in the agreed-upon search locations. At the same time, JLL also reviewed the sites submitted through the expression of interest process. JLL has access to extensive market information and databases, which enables it to identify and evaluate a wide range of available on- and off-market properties that meet clients' requirements. During the site-search process, it reviews various sources, including online listings, industry networks, and direct contacts with landlords and brokers to identify potential properties. Furthermore, JLL considers all relevant opportunities in the market, regardless of whether the property is marketed by JLL or other firms.

JLL's objective was to provide Circle-8 with a comprehensive selection of suitable properties that align with their specific needs and preferences.

The longlist of sites JLL identified was merged with the previously identified sites brought forward by Circle-8. All sites were then reviewed collectively in terms of size, high-level costs, availability in relation to Circle-8's timelines, lease terms, power, and overall feasibility.

Following this review, JLL and Circle-8 were able to determine and collectively agree on an initial list of 11 sites which were most suited to the specifications and requirements. As part of this process, JLL and Circle-8 were able to:

- **Focus on alignment:** JLL and Circle-8 demonstrated how each property operation aligned with or deviated from Circle-8's original requirements and identified whether any compromises needed to be made.
- **Share market context:** JLL provided relevant market information such as labour demographics, labour costs, proximity to ports, and travel times to understand how each property fitted within the wider end-to-end supply chain.
- **Provide a balanced overview of property availability:** JLL delivered enough detail for the operator to make informed decisions relating to the general conditions of the property market.
- **Explain exclusions:** If certain properties were excluded from the longlist, the reason was explained, and Circle-8 confirmed the removal of that site from the longlist.
- **Prioritise clarity:** All site information was presented in a clear, concise format allowing easy comparison across properties.

Reviewing the longlist together ensured clear communication and demonstrated expertise. This ultimately guided Circle-8 towards selecting the most suitable properties for the next stage of the process and built trust in the JLL's capabilities and process.

The key learning from the process was that the number of available properties that met key requirements was limited.

4.3.2. Supply chain and transportation analysis

JLL's supply chain consultancy team ran a transportation and CO_2 analysis for the 11 selected sites.

This incorporated the analysis of inputs and outputs, suppliers and customers, and stakeholder requirements. These stakeholder requirements included factors such as the site's proximity to end customers or markets, expansion potential and room for future growth, and community relations opportunities, such as corporate social responsibility initiatives.

Integrating transportation analysis with property searches enables the selection of premises that are strategically connected, operationally efficient, cost-effective, and optimally positioned in relation to the ATSP's centre of gravity, which refers to a model used to determine the optimal location based on the distribution of demand and supply points of Circle-8. When choosing a warehouse location, the aim is to minimise transportation time and costs for both inbound and outbound logistics. By calculating the centre of gravity, JLL could advise and identify the most strategic location that minimises the overall distance and travel time for Circle-8 and its key stakeholders.

Circle-8 was able to provide the various input cohorts (including collector/seller private and charity, brand/retailer pre- and post-consumer, post-commercial, manufacturer, local authority, destruction companies, textile/broker, and others) and their locations (by postcode), the output information (e.g., UK ports), and the volumes by form (bales, cages, sacks, or other) of NRTs from each.

Using typical trailer load by truck type, JLL could calculate the travel distances of heavy goods vehicles by routing the suppliers to each of the potential warehouse locations and estimate a cost per mile for the third-party logistics transport provision. This was multiplied by the approximate number of annual trips to generate a yearly figure per site. The formula used was:

vehicle cost x journey time per trip + £ per driver hour x hrs of each trip + trip miles x cost of fuel per mile.

From the analysis, it was possible to rank the 11 sites in order of transportation cost and, therefore, the closest site to the operation's centre of gravity.

The transportation analysis was undertaken using two scenarios: a single site and a dual-site ATSP. This was done to understand the implications of future ATSPs. The analysis was run a second time once a more detailed understanding of suppliers and customers had been developed with the business model. Figures 64 and 65 demonstrate both scenarios.

JLL was also able to provide a carbon emissions analysis based on the total number of miles travelled by truck and CO2 emissions per mile. This was to assess and understand the carbon footprint and environmental impact of each property location based on the input and output volumes feeding into the ATSP.



Figure 64: Single-site ATSP solution

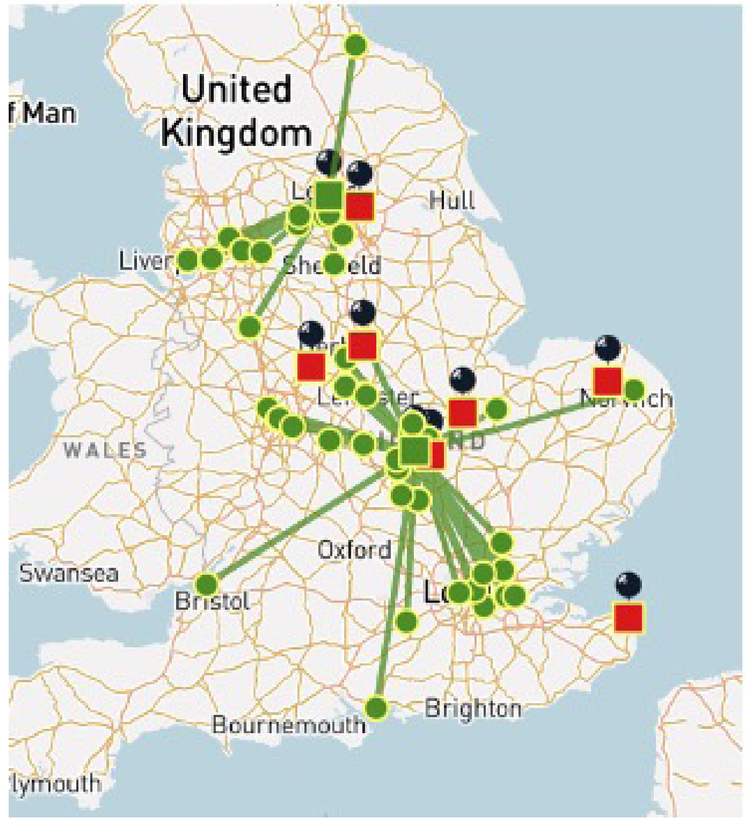


Figure 65: Dual-site ATSP solution

3.4.4. Labour market analysis

A labour market analysis was undertaken based on the areas (and 10km radius) of the initial longlist of sites. JLL provided market segmentation, identifying specific labour pools and understanding their availability and characteristics in relation to the ATSP operation. JLL also provided workforce demographics, including age, education levels, and labour force participation, to identify potential workforce challenges and opportunities.

3.4.5. Cost analysis

The cost analysis included the following components:

- **Rent per square foot:** Encompassing the base rent that Circle-8 is required to pay for occupying the area. This is determined by location, size, condition, and market demand.
- **Service charge (where applicable):** In addition to the base rent, these charges include various facilities and services provided by the landlord or property management, including common area maintenance, security, waste management, utilities, and other shared amenities, calculated typically on a per square feet basis.
- **Site specification:** The value and cost depend on the ‘as built’ fit-out and any additional tenant fit-out that might be required.
- **Deposit:** The deposit is usually the equivalent of multiple months’ rent, which is held as security against any damages or breaches of a lease agreement. The deposit amount varies depending on the landlord’s terms and negotiation and will depend on the occupier taking the lease.
- **Business rates:** Levied by the local government and reflected in the assessed value of the property. The rates vary depending on the size, location, and usage classification of the warehouse.

By providing a comprehensive cost analysis, Circle-8 could use the analysis to assess the financial feasibility of leasing the warehouses identified in the site selection process and plan their budget accordingly. From here, it was possible to determine the sites Circle-8 requested to view, and subsequently, JLL organised site visits to each location.

3.4.6. Site visits

JLL organised and facilitated site visits. The inspections enabled Circle-8 to evaluate the warehouse conditions, suitability, and practicality for its specific operational needs. The visits included:

- **Physical evaluation:** The warehouse visit enabled Circle-8 to assess the property firsthand, exploring its layout, size, storage capacity, and features, ensuring each aligns with its specific operational requirements. Circle-8 could also check the condition of the infrastructure, such as the roof, floors, walls, and other elements, to ensure their standards are met.
- **Suitability confirmation:** Circle-8 could evaluate if the space fits its intended use, considering factors such as ceiling height, door access, dock facilities, and storage configuration. The visit enabled the operator to ensure the warehouses can be efficiently utilised for their business operations.
- **Engaging stakeholders:** Bringing Circle-8 to the warehouse involves key stakeholders within the project, enabling them to collaborate, share perspectives, and ask questions. It enabled a comprehensive understanding of the site’s potential and facilitated informed decision-making overall.

After viewing all sites, JLL worked with Circle-8 to filter the list further to a final shortlist of three properties to take forward to negotiation.

3.5. Securing a preferred site

When the final three properties were confirmed with Circle-8, JLL started the negotiations. The process followed four steps, detailed here:



Step one: Request for Proposal (RFP) issued to shortlisted properties:

RFPs typically include several key components to ensure all necessary information is gathered for evaluation. This is typically tailored to the specific needs of the industrial operation planned for the space, but some components included were:

- Confirmed property details (eg, sqft, overall specification, office space configuration)
- Lease terms (proposed lease duration, rent structure, renewal options)
- Financial information (base rent, operating expenses, tax, insurance, utilities)
- Maintenance and repair responsibilities
- Timeline for availability and move-in date
- Sublease and assignment rights
- ESG and sustainability considerations

The responses to the RFPs were analysed to determine whether they aligned with Circle-8's original specification requirements and goals. All proposals were compared, enabling JLL to highlight the strengths and weaknesses of each option. In doing so, JLL could create a solid foundation to secure the best possible terms for Circle-8.

Step two: Negotiations and heads of terms:

Counter proposals were created and submitted to the landlords for review. Then, working with Circle-8, a preferred solution was identified and an agreed set of heads of terms was agreed upon. The heads of terms outline the key points of a proposed agreement between a tenant (in this case, Circle-8) and the landlord before a formal lease is drafted, detailing the financial and non-financial principles of the transaction. Key components typically include the parties involved, the property description, rent amount, payment terms, permitted use, etc. It was the responsibility of JLL's tenant representation team to draft and negotiate the heads of terms, liaising between Circle-8, the landlord, and respective legal teams.

Further due diligence, encompassing building condition surveys, was undertaken to assess and mitigate risks associated with defects requiring pre-occupation works or covered by outstanding warranties.

Step three: Legals:

After the commercial negotiations and a preferred site was chosen by Circle-8, JLL supported the project in the closing stages of the acquisition. This included working with Circle-8's solicitor to request initial legal drafts from the landlord, liaising with the operator's legal advisors to finalise legal due diligence, and providing comments on the commercial terms in the legal documentation,

Step four: Closing:

From this point, and once an offer had been accepted, the lease agreement was prepared, reflecting the agreed-upon terms and conditions. Once all parties were satisfied with the terms of the lease, the lease agreement could be executed.

4. DISCUSSION

This section outlines the key findings and recommendations from this chapter, across:

- Engineering and operations
- Site selection

4.1. Findings and recommendations: Engineering and operations

- **Mixed NRT and RT:** Based on the cost analysis and business case modelling, Circle-8 quickly ruled out the option of taking in mixed RT and NRT due to the associated manual labour costs within the facility and the potential for other parties to perform a pre-sort step more efficiently.

- **Collaboration:** The design of the ATSP needs to align with a business model – and a sourcing and sales strategy – that is supported by partnerships and levers that incentivise supply and deliver cost efficiencies for NRT handling and logistics.

- **Incoming supply:** It is essential to understand incoming fibre compositions and form factors. A Supply Specifications Guide (see Appendix 1) for incoming supply will support the standardisation of inputs, e.g. inputs to arrive in bales, and limiting out-of-scope materials from entering the ATSP.

- **The transition:** Understanding the current markets for processed NRT, including their limitations, and developing customer relationships for future products and outputs will help to plan the transition from the ‘as is’ scenario to a steady state for F2F recycling.

The DES operations model study

This study indicated that:

- The system cannot meet target (12,500 or 25,000 tonnes per year) with the baseline configuration.

- The main bottleneck (non-sorting line) is caused by the machine cleaning protocol and cycle times.
  - Additionally, the cleaning of the non-sorting machines limits the working utilisation of the sorting machines and causes inherent inefficiency in the system
  - Baler machines contribute most to upstream blockages which reduces utilisation for non-sorting machines

- The system is most sensitive to shift patterns and cleaning cycle times. This is expected as:
  - More shifts increase effective production time and allow for more products to be created (~4740 tonnes per year)
  - Reducing cleaning cycle times reduces system blockage and allows for more product creation (~2990 tonnes per year)

- The system is also sensitive to the following, but are less impactful:
  - Improved machine performance
  - Reduced yield loss and improved sorting accuracy

- Changes in the garment source distribution has no significant impact on system performance.

From the above analysis, the following conclusions can be drawn from the DES modelling:

- The capability of the modelling and simulation techniques can evaluate various system options and quantify the impact on an ATSP system’s performance.

- The sensitivity analysis of the system’s parameters has highlighted the main contributors and constraints of a generic ATSP system as:
  - Shift patterns: The working time per year increases significantly with an additional shift per day, allowing for much higher throughput but at the expense of additional operating expenses;
  - Cleaning cycle times: This can be reduced, which reduces non-working time and increases throughput. However, the cleaning protocol needs assessment to ensure it is achievable.

- The system set-up required to meet 99.28% throughput with baseline machine quantities is: Two shift patterns, machine profile X, active accuracy and yield loss, 7.5-minute cleaning cycle time (St-7.2 – see ‘Analysis of study 7’ in section 2.3.4).

- The system support requirements to meet the feedstock throughput targets over a yearly production period are:
  - System utilisation: 31.91%
  - Energy consumption: 780,723.08 kWh
  - Operational expenditure: £179,566.31

- The strategies to increase shift patterns and reduce cleaning cycle times should be assessed for both their cost and feasibility, as they may not be achievable.

- Additionally, they may not allow for increased capacity should demand for products from an ATSP grow from 12,500 tonnes per year.

- An improved machine profile only provides marginal gains at a higher running cost. Therefore, increasing machine count may be the most appropriate strategy to meet system throughput.

4.2. Findings and recommendations: Site selection

- **Key requirements:** The main factors critical to creating the building shortlist were the floorspace, height, and having B2 use already in place. These requirements considerably shortened the list of available buildings. It was also noted that the space required put the ATSP in competition with buildings being used for warehousing, which is a very competitive space.
- **Deposits:** Deposits were a significant factor in the 10-year financial analysis. Deposits are higher for start-ups and can be reduced by improving the financial covenant of the entity signing the lease or by providing a guarantor.
- **Movement of materials:** The transport and logistics analysis played a significant role in deciding on the areas chosen for the first ATSP because the movement of materials to and from the ATSP is a key cost factor.
- **Permit uncertainty:** Permitting is anticipated to be lengthy, and there remains a lack of clarity about upcoming changes and what the new requirements will entail.

APPENDIX

Appendix 1: ATSP Supply Specifications Guide
For the supply of (NRT inputs into the ATSP).

Form factor (highly preferred):

- Delivered as baled textiles, all sizes suitable but larger preferred for efficiencies.

Form factor (not preferred: additional cost if required to be carried out by ATSP):

- Separation of RT from NRT
- Un-packaging (individually packaged items, e.g. unsold shirts), unboxing, unpacking, labels removed
- Textiles with large prints

Contents received by the ATSP shall not contain the following materials:

- The handling/disposal costs for any of the following received at the ATSP will be charged to the supplier or sent back:
- Damp, dirty, or smelly material
- Textile materials soiled by paint, oil, or other contaminants
- Bags, plastic packaging, or other types of packaging
- Stuffed materials, e.g. cushions, down duvets, and down jackets
- Balls of yarn or longer items rolled up
- Shoes, belts, bags, accessories, toys, or similar
- Flame-retardant-treated materials
- Multiple textiles bundled or packed together, e.g. textiles in laundry bags
- Multi-layered products and textile materials, e.g. coats, shell jackets, lined garments, and jackets

Preferred fibres:

1. Pure cotton
2. Pure polyester
3. Pure polyester/cotton blend
4. Blended fabrics with high content of either of the three above

Appendix 2: Civil works
JLL's Project and Development Services (PDS) team provided a comprehensive service focusing on strategic planning, design, and construction management solutions.

Working alongside Circle-8, with support from TOMRA, Circle-8's engineering partner, the JLL PDS team was able to provide the following services:

Project management for delivery of the ATSP operation: Providing end-to-end management of the warehouse fit-out, including overseeing project timelines, budgets, and resources, as well as coordinating and communicating with the project stakeholders along the way.

Design management: Collaborating with architects, engineers, and other design professionals to ensure that the project design aligned with the ACT Project's objectives. This included reviewing and evaluating design concepts, coordinating design disciplines, and ensuring compliance with building codes, regulations, and sustainability standards.

Construction management: Overseeing the execution of the project. This included managing the bidding process, contractor selection, contract administration, construction scheduling, quality assurance, and safety management, as well as managing the construction progress, budget control, and change management.

Cost and budget management: Providing the project with cost estimation, budget development, and financial analysis to ensure projects are delivered within budget.

Sustainability and MEP (mechanical, engineering and plumbing) consulting: Incorporating sustainable design principles and practices into the project to enhance energy efficiency and reduce environmental impact.

All services were underpinned by JLL technology and innovation solutions, including BIM (building information modelling), virtual reality, and data analytics to enhance decision-making, improve efficiency, and drive cost savings.

Throughout the project, JLL's service was customised to meet specific ACT Project needs and ensure a seamless execution from concept to completion.

Appendix 3: Permits

JLL was required to support Circle-8 in identifying and securing relevant permits to acquire and run the facility.

Permits are an official authorisation granted by local planning authorities or relevant government bodies which ensures that the proposed use, modification, or development of the warehouse complies with UK planning laws, building regulations, and environmental standards. This may include change of use permissions, listed building consents (if applicable), or specific approvals for industrial activities, depending on the warehouse location and intended use.

The ATSP operation will sort NRTs by fibre composition and colour, in addition to the removal of disruptors such as buttons, zippers and trims, and cutting materials to sizes that make them suitable for textile-to-textile recycling processes. Based on the ATSP use, it was identified that a T4 exemption would be required, which authorises an operator to treat 'waste' to reduce its volume for transport to another site for reuse, recycling, or to make handling easier. T4 exemption for textile recycling can be applied based on capacity processing volumes and anticipated capacity volumes of the ATSP, as detailed below;

Total anticipated capacity of the ATSP:

- Capacity is based on total anticipated volume (not historical or current actual at that time).
- ATSP projected input volume: 25,000 tonnes per year (approximate)

Currently, the limits under which a textiles processor can operate under a T4 exemption are:

- Treat up to 1,000 tonnes outside in any 7-day period
- Treat up to 3,000 tonnes indoors in any 7-day period
- Store up to 1,000 tonnes at any one time

Therefore, under current regulation, T4 exemption is sufficient. However, waste exemptions are changing, impacting the permits required for the ATSP when the changes are made. Changes to the exemptions are likely to start in 2025, but timescales have not been finalised. Operators will also have a 'grace period' to apply for such changes.

Under the new proposed changes, the limits will change to 5000 tonnes per year / 100 tonnes per week. If this legislation comes into play, a full environmental permit will be required. There are no standard rules permits for this activity, as they are currently under the T4 Exemption Rules.

How the activity is classified according to the Environmental Permitting Regulations will depend on whether the permit is applied for via the local council (Part A1 or Part B classification) or Environmental Agency (Part A2 classification).

As the function of the ATSP is 'new' to the market, it was recommended to engage with the Environmental Agency to determine the right permits to apply for to ensure all required and correct permits are obtained.

Other permits that may be included are:

- Industrial Fire Permit
- Industrial Environmental Permit
- Environmental Impact Assessments

Permit	How/ Where to apply
T4 Exemption	A T4 Exemption permit allows you to: • Treat up to 1,000 tonnes outside in any 7-day period • treat up to 3,000 tonnes indoors in any 7-day period • Store up to 1,000 tonnes at any one time[26] T4 exemption permits are via the Environmental Agency, they are free, and last for three years.
New Environmental Permit (when legislation changes)	As activity of ATSP is 'new', the regulations set forth by the Environmental Agency are unclear in terms of usage. Under new proposed changes (legislation not in place, effective date still TBC), the limits will reduce to 100 tonnes in any seven-day period, above which is a full environmental permits will be needed. This is a more complicated process (and so more costly), which will potentially require a full environmental assessment. Depending on activity the application will be made via the Environment Agency or Local Authority. Guidance will be taken from the Evironmental Agency when changes to waste exemptions are confirms.
Industrial Fire Permit	Fire preventation plan required, ask landlord for source of water for fire extinction. Responsibility of operartor[27].
Industrial Environmental Permit	Responsibility of operartor[28].

Figure 66: Permit summary table



Chapter 5:

Textile recycling supply chain trials

Assessing ATSP feasibility through cotton, polyester, and wool trials



CONTENTS

Introduction

Market review of circularity components
- Methodology: Market review
- Results: Market review
- Discussion: Market review

Mechanical recycling of cotton trial
- Methodology: Mechanical recycling of cotton
- Results: Cotton trial
- Discussion: Cotton trial

Polyester trial
- Methodology: Polyester trial
- Results: Polyester trial
- Discussion: Polyester trial

Wool trial
- Methodology: Wool trial
- Results: Wool trial
- Discussion: Wool trial

Discussion
- Automated sorting and pre-processing
- Chemical risk
- Coloured feedstock
- Recommendations for further research

Appendix
- Appendix 1: Cotton
- Appendix 2: Polyester
- Appendix 3: Wool

1. INTRODUCTION

The objective of this chapter's work was to demonstrate whether the output generated by an Advanced Textile Sorting and Pre-processing (ATSP) facility is of good enough quality to be used within a manufacturing environment, and ensure that it can provide feedstock for correct specifications.

To achieve this, recycling supply chain trials were conducted with project partners between April 2024 and February 2025. The trials consisted of processing textile materials through the individual ATSP sorting and pre-processing steps to prepare them as feedstock for mechanical textile recycling systems.

The work undertaken included a review of circularity services – defined as services that enable the auditing, traceability, and transparency of material circularity – and the collection of traceability metrics. The objective was to identify suitable services to verify the recycling supply chain trials.

The fibre-to-fibre (F2F) material trials were:

- Mechanical recycling: Cotton (University of Leeds)
- Thermomechanical recycling: Polyester (SATCoL)
- Mechanical recycling: Wool and cashmere (Camira)

Primary data and learnings were documented throughout the physical processing and recycling of the post-consumer NRTs to support the business case for textile-to-textile recycling within an ATSP facility. Measurements included the physical and chemical properties of the trial fibre and yarn outputs, as well as the loss of volume during processing.

Due to timeline constraints, the manufacturing of fibres, yarns, and non-wovens into products was outside the scope of the mechanical cotton and thermomechanical polyester trials. The output of the mechanical wool trial produced 20 blankets.

This chapter presents the research and trial results and discusses their relevance to the ATSP facility. It starts with a market review of key existing and emerging circularity components in section 2. Sections 3, 4, and 5 then examine the cotton, polyester, and wool trials, respectively, outlining methodologies, results, findings, and conclusions.

The chapter concludes by discussing the key overall findings in section 6 and presenting recommendations for further action and research.

2. MARKET REVIEW OF CIRCULARITY COMPONENTS

2.1. Methodology: Market review

Ahead of the textile recycling supply chain trials, this market review aimed to assess existing and emerging circularity components and explore the integration of circularity services, products, and platforms (e.g. product passports, tracers, blockchain, and data protocols) in the context of the ATSP value chain. It also aimed to provide evidence to identify and recommend relevant circularity components and tools to pilot in the trials.

Key industry reports were analysed to compile existing circularity components covering 55 technologies – 25 physical tracer technologies and 30 digital traceability platforms – and three standards and certification bodies. The review identified the various types of available circularity components and their underlying processes, and included relevant case studies. A RAG-rating (red-amber-green) system was used to highlight technologies compatible with recycled content and, therefore, ATSP facilities.

2.2. Results: Market review

It was noted that both physical and digital tools should be implemented in tandem. Physical tracers enable the physical verification of a recycled material, while digital components enable real-time tracking, analysis, and data upload.

Therefore, the following recommendations for both physical and digital circularity components were made for the recycling supply chain trials:

2.2.1. Recommendations: Physical tracer

Additive tracers were recommended as the most suitable to pilot in the recycling supply trials due to their:

- Flexibility to be added and detected at various stages during the trial process
- Suitability for natural and synthetic fibres
- Capability to prove end-to-end circularity in a circular textiles ecosystem

2.2.2. Recommendations: Digital platform recommendations

Many of the digital platforms were found to be product-focused rather than material-focused. The digital supply chain platform is most suitable for integration in the recycling trials, as it captures material-level information. If required post-trial, it can extend to ‘circularity’ types or product-level. Please note that this trial would uncover only a small aspect of a digital platform’s potential capabilities for wider circularity.

As a result of the review, a recommendation was made to use an additive tracer in partnership with a digital supply chain platform. Due to time constraints, it was recommended that an offering from the market review with an existing partnership should be selected. Therefore, Tailorlux was chosen and added to the spinning stage of the cotton recycling supply chain trial.

2.3. Discussion: Market review

Requirements were defined for integrating circularity components into the recycling supply chain trials. Circularity services should be:

- Applied at the material level rather than at the finished product level to identify and trace recycled content through the recycling supply chain
- Applicable for post-consumer NRTs entering an ATSP system
- Suitable for application on natural and synthetic fibres (with a focus on cotton, wool, and polyester for the trials)

3. MECHANICAL RECYCLING OF COTTON TRIAL

3.1. Methodology: Mechanical Recycling of Cotton

Trial aims

The aim of the cotton trial was to:

- Sort, pre-process, mechanically recycle, and spin yarns from UK-sourced post-consumer cotton textiles
- Compare recycled fibre and yarn output properties against benchmark performance requirements
- Evaluate the effect of feedstock lot, cut shape size, colour, and fabric structure (knit/woven ratio) on output fibre quality to support successful yarn spinning trials and inform pre-processing requirements in the context of an ATSP facility

Supply Chain Step	Project Partner
Collector/Sorter	SATCoL
Recycler	University of Leeds (UoL)
Yarn spinner	University of Leeds (UoL)
Testing	Recover, Bureau Veritas, Reiter, University of Leeds
Traceability	Tailorlux

Figure 67: Table of cotton recycling supply chain partners

Specification Type	Trial Specification
Feedstock volume	Recycling trial: 9.42kg Spinning trial: 1.85kg
Source	Post-consumer textiles
Fibre Type	Cotton
Fibre composition	>95%
Fabric construction	Knitted, woven
Colour	White, dark, others
Additional information	Clothing, home textiles
Sorting type	Auto-mated NIR sorting: composition Manual sorting: construction
Pre-processing type	Manual: scissors
Pre-processing output	Irregular cut (max. 300mm x 50mm) Regular cut (50mm x 50mm)

Figure 68: Table of cotton feedstock specification





Image 22: Cotton feedstock

Trial process

Action: SATCoL sorted feedstock using the same automatic fibre sortation machine settings at four different times, creating four ‘lots’. Each lot was sorted into light, dark, and ‘other’ coloured garments.

Action: The University of Leeds (UoL) manually sorted the garments into knits and wovens. Scissors were used to remove disruptors such as buttons, zippers, trims, labels, tags, and shirt collars to avoid contaminants in recycled fibres and prevent damage to the tearing machine. The garments were then cut into regular or irregular shapes.

Action: Eleven recycling trials were conducted to assess the effect of lot, cut shape size, colour, and fabric structure (knit/woven ratio) on the quality of the output fibre. Each trial was given a ‘Trial Code’ which demonstrates its lot (number), cut shape (regular or irregular), colour (light, fark, or other) and fabric structure (knit, woven, or mixed). For example, the feedstock for Trial 1 was lot 1, regular cut, light coloured, mixed knit, and woven structures. A summary of this is shown in Figure 69: Table of cotton recycling trials.

Trial	Trial Code	Material Lot #	Cut Shape (R/I)	Colour	Knit/Woven Ratio (K/W/M)	# Tearing
1	1RL-M	1	Regular	Light	Random	3
2	2RL-M	2	Regular	Light	50:50	3
3	3RL-M	3	Regular	Light	50:50	3
4	4RL-M	4	Regular	Light	50:50	3
5	4RL-W	4	Regular	Light	Woven	3
6	4RL-K	4	Regular	Light	Knit	3
7	4IL-M	4	Irregular	Light	50:50	3
8	1IL-M	1	Irregular	Light	Random	3
9	3RD-M	3	Regular	Dark	50:50	3
10	3RO-M	3	Regular	Other	50:50	3
11	3RO-M2	3	Regular	Other	50:50	8

Figure 69: Table of cotton recycling trials

Action: The cut garment pieces were passed through a laboratory-scale Laroche Cadette tearing machine three times and further processed three times on a laboratory-scale roller-stripper carding machine at UoL to achieve further opening of leftover yarns and fabric fragments.

Action: Fibre outputs from each trial were tested for composition, strength, length (mean fibre length, short fibre content, upper half mean length), and elongation properties.

Action: As a result of analysing fibre properties from each trial, a decision was made to proceed to the spinning trial with a mix of light-coloured post-consumer textiles (PCT) from all four lots. A further 1.85kg of material was pre-processed and recycled.

Action: Output fibre was tested on a risk-based approach for restricted chemicals, fibre composition, strength, elongation, and length (mean fibre length, short fibre content, upper half mean length) properties.

Action: Three yarn lots were created using blends of recycled materials and virgin upland cotton, shown in Figure 70. Recycled cotton fibres are typically shorter and weaker than virgin cotton fibres, with coarser yarns able to tolerate a higher proportion of short fibres. Therefore, three different blends were spun to explore the implications of this. Each yarn count was also spun in a 100% virgin cotton yarn for benchmarking. The original aim was to spin a 30Ne yarn with 20% recycled content, but this was not physically possible due to the quality of recycled fibres, and a 26Ne yarn was spun instead. Tailorlux fibre was added to one yarn to support traceability. Please note that ‘Ne’ refers to ‘Number English’, which is an indirect method of expressing the size of a cotton yarn (as the number increases, the physical yarn size decreases[29]).

Yarn	Yarn Count	Material Content
1	Ne10	60% virgin cotton, 40% recycled cotton
2	Ne20	70% virgin cotton, 30% recycled cotton
3	Ne26	80% virgin cotton, 20% recycled cotton

Figure 70: Table of Cotton yarn trials

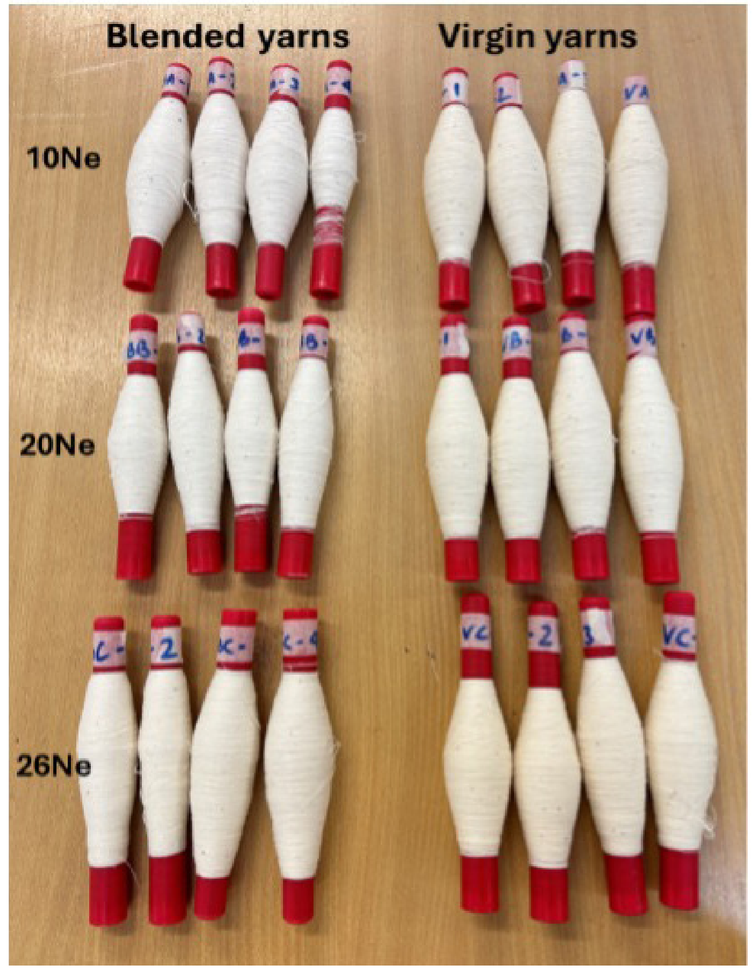


Image 23: Cotton spinning trial yarn outputs

Action: Finally, the output yarns were tested for evenness and strength. Due to timing, traceability testing was outside the scope of this report.

3.2. Results: Mechanical Recycling of Cotton

3.2.1. Process efficiency

Figure 71 demonstrates that 11% of the auto-sorted NRT textiles were lost during pre-processing. This is due to the removal of disruptors and contaminated items.

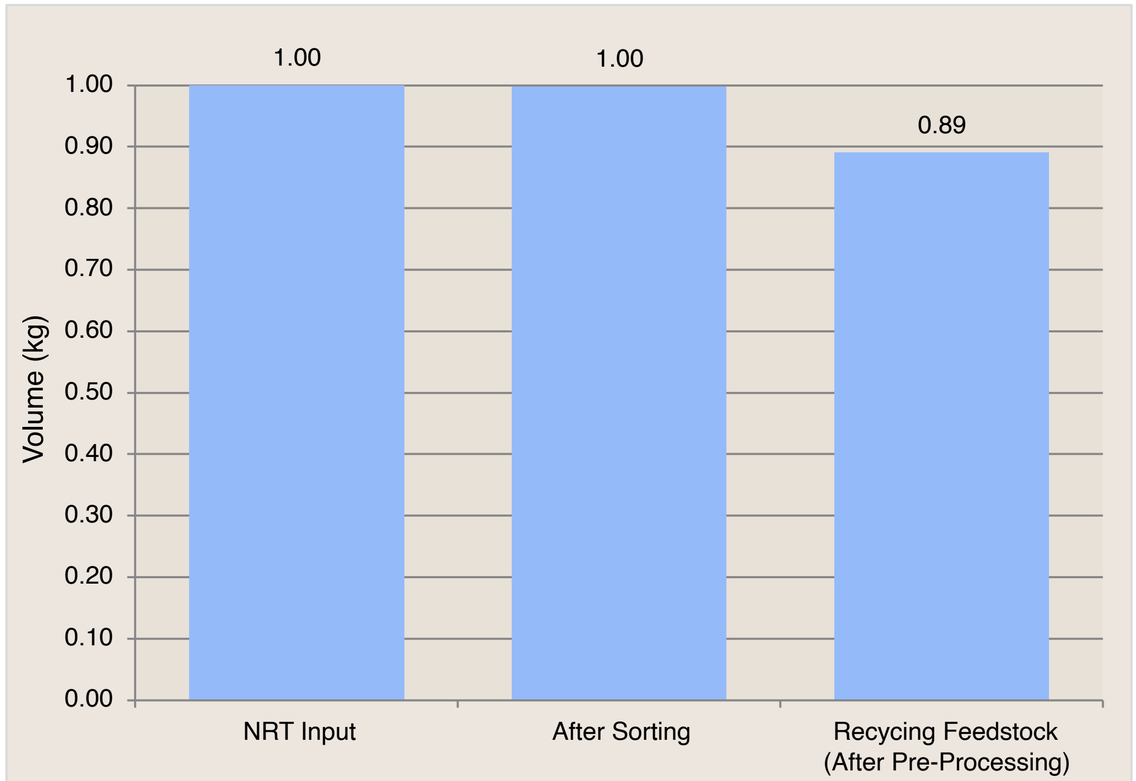


Figure 71: Cotton trial output per kg

Figure 72 shows that sorting and pre-processing took up 24% of the processing time. An ATSP facility would need to use automation to reduce this time to achieve necessary economies.

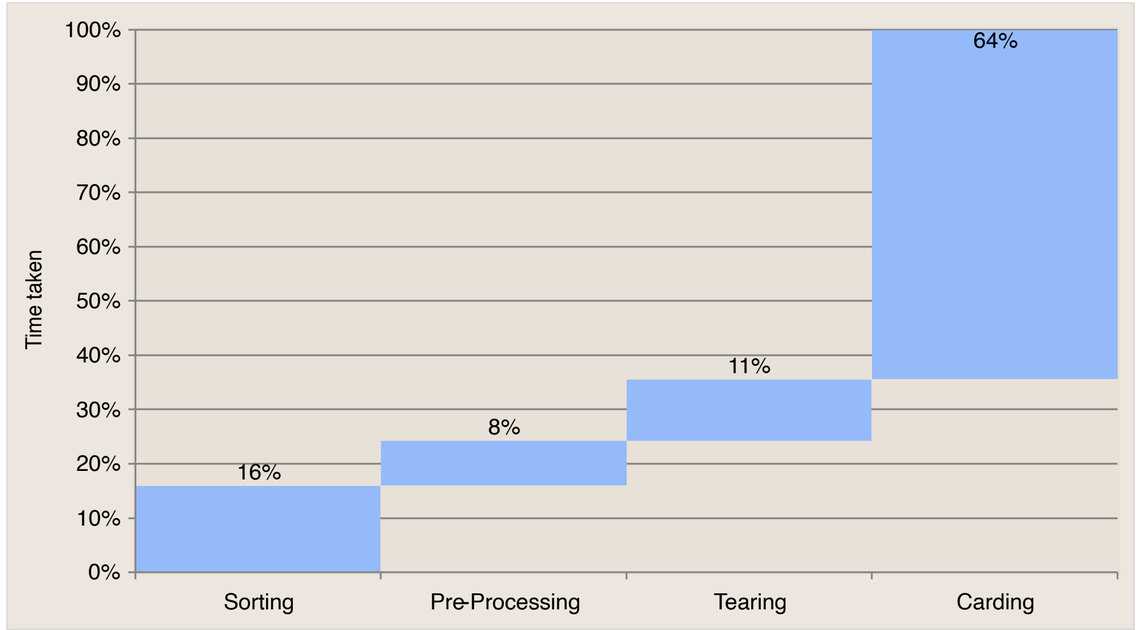


Figure 72: Cotton trial time taken per kg

3.2.2. Fibre performance

In the following analysis, the term ‘recycling trial’ refers to the results of the 11 fibre samples produced using a combination of cut shape, lot, colour, and fibre structure. The term ‘spinning trial’ refers to the results of the fibre and yarn samples produced using light, mixed-structure materials from all lots.

Physical testing

Fibre composition:
The aim of the research was to recycle post-consumer cotton textiles with a cotton content exceeding 95%. Despite this, only two fibre samples from light, mixed-structure garments had a cotton content above this threshold in the 11 recycling trials. Notably, the only dark-coloured sample tested contained the lowest cotton content at 36.1% and the highest polyester content at 44.9%. Additionally, a proportion of viscose, elastane, and wool were detected in these fibres. Full results are shown in Figure 91 in the Appendix.

Length analysis:
Several lengths were analysed:

Mean fibre length test: This measured the average length of fibres in a sample, which is used to reflect overall staple length. For most recycling trials, the mean fibre length was between 14mm and 16mm. Only two of the recycling trials processed knitted and woven materials separately. The knitted feedstock had the shortest fibre length of 12.44mm, versus woven at 14.93mm. The results show that the variables of regular or irregular cuts and controlled mixing of fabric structure and colour did not significantly impact fibre length. The mean length of fibre processed for the spinning trial was 14.28mm, demonstrating comparable results to the recycling trial mixed feedstocks but outperforming knitted feedstock alone. Full results are shown in Figures 92 and 97 in the Appendix.

Upper half mean length test: This focused on testing only the average length of the longest 50% of fibres, offering insight into fibre distribution and the quality of longer fibres. The upper half mean length for all recycling trial samples was in a close range, averaging around 20mm. The results of the fibre processed for the spinning trial were comparable at 19mm. Full results are shown in Figures 93 and 97 in the Appendix.

Short fibre content test: This measured the percentage of short fibres in the sample, classified as less than 12.7mm. High levels of short fibre content can cause significant processing loss, increased ‘fly’ (fibres which fly out into the atmosphere during processing) concentration in the workspace, higher end-breakage rates during spinning, reduced yarn strength, and poorer yarn uniformity, resulting in pilling. Recycling trial 5 – using only knitted materials – had the highest short fibre content at 64.3%. Across all recycling trial samples, short fibres made up approximately 30% to 46% of the total content. There is no industry average to compare this to, but based on the experience of the technical team, the quality of recycled fibres from post-consumer waste was classed as poor. It was generally understood that this result is higher than either virgin or recycled fibres from post-industrial cotton textiles. The fibres from the spinning trial had 42% short fibre content, which is in line with the results from the recycling trials, which would limit applications for clothing. Full results are shown in Figures 94 and 97 in the Appendix.





Fibre strength:
Poor fibre strength can make spinning and fabric manufacturing more complex and affect final product performance.

For virgin upland cotton, a strength of <23g/tex (the number of grams of force that can be applied before the fabric is damaged) is classified as weak. All recycling trials demonstrated fibre strength between 4.5g/tex and 22.4g/tex, classifying all fibres as weak. Notably, in Trial 11 – the only trial with mixed-coloured garments – the fibre strength was notably higher than all other trials at 22.4g/tex. The next closest trial result scored 11g/tex.

The fibre strength and elongation test for Recycling Trial 5 could not be undertaken because the analysed sample was too strong, exceeding the maximum force capacity required of the load cell to break or stretch the fibre. Additionally, fibre strength and elongation for Recycling Trial 6 were unattainable because the fibre length was too short for testing. These two trials were the only two to process woven and knitted material. Given the small sample size and the presence of other fibres in the blend, no conclusions can be reached regarding the reason for these results. Further research is needed. Full results are shown in Figure 95 in the Appendix.

The fibre used in the spinning trials was a mix of white-coloured textiles from different lots. The spinning trial fibre was shown to have a strength of 5.41g/tex, a lower strength than 8 out of 11 recycling trials. Full results are shown in Figure 97 in the Appendix.

Fibre elongation:
Virgin cotton typically has an elongation rate of 4% to 8%, but the recycling trial samples demonstrated elongation between 8.9% and 32.6%. After undergoing tearing and carding processes, they exhibited increased flexibility compared to virgin cotton as a result of being heterogenous PCT. This enhancement may be due to the presence of polyester, viscose, wool, and elastane in the samples, which are significantly more flexible than cotton.

Notably, Recycling Trial 9 exhibited the highest elongation at break, attributed to its content of 45% polyester and 15% wool. Both polyester (elongation around 37%) and wool (elongation around 43%) have naturally higher elongation properties than cotton (elongation between 4% and 8%). There was also high variability in the results; the performance of recycling trials with the most cotton in their composition was the closest to 8% of virgin cotton. Full results are shown in Figure 96 in the Appendix.

The fibre processed for the spinning trial demonstrated an elongation of 18%. Considering the sample was found to have 98.7% cotton and the elongation of virgin cotton is 4%-8%, this suggests that impurities of other fibres and/or degradation of cotton fibres are likely to have impacted elongation values. Full results are shown in Figure 97 in the Appendix.

3.2.3. Yarn performance

Physical testing

Tensile strength: Yarns that integrated recycled fibre from post-consumer waste demonstrated a 20% to 29% reduction in tensile strength compared to virgin cotton yarns of the same count. The most significant decrease in tensile strength between virgin and recycled content yarn was in the finest count yarn, 26Ne. The relationship between yarn count and tensile strength reduction due to the integration of recycled materials was not linear, but each yarn count was blended with a different percentage of recycled materials. Full results can be seen in Figure 73.

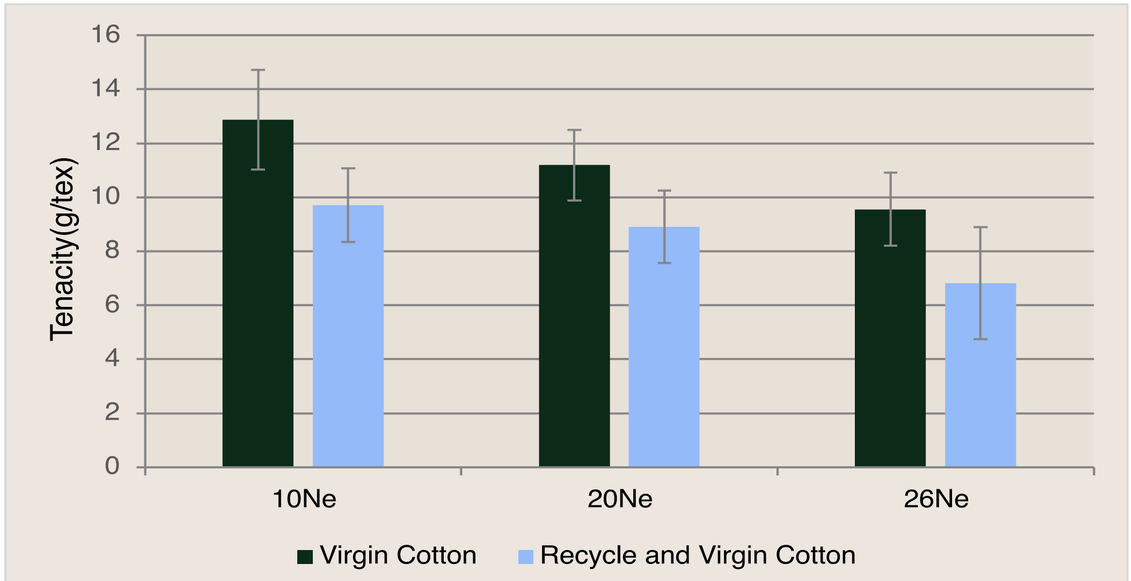


Figure 73: Tensile strength between virgin and recycled blend yarns at 10Ne, 20Ne, and 28Ne

Elongation: 10Ne yarns integrating 40% recycled content were found to have comparable elongation to 100% virgin cotton yarns at the same count. The difference in 20Ne and 26Ne yarns integrating recycled content versus their virgin cotton counterparts was 14% and 12%, respectively. In general, introducing recycled content led to a slight decrease in yarn elongation. Given the variation in results, this small difference is not statistically significant.

Evenness: Yarns were tested using Uster Technologies' testing equipment for unevenness, coefficient of mass variation (CMV), and imperfection index. Unevenness testing showed a 5% difference in unevenness between a 10Ne virgin cotton and blended recycled yarn, with the difference only 1% in a 26Ne yarn. This demonstrates that coarser yarns integrating recycled materials are more uneven than finer yarns. The difference in CMV between virgin cotton and blended recycled yarn ranged from 7% to 0% in 10Ne to 26Ne yarns, respectively, and from 163% to 28% for the imperfection index, showing a negative correlation between the result and yarn count. All these results demonstrate that unevenness reduces in finer yarns as they integrate a smaller proportion of recycled content. Full results are shown in Figures 101-104 in the Appendix.

Chemical testing

Fibres from the spinning trials were tested for bisphenols, heavy metals (extractable) and Nonylphenol ethoxylates (NPEOs). As there is little industry guidance on the risks of legacy chemicals in post-consumer materials, these tests were determined using a risk-based analysis from the largest public industry study on this topic from IKEA and H&M[30] and expert knowledge of risks. Each chemical returned a 'not detected' result, resulting in a pass. Full results are shown in Figure 105 in the Appendix.

3.3. Discussion: Mechanical Recycling of Cotton

Below are key findings, discussion points, and recommendations from the cotton trial.

3.3.1. Sorting and pre-processing

The pre-processing stage was notably time-consuming, with only 0.4kg being processed per hour and generating an 11% loss in weight in comparison to input volume. It is important to note that this was a lab-scale trial, and this could be optimised at scale through an ATSP facility. If manual trim removal could be replaced by machinery, the process could become significantly more productive and efficient. However, even with automation, some pieces may not be fully processed, and there would still be a need for a manual process within an ATSP facility.

Feedstock product categories:
There was a clear difference in the most prevalent product categories per feedstock colour. White feedstock tended to have more bedding and t-shirts, which generally have fewer trims and, therefore, require less pre-processing. Dark feedstock contained more hoodies and sweatshirts, which generally have more trims to be removed. Additionally, dark colours were much more likely to be knitted garments than woven, which made trim removal more difficult due to the thickness of the knitted material. This could impact feedstock process loss and, ultimately, pricing at scale.

It was found that trims are generally similar per product category; some examples are shown in Figure 74. Thick prints, which were most prevalent on t-shirts, needed to be removed as they would disrupt the tearing machine roller. These findings suggest that implementing category-level guidelines could improve pre-processing quality. Furthermore, in an ATSP facility, scanning technology that can sort products by category would be advantageous, enabling the separation of target from non-target items.

Product Category	Most Common Trims
Shirts & cardigans	Buttons, collars, shirt cuffs, thick trims, wash tags, brand labels
Trousers	Thick waistband, zip, elastic, trims, wash tags, brand labels
Hoodies	Thick trim, strings, zips, pockets, wash tags, brand labels
T-shirt	Care label, hanging loop, prints
Traceability	Side trims, care label

Figure 74: Table showing common trims per category

Feedstock hygiene:
Feedstock hygiene was raised as a key consideration for reaching scale within the trials. Some of the NRTs were dirty and smelly and, in some cases, unhygienic with blood stains. It is generally accepted that NRTs which pose a risk to human health should be disposed of during the sorting process, so their presence within the feedstock raised the question of whether there should be further communications and training for sorters to correctly remove items of concern.

Furthermore, a sanitisation process for post-consumer feedstock before recycling could be considered. However, there are arguments for and against a sanitisation process. While it would guarantee staff safety, it would also add more processing costs to already low-value feedstock and could further negatively impact the business case for F2F recycling. It could also be argued that the materials will be effectively sanitised in processes upstream in the supply chain. While the sanitisation of feedstock is more commonplace in the U.S. than in Europe, in some countries, such as Bulgaria, sanitisation of post-consumer clothing for the second-hand market is required by law. However, this is not currently required in the UK, as it is assumed donors wash the clothing before they receive it. Without sanitation, the correct personal protective equipment (PPE) and standardised sortation guidelines should be considered as a minimum precautionary principle in an ATSP facility.

3.3.2. Recycling

Effect of feedstock variables:
The preliminary recycling trials, which aimed to test the effect of cut shape size, lot, colour, and fabric structure (knit/woven ratio) on output fibre quality, did not demonstrate conclusive trends. This was due to the low volume of material, the number of lots tested, and the variation in fibre composition. While the single trial sample comprising solely knitted feedstock consistently underperformed relative to all other recycling trial samples, definitive conclusions cannot be drawn from one trial alone. Therefore, further research is recommended.

On the sample tearing machine, there was a gap between the conveyor and the tearing roller. This meant that the fabric pieces needed to be stacked or overlapped and kept at a sufficient size to prevent them from falling into the gap. Additionally, feeding fabrics into the roller required manually poking them. This demonstrates the need to ensure that pre-processing systems in the ATSP facility can meet specific physical commercial recycling systems requirements, which will not be consistent across all recycling systems.

Process loss:
Contaminants and dirt on the PCT feedstock did not inhibit the mechanical recycling process in any way. It was found that dirt is part of the fibre in tearing, mainly smaller fragments. Due to the higher number of short or dirty fibres, there was a higher proportion of fibre floating out of the machine, and the correct PPE should be considered for recycling at scale to prevent harm to human health.

3.3.3. Fibre and yarn performance

It should be first highlighted that tearing, carding, and spinning were completed on a lab-scale machine. Therefore, the results cannot be used to represent industrial processes.

Fibre composition:
The feedstock was sorted using a near-infrared (NIR) fibre sortation line that aimed to deliver a bale averaging >95% cotton but permitting individual items of <95% cotton, as the NIR sortation identifies composition per item rather than weight.

The sorting technology could be more stringently set to eject only >99% cotton, but average data and experience were used to determine the settings to try to create a >95% bale average. This increases the fraction that can go in the bale and helps sorters increase the commercial value of PCT, which will be important to create a viable business case for an ATSP facility. In practice, this meant there were various fibre compositions in the feedstock, with some individual pieces found to be 50% polyester and 50% cotton. Viscose, wool, and elastane were also found within the mix because these were permitted in the settings for the other non-cotton material.

In some cases, the sorting technology had misclassified the garment. For example, one sample of darker colour was determined to be only 36% cotton, but the majority were between 80% and 95%. It is known that NIR technology has challenges in sorting darker colours.

Product labelling legislation requires a +/-3% tolerance in stated care label composition versus actual garment composition. Therefore, the ability to provide accurate compositions of recycled feedstock for F2F recycling to control output quality and final garment compositions will be important in scaling.

The properties of virgin cotton are tested by taking and testing a sample whose properties represent the entire bale. This trial showed product composition can vary within the same lot and resulting bale. In the context of ATSP, a fine balance must be struck between automated sorting settings, recycler requirements, and the commercial need to sell larger volumes of material to the market.

Fibre and yarn strength:
All recycling and spinning trial fibres were classified as having weak strength, which is likely due to the high level of short fibres that were found. During the product lifecycle, PCTs are exposed to UV, washed, and worn many times, and the fibre is likely degraded throughout this phase. This weakness was evident in the yarn results, showed that yarns with 20-40% recycled content demonstrate 29% lower tensile strength compared to 100% virgin yarns. The variation in tensile strength was also high, which would realistically make upstream processes such as weaving more difficult. Interventions such as lower loom speed or blending with other fibres could be used in production processes to mitigate against this, but the evidence shows that concessions would need to be made in processing recycled cotton from post-consumer sources.

The only trial that consisted solely of knitted garment feedstock displayed both the weakest fibre strength and highest short-fibre content. This finding is contrary to general industry understanding. Most recyclers specify working with knitted textiles only – particularly in post-industrial recycling – because the knitted structure is easier to open than a woven fabric structure. This data point suggests that the fibre is of poorer quality from knitted garment feedstock than woven garment feedstock. However, as this is based on only one data point, no conclusion can be made, and further research is needed.

Legacy chemicals:
The chemical analysis showed no detection of selected legacy chemicals, which is a promising result for the ATSP business case. This result suggests that UK REACH legislation – which applies to the majority of chemical substances manufactured in or imported into Great Britain[31] – is controlling the risk of restricted chemicals in products placed on the UK market. Again, as this is only one data point, more research is needed.

3.3.4. Yarn performance

Yarn unevenness:
Coarser yarns were found to be much more uneven than finer yarns in both their virgin states and when incorporating recycled content. However, the difference in unevenness grew when recycled content was introduced. The findings align with the industry understanding that coarser yarns demonstrate less unevenness while integrating a higher level of recycled material, showing that recycled content is better suited to coarser yarns such as denim, towel, and heavyweight knit.

3.3.5. Conclusions

- This trial successfully processed non-reusable PCT into yarns
- The variability of the fibre composition in different lots made it difficult to draw conclusions on the effect of feedstock lot, cut shape size, colour, and fabric structure (knit/woven ratio) on the quality of output fibre
- Further research is needed to establish the optimum settings of automated NIR machines to produce feedstock with bale composition standardised enough to incorporate fibre back into products and meet labelling guidelines
- It was demonstrated that pre-processing guidelines could improve the accuracy of de-trimming, as trims appear in a similar place per category
- Importantly, it showed no presence of legacy chemicals
- Clear evidence was found to show that weak fibre strength and the tensile strength of the resulting yarns could affect the upstream processing of post-consumer fibre



4. POLYESTER TRIAL

4.1. Methodology: Polyester trial

Trial aims

The aim of the polyester trial was to:

- Sort, pre-process, thermomechanically recycle, and spin polyester yarn from UK-sourced post-consumer polyester textiles
- Compare PET pellets and yarn output properties against virgin polyester and benchmark performance requirements. PET (Polyethylene Terephthalate, a type of polyester resin, a thermoplastic polymer). PET pellets refers to virgin polyester in pellet form. Additionally, rPET is from recycled rather than virgin sources, such as recycled plastic bottles or recycled polyester textiles

The trial aimed to test the viability of sorting and pre-processing feedstock to meet the purity requirements of thermomechanical recycling in the context of an ATSP facility. Thermomechanical recycling is predominantly used on post-industrial, pre-consumer, or post-consumer business textiles as the technology needs a high level of feedstock purity, which is more difficult with mixed and heterogeneous household PCT. The expected output of the trial was pellets and yarn.

Supply Chain Step	Project Partner
Collector/sorter	Salvation Army Trading Company Limited (SATCoL)
Recycler	Project Re:claim LLP (Project Plan B and SATCoL)
Yarn spinner	University of Leeds (UoL), Fibre Extrusion Technology Limited (FET)
Testing	University of Leeds (UoL), Fibre Extrusion Technology Limited (FET)

Figure 75: Table of polyester recycling supply chain partners

Specification Type	Trial Specification		
Feedstock volume	5,438kg		
Source	Household PCT	Household PCT	Household PCT
Fibre Type	Polyester	Polyester	Polyester
Fibre composition	100%	100%	100%
Fabric construction	Mixed	Mixed	Mixed
Colour	White	White	Mixed
Additional information	Duvet, washed and unwashed	Clothing, washed and unwashed	Clothing, washed and unwashed
Sorting type	Hand NIR sorting	Automated NIR sorting	Automated NIR sorting
Pre-processing type	Rotary blade seam and trim removal	Rotary blade seam and trim removal	Rotary blade seam and trim removal
Pre-processing output	De-trimmed household textiles	De-trimmed garments	De-trimmed garments

Figure 76: Table of polyester feedstock specification

Trial process

- **Action:** SATCoL segregated four feedstock batches: duvets (unwashed and washed), white clothing, and coloured clothing.
- **Action:** The duvet feedstock was sorted using a NIR hand scanner since duvets are bulky and too big for a sorting line such as the one used in these trials. The operator slashed the outer open to check the inner composition as well as the outer.
- **Action:** The clothing feedstock was sorted using automated NIR fibre sortation technology. Items with multiple layers, such as outerwear, were removed before, as they had a higher risk of containing other fibres in other layers.
- **Action:** The feedstock was pre-processed manually. This included removing trims and contaminants using a rotary blade.
- **Action:** The unwashed duvet feedstock was recycled into rPET pellets, whose properties were tested at UoL.
- **Action:** Due to the high organic and moisture content in the unwashed duvet feedstock, a second batch of washed duvets was recycled, producing pellets.
- **Action:** The batch of coloured clothing feedstock was unsuccessful in the recycling process due to the machine not reaching sufficient pressure, and the trials continued with light and white coloured feedstock only.
- **Action:** The duvet and clothing (washed and unwashed) pellet batches underwent melt-flow index (MFI) testing by Fibre Extrusion Technology Ltd (FET). It also underwent Fourier transform infrared spectroscopy (FTIR), differential scanning calorimetry (DSC), and thermogravimetric analysis (TGA) testing by UoL. Please see section 4.2.2 for full explanations of MFI, FTIR, DSC, and TGA.
- **Action:** As best performing in the analysis, the 100% recycled pellets from unwashed duvet feedstock were taken forward into the spinning trials. The spinning trials compounded recycled pellets with virgin pellets to create yarns. Some recycled pellets were also compounded with additives in the recycling process. The objective of each trial is outlined in Figure 77: Table of spinning trials.

Spinning Trial	Yarn Composition	Trial Objective
1	1. 100% virgin PET 2. 15% virgin PET, 85% unwashed duvet recycled pellets	• Test whether the extrusion of yarn integrating 15% recycled content is possible • Compare the properties of yarn extruded with 15% recycled content against virgin yarn of the same specification
2	1. 85% virgin PET, 15% unwashed duvet recycled pellets 2. 85% virgin PET, 15% unwashed duvet recycled pellets, 0.25% additive 3. 85% virgin PET, 15% unwashed duvet recycled pellets, 0.5% additive	• Compare the properties of yarn extruded with 15% recycled content and different levels of master-batch additive, to determine how the additive changes yarn properties
3	1. 100% virgin PET 2. 85% virgin PET, 15% unwashed duvet recycled pellets, 0.25% additive 3. 75% virgin PET, 25% unwashed duvet recycled pellets, 0.25% additive	• Compare the properties of yarn extruded with 15% and 25% recycled content and 0.25% master-batch additive with increasing spin holes against virgin yarn of the same specification
4	1. 100% virgin PET	• Compare the properties of yarn extruded with 100% virgin material at different draw ratios
5	1. 100% virgin PET 2. 85% virgin PET, 15% unwashed duvet recycled pellets, 0.25% additive	• Compare the properties of yarn extruded with 15% recycled content and 0.25% master-batch additive against virgin yarn of the same specification and machine parameters

Figure 77: Table of spinning trials

Textile recycling supply chain trials

Action: Yarns from all spinning trials were tested for linear density, tensile strength, and elongation at break in comparison to virgin material.

Action: Yarns from Spinning Trial 3 were additionally tested for DSC and TGA.

Melt Blow Trial	Input Composition	Trial Objective
1	1. 100% Undried post-consumer duvet recycled pellets, 0.25% additive.	• To test whether the pellets could be processed through an extruder and melt blown to create fibres. • To produce fibre webs in a range of formats with varying thickness, weight and fibre diameter.

Figure 78: Table of melt blow trial

Action: In the production trials, a variety of fibre webs with a base weight range of 20 to 300g/m2 and thickness range of 0.2mm to 2.5mm were produced on the conveyor. Further research and development could make them loftier. Images can be found in Image P9 in the Appendix.

Next steps outside the scope of this report include:

- Process dressing gown/fleece feedstock with a more standardised density/surface, as previous trials showed that fabric density impacted extrusion

Further research outside the scope of the trials includes:

- Process further sorted and prepared clothing and duvet feedstock to see whether the properties from trials can be improved upon and commercially spin yarn
- Explore the impacts of differently sorted and prepared feedstock on the resulting mechanical and chemical properties of pellet outputs and spun yarn
- Explore the impact of varying spinning processing parameters on output yarn quality. This includes adjusting the fibre blend ratios, refining the spinning tension, and exploring alternative draw ratios to improve yarn uniformity and tensile properties



4.2. Results: Polyester trial

4.2.1. Process efficiency

Figure 79 demonstrates that for every kg pre-processed in the steps at an ATSP facility, there would be 0.86kg output into the recycling process. The most time-intensive process in this trial was pre-processing, shown in Figure 80. This was due to the mixed heterogeneous feedstock and the recycling technology requiring consistent composition.

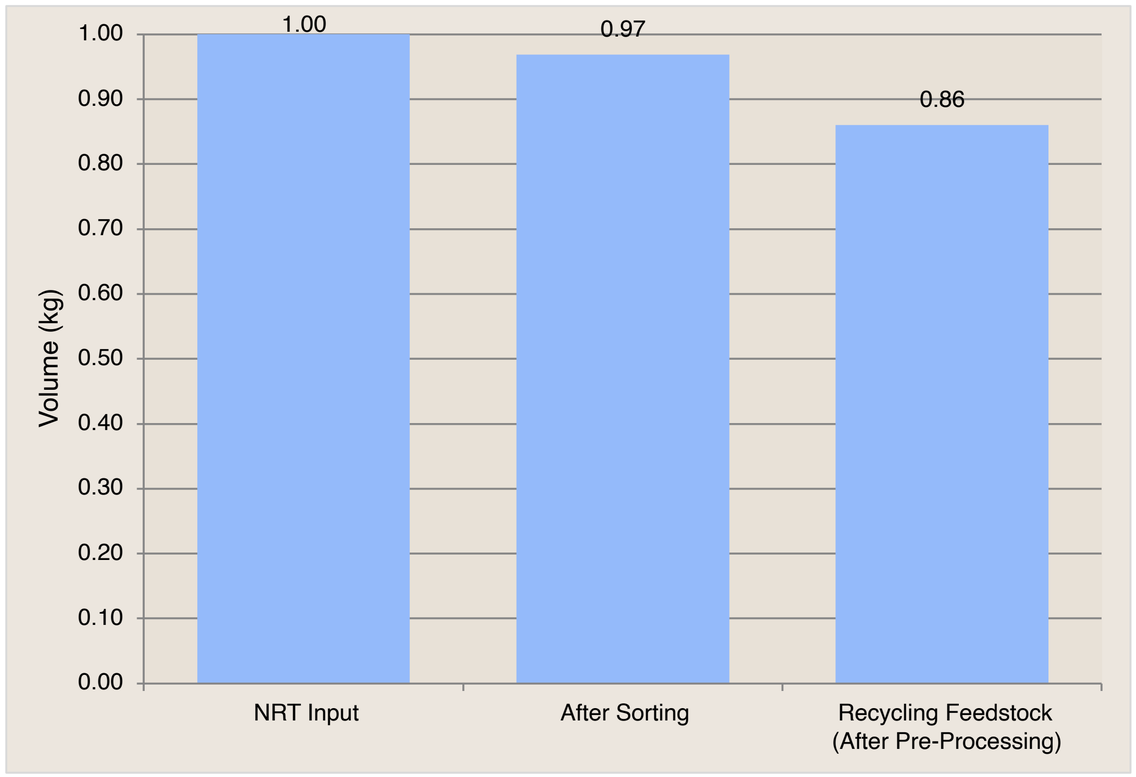


Figure 79: Polyester trial output per kg

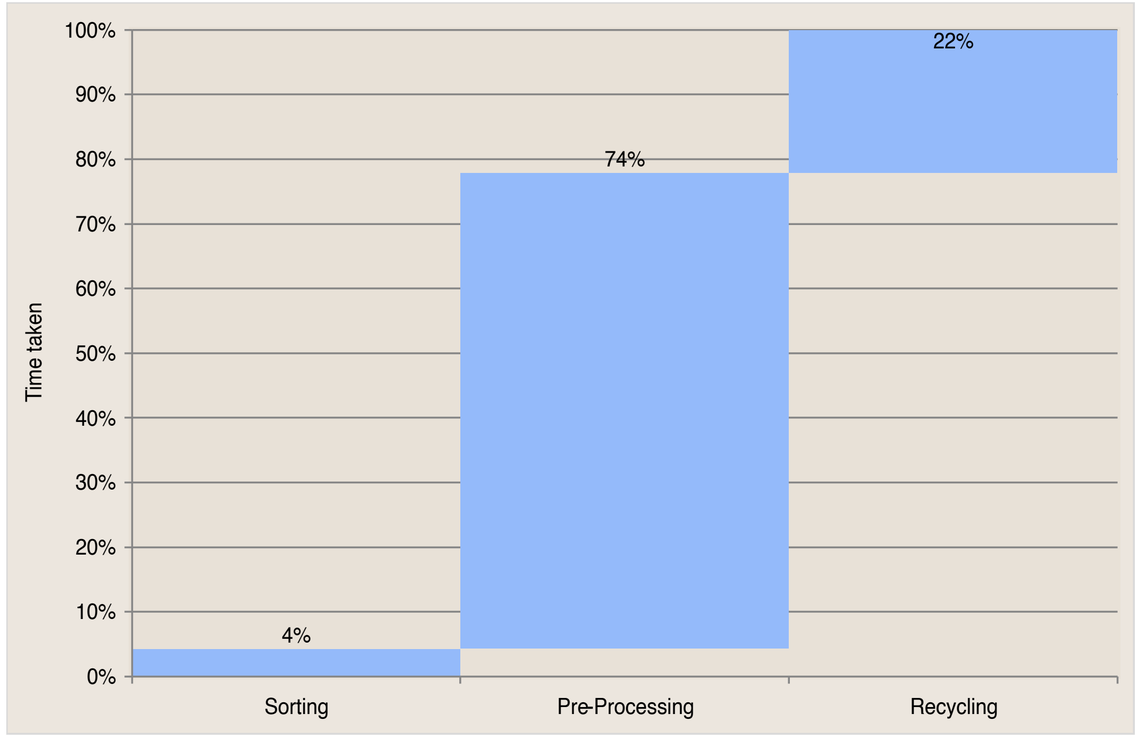


Figure 80: Polyester trial time taken per kg

4.2.2. Spinning Trial 1





Image 24: Polyester Spinning Trial 1 PET pellets (left); Spinning Trial 1 hollow PET pellets (right)

PET pellet performance

Melt-flow index (MFI):
An MFI analysis measures the mass of polymer produced in a specific amount of time, in grams of polymer per 10 minutes (g/10 minutes), to indicate the viscosity of the tested material. FET conducted an MFI analysis on five recycled pellets versus a control pellet.

The pellets from post-consumer duvets and clothing (washed and unwashed) were shades of grey and brown and uneven in shape. They measured between 137g/10min and 246g/10min, indicating that they are much lower in viscosity than bottle flake PET (small fragments of PET bottles) or virgin PET. This indicates that the recycled textile polyester pellets need to be optimised to achieve higher viscosity or molecular weight by using polymerisation, a chain extender, or blending with high-viscosity virgin PET.

The MFI for the virgin PET control pellet was 27g/10 min, and the bottle flake PET pellet was 75g/10 min. This data informed the decision to use virgin rather than bottle flake for the blending and spinning trials.

Fourier transform infrared spectroscopy (FTIR):
FTIR is an analytical method used to identify functional groups and provide information on covalent bonding by analysing the infrared radiation spectrum. The vibrational bands that were detected confirmed that all five batches of PCT pellets were composed of polyester. Full results are shown in Figures 107-108 in the Appendix.

Differential scanning calorimetry (DSC):
DSC is a thermal analysis technique that measures the heat flow into or out of a sample as it undergoes heating or cooling, or remains at a constant temperature. It is used to assess the physical and chemical ageing of recycled PET, as well as to examine its melting behaviour. PET pellets were analysed by heating them from 0°C to 300°C, cooling them from 300°C back to 0°C, and reheating them from 0°C to 300°C at a rate of 10°C/min under a 100% N2 atmosphere.

The recycled PET pellets from PCT exhibited a glass transition around 75°C, a cold crystallisation exotherm near 120°C, and a melting point around 250°C during the first heating. In contrast, no glass transition or crystallisation peaks were observed in the recycled bottle PET pellets, indicating a high level of crystallinity. This means the recycled PET pellets from the trial are not very suitable for polyester spinning because they lack the necessary crystallinity and molecular orientation required for fibre formation.

In the cooling phase, the textile-based recycled PET pellets showed cold crystallisation peaks at approximately 210°C, which were higher than the 192°C peaks seen in the recycled bottle PET pellets. During the second heating cycle, all five batches of recycled PET pellets exhibited similar melting behaviour to that observed in the first cycle. This indicates that these recycled PET pellets can endure multiple recycling processes. Comparing DSC results, the bottle rPET exhibited a higher degree of crystallinity than the textile-based pellets. The similarity between the second and first heating cycles in DSC thermographs for textile-based recycled PET pellets suggests they are capable of withstanding multiple recycling processes. This is a key finding, and full results are shown in Figures 109-113 in the Appendix.

Thermogravimetric analysis (TGA):
TGA analysis is a thermal analysis technique used to monitor changes in the mass of a sample over time as the temperature varies. The PET pellets were heated from 30°C to 700°C at a rate of 10°C/min in a 100% N2 atmosphere. TGA analysis assesses the thermal stability and decomposition behaviour of materials, and the results for five batches of recycled PET pellets revealed very similar thermograms, showing approximately 80% weight loss between 380°C and 460°C, corresponding to the decomposition of virgin PET. Full results are shown in Figures 114-118 in the Appendix.

Yarn performance

In Spinning Trial 1, only the unwashed duvet pellets were extruded into yarn using a master-batch. The master-batch additive was added during yarn extrusion.

Linear density (dTex):
The yarn titer is the weight per unit length and was measured in d/Tex. The machine parameter settings suggested the output yarn should be 93.3 dTex. In reality, the 15% textile-textile rPET, 85% virgin PET yarn demonstrated a yarn titer of 101.47 dTex. This was versus the 100% virgin PET yarn measuring closer to the predicted result of 91.26 dTex. Full results are shown in Figure 120 in the Appendix.

Tensile strength:
The tensile strength of the 15% textile-textile rPET/85% virgin PET yarn was approximately half of the 100% virgin PET yarn. The reduced tensile strength in the virgin PET/duvet blend was attributed to moisture presence during compounding. During the extrusion of the virgin/duvet PET blend, unstable extrusion and melt pump pressures occurred due to moisture in the post-consumer duvet pellets, significantly reducing the textile strength compared to virgin PET filaments. Full results are shown in Figure 121 in the Appendix.

Elongation at break:
The elongation at break of the 15% textile-textile rPET/85% virgin PET yarn was approximately double that of the 100% virgin PET yarn. This indicated the need for increased drawing during spinning. Full results are shown in Figure 121 in the Appendix.

4.2.3. Spinning Trial 2

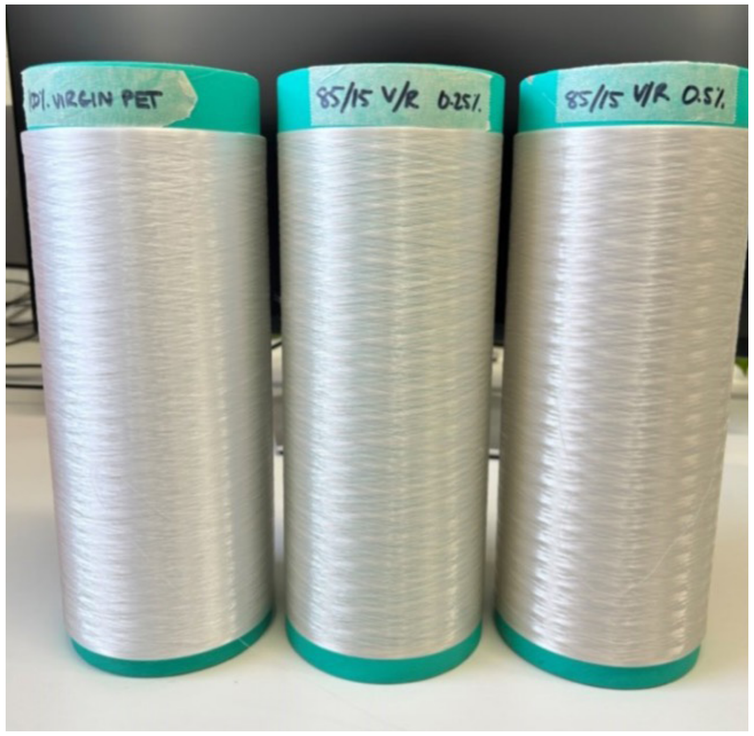


Image 25: Polyester spinning trial 2 yarns

Yarn performance

The unwashed duvet pellets, including 0%, 0.25%, and 0.5% master-batch, were extruded into yarn in Spinning Trial 2 with 85% virgin material. The pellets with no master-batch additive could not be spun into yarn, as there were too many breakages at the spinneret. The following results relate to the yarns with 0.25% and 0.5% additives only.

Linear density (dTex):
The machine parameter settings expected the output yarn to be 93.3 dTex for the virgin yarn, but 66.7 dTex for the 15% textile-textile rPET/85% virgin PET yarn as the metering pump speed was set lower. The output actual linear density for the virgin yarn was 91.26 dTex, within 3% of the expected result. The 15% textile-textile rPET/85% virgin PET yarn with 0.25% additive master-batch pellets was a lower dTex (or finer) than the same yarn with 0.5% and the same machine settings. Both recycled yarns were over 15% away from the expected output dTex, even with a lower metering pump speed. Full results are shown in Figure 122 in the Appendix.

Tensile strength:
The tensile strength of the 15% textile-textile rPET/85% virgin PET yarns with additive was higher than virgin PET, despite being of a lower dTex, as seen in Figure 81. Full results are shown in Figure 123 in the Appendix.

Elongation at break:
The elongation at break of the 15% textile-textile rPET/85% virgin PET yarn with 0.25% additives performed better than the yarn with 0.5% additives. Both yarns with recycled content performed lower in comparison to the virgin yarn. This indicates that the recycled yarns have lower consistency than virgin yarns. Full results are shown in Figure 123 in the Appendix.

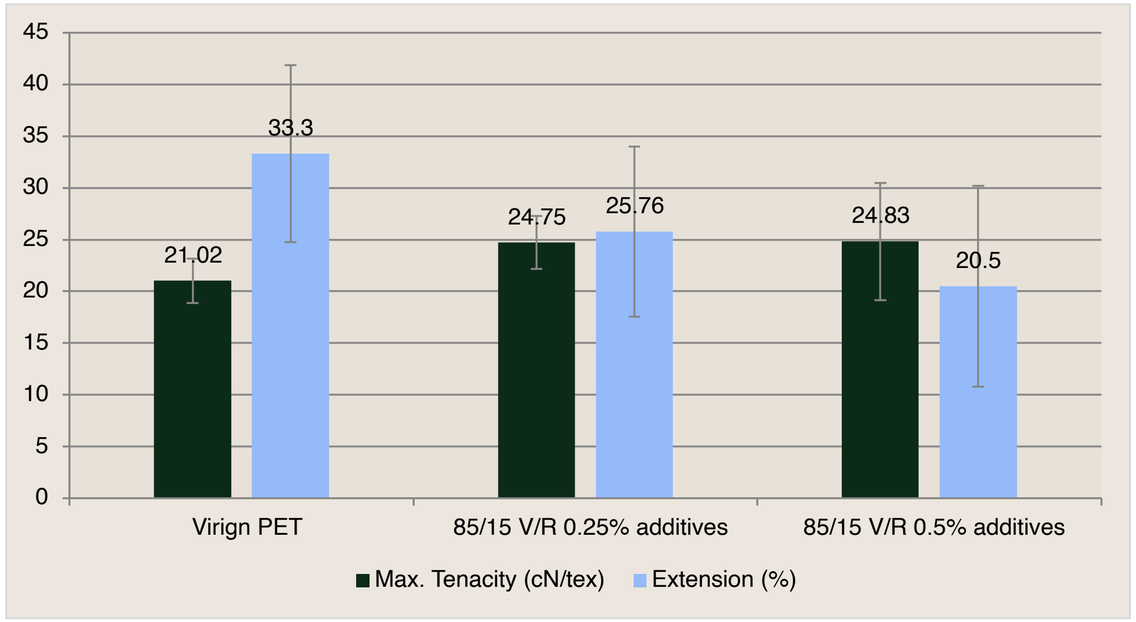


Figure 81: Tenacity and elongation at break for spun PET multifilaments

4.2.4. Spinning Trial 3



Image 26: Polyester spinning trial 3 yarns

Yarn performance

Pellets from unwashed duvet feedstock, including 0.25% master-batch, were extruded into five yarns in Spinning Trial 3, with a mixture of draw ratios, recycled content, and a number of multifilaments. The aim of the trial was to be able to compare recycled yarns with virgin yarns.

For a fair technical comparison of yarns, the machine parameters and output linear density (dTex) need to be comparable. When the same parameters from processing virgin yarns were used for the recycled content yarns, there were yarn breakages. This meant there could be no meaningful comparison to virgin yarns. This trial informed Spinning Trials 4 and 5, which focused more on machine settings for draw ratios and their effect on the resultant properties. Full results are shown in Figure 124 in the Appendix.

4.2.5. Spinning Trial 4

Yarn performance

This trial produced seven virgin yarns with different metering pump speeds, drawing roller speeds, and drawing ratios. The drawing ratio is the difference in speed between the first and last roller in drawing. The first roller can be set at different speeds but still have the same draw ratio with subsequent rollers. These settings can also be combined with changes to the metering pump speed (which affects polymer flow) to alter yarn properties.

The objective was to examine how these parameters impact yarn properties and compare them with yarns with recycled content.

Yarn Sample	Metering Pump Speed	Drawing Roller Speed		Draw Ratio
		Godet Speed 1 (mph)	Godet Speed 3 (mph)	
1	5.0	400	900	2.25
2	5.0	400	1000	2.50
3	5.0	400	1100	2.75
4	5.0	400	1400	3.50
5	5.0	400	1500	3.75
6	7.0	400	900	2.25
7	7.0	400	1400	3.50

Figure 82: Table of Spinning Trial 4 yarn machine parameters

Linear density (dTex):
The actual yarn dTex was comparable to the expected yarn dTex for all yarns. The results showed that draw ratios and speed of the first roller during the spinning of PET pellets have a significant impact on the linear density of the resulting multifilaments. Yarn dTex decreased linearly with increasing draw ratios at the same metering pump speed. In addition, the results showed that increasing the metering pump speed increases the dTex of the yarn, or produces a finer yarn. Full results are shown in Figures 132 and 133 in the Appendix.

Tensile strength:
The results across all yarns showed that the draw ratios and speed of the first roller during the spinning of PET pellets also significantly impact the tensile strength of the resulting multi-filaments. Tensile strength increased exponentially with higher draw ratios at the same metering pump speed, which supports the assumption in Spinning Trial 3 that to meaningfully compare tensile strength between yarns, the draw ratio machine setting needs to be comparable. Full results are shown in Figures 134 and 135 in the Appendix.

Elongation at break:
The results showed that elongation decreases as the draw ratio increases. This is due to enhanced molecular orientation and reduced chain mobility. Full results are shown in Figure 136 in the Appendix.

4.2.6. Spinning Trial 5

Yarn performance

This trial produced eight yarns with 15% recycled content, using different metering pump speeds, drawing roller speeds, and drawing ratios. The objective was to create a yarn using the same machine parameters and linear density as Spinning Trial 4 so the yarn properties could be meaningfully compared to a virgin equivalent. When the recycled content yarns were produced using the same machine settings as virgin materials, the yarns underwent frequent breakages. As such, the metering pump speed and draw ratio had to be reduced further. This results in fewer yarns that could be compared with virgin counterparts.

Yarn Sample	Metering Pump Speed	Drawing		Draw Ratio
		Godet Speed 1 (mph)	Godet Speed 3 (mph)	
1	5.0	350	500	1.43
2	5.0	1000	1500	1.5
3	5.0	750	1500	2
4	5.0	600	1200	2
5	5.0	550	1100	2
6	5.0	175	350	2
7	5.0	155	350	2.26
8	3.0	700	900	1.29

Figure 83: Table of Spinning Trial 5 yarn machine parameters

Linear density (dTex):
The actual yarn dTex was comparable to the expected yarn dTex for all yarns.

Tensile strength:
The results showed that a higher draw ratio increases the tensile strength of the yarn, as with virgin materials. However, introducing recycled material also limited the draw ratios that could be used to extrude yarn successfully. The properties of yarn can only be compared if they have comparable draw ratios and linear density. As machine settings needed to be further altered from Spinning Trial 4, only two yarns with a comparable dTex could be meaningfully compared between Spinning Trial 4 and 5, as shown in Figure 84.

Yarn Sample	Metering Pump Speed	Drawing		Draw Ratio	Actual Yarn (dTex)	Tenacity (cN/tex)
		Godet Speed 3 (mph)	Godet Speed 3 (mph)			
Virgin 3	5.0	400	1100	2.75	146.3	17.4
Recycled 5	5.0	550	1100	2.00	140.3	10.1
Virgin 4	5.0	400	1400	3.50	110.0	25.3
Recycled 3	5.0	750	1500	2	103.7	13.1

Figure 84: Table of Spinning Trial 5 tenacity comparison for yarns with comparable linear density

These results showed that the tensile strength was significantly lower in recycled blended filaments versus virgin filaments with comparable dTex. Recycled yarn sample 5, originally drawn at a ratio of two, was extended by 75% on the tensile tester at UoL so that its draw ratio was identical to virgin yarn 3, as shown in Figure 85.

Yarn Sample	Metering Pump Speed	Drawing		Draw Ratio	Actual Yarn (dTex)	Tenacity (cN/tex)
		Godet Speed 1(mph)	Godet Speed 3(mph)			
Virgin 3	5.0	400	1100	2.75	146.3	17.4
Recycled 5	5.0	550	1100	2.00	140.3	10.1
Recycled 3	5.0	550	1100	2.75	80.15	18.3

Figure 85: Table of Spinning Trial 5 tenacity comparison for yarns with comparable draw ratio

These results show that when a recycled blended filament was drawn at the same ratio as a virgin filament, the tensile strength was equivalent to that of virgin filaments.



4.3. Discussion: Polyester trial

Below are key findings, discussion points, and recommendations from the polyester trial.

4.3.1. Sorting and pre-processing

Manual pre-processing was notably time-consuming, particularly for clothing items. Each garment required between 10 seconds and 1 minute, with the entire trial process extending beyond a month. While this level of pre-processing would be challenging to implement at scale, it was essential for validating the recycling technology, as the process demands high feedstock purity. The time taken for pre-processing was higher for clothing than duvets due to a greater variety of product types and additional trims. While the fraction was found to be readily available within the feedstock, the business case for recycling is not currently viable due to the costs associated with manual pre-processing.

The market for mechanically recycled polyester pellets does not yet exist to fund the production of feedstock processing. This needs to be considered as part of the ATSP business case, as it implicates the need to target certain product categories and anticipate trim removal requirements as the input feedstock, while also pre-processing to match feedstock specifications for a range of recycling technologies as an output.

Duvet feedstock and NIR technology:
Duvet feedstock was selected for trial as it was assumed to be one of the purest fractions. However, the duvet feedstock was not as pure PET as expected. A manual pre-sort can determine synthetic versus natural fill duvets, which can be part of the sorting for re-use process. However, NIR technology is still required to confirm textile fibre purity, particularly for the inner filler. It was found the inner could be a mixture of materials – sometimes polyester, sometimes polypropylene and other materials. This was checked by slashing open the outer and using a handheld scanner, which added time to pre-processing. Whichever type of scanner device is being used, NIR technology is still not perfect.

Broadly, this indicates that standardising product design via recyclability guidelines could reduce the time needed to process duvets through an ATSP system. It also highlights the need for further development and innovation in the fibre scanning space to address layered and filled products.

It should also be noted that the duvet feedstock was too large to pass through the automated fibre sort machine. Therefore, product size should be considered in the design of a fully automated ATSP facility, as accommodating larger items such as duvets could unlock a significant volume of underutilised feedstock.

Trim types:
It was found that the trim types and placement are similar per product category. Easy-to-understand guidelines for de-trimming should be set, but they must also be updated as operators learn about the feedstock. It should also be assumed that feedstock compositions might change over time. For an ATSP facility, this would mean having a mechanism to regularly monitor and update guidance for any manual or automatic pre-processing.

Chemical risks:
The role of product risk assessment in controlling chemical contaminants in feedstock was discussed as part of the trial, as it is not feasible to test every post-consumer garment for chemicals of concern. Products that are of concern – such as those with waterproof finishes or multi-layers – can be removed during pre-sort. This approach eliminates products with known or higher chemical risks in the feedstock sorting process, thereby reducing hazards in the resultant material and minimising the need for testing. This could be implemented when scaling compliant feedstocks in an ATSP facility.

Dehumidifying:
After the first round of feedstock trials, it was found that the textile-textile pellets from washed feedstock were hollow. It was concluded this was due to excess moisture within the feedstock when it was processed, and the material needed to be dehumidified before processing. It was difficult for SATCoL to find a partner to de-humidify the unwashed post-consumer duvets due to fire risk, and a solution had to be found at the SATCoL site. In the context of ATSP, this could mean that an environment that allows humidity control should be considered. Alternatively, a location adjacent to complimentary services should be chosen.

4.3.2. Recycling

The feedstock was fed into the machine whole, which eliminated the need for de-sizing. The recycling equipment features a shredder at the start of the process, which only occasionally blocked as feedstock was fed in whole. In the context of an ATSP facility, further research is needed to understand whether automatically pre-processed materials that are de-sized in addition to de-trimmed would be suitable for this type of recycling technology.

Washed and unwashed clothing fractions:
White duvets and clothing were successfully recycled into pellets. However, neither the washed nor unwashed coloured clothing fractions could be recycled through either the 50- or 150-micron filter, and the feedstock did not meet the required machine pressure to produce a pellet. It is unclear whether the detergent that was used influenced the ability of the feedstock to be recycled, or whether it was the feedstock itself. It was noted that dark and brightly coloured dyes and organics, plus treatments such as starch, affect density or block filters. At present, this reduces the feasibility of processing coloured pellets, which supports the findings from other trials, such as those by Accelerating Circularity, where colours or finishes can affect machine pressure. It should be noted that there was no master-batch added to the clothing fraction, and this is an area that requires further research and development.

In the context of an ATSP facility, dye removal for colours and removal of organics could be considered to increase the viability of the feedstock.

Coloured feedstock:
The coloured feedstock had more product variation, with the fraction consisting of a variety of fleece tops, t-shirts, and tracksuits. Fabric texture was found to be an issue, with a mix of whole flat items and thick fleece fabrics affecting feedstock density and creating surges that meant the pressure was not stable or regulated. This remains a technical limitation of the recycling technology.

Further research is needed into enhanced preparation to blend and homogenise feedstock, including sorting for fabric type, shredding, drying, and removing disruptors. During the processing of the first batch – post-consumer unwashed duvet feedstock – a high amount of organic content was found. This was felt to be specifically because of the nature of the product, with regular use and close contact with human skin. The result of this first batch led to subsequent batches being washed to understand its impact, with the washing of feedstock commonly built into plastic recycling processes. The impact of washing on pellet performance can be found in the next section, 4.3.3.

4.3.3. Pellet performance

The MFI analysis of Spinning Trial 1 pellets with no master-batch added showed that the recycled material has a much higher viscosity than virgin materials. A master-batch chain extender can be compounded with the pellets to improve this, shown in Spinning Trial 2 to be optimum at 2.5%.

The MFI analysis did not conclude that laundering improves pellet quality. While the washed duvet performed better than the unwashed duvet, the unwashed clothing performed better than the washed clothing. The results of the washed duvets could have been driven by the fact that they were wet when they were recycled. This could warrant further testing of washed feedstock for thermomechanical recycling.

The bottle flake was less homogenous and performed worse than expected versus virgin in the MFI analysis, so the yarn trials were compounded with virgin materials rather than bottle flake. PET melts at 250-260oC, so the machine was first set to this in the MFI analysis. None of the samples melted at 250oC or 255oC, so the temperature was increased to 260oC. This suggests that recycled pellets with no master-batch added have a higher melting point than virgin PET. FTIR analysis showed all samples to be polyester.

4.3.4. Yarn performance

The feedstock was fed into the machine whole, which eliminated In Spinning Trial 1, the textile-textile pellets were compounded with virgin material and master-batch in spinning to create a yarn that was 85% virgin PET and 15% textile pellet. Bottle flakes were not used as they performed poorly in the MFI analysis. It was at yarn extrusion that it was realised that the pellets were hollow, and this caused an issue in processing due to fluctuations in pressure as the air pockets went through the spinneret. They could not be spun as there were frequent breakages. It was concluded that the hollow pellets were caused by moisture content within the feedstock, and a solution was needed to de-humidify the material and add master-batch before processing the material in the subsequent trials.

Further batches of unwashed duvet pellets were dried with a fan and dehumidifier in a polytunnel and subsequently recycled into more spherical pellets with no air spaces or hollowing. A key learning from this trial is that the feedstock needs to be dry.

Recycled vs virgin:
Subsequent spinning trials demonstrated differences in the material's behaviour when spinning yarns with recycled content versus virgin material. Due to frequent breakages, recycled materials needed a lower draw ratio and speed than virgin materials, and it was found that increasing the draw ratio has an exponential impact on the tensile strength of the resultant yarn.

Ultimately, the results showed that the primary challenges in spinning blended recycled multi-filament yarn lie within the spinning process and optimisation of machine settings. Comparing a blended recycled multi-filament yarn with a virgin yarn produced at the same draw ratio demonstrated comparable tensile strength. This trial was limited in time, and further research is needed to optimise machine parameters.

The melt-blow trial demonstrated the potential for post-consumer polyester pellets to be melt-blown at 100% recycled content for potential applications such as duvet and pillow filling, wadding in jackets, and composite products. Further research is needed to explore and optimise outputs.

4.3.5. Conclusions

- This trial successfully processed non-reusable post-consumer duvets into yarns using thermomechanical recycling technology
- It demonstrated that duvet feedstock can be extruded into multi-filament yarns when blended with virgin PET and melt-blown for non-woven textile applications at 100% recycled
- Further research and investment are needed regarding feedstock preparation and optimum settings to spin yarn that integrates recycled content and the potential of colour removal technologies



5. WOOL TRIAL

5.1. Methodology: Wool trial

Trial aims

The aims of the trial was to:

- Sort, pre-process, mechanically recycle fibre, spin yarn, and manufacture woven blankets from UK-sourced post-consumer wool textiles
- Compare the output properties of yarn and the final product against commercial market requirements

Supply Chain Step	Project Partner
Collector/Sorter	SATCoL
Recycler	Iinouiio
Yarn spinner	Camira
Product manufacture	Alex Begg
Testing	Bureau Veritas

Figure 86: Table of wool recycling supply chain partners

Specification Type	Trial Specification
Feedstock volume	265kg
Source	Post-consumer textiles
Fibre type	95% wool, 5% other fibres
Fibre composition	>95%
Fabric construction	Knitted
Colour	Light (Grey – like shade iinouiio shade ‘Nippy Squirrel’) Dark (Blue – like iinouiio shade ‘Daybreak in Dewsbury’)
Additional information	Clothing, home textiles
Sorting type	Auto-mated NIR sorting: composition Manual sorting: construction
Pre-processing type	Semi-automated: Eastman cutting machine
Pre-processing output	De-trimmed garments

Figure 87: Table of wool feedstock specification

Trial process

Action: SATCoL sorted feedstock using a manual process, collecting 2mt over a four-week period. Knits were manually separated from wovens. The material was pre-processed to remove contaminants using an Eastman cutting machine.

Action: The material was processed on the NIR automated fibre sortation line to select the two colours outlined by Iinouiio, ‘Nippy Squirrel’ and ‘Daybreak in Dewsbury’. When they inspected the feedstock, Iinnuiio also conducted an additional removal of contaminants, including buttons, safety pins, and labels. Other than contaminant removal, the garments were kept whole.

Action: A lubricant was added to the material’s surface to preserve fibre length and prevent ‘fly’ 24 hours before the recycling process.

Action: The spinning process was conducted to create 3nm Z twist yarns, which were tested for average oil content, average count, strength, elongation, and unevenness, CMV, and imperfection index.

Action: To trial the loom set-up, a sample piece was woven at Alex Begg, creating nine blanket units. Two sample blankets were tested for their chemical and physical properties versus market requirements.

Action: Following a successful trial, the loom settings were adjusted, and the remaining yarn was used to weave the bulk piece, resulting in 20 units.

5.2. Results: Wool trial

5.2.1. Process efficiency

Figure 88 demonstrates that for every kg pre-processed in the steps at an ATSP facility, there would be 0.994kg output into the recycling process. The most time-intensive process in this trial was sorting, shown in Figure 89. This reflects that the recycling of post-consumer wool textiles already exists commercially.

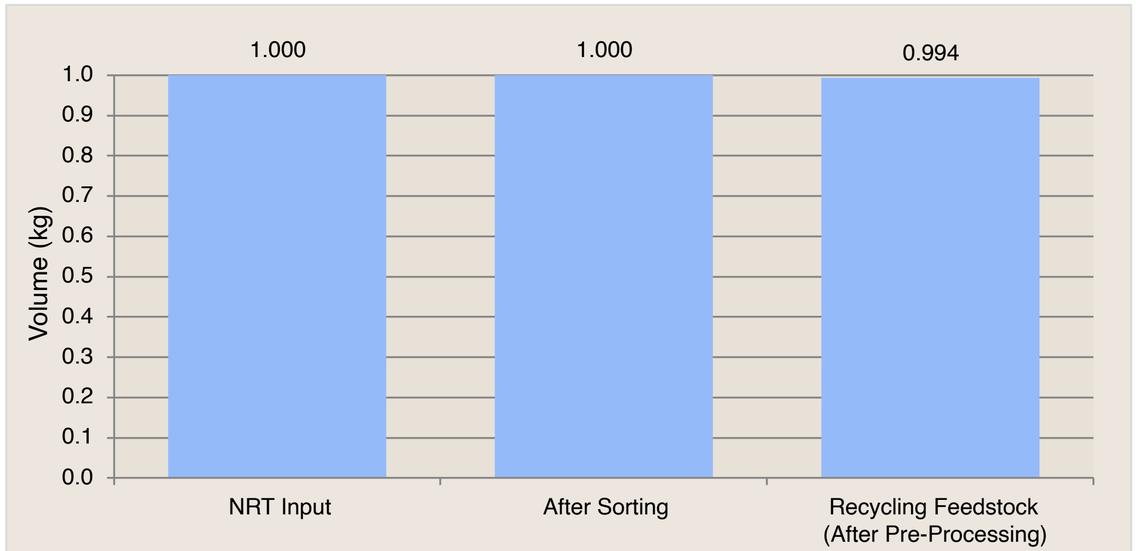


Figure 88: Wool trial output per kg

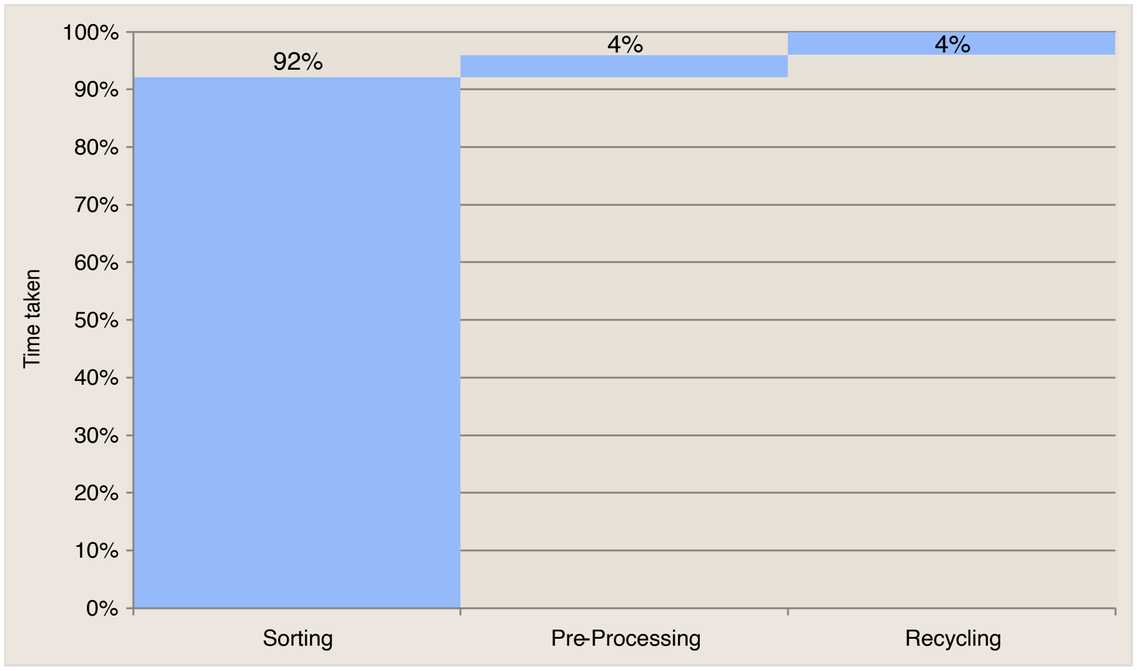


Figure 89: Wool trial time taken per kg

5.2.2. Yarn performance

Yarn was tested to show 100% recycled content, and the average oil content was 5.83%.

As the feedstock comprises mixed wool fibre types, no comparison can be made to a standard yarn whose performance is influenced by the specific wool type used as inputs.

Yarn Performance Parameter	Result
Recycled content	100%
Average oil content	5.83%
Average count (yarn size YSW)	6.15 YSW
Strength	673.48 g/f
Elongation	9.81%
Unevenness, CMV, and imperfection index (thin - 40%/Km)	20
Unevenness, CMV, and imperfection index (thin - 50%/Km)	0
Unevenness, CMV, and imperfection index (thick - 35%/Km)	130
Pre-processing output	De-trimmed garments

Figure 90: Table of wool yarn performance

5.2.3. Physical product performance

Colour fastness to light, perspiration, and rubbing performed well, achieving 4-5 rating for ISO 105-B02:2014. Pilling performed worse than expected, achieving only a 2. Full results are shown in Figure 142 in the Appendix.

5.2.4. Chemical product performance

The blankets were tested for alkylphenol (AP) and alkylphenol ethoxylates (APEOs), azo-amines, arylamine salts, chlorophenols, and extractable heavy metals. As there is little industry guidance on the risks of legacy chemicals in post-consumer materials, these tests were determined using a risk-based analysis from the largest public industry study on this topic from IKEA and H&M[32], as well as expert knowledge. Each chemical returned a ‘Not Detected’ result. Full results are shown in Figure 143 in the Appendix.

5.3 Discussion: Wool trial

5.3.1. Sorting and pre-processing

While SATCoL removed the trims in pre-processing, Iinouiio needed to complete another round of trim removal before fibre shredding to ensure no obstruction in the fibre-tearing machine could damage its mechanics. This included the removal of further buttons, safety pins, and labels, as well as a few garments with multiple small embroideries that were unfeasible to de-trim.

Therefore, to ensure only one round of pre-processing is required, an ATSP facility should establish an agreement or Standard Operating Procedure that details contaminants and unsuitable items that must be removed and where they are likely to appear.

De-sizing, cutting, and de-trimming:
De-sizing garments into smaller shapes would impact the quality of the resultant fibre. At the same time, any cutting reduces the fibre length in the mechanical recycling of wool, so only de-trimming was applied. This is acceptable in the current set-up at Iinouiio, as garments are hand-fed into the machine, but it is unknown how scalable this method is. This requirement may vary per mechanical wool recycler, and an ATSP facility would need to ensure it met specific recycler or customer requirements.

Colour:
Sorting for colour in this trial demonstrated that colour is highly subjective. Particularly with NIR technology, colours look different under different background lights and angles, reflecting from a non-uniform textile surface. The camera's position plays a role in detecting colour, and the feedstock colour did not match on-screen expectations. The machine had to be trained to eject additional colours in the palette from the pre-determined NIR technology colour guideline.

In the context of an ATSP facility, it would be time-consuming to train the machine for potentially infinite customer colour palette requirements. Therefore, some level of standardisation could be considered to scale colour-sorting resources effectively. Brands and retailers traditionally work with very specific colour standards, such as Pantone, and will reject developments if they are outside of a colour tolerance. This specificity will be difficult to achieve for wool, particularly as it is relatively low volume compared to other fibres passing through an ATSP facility.

5.3.2. Recycling

The two-coloured batches of feedstock behaved differently in processing and spinning. Machine parts were cleaned and settings tweaked between the batches, and the second batch performed much better. This is normal in the woollen spinning process, where each batch behaves differently, and expertise is needed to ensure the materials are treated correctly to make them suitable for upstream processing. However, it should be noted that wool recycling is already an established process within the industry.

5.3.3. Yarn performance

The trial revealed that there was no way to compare yarn properties to an industry standard. This was due to the large variation in product types in the feedstock (coarse and fine yarns and the subsequent wool micron). As a result, there can be no comparison to virgin yarns, and there was found to be no specific market requirement for yarn quality.

The NIR automated fibre sorting technology cannot distinguish between animal hairs such as wool and cashmere, so the feedstock could contain both.

5.3.4. Product performance

Alex Begg observed that, while the yarn strength was weaker than standard virgin wool yarns, it was usable.

The fibre length was shorter, which meant the yarn pulled apart more easily. The trial lowered the speed of the loom from 350rpm to 300rpm for sampling and 250rpm in final blanket production to reduce breakages (it is important to note that breakages also occur in virgin yarns). This represents a decrease in loom efficiency by one-third, with the aim to reduce the time needed to repair the blankets afterwards. Additionally, hand-repairing the blankets when they are taken off the loom is time-consuming, so it is best to reduce breakages in manufacturing to a minimum. At scale, slowing the production to such an extent would impact the efficiency of the process.

While two out of nine blankets needed repairing after the sample weaving process, they were still woven successfully. Despite slowing the machine for the bulk trial, 12 out of 20 units needed to be repaired after the bulk weaving process. Commercially, this would mean the product is rejected. Another variable that could be adjusted to reduce breakages is to use more weft selectors on the loom. Additionally, it is important to note that the yarn in this trial was 100% recycled, and blending with virgin material could greatly improve product performance, as could experimenting with product design.

Chemicals:
According to a large-scale study by IKEA and H&M[33], APEOs are a significant risk within post-consumer wool textiles. The study showed non-compliant levels of APEOs in 100% of 153 post-consumer samples tested across different regions. This was the only publicly available large-scale study of legacy chemicals in post-consumer feedstock and was not specific to PCT in the UK.

The test results in this trial showed no restricted chemicals above the standards set by AFIRM Group and Oeko-tex. While this is a positive result for the trial and the business case for F2F recycling, it was only one data point. Therefore, more research is needed to best understand how to mitigate risks and embed chemical testing within the product development process, as is in place for virgin materials. As UK REACH[34] lists are updated every six months, this result could show that strengthening legislation is beginning to control the risk of legacy chemicals in post-consumer feedstock, but further publicly available research is needed on this topic.

Design:
Alex Begg purposefully designed products with a recycled yarn in mind by:

- Creating a product specification that was ‘chunky’. The chunkier texture would allow for repairs that remain hidden within the fabric, unlike a lighter blanket where mending would be more visible
- Using Donegal yarn rather than a block colour in the speckled effect. Solid-coloured yarns remain difficult to achieve as the colour-sorting process is not accurate enough, and the feedstock is heterogeneous
- Adjusting the finishing. The blankets were finished with scouring and steaming. It was purposefully not milled or finished with any raising processes to try and safeguard the fibre strength

Despite this, further development work would be needed to create a product with fewer breakages in commercial production. This could include plying the yarn to double the thickness or blending with virgin materials.

Regarding colour, Alex Begg has experienced that its customers demand more uniform colour quality than can be expected in recycled products. In scaling, it will also be difficult to ensure colour continuity batch to batch because each run will be unique. This would be a very different way of working for consumers and retailers than currently, where colour uniformity is an exact science.

5.3.5. Conclusions:

- This trial successfully processed non-reusable post-consumer woollen garments into blankets with 100% recycled content
- It demonstrated that a Standard Operating Procedure is required to ensure accuracy in pre-processing
- Further research is needed regarding product design and optimum yarn specifications that can incorporate recycled materials and meet commercial product requirements
- Materials were found to be UK REACH compliant, but further investigation is needed into how to manage the risks of legacy chemicals at scale

6. DISCUSSION

This section summarises the key findings and conclusions of the recycling supply chain trials.

It should be noted that the difficulty in processing materials in all trials was driven by the heterogeneous nature of the feedstock. There were unknowns in terms of age, composition, and chemical contaminants. Therefore, in addition to the key findings listed below, there is a clear need for an industry-wide approach to designing for recyclability and integrating circularity components. This would enhance traceability and provide clarity on an ATSP facility's processing feedstock.

6.1. Automated sorting and pre-processing

Automated feedstock sorting and pre-processing is pivotal for a commercially viable ATSP business case.

Key finding:
A common theme between all trials was the time needed to manually pre-process the PCT. As the feedstock is low value and does not yet have a market, trial participants repeatedly raised that this is, at present, not commercially viable through manual preparation methods. This was particularly important in the cotton trial, where de-trimming was accompanied by the need to manually cut pieces to a set size, while the mechanical wool and thermomechanical polyester trials only required de-trimming. An ATSP facility must consider the different material preparation specifications for each recycling technology because, for example, wool mechanical recycling requires the need to preserve fibre length, whereas, with other methods, there is a need for de-sizing. Additionally, the research showed that seam removal is not necessary for mechanical cotton recycling but is required for thermomechanical polyester.

Key finding:
The trials resulted in 11%, 14%, and 0.6% of material being lost in pre-processing for cotton, polyester, and wool, respectively. A common finding across all trials was the need to set guidelines per product category to consistently identify trims and target categories to maximise material for recycling. The volume of material expected to be lost is an important part of the business case, as there is also material lost in recycling and spinning. With low-value material, there is a commercial need to maximise the value per bale. An area for further research would be exploring whether there are other potential streams for trims, such as remanufacturing or recycling, to generate further income for an ATSP facility.

Key finding:
Where possible, using readily recyclable compositions and reducing the number of trims to be removed from garments will clearly increase processing efficiencies.

Key finding:
Sanitation and hygiene should be an essential consideration for an ATSP facility design. While multilayer and dirty textiles were removed during the sorting process, some dirty and blood-stained items remained among the NRTs sent to the mechanical cotton trial (but not the thermomechanical polyester or mechanical wool trials). This perhaps demonstrates differing attitudes towards hygiene between individuals and, therefore, further research should be conducted into best practices for risk management and how to minimise cost. There is no standard for this, and approaches seemingly vary across geographical regions. The volume of NRTs that are soiled and unhygienic and, therefore, cannot be sent forward to recycling should also be researched and considered in the ATSP business case.

6.2. Chemical risk

A legacy chemical risk in post-consumer feedstock must be controlled in ATSP facilities.

Key finding:
While no UK REACH non-compliant materials were found in the cotton and wool trials, and the results for polyester are outside the scope of this report due to timing, the topic of legacy chemicals in feedstock was discussed at length throughout the trials. There was an acknowledgement from all supply chain actors that this is a risk. The current standard industry practice is that the cost of compliance is borne by the actor selling the material. To this end, upstream actors felt it was the responsibility of sorters to guarantee the compliance of recycled materials.

However, it was discussed that it is not physically or financially feasible to test every separate garment for legacy chemicals. One possible solution would be to introduce a risk-based approach per fibre type. Project participants suggested that this could be controlled by eliminating product categories most likely to contain legacy chemicals, such as finishes or prints. However, further research is required to understand what those controlled categories should be, as there was found to be little publicly available data on feedstock availability and associated risks. This needs to be considered in the business case of an ATSP facility.

Key finding:
It should be noted that UK REACH regulation is revised every six months, which can alter the compliance requirements for legacy chemicals. Changes to legislation such as UK REACH should be transparently documented over time for specific chemicals in a data-readable format so they might be used to create risk-based assessments of PCT. Digital Product Passports and similar circularity data collection mechanisms should also record compliance data for restricted chemicals. This supports future assessments against updated legislation and market standards.

6.3. Coloured feedstock

An ATSP facility must consider solutions for coloured feedstock.

Key finding:
In the cotton trial, the dark-coloured feedstock had been less accurately detected by the automatic fibre sorting technology, leading to a lower cotton content on average. This is a known limitation of NIR technology, which has a higher level of certainty in detecting composition on light-coloured feedstock.

Key finding:
The NIR automated fibre sorting technology needed specific training for colours within the mechanical wool recycling trial. At scale, it will be impractical to sort for a new colour for each client specification. Therefore, an ATSP facility could consider a standardised colour offering for mechanical recycling technologies.

Key finding:
Colour also had implications in the polyester thermomechanical recycling trial, where the coloured post-consumer feedstock could not be processed by the recycling technology. White polyester is processed better than dark-coloured polyester, indicating that the numerous dyestuffs present in coloured post-consumer clothing are unknown and impact the feasibility of recycling. An ATSP facility could investigate colour removal technologies on-site, and at what stage they might be most beneficial. If this was done before automatic fibre sorting, it could not only enhance sorting accuracy but also improve the recyclability of the output for mechanical technologies in particular.

6.4. Recommendations for further research

These trials provided insights into a textiles ecosystem within the UK, but there remain some areas which require further research to reach meaningful conclusions. These include:

- Piece size for cotton and wool mechanical recycling to optimise fibre length
- If and how feedstock sanitation could be achieved cost-effectively at scale
- The technical feasibility of automatic pre-processing per recycling technology and the potential for removed trims as an additional value stream via remanufacturing or recycling
- The development of further detailed pre-processing guidelines as part of feedstock requirement guidelines to optimise resource efficiency
- Mechanisms to embed risk management for legacy chemicals in post-consumer feedstock.
- Partnerships with colour removal technologies

The recycling supply chain trials demonstrate the technical potential for the UK to utilise its post-consumer NRTs as a resource stream rather than a waste stream. Standardised and automated processes, procedures, and guidelines for design, sorting, and pre-processing will need to be utilised to enable the efficient transformation of low-value NRT products into a higher-value output of feedstock for F2F recycling. Finally, avenues for further output value streams could be explored around dyes and components for reuse and remanufacture.

APPENDIX

Appendix 1: Cotton



Image 27: Laboratory-scale Laroche Cadette tearing machine (left) and Mesdan carding machine (right)



Image 28: Recycled cotton yarns

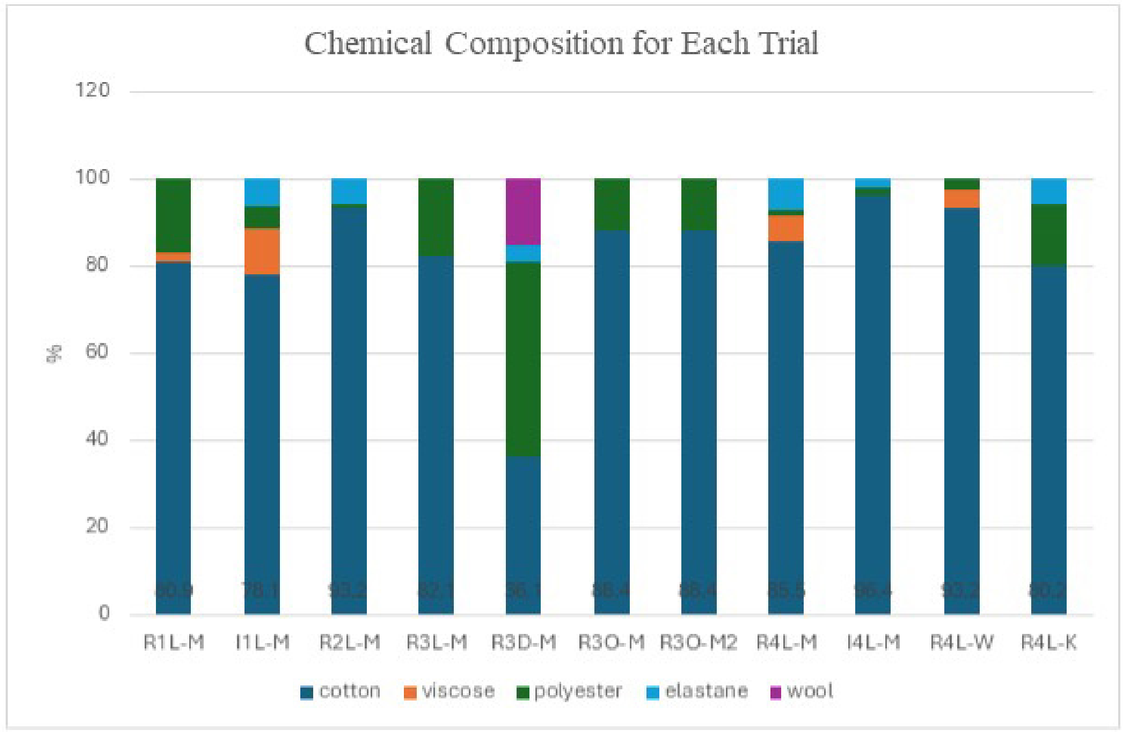


Figure 91: Cotton fibre analysis: Composition

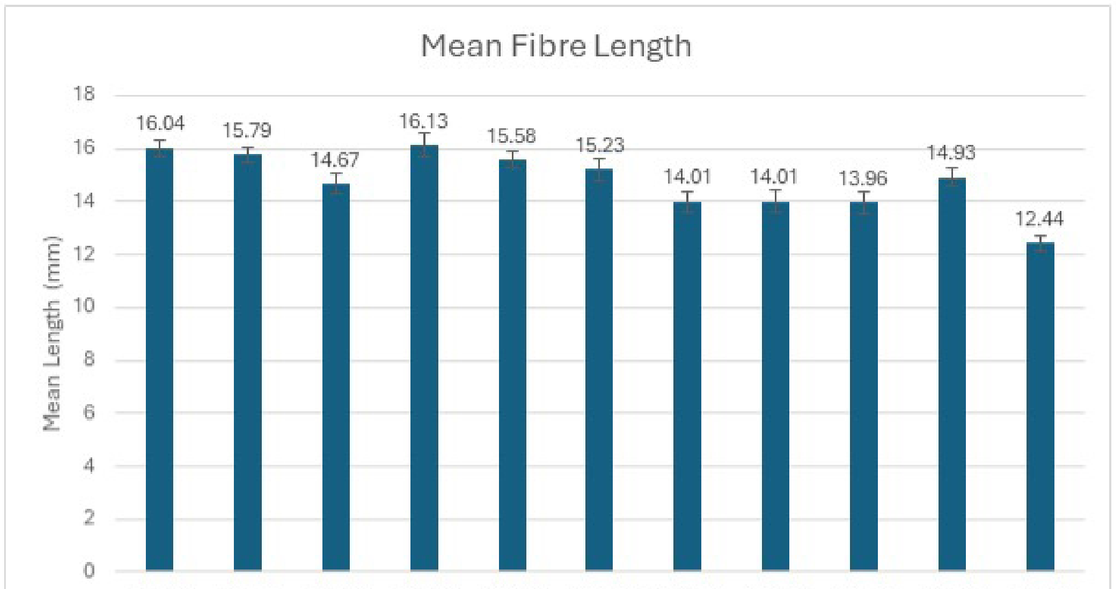


Figure 92: Cotton fibre analysis: Mean fibre lengths

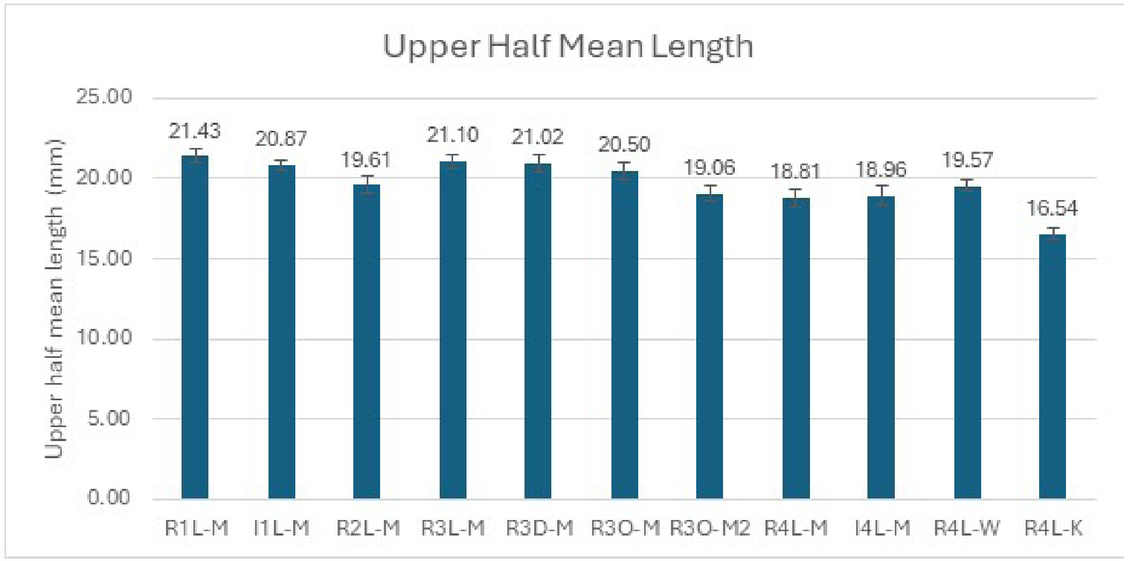


Figure 93: Cotton fibre analysis: Upper half mean length

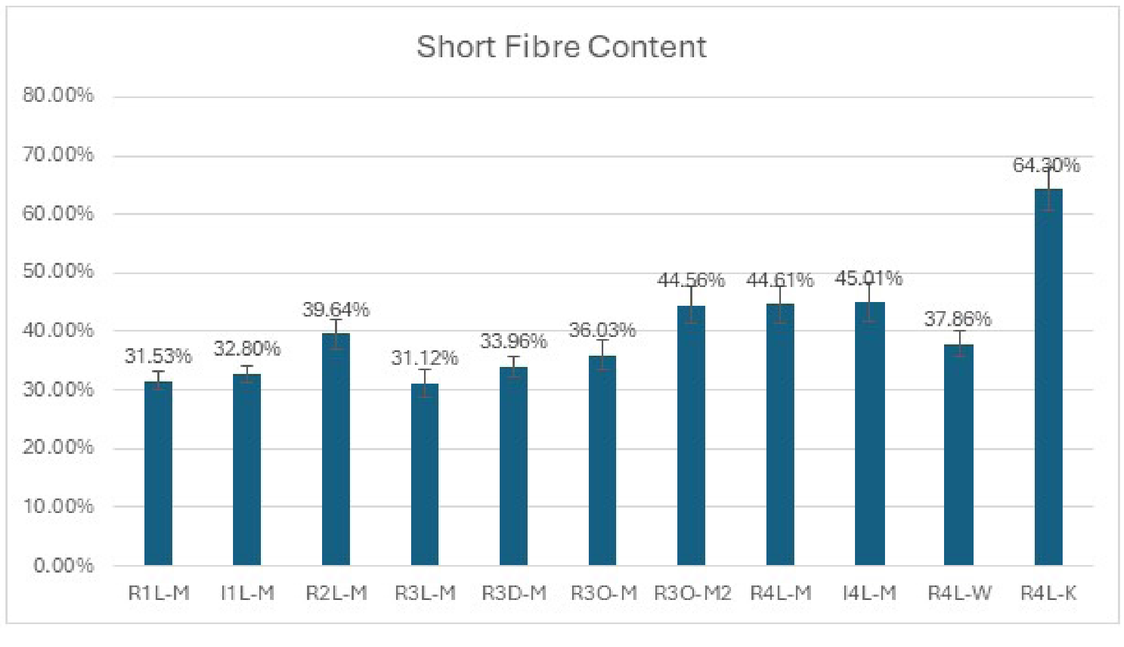


Figure 94: Cotton fibre analysis: Short fibre content

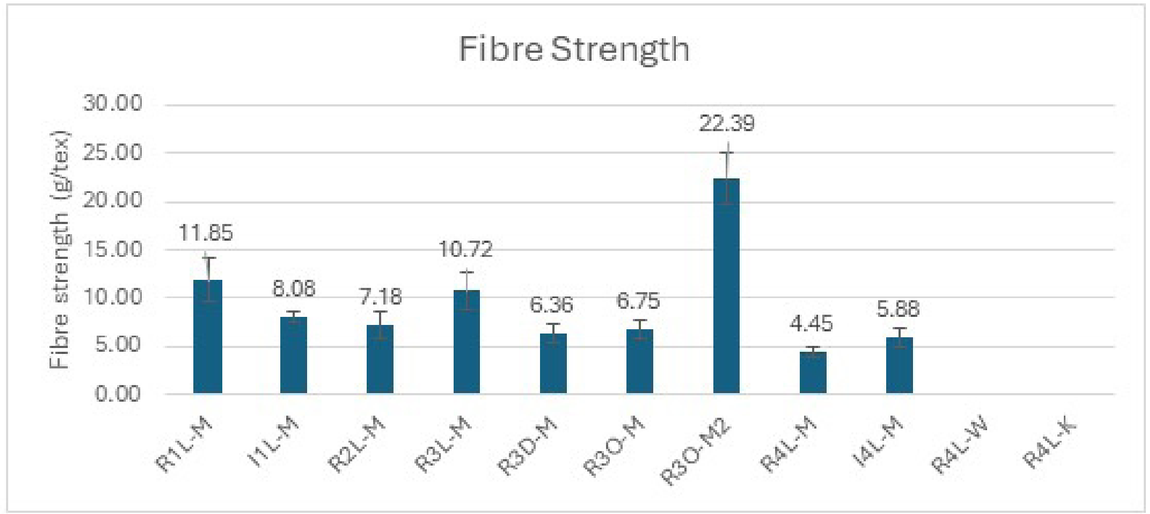


Figure 95: Cotton fibre analysis: Strength

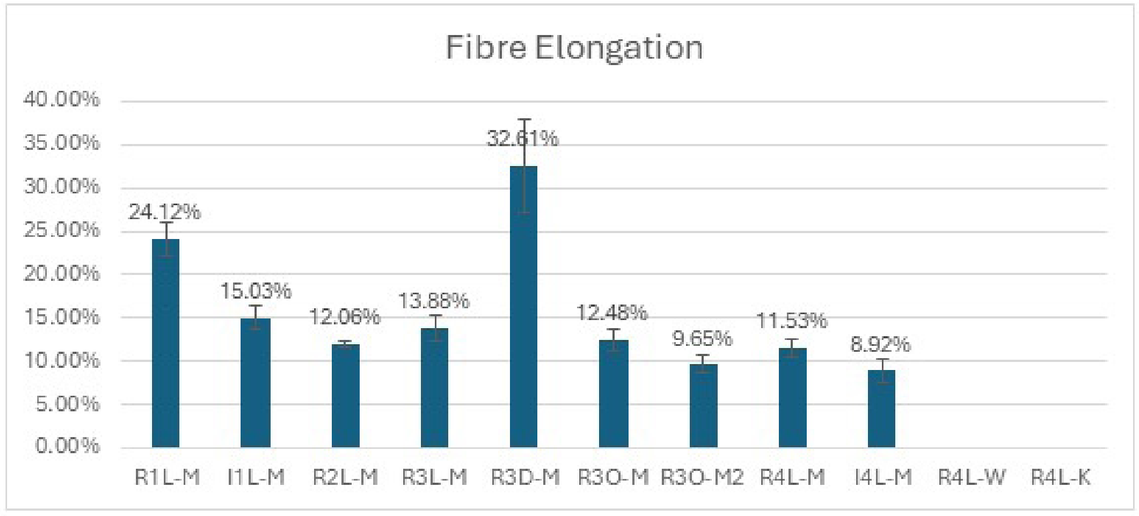


Figure 96: Cotton fibre analysis: Elongation

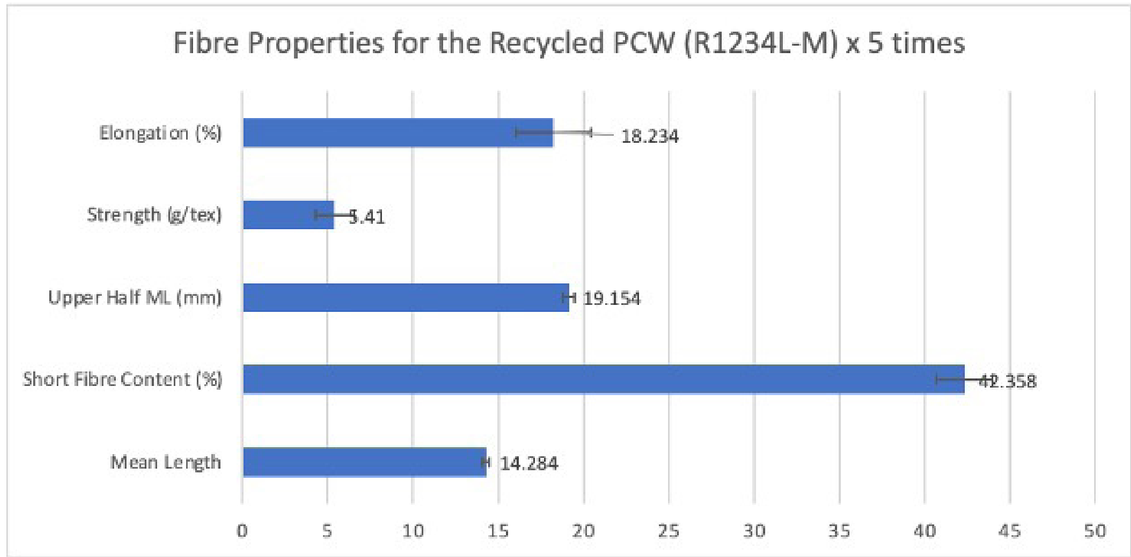


Figure 97: Cotton spinning trial: Fibre properties

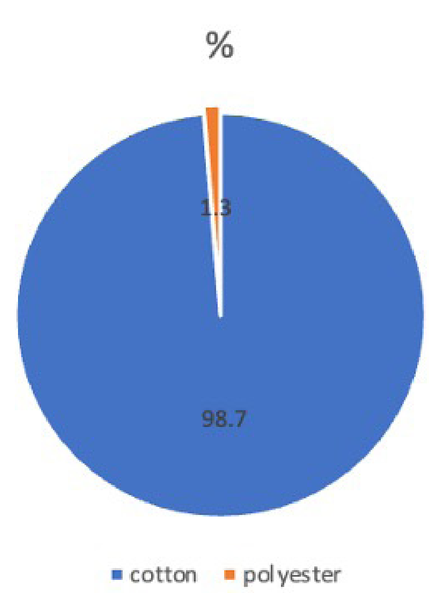


Figure 98: Cotton spinning trial: Fibre composition

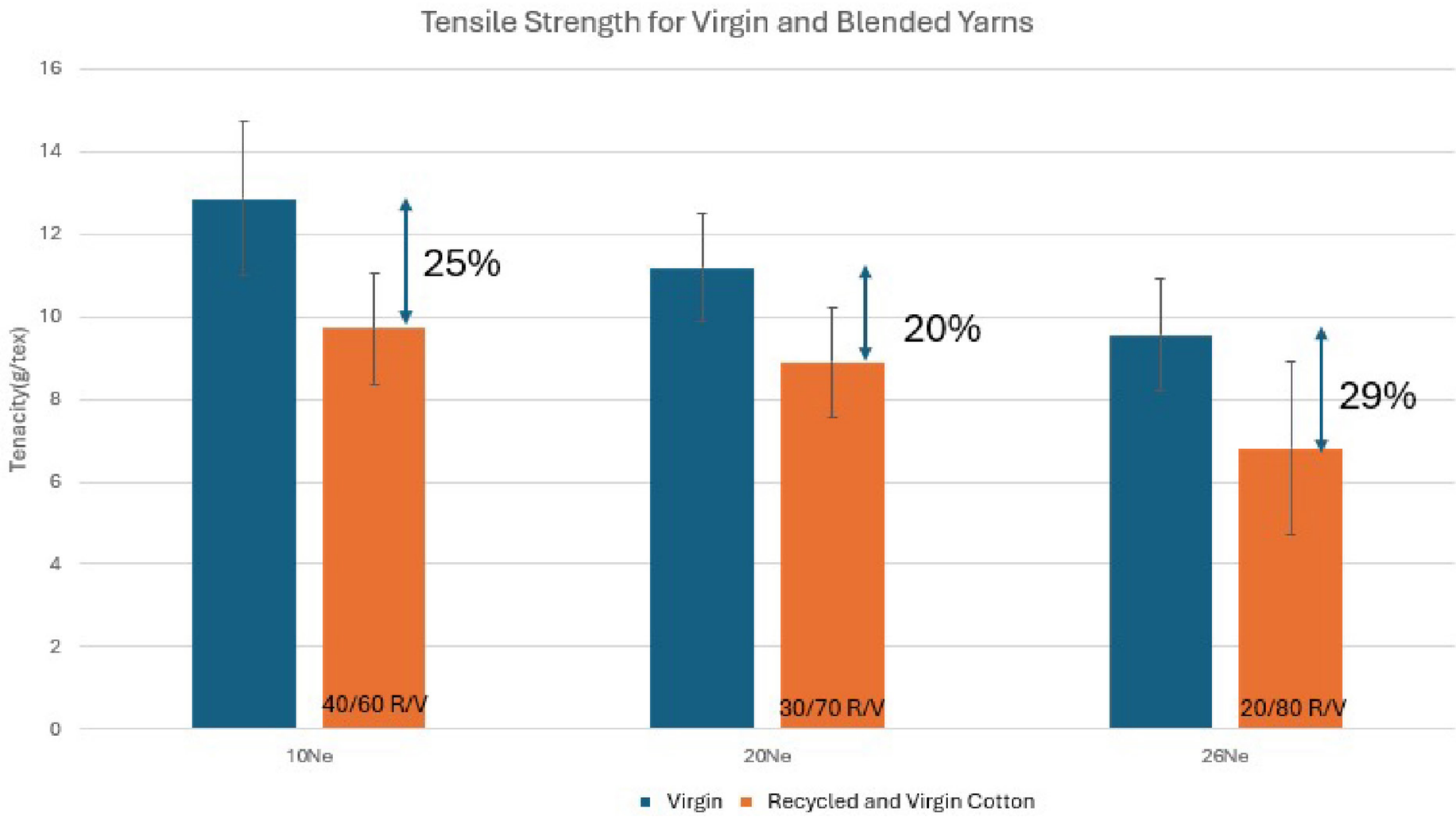


Figure 99: Cotton spinning trial: Yarn tensile strength

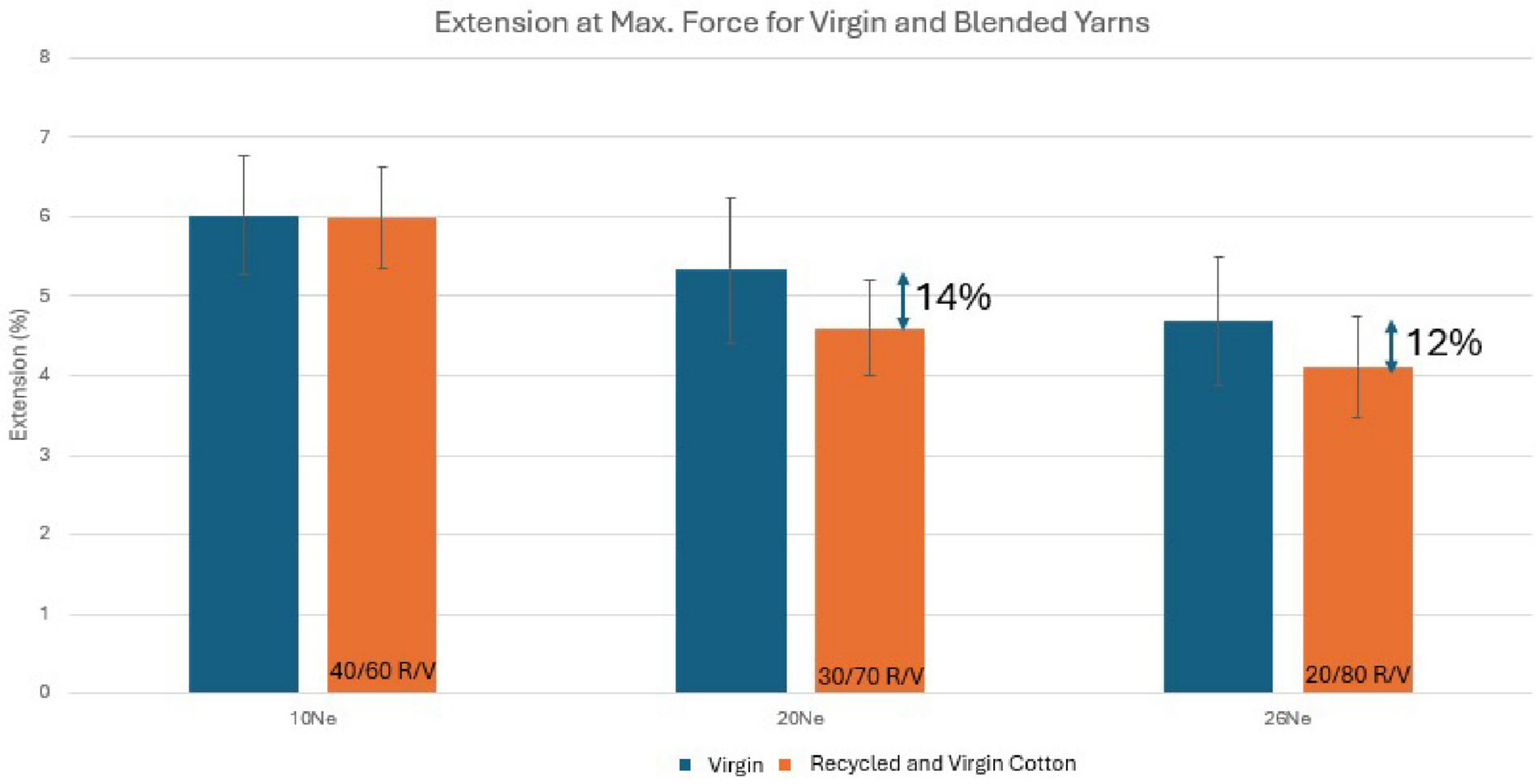


Figure 100: Cotton spinning trial: Yarn elongation at max force

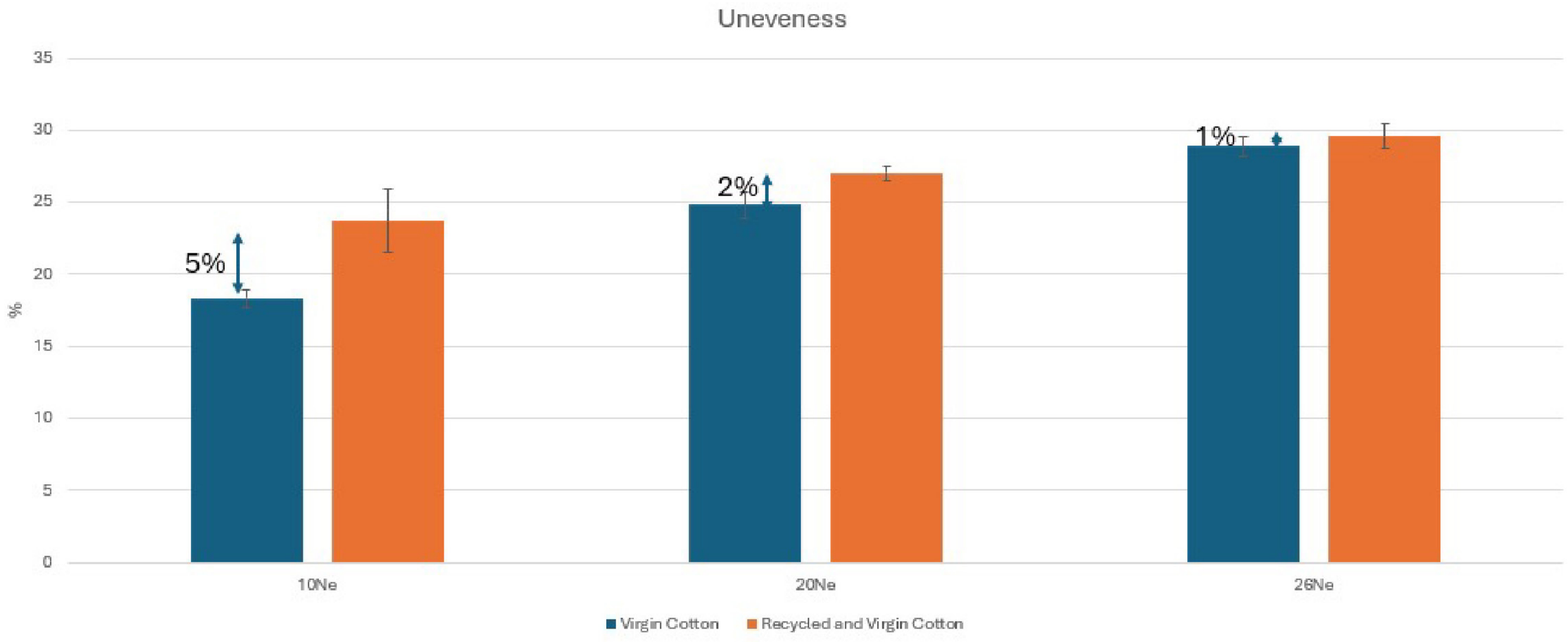


Figure 101: Cotton spinning trial: Yarn unevenness

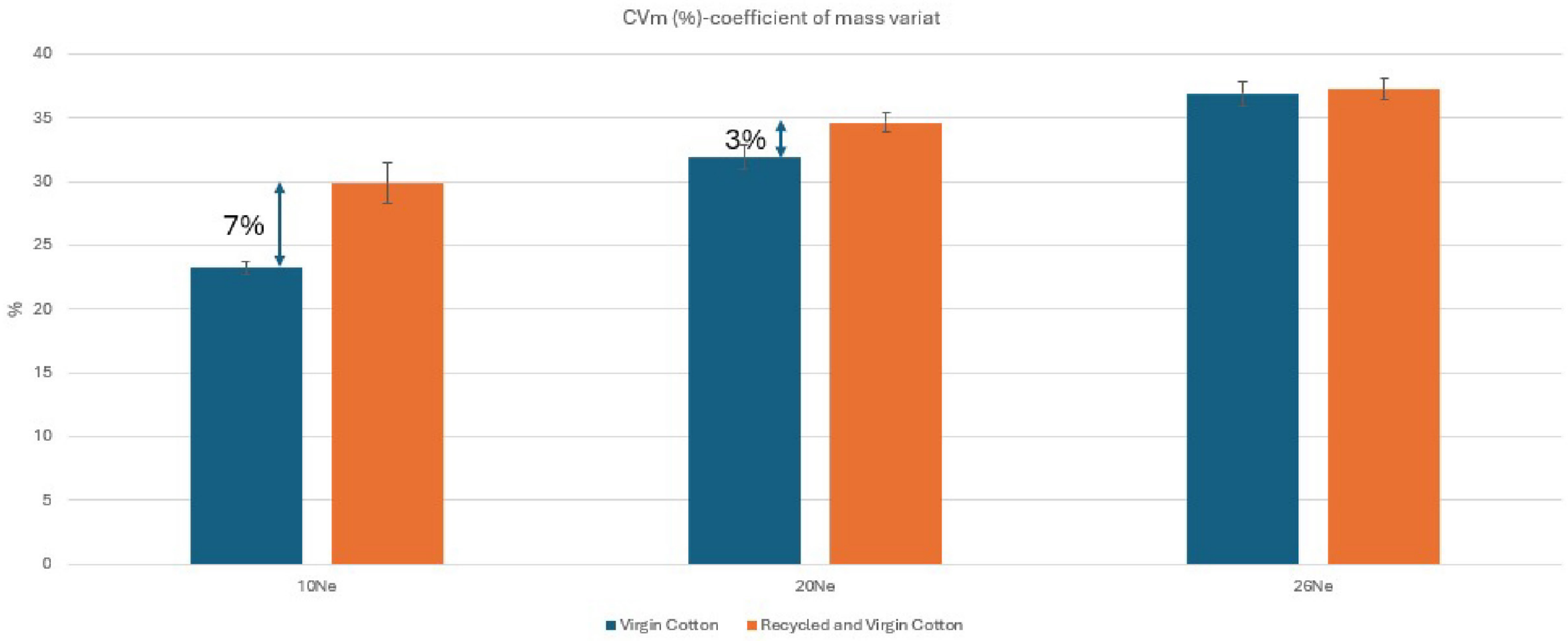


Figure 102: Cotton spinning trial: Yarn CVM results

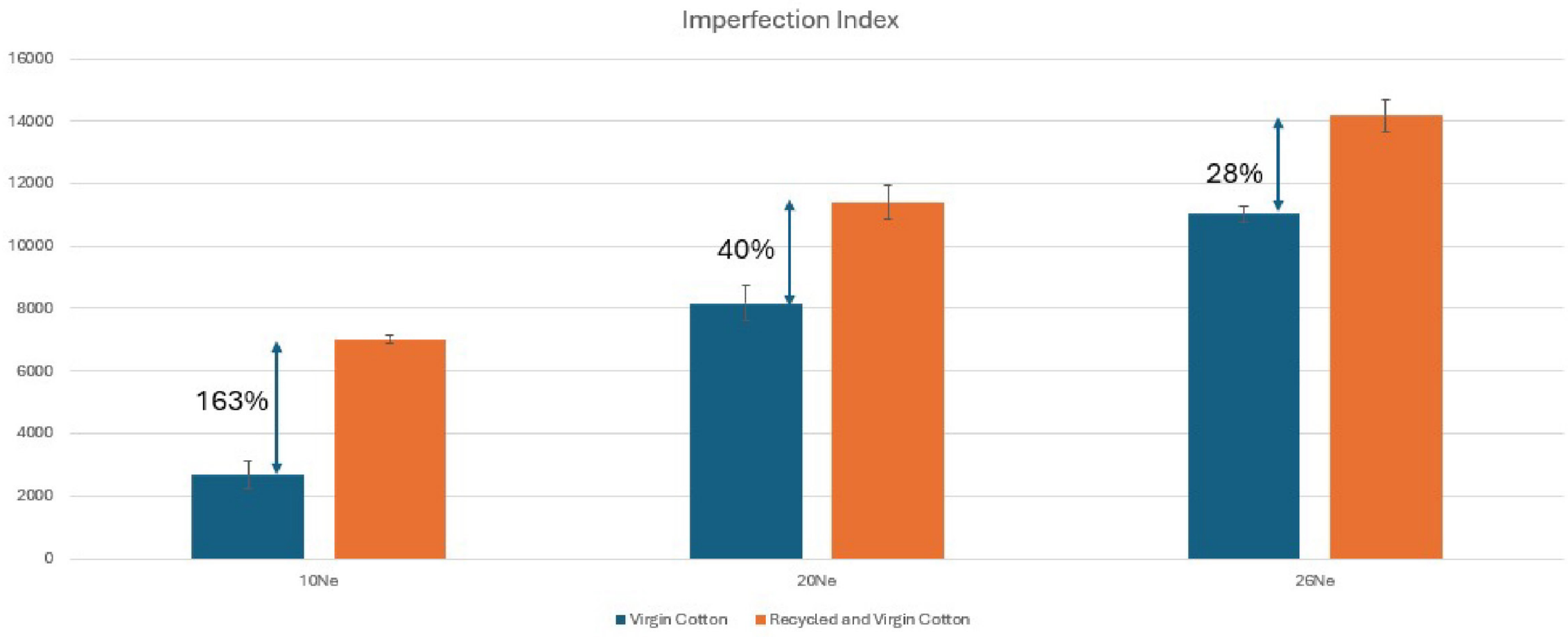


Figure 103: Cotton spinning trial: Yarn imperfection index results

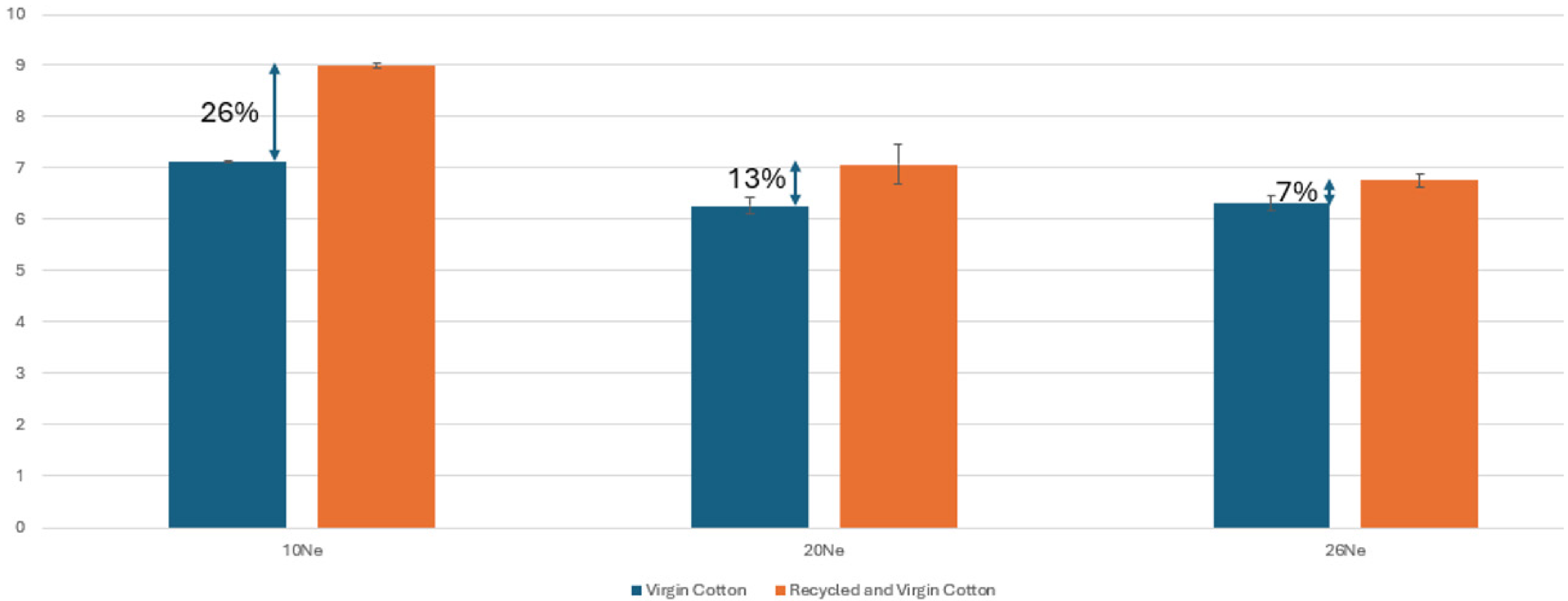


Figure 104: Cotton spinning trial: Yarn hairiness

Test results

Tested according to “ordered” requirements

Sample description:	1. Wadding white	**Lab reference no:**	595643-01
Test method:	Nonylophenolethoxylates (NPEO) in washable textiles: DIN EN ISO 18254-1:2016-09, Solvent extraction: Methanol, LC-MS, quantification based on Igepal CO-630 (2-18 EO units), only compunds with 2-18 ethoxylate units are quantified, reporting limit: 50 mg/kg/ 0.005%		
Test location & accreditation:	Parameter has been analysed at accredited BVCPS laboratory Schwerin		

Parameter	Limit	Value	Evaluation
Nonylphenolethoxylates (NPEOs)	< 100 mg/kg	< 50 mg/kg	Pass

Test method/ standard:	Bisphenols: BVCPS inhouse method: CPSD-AN-00169-MTHD:2023-02, extraction with organic solvent, LC-QQQ analysis, reporting limit: 1mg/kg/ 0.00001%		
Test location & accreditation:	Parameter has been analysed at accredited BVCPS laboratory Schwerin		

Parameter	Limit	Value	Evaluation
Bisphenol A		< 1 mg/kg	No specification
Bisphenol AF		< 1 mg/kg	No specification
Bisphenol AP		< 1 mg/kg	No specification
Bisphenol B		< 1 mg/kg	No specification
Bisphenol C		< 1 mg/kg	No specification
Bisphenol C2		< 1 mg/kg	No specification

Parameter	Limit	Value	Evaluation
Bisphenol E		< 1 mg/kg	No specification
Bisphenol F		< 1 mg/kg	No specification
Bisphenol M		< 1 mg/kg	No specification
Bisphenol P		< 1 mg/kg	No specification
Bisphenol S		< 1 mg/kg	No specification
Bisphenol T		< 1 mg/kg	No specification
Bisphenol Z		< 1 mg/kg	No specification

Test method/ standard:	Heavy metals, extractable: DIN EN 16711-2:2016-02, ICP-MS analysis, *If Chromium exceeds 1mg/ kg, additional testing of Chromium(VI)
Test location & accreditation:	Parameter has been analysed at accredited BVCPS laboratory Schwerin

Parameter	Limit	Value	Evaluation
Arsenic (As)	< 1 mg/kg	< 0.1 mg/kg	Pass
Cadmium (Cd)	< 1 mg/kg	< 0.02 mg/kg	Pass
Chromium (Cr)*	< 1 mg/kg	< 0.1 mg/kg	Pass
Chromium (VI) (CrVI)		No additional testing neccessary	No specification
Lead (Pb)	< 1 mg/kg	< 0.02 mg/kg	Pass

Figure 105: Cotton spinning trial: Chemical analysis

Appendix 2: Polyester



Image 29: Polyester trial PET pellets



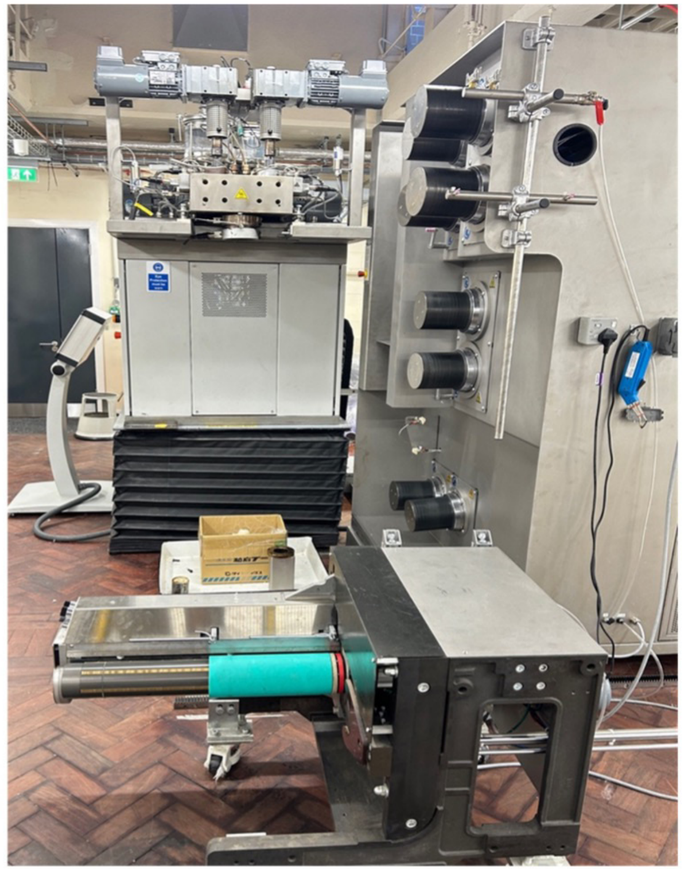


Image 30: Mortan dryer (left) and FET multifilament spinning line (right)



Image 31: Cross sections of unwashed post-consumer duvet pellets



Image 32: Polyester Trial 2: Pellets

Image 32: Polyester Trial 2: Pellets

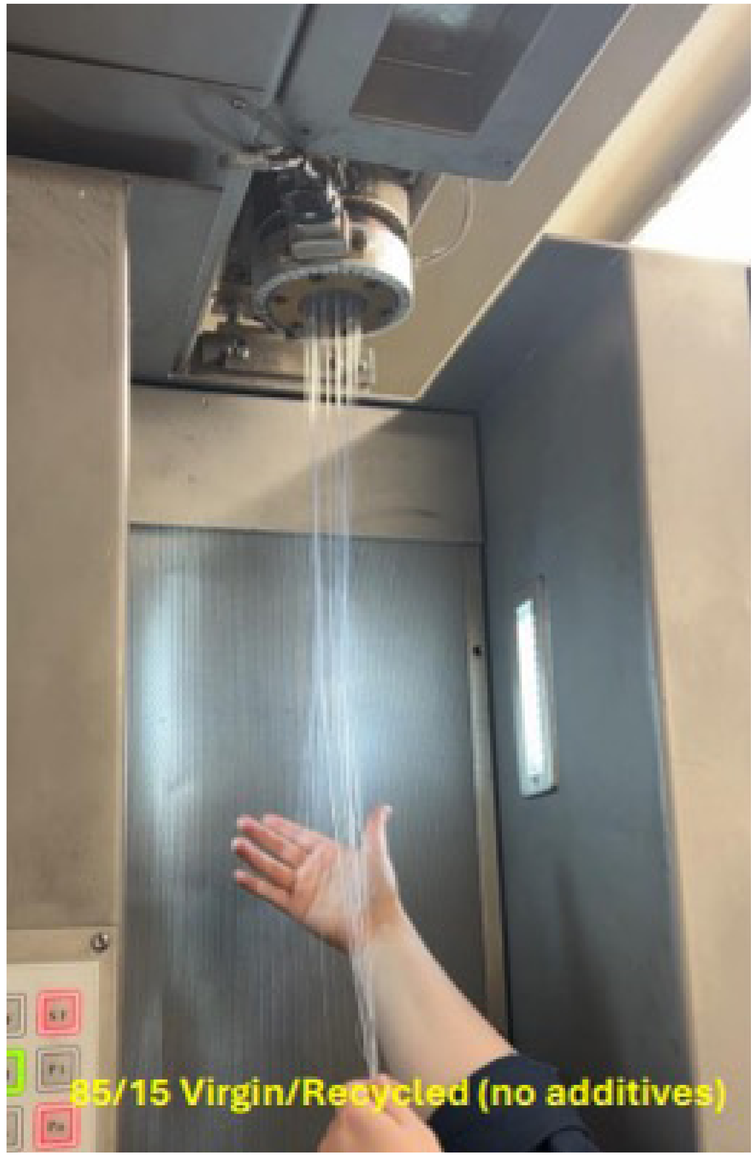


Image 33: 85% virgin polyester 15% recycled yarn extrusion, no master-batch



Image 34: Spinning Trial 3 yarns

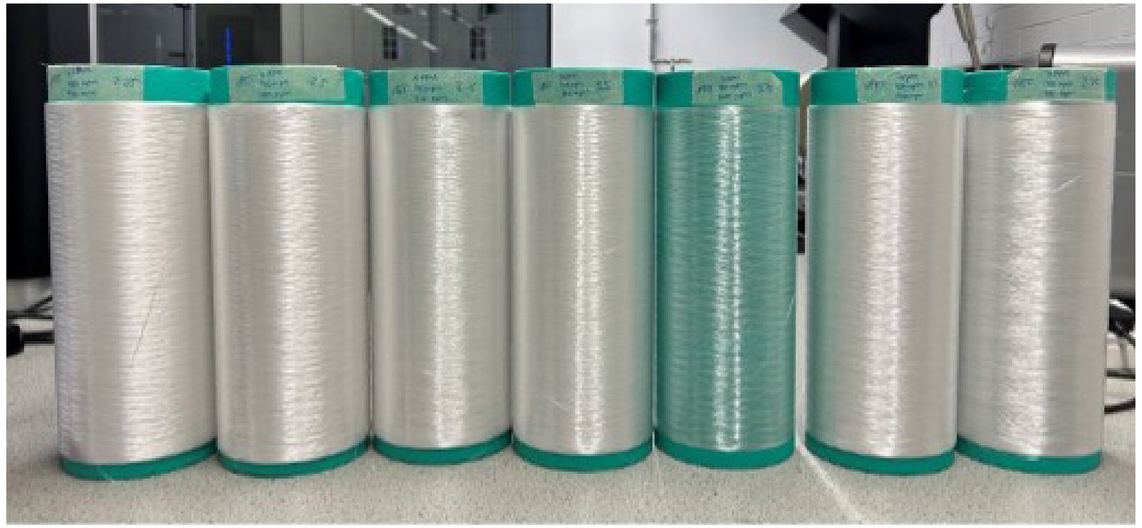
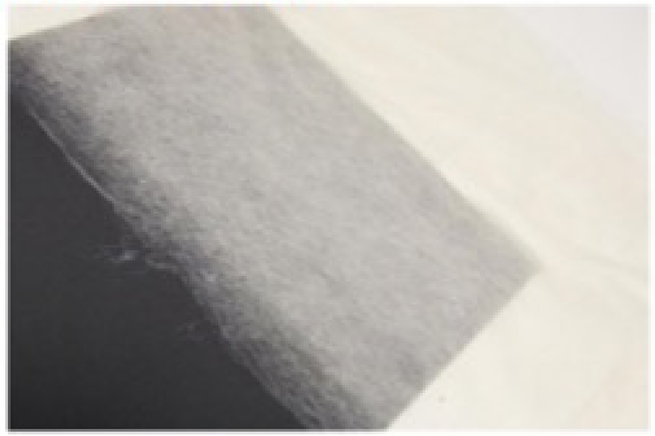


Image 35: Spinning Trial 4 & 5 yarns

Example fibre web products produced at two fibre diameters with different gsm





Example lofted fibre web products produced at two fibre diameters with different gsm





Image 36: Melt-blown samples

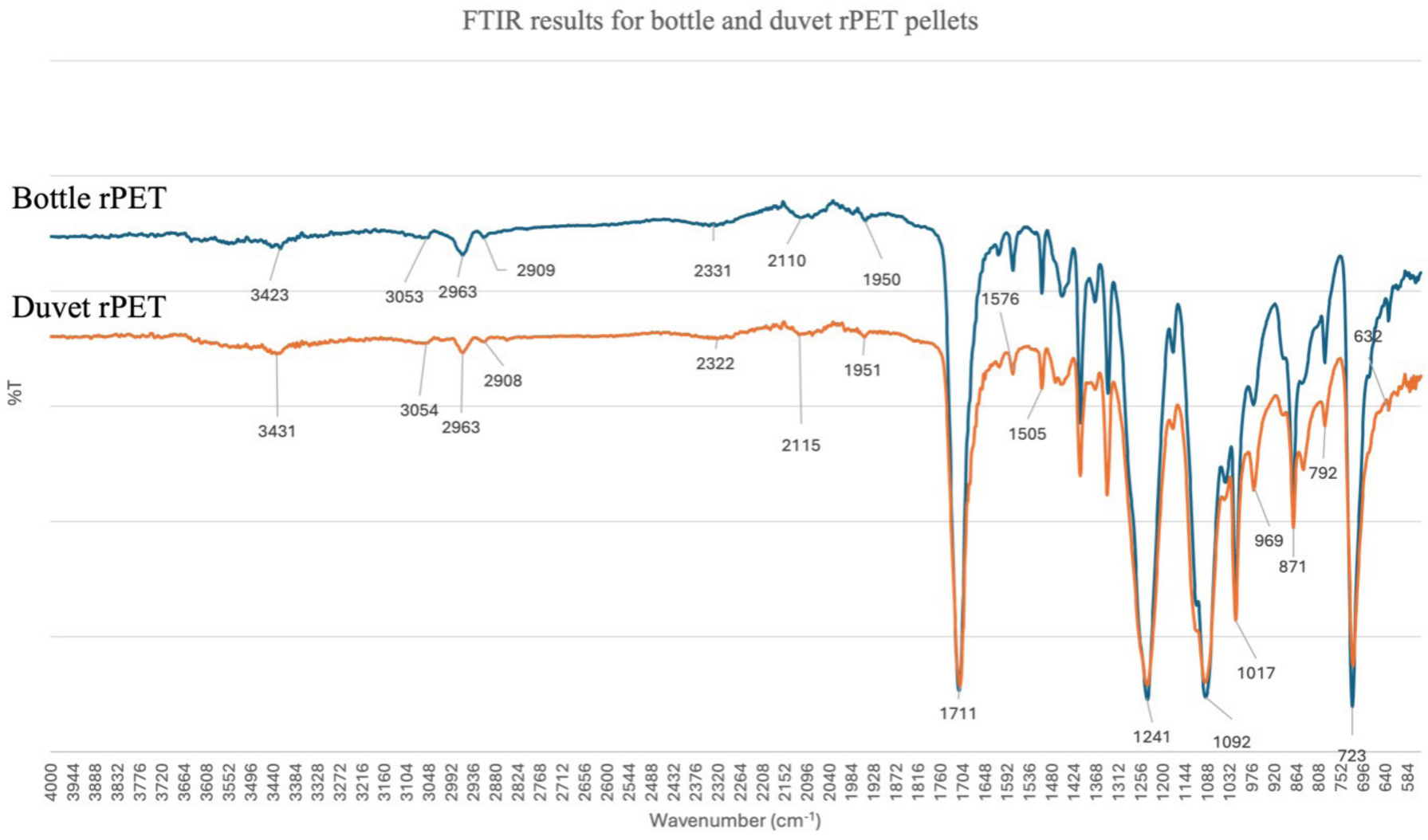


Figure 106: FTIR spectrum for bottle flake rPET pellets and PCT duvet rPET pellets

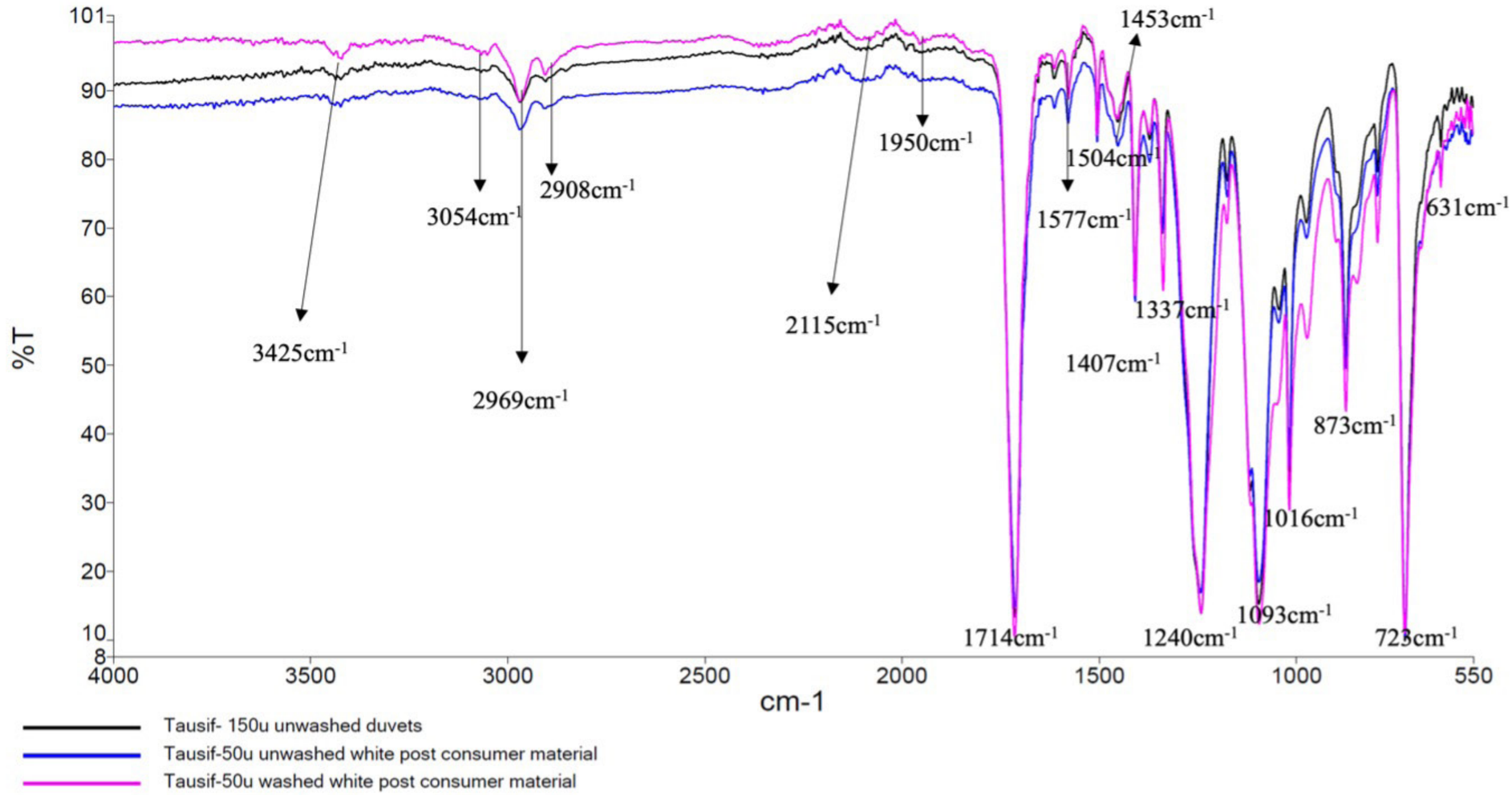


Figure 107: FTIR spectrum of 150 micron unwashed duvet pellets, 50 micron unwashed white duvet pellets, and 50 micron washed white PCT pellets

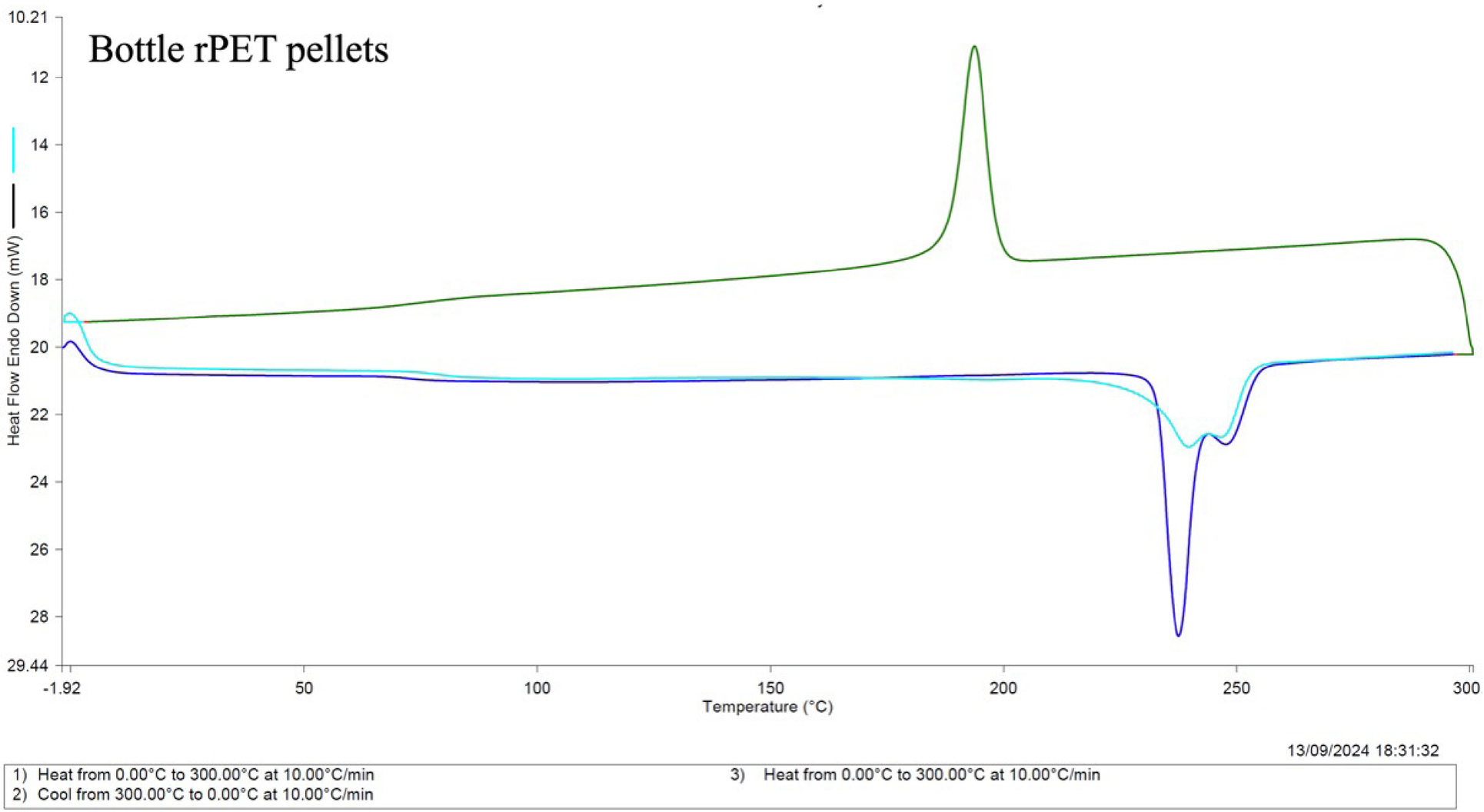


Figure 108: DSC analysis: Results for five batches of rPET pellets following a heating cooling cycle at a rate of 10 degrees C/min: Bottle flake rPET pellets

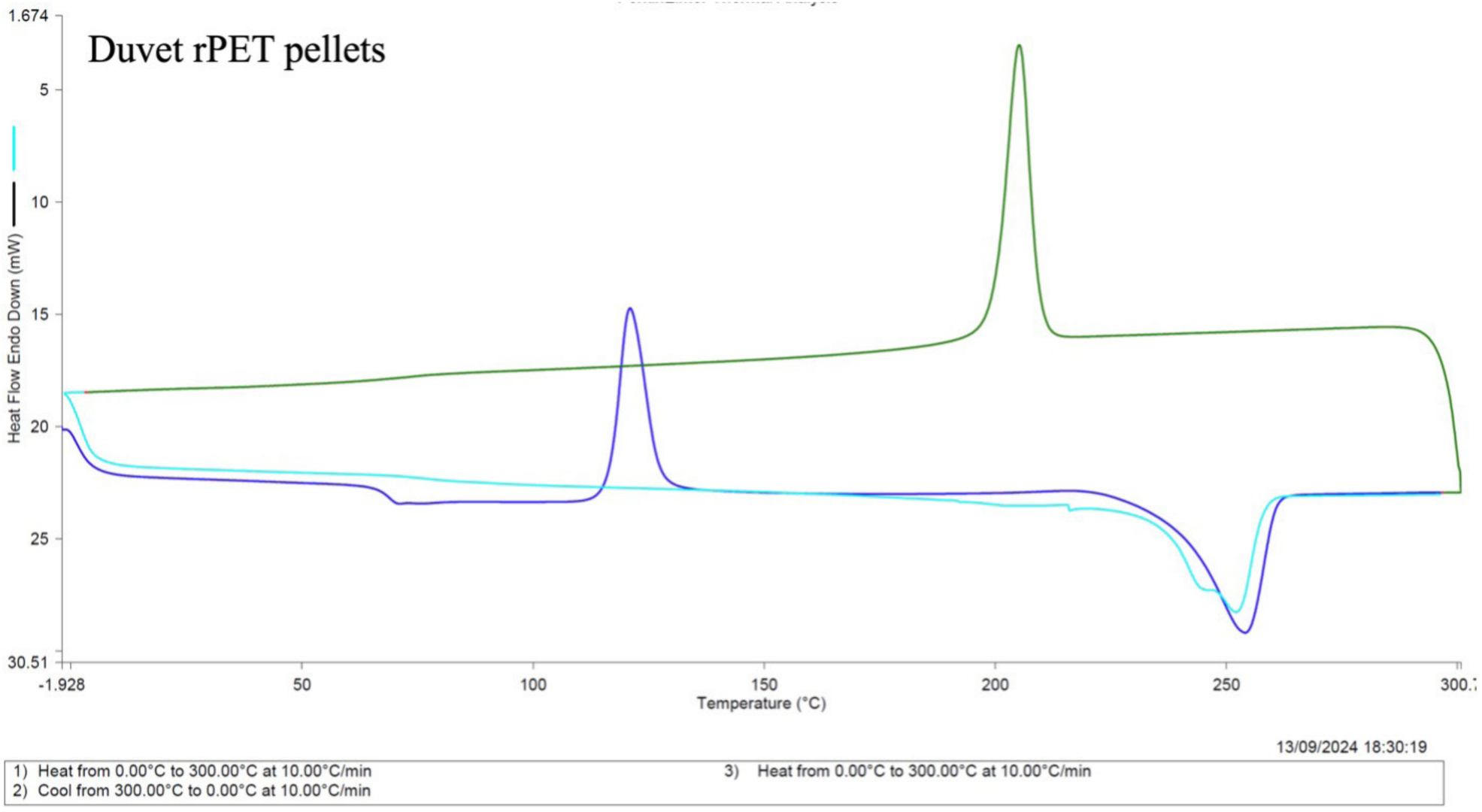


Figure 109: DSC analysis: Duvet rPET pellets

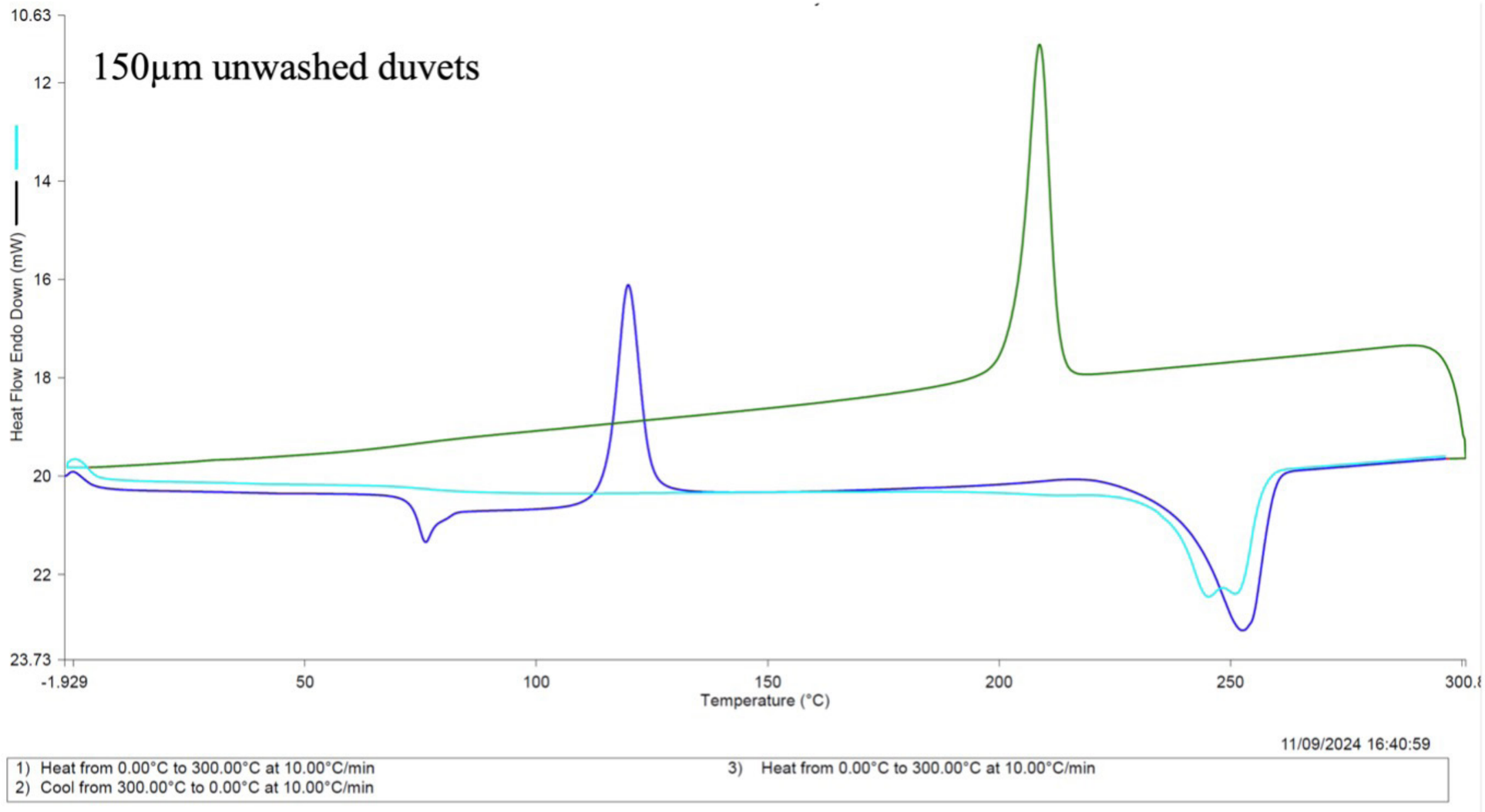


Figure 110: DSC analysis: 150 micron unwashed duvet rPET pellets

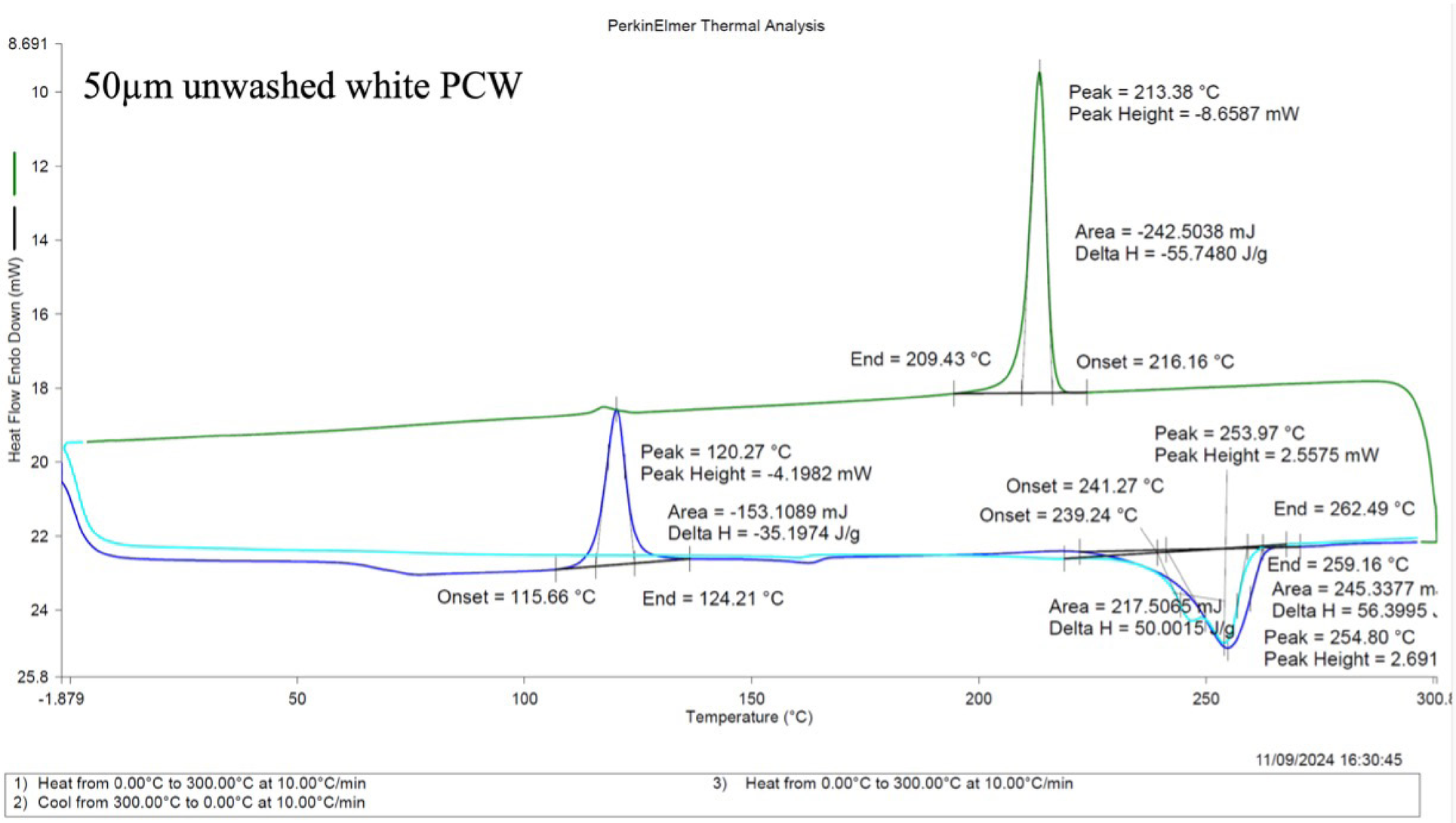


Figure 111: DSC analysis: 50 micron unwashed white PCT pellets

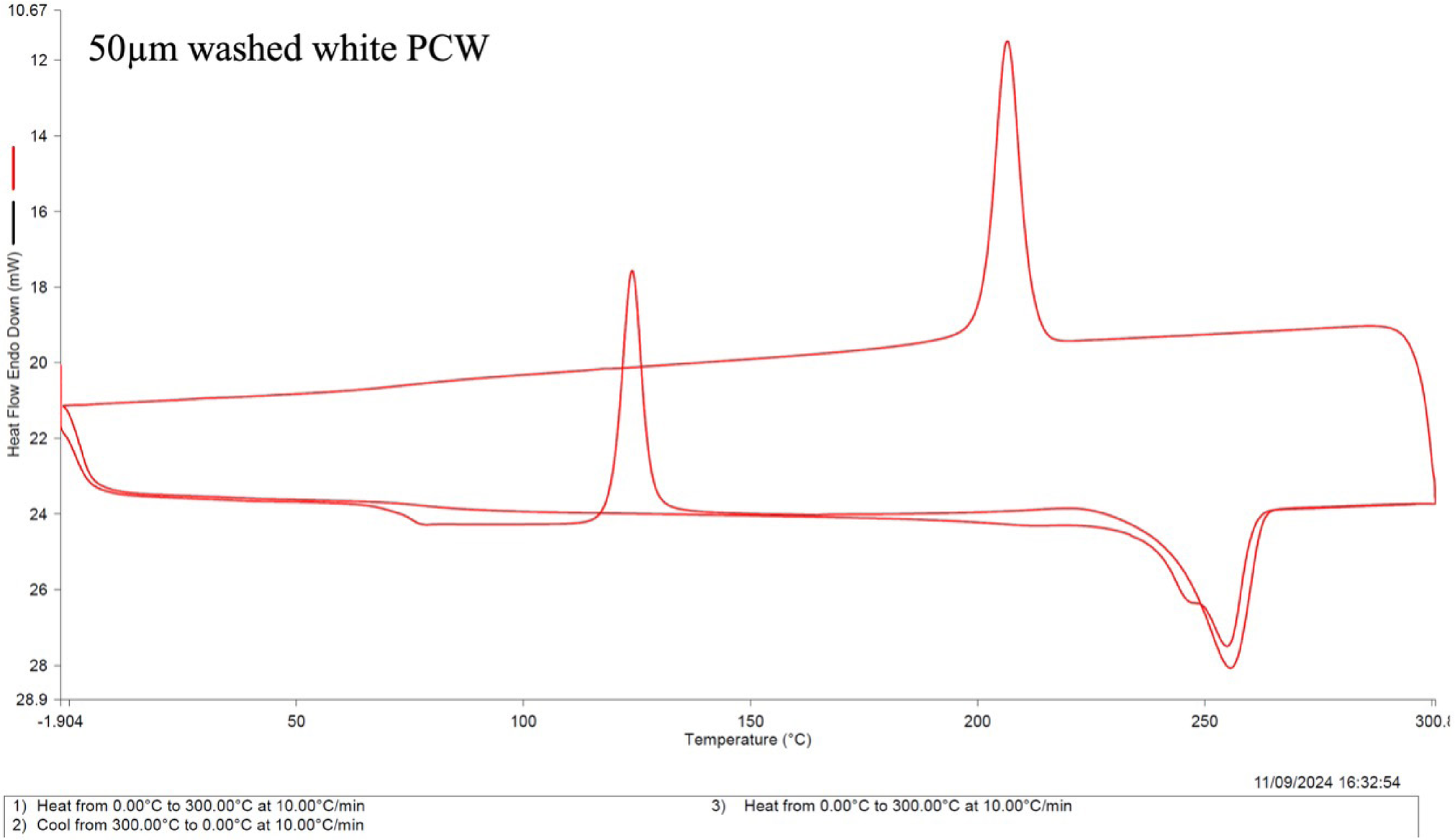


Figure 112: DSC analysis: 50 micron washed white PCT pellets

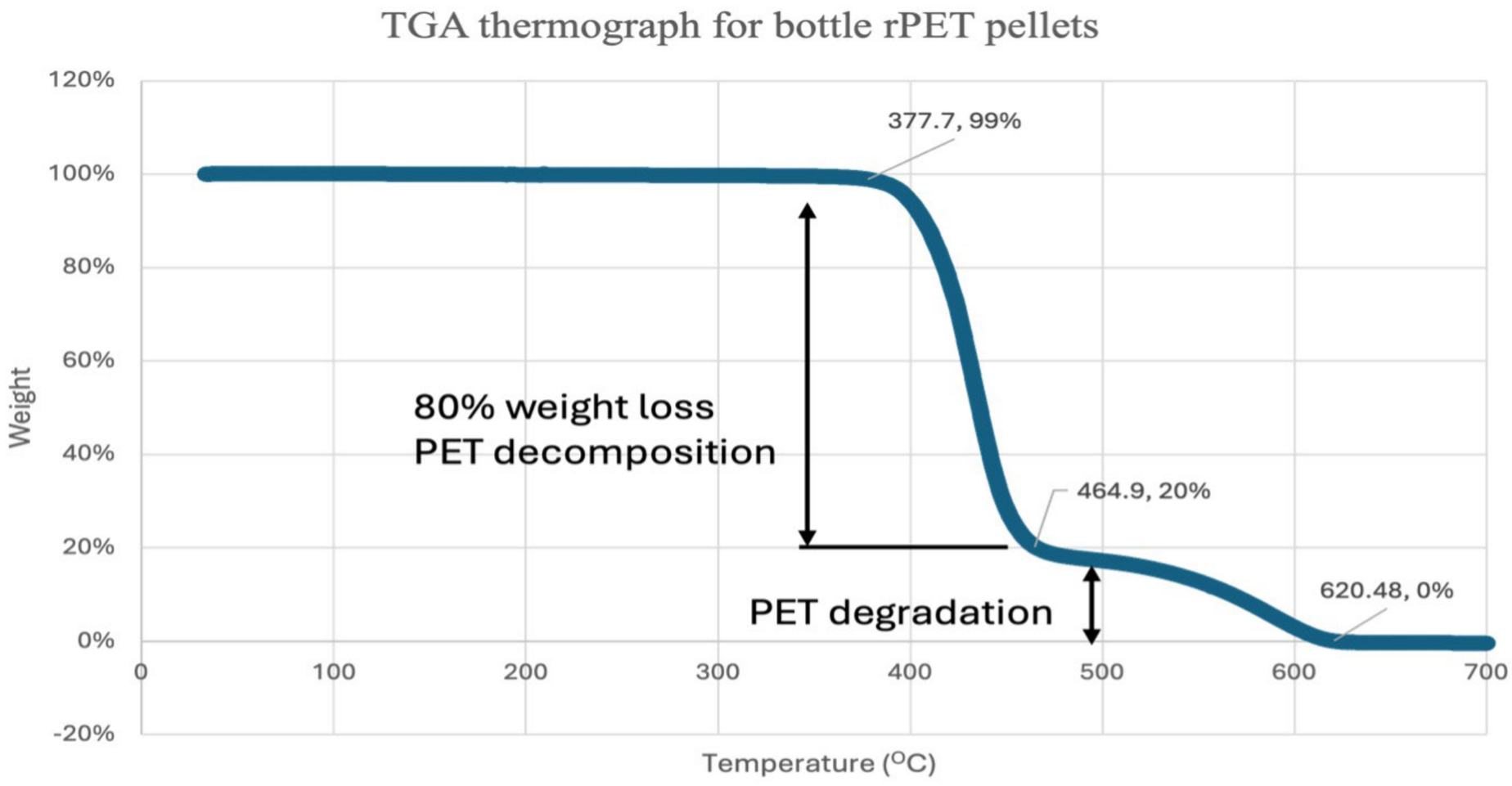


Figure 113: TGA analysis: Thermograph for bottle rPET pellets

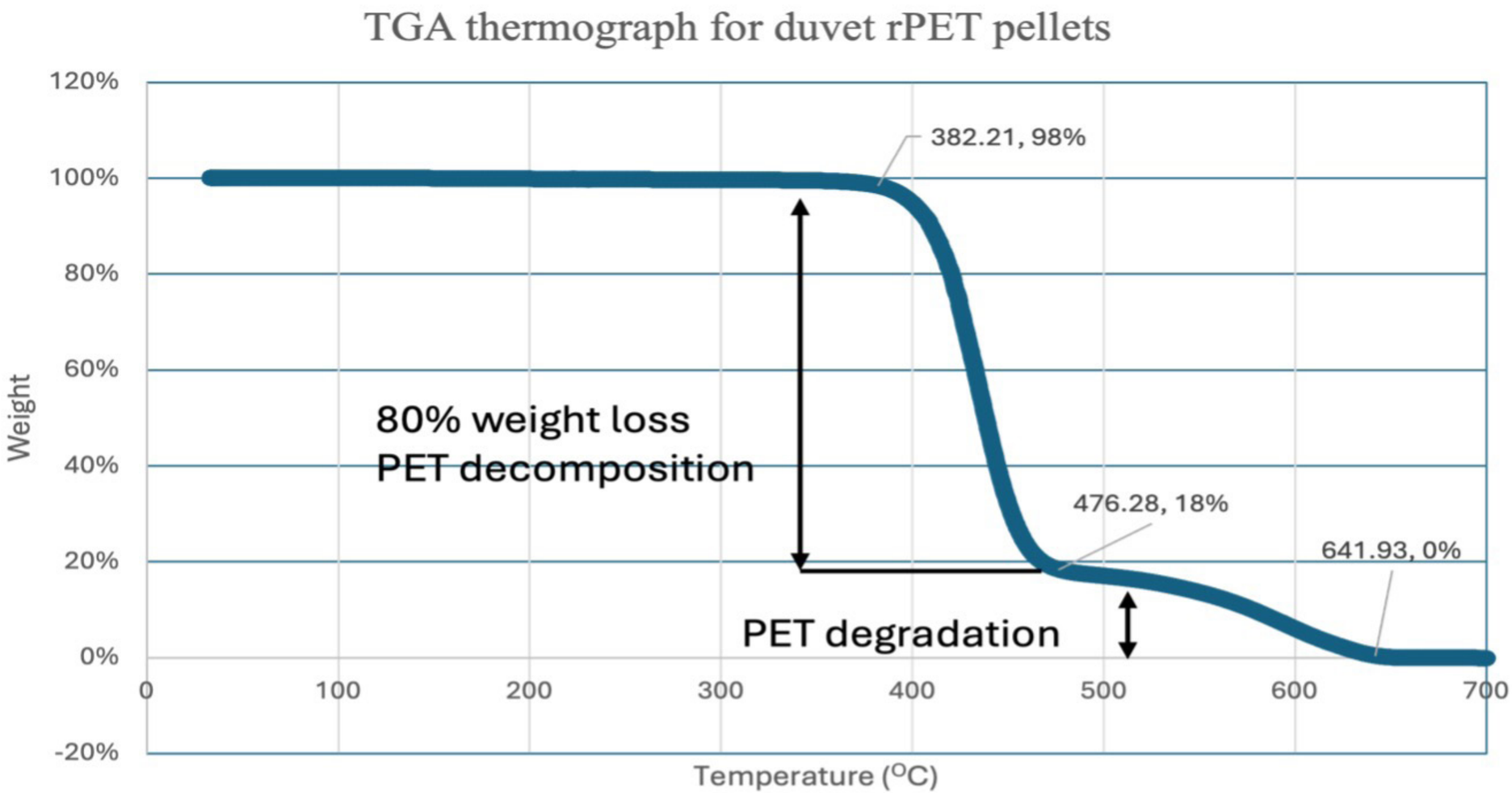


Figure 114: TGA analysis: Thermograph for duvet rPET pellets

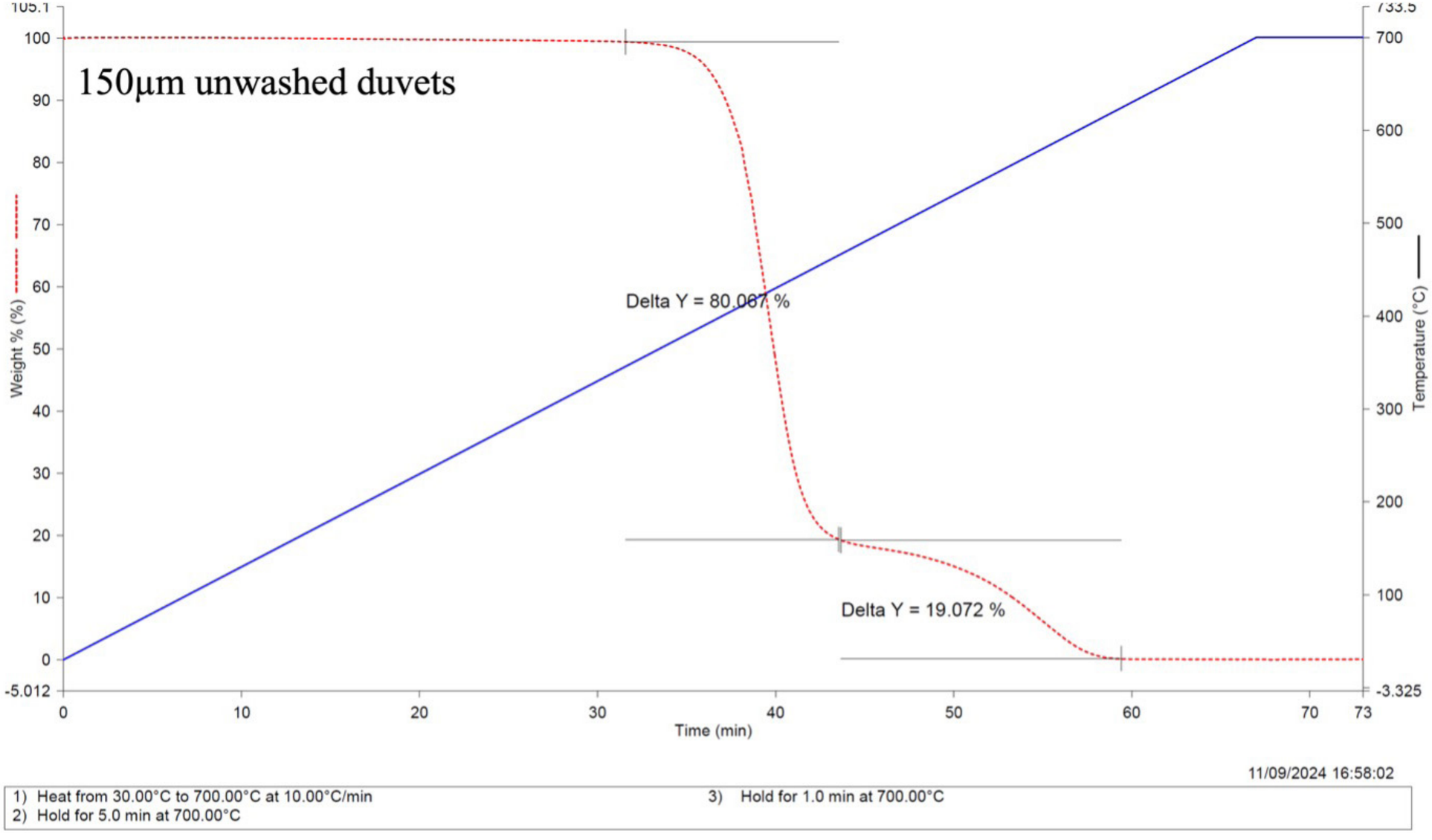


Figure 115: TGA analysis: Thermograph for 150 micron unwashed duvet pellets

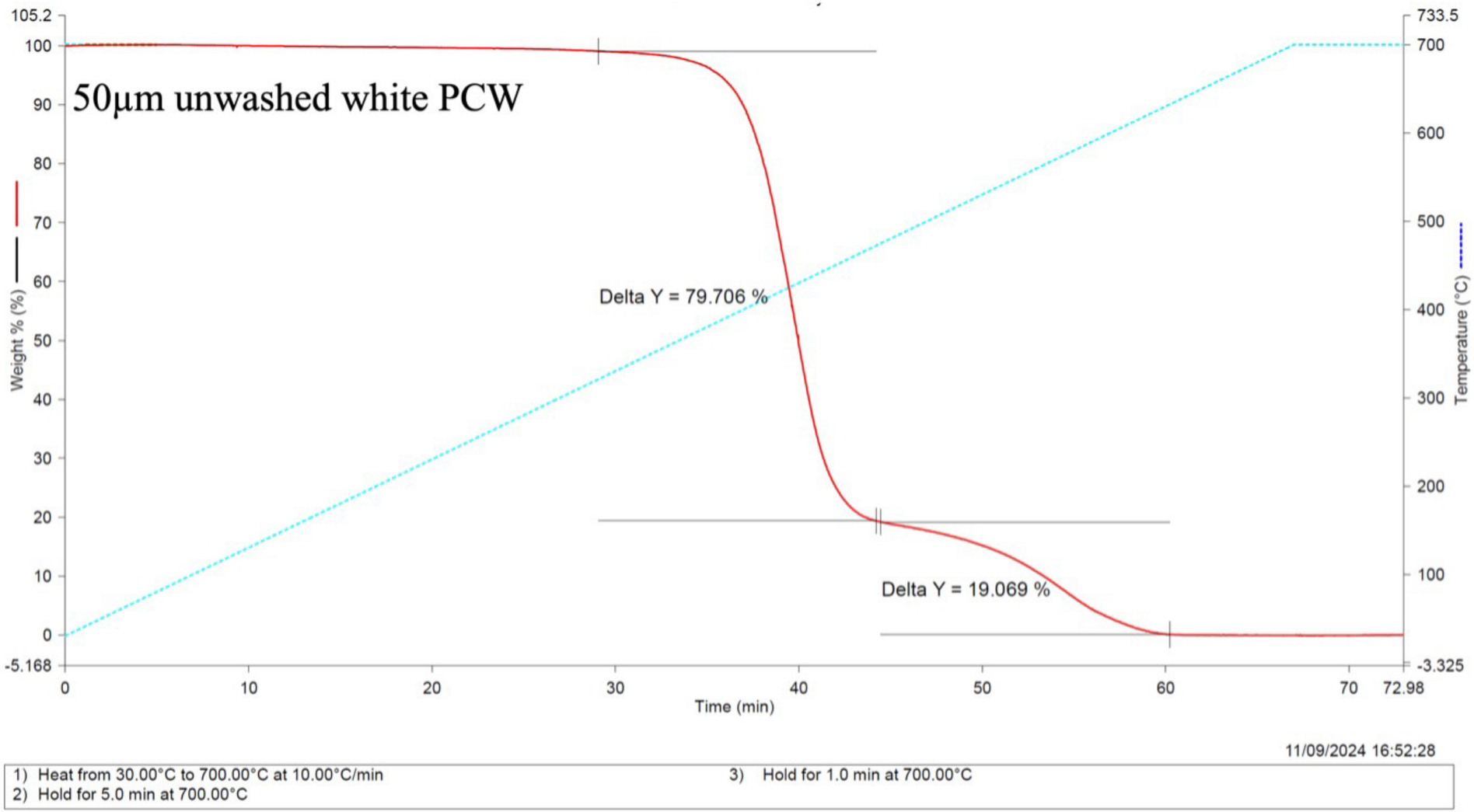


Figure 116: TGA analysis: Thermograph for unwashed white PCT pellets

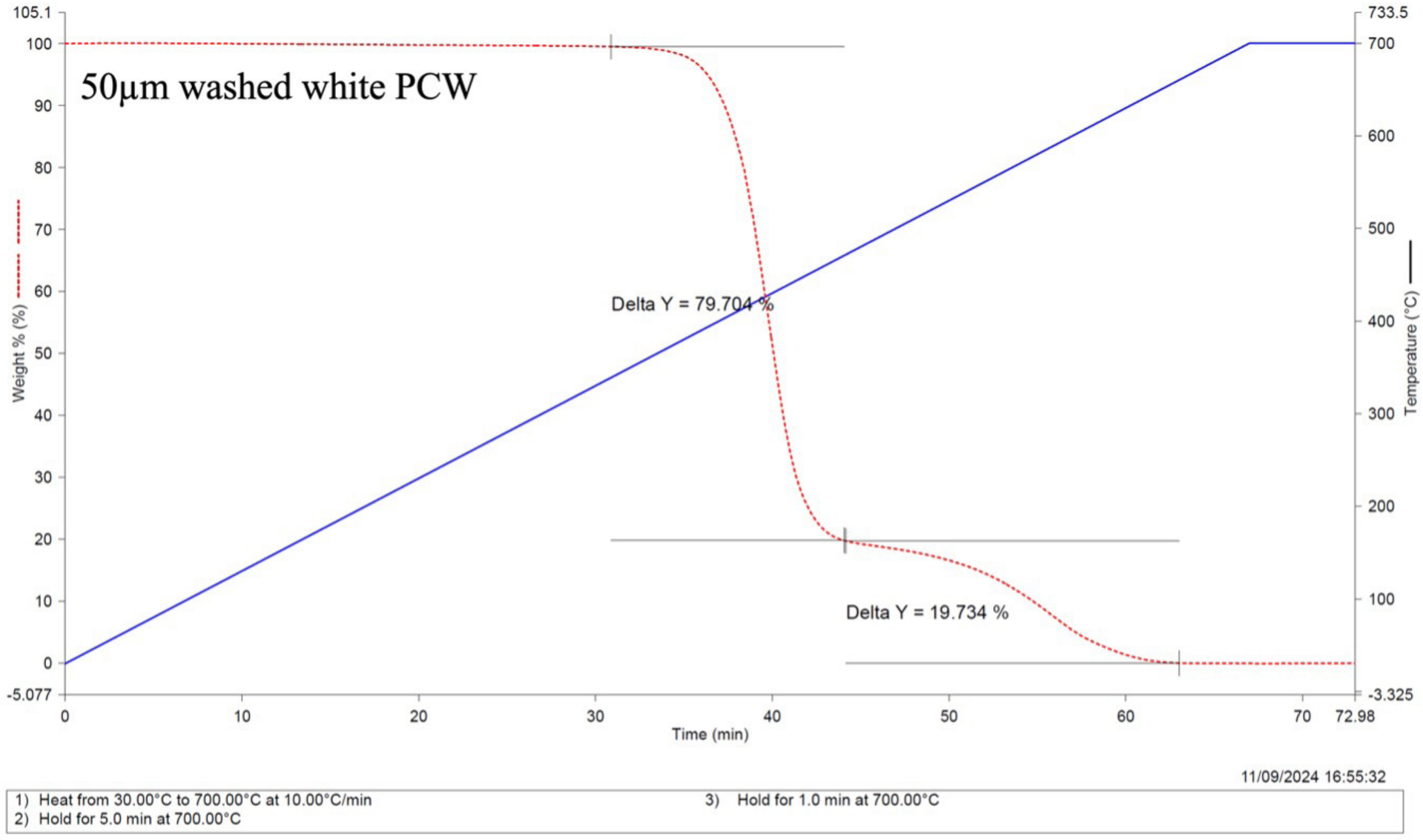


Figure 117: TGA analysis: Thermograph for 50 micron washed white PCT rPET pellets

Spun Sample	Polymer	Polymer flow		Drawing				Expected Final Yarn Titer (dTex -- From Calculation
		Metering pump capacity (ml/ rev)	Metering pump speed (rpm)	Godet speed 1 (mpm)	Godet speed 2 (mpm)	Godet speed 3 (mpm)	Godet speed 4 (mpm)	
Virgin PET	PET	1.0	7.0	400.0	402	900	900	93.3
85% Virgin PET +15% unwashed duvet pellets	PET	1.0	7.0	400.0	402	900	900	93.3

Figure 118: Polyester Spinning Trial 1 properties

Spun Sample	Yarn weight per 50m			Average weight per 50m (g)	dTex
	No. 1 (g)	No. 2 (g)	No.3 (g)		
Virgin PET	0.4614	0.4589	0.4487	0.4563	91.26
85% virgin PET & 15% unwashed duvet pellets	0.5071	0.5069	0.5080	0.5073	101.47

Figure 119: Polyester Spinning Trial 1 analysis: Weight

Spun Sample	dTex	Force at Break Point (cN)	Max. Tenacity (cN/tex)	Elongation at break (%)
Virgin PET	91.26	191.70	21.01	33.30
85% virgin PET & 15% unwashed duvet pellets	101.47	103.00	10.15	77.13

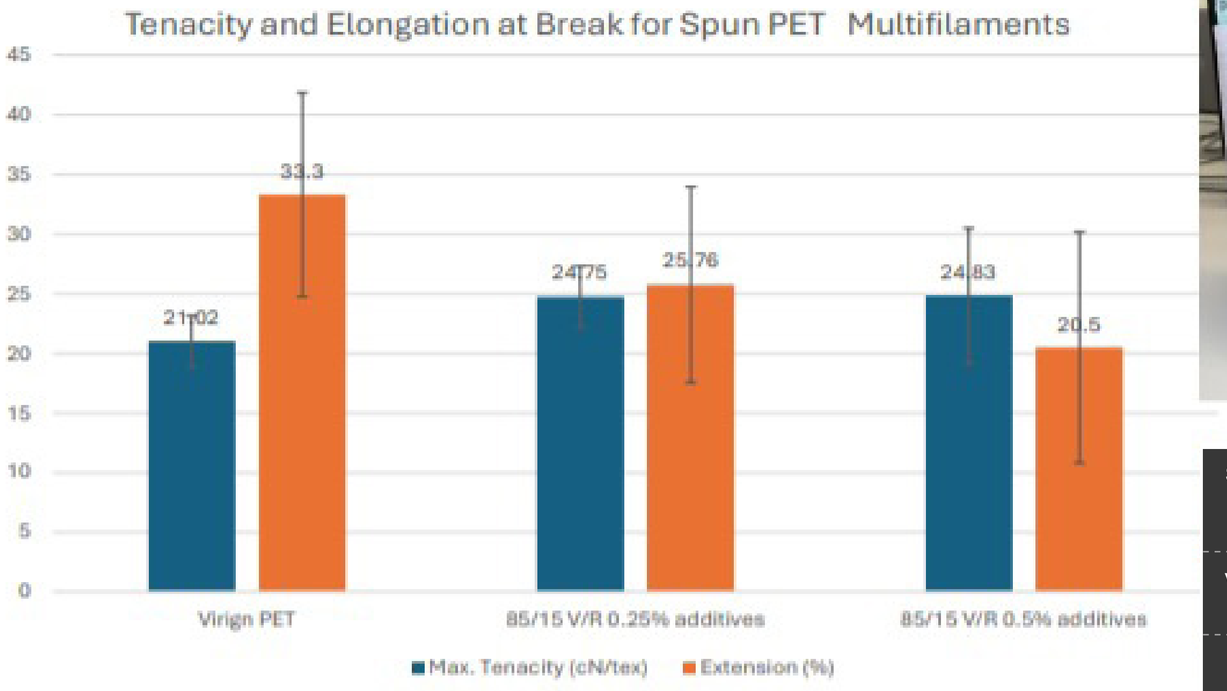
Figure 120: Polyester Spinning Trial 1 analysis: Tensile strength

Yarn count of spun PET multifilaments

Spun Sample	Polymer	Polymer flow		Drawing				Expected Final Yarn Titer (dTex -- From Calculation
		Metering pump capacity (ml/ rev)	Metering pump speed (rpm)	Godet speed 1 (mpm)	Godet speed 2 (mpm)	Godet speed 3 (mpm)	Godet speed 4 (mpm)	
Virgin PET	PET	1.0	7.0	400	402	900	900	93.3
85/15 Virgin/ duvet (0.25% additives) pellets	PET	1.0	5.0	400	402	900	900	66.7
85/15 Virgin/ duvet (0.5% additives) pellets	PET	1.0	5.0	400	402	900	900	66.7

Spun Sample	Yarn weight per 50m			Average weight per 50m (g)	dTex
	No. 1 (g)	No. 2 (g)	No.3 (g)		
Virgin PET	0.4614	0.4589	0.4487	0.4563	91.26
85/15 Virgin/ duvet (0.25% additives) pellets	0.2450	0.2650	0.2583	0.2561	51.23
85/15 Virgin/ duvet (0.5% additives) pellets	0.2667	0.2850	0.2900	0.2806	56.11

Figure 121: Polyester Spinning Trial 2 analysis: Multifilament yarn count





Spun Sample	dTex	Force at Break Point (cN)	Max. Tenacity (cN/tex)	Elongation at break (%)
Virgin PET	91.26	191.70±19.60	21.01+2.16 (CV:10%)	33.30 ±.56 (CV:26%)
85/15 Virgin/ duvet (0.25% additives) pellets	51.23	126.72±13.11	24.75±2.56 (CV:10%)	25.76±8.21 (CV:32%)
85/15 Virgin/ duvet (0.5% additives) pellets	56.11	139.31±31.72	24.83±5.66 (CV:23%)	20.5±9.69 (CV:47%)

Figure 122: Polyester Spinning Trial 2 analysis: Multifilament tensile strength

Sample	Holes no.	Meter pump speed (rpm)	dTex	Force at Break Point (cN)	Max. Tenacity (cN/ tex)	Elongation at break (%)
Virgin PET	24	5	172.8	180.42 ±.37.69	10.44 ±2.18 (CV:21%)	72 ±31.48 (CV:44%)
Virgin PET	24	7	91.26	191.70± 19.69	21.01±2.16 (CV:10%)	33.30±8.56 (CV:26%)
85/15 V/R 2nd batch	24	7	101.47	103.00±9.07	10.15±0.89 (CV:9%)	77.13±27.36 (CV:35%)
85/15 V/R (0.25% additives) 4th batch	24	5	51.23	126.72±13.11	24.75±2.56 (CV:10%)	25.76±8.21 (CV:32%)
85/15 V/R (0.25% additives) 4th batch	48	5	180.5	67.76±26.87	3.75±1.49 (CV:40%)	1.37±1.09 (CV:80%)
85/15 V/R (0.5% additives) 4th batch	24	5	56.11	139.31±31.72	24.83±5.66 (CV:23%)	20.5±9.99 (CV:47%)
75/25 V/R (0.25% additives) 4th batch	24	5	56.7	149.71±15.12	25.5±2.58 (CV:10%)	23.0±5.99 (CV:26%)

Figure 123: Polyester Spinning Trial 3 analysis: Multifilament tensile strength

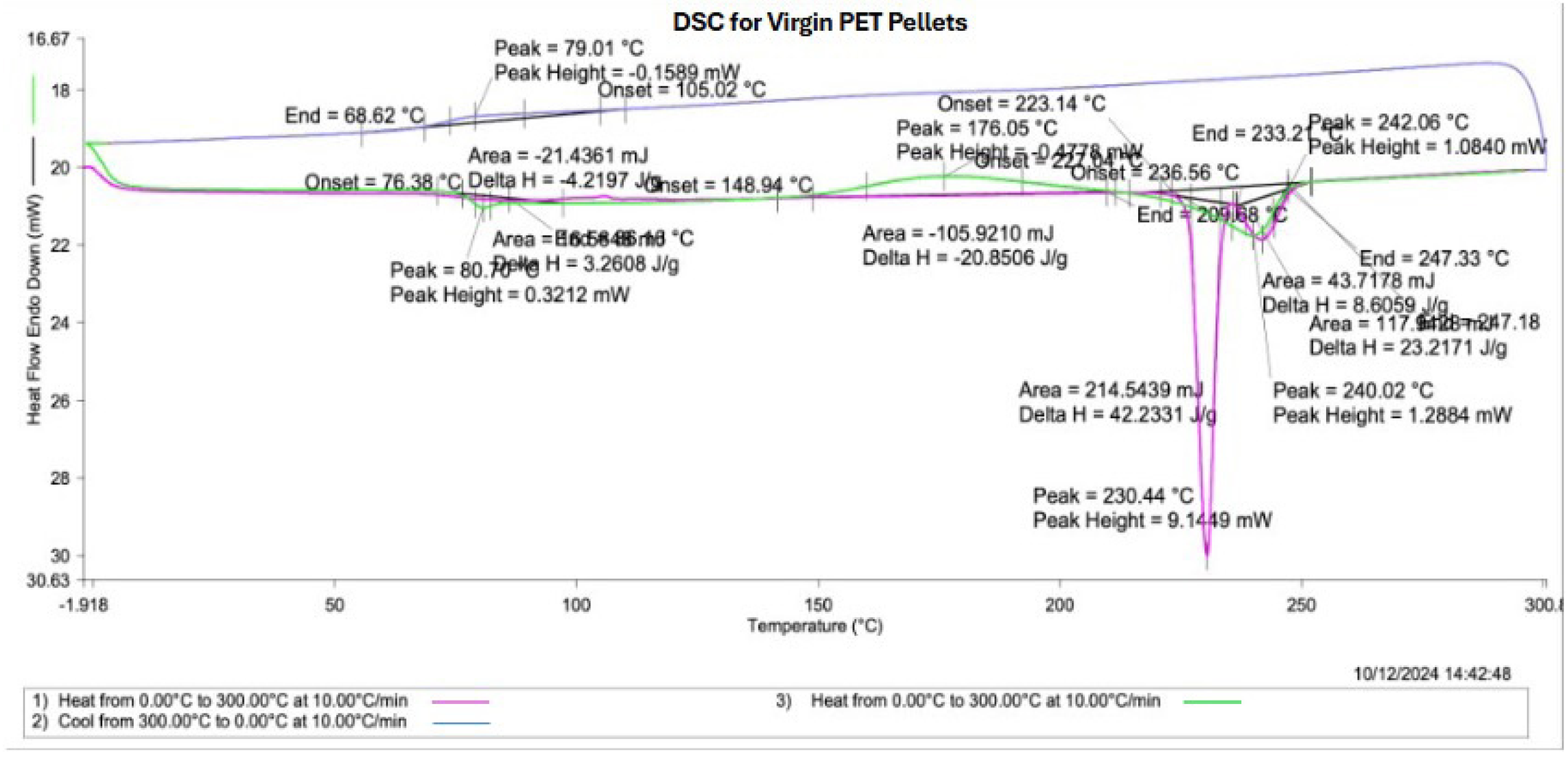


Figure 124: Polyester Spinning Trial 3 analysis: DSC for virgin PET pellets

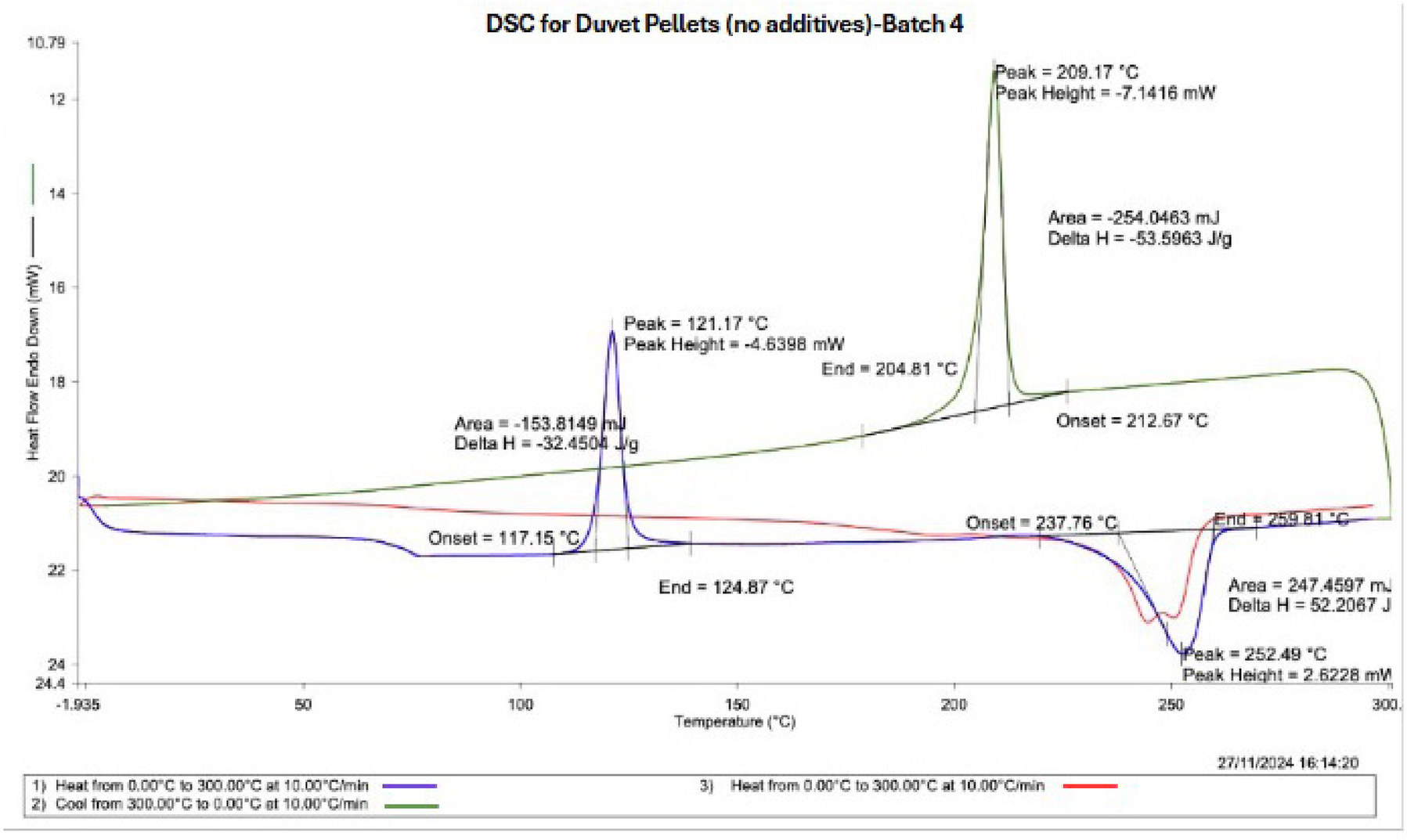


Figure 125: Polyester Spinning Trial 3 analysis: DSC for duvet pellets (no additives)

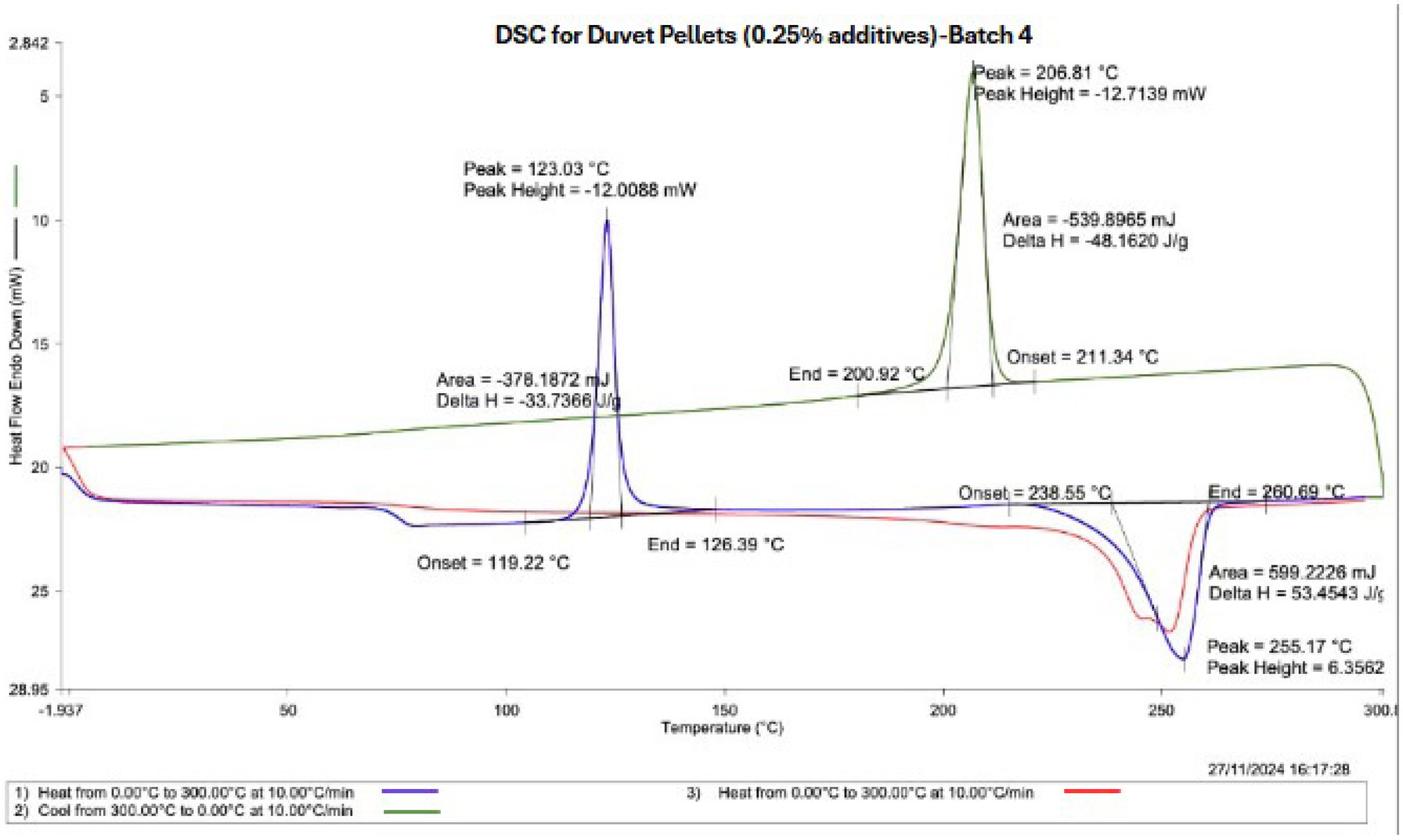


Figure 126: Polyester Spinning Trial 3 analysis: DSC for duvet pellets (0.25% additives)

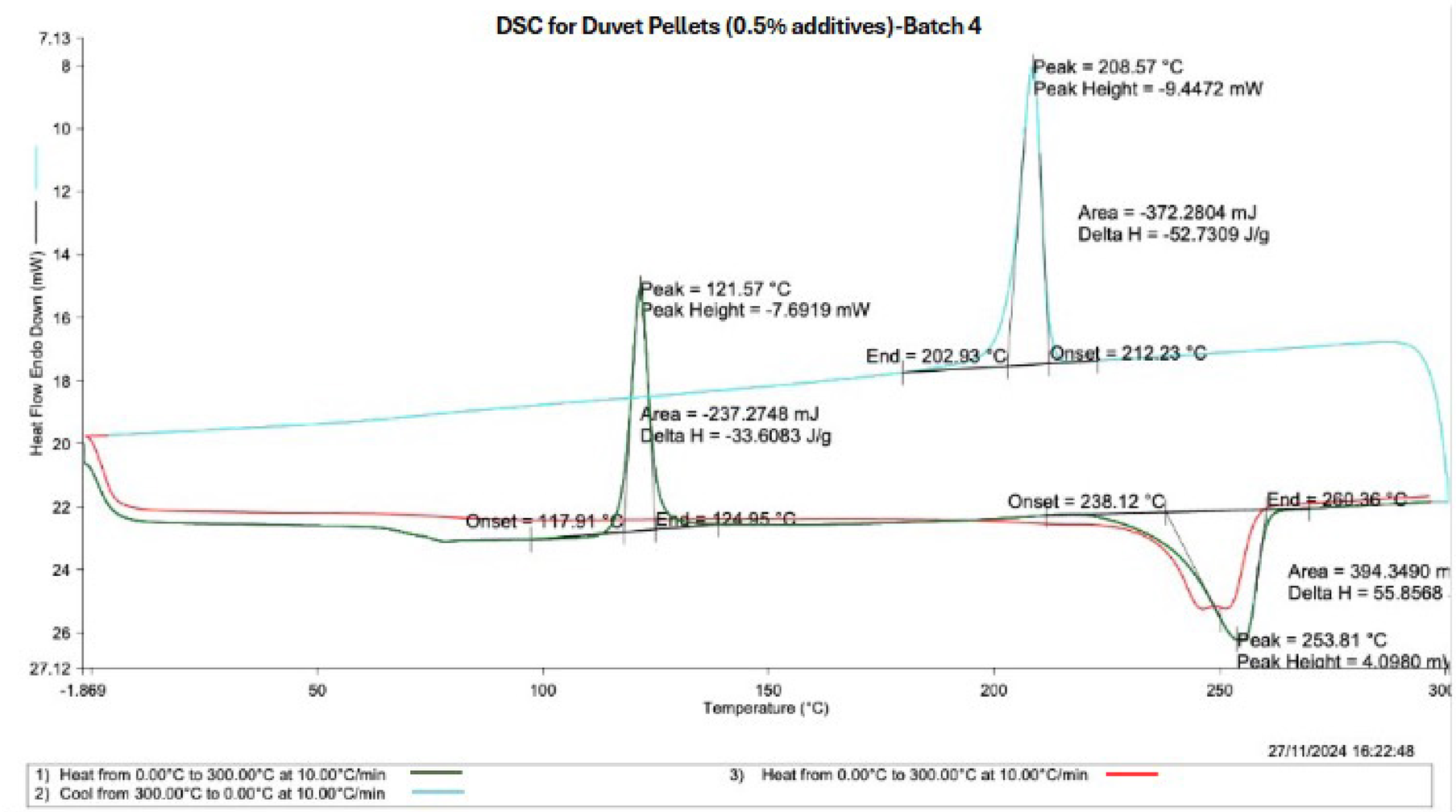


Figure 127: Polyester Spinning Trial 3 analysis: DSC for duvet pellets (0.5% additives)

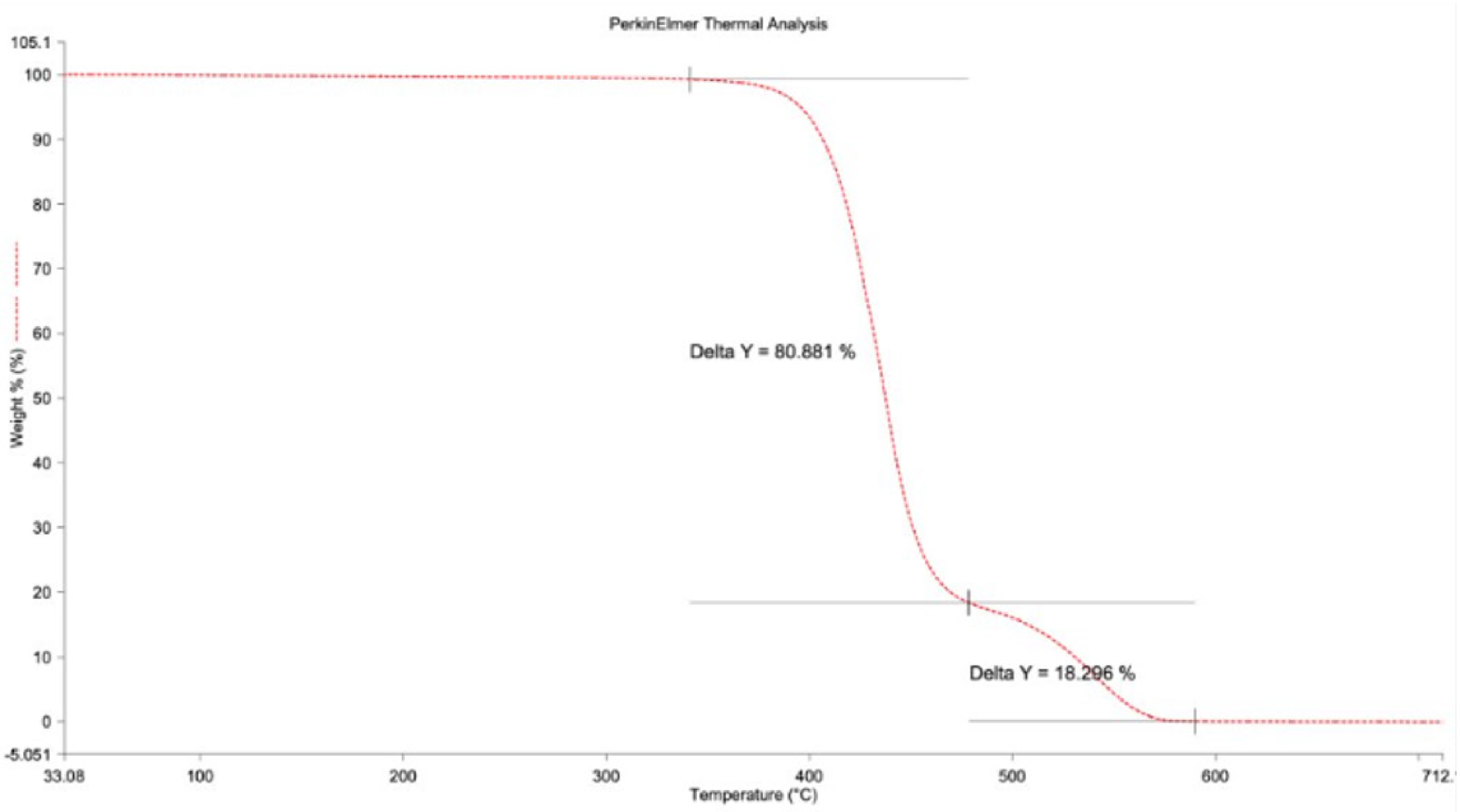


Figure 128: Polyester Spinning Trial 3 analysis: TGA for duvet pellets (no additives)

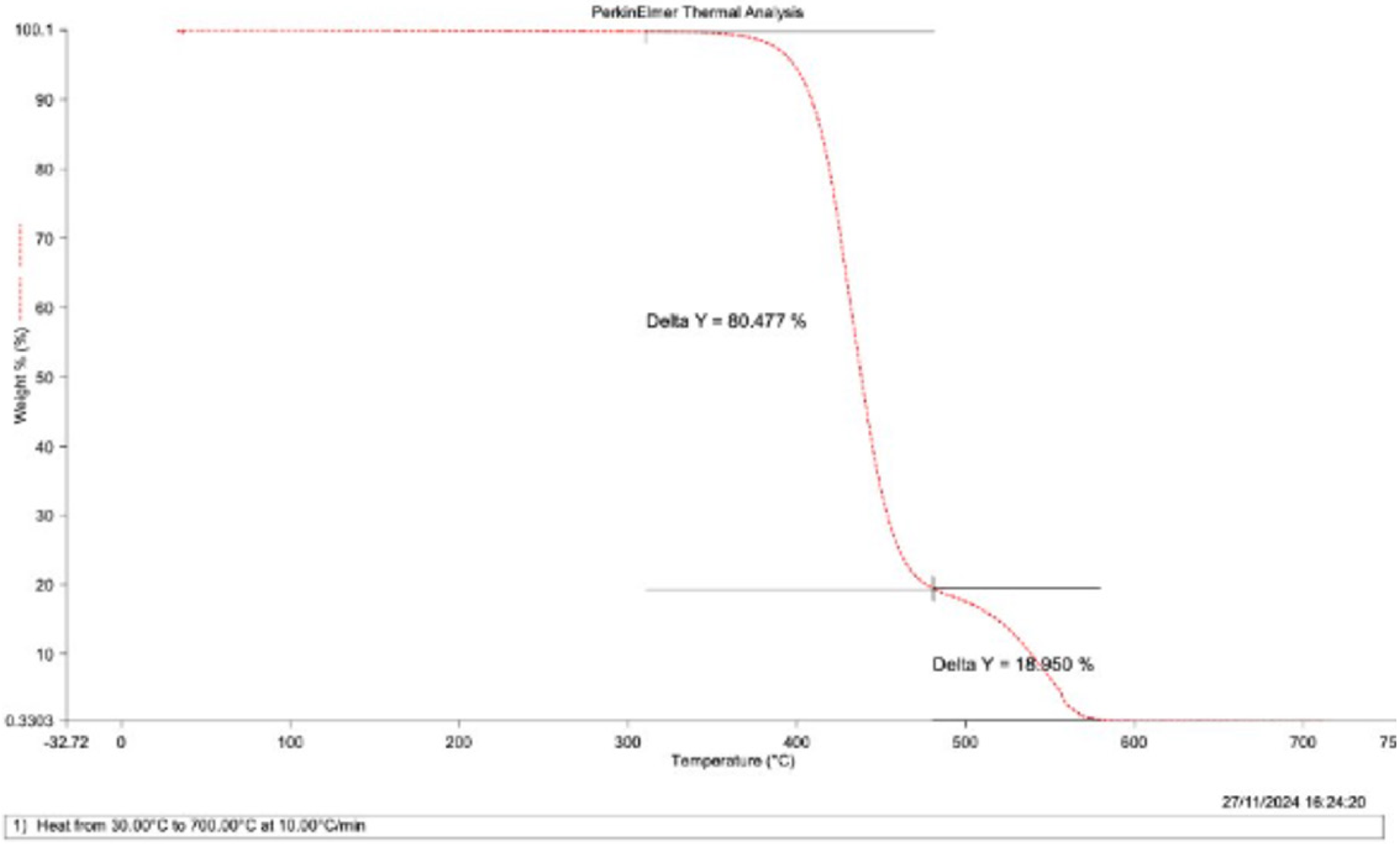


Figure 129: Polyester Spinning Trial 3 analysis: TGA for duvet pellets (0.25% additives)

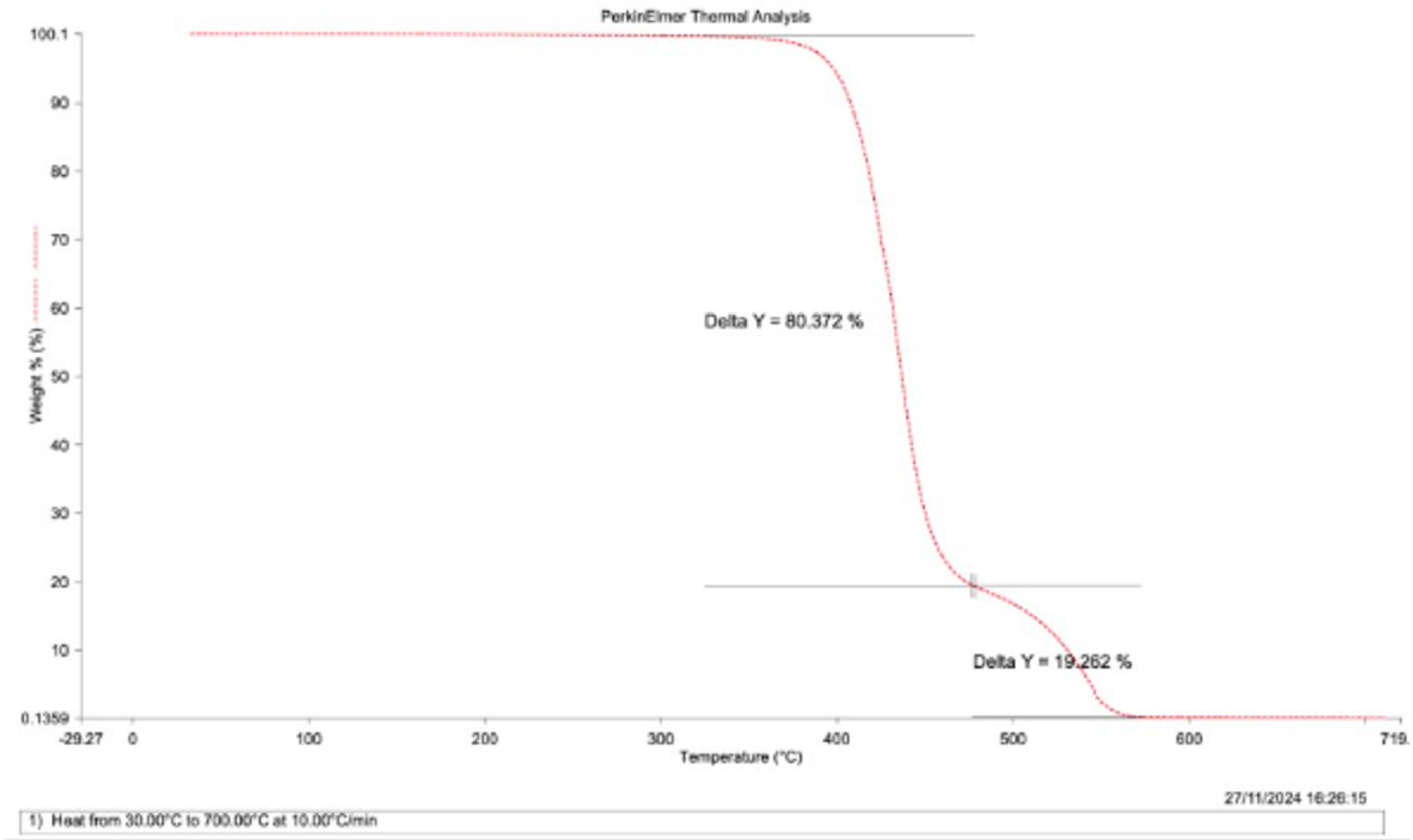


Figure 130: Polyester Spinning Trial 3 analysis: TGA for duvet pellets (0.25% additives)

Spun Sample	Polymer flow		Drawing		Draw Ratio	Expected yarn dTex	Actual yarn dTex
	Metering pump capacity (ml/rev)	Metering pump speed (rpm)	Godet speed 1 (mpm)	Godet speed 3 (mpm)			
Virgin (V5, 2.25)	2.5	5.0	400	900	2.25	166.7	171.1
Virgin (V5, 2.5)	2.5	5.0	400	1000	2.75	150.0	153.2
Virgin (V5, 2.75)	2.5	5.0	400	1100	2.75	136.4	146.3
Virgin (V5, 3.5)	2.5	5.0	400	1400	3.50	107.1	110.0
Virgin (V5, 3.75)	2.5	5.0	400	1500	3.75	100.0	97.4
Virgin (V5, 3.75)	2.5	5.0	400	1500	3.75	100.0	97.4
Virgin (V7, 2.25)	2.5	7.0	400	900	2.25	233.3	237.1
Virgin (V7, 3.5)	2.5	7.0	400	1400	3.50	150.0	155.7

Figure 131: Polyester Spinning Trial 4 analysis: Draw ratios for virgin tarns

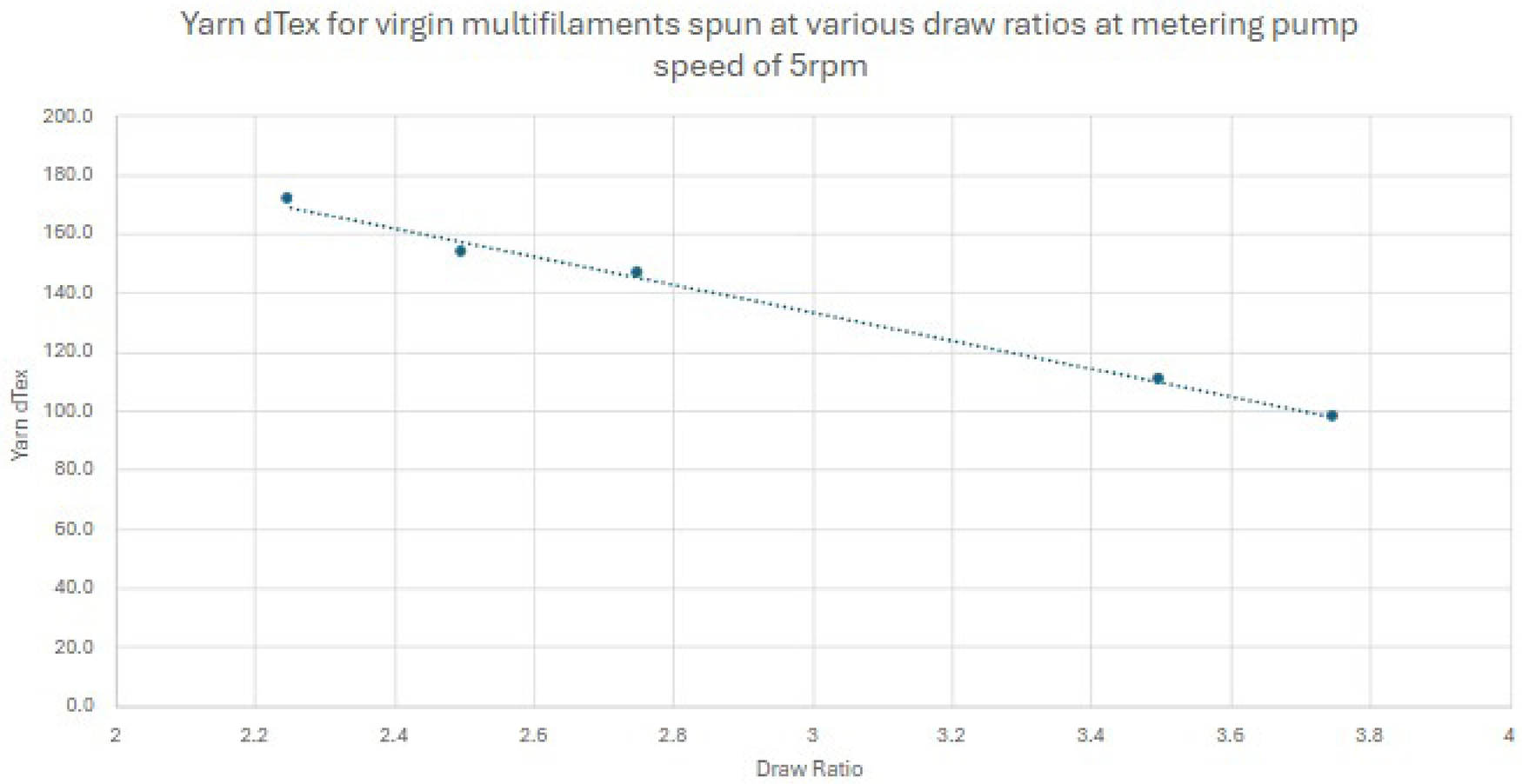


Figure 132: Polyester Spinning Trial 4 analysis: Yarn tex for virgin filaments spun at various draw ratio at 5rpm

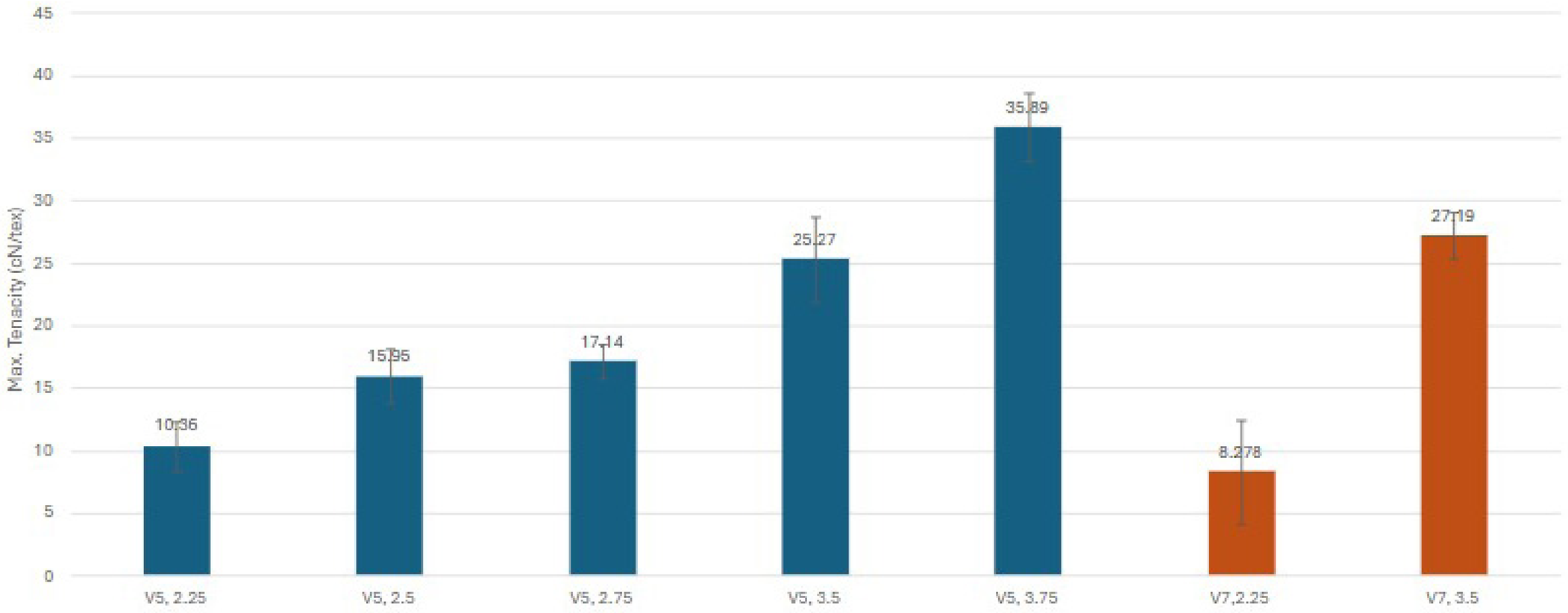


Figure 133: Polyester Spinning Trial 4 analysis: Tensile strength for spun virgin filaments at different draw ratios

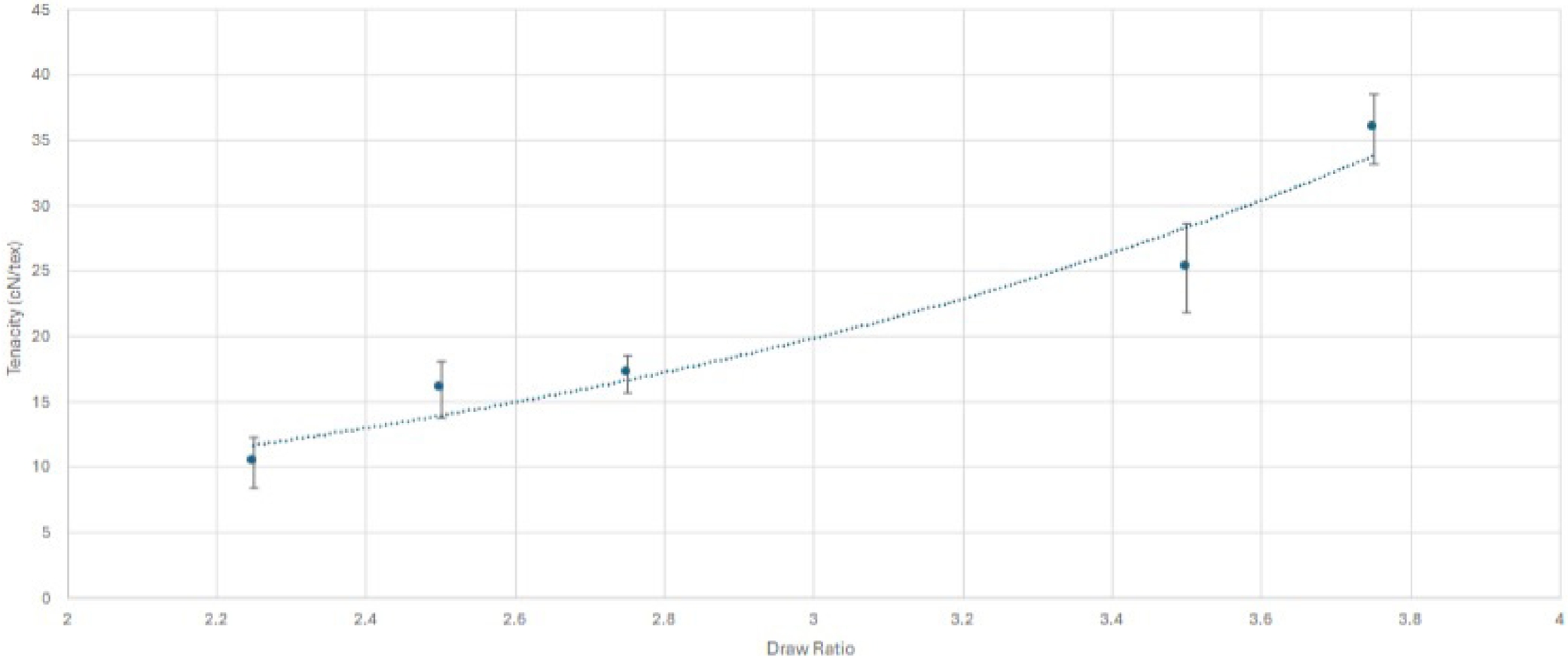


Figure 134: Polyester Spinning Trial 4 analysis: Tensile strength for spun virgin filaments at different draw ratios at metering pump speed of 5rpm

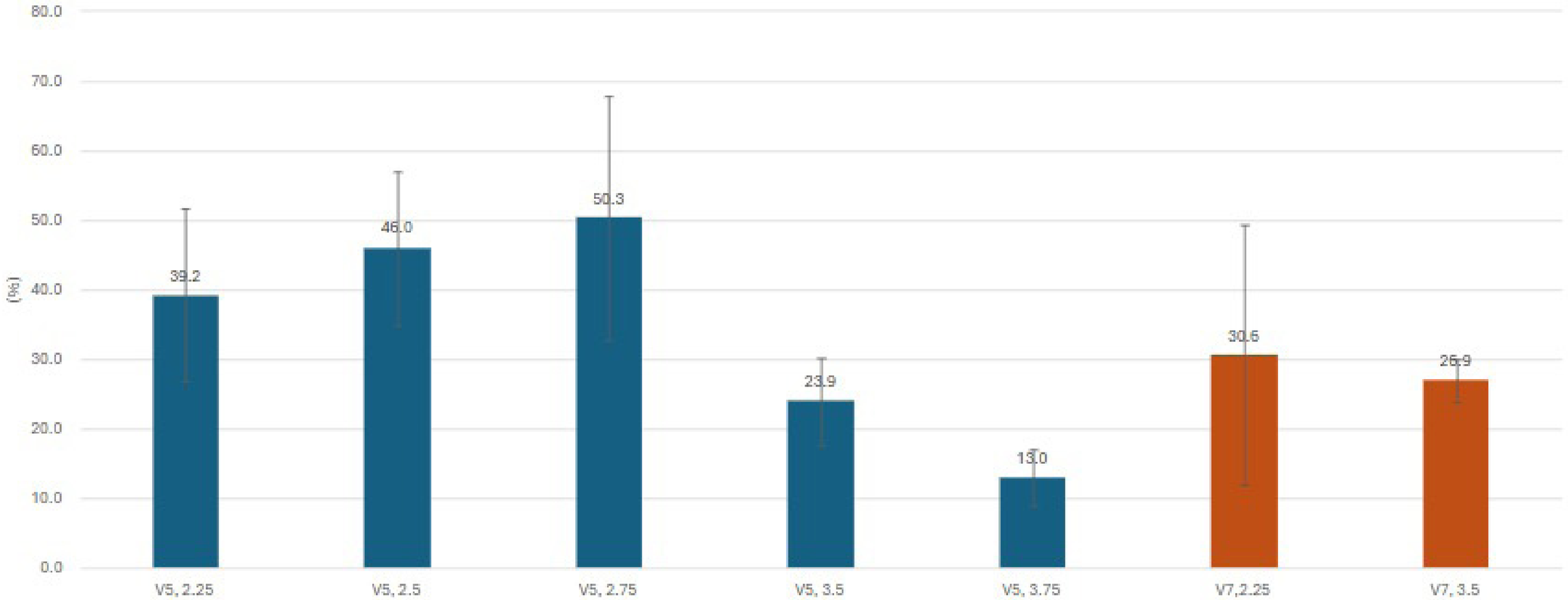


Figure 135: Polyester Spinning Trial 4 analysis: Elongation at break for spun virgin filaments at different draw ratios

Spun Sample	Polymer flow		Drawing		Draw Ratio	Expected yarn dTex	Actual yarn dTex
	Metering pump capacity (ml/rev)	Metering pump speed (rpm)	Godet speed 1 (mpm)	Godet speed 3 (mpm)			
R5, 350/500	2.5	5.0	350	500	1.43	300.0	291.33
R3, 700/900	2.5	3.0	700	900	1.29	100.0	101.97
R5, 1000/1500	2.5	5.0	1000	1500	1.5	100.0	103.49
R5, 750/1500	2.5	5.0	750	1500	2	100.0	103.66
R5, 600/1200	2.5	5.0	600	1200	2	125.0	129.59
R5, 550/1100	2.5	5.0	500	1100	2	136.4	140.27
R5, 175/350	2.5	5.0	175	350	2	428.6	447.64
R5, 155/350	2.5	5.0	155	350	2.26	428.6	451.90

Figure 136: Polyester Spinning Trial 5 analysis: Draw ratios for recycled yarns

85/15 V/R PET	Draw rato	Actual dTex	Tenacity (cN/tex)	Elongation at break (%)
R5, 350/500	1.43	291.33	2.42 ±0.59 (CV:24%)	40.66 ±16.07 (CV:40%)
R3, 700/900	1.29	101.97	8.2 ±2.27 (CV:28%)	61.8±4.21 (CV:7%)
R5, 1000/1500	1.5	103.49	6.16 ±1.72 (CV:28%)	30.93±8.67 (CV:28%)
R5, 750/1500	2	103.66	13.05 ±1.68 (CV:13%)	60.53±8.7 (CV:14%)
R5, 600/1200	2	129.59	11.28 ±2.05 (CV:18%)	72.11±12.07 (CV:17%)
R5, 550/110	2	140.27	10.09 ±2.26 (CV:22%)	81.37±13.42 (CV:16%)
R5, 175/350	2	447.64	3.93 ±1.09 (CV:28%)	77.16±41.09 (CV:53%)
R5, 155/350	2.26	451.90	4.57 ±0.89 (CV:19%)	52.19±27.7 (CV:53%)

Figure 137: Polyester Spinning Trial 5 analysis: Tenacity and elongation at break for recycled yarns

Material	Results (g/10min)	Temperature (°C)
Virgin PET	22	260
	34	
	26	
Average	27	
Recycled duvet PET with 0.25% additives	121	255
	125	
	118	
	121	

Figure 138: Polyester Spinning Trial 5 analysis: MFI results for virgin and recycled duvet pellets

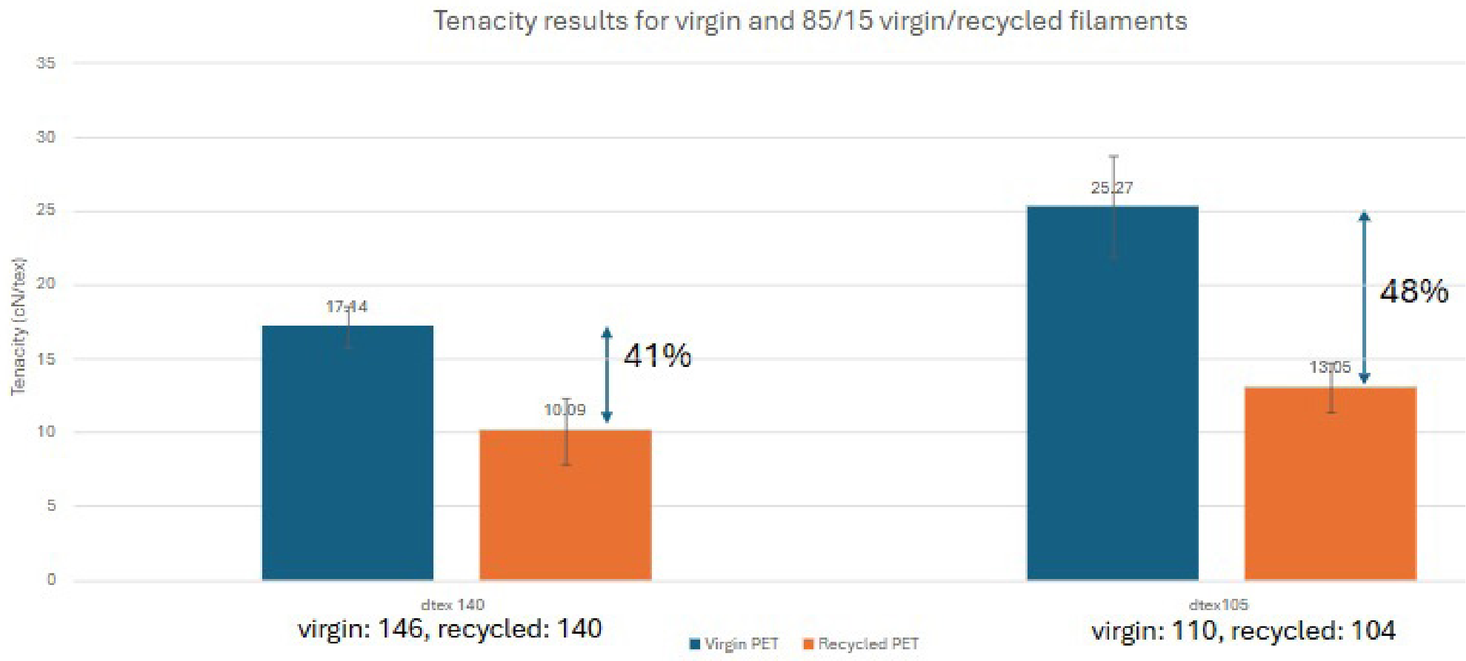


Figure 139: Polyester Spinning Trial 5 analysis: Tenacity results for virgin and recycled duvet pellets at same DTex

Spun Sample	Polymer flow		Drawing		Draw Ratio	Actual yarn dTex	Tenacity (cN/tex)
	Metering pump capacity (ml/rev)	Metering pump speed (rpm)	Godet speed 1 (mpm)	Godet speed 3 (mpm)			
First Comparison							
Virgin (V5, 2.75)	2.5	5.0	400	1100	2.75	146.3	17.14
R5, 550/1100	2.5	5.0	500	1100	2	140.27	10.09
Second Comparison							
Virgin (V5, 3.5)	2.5	5.0	400	1400	3.50	110.0	25.27
R5, 750/1500	2.5	5.0	750	1500	2	103.66	13.05

Figure 140: Polyester Spinning Trial 5 analysis: Yarn tex and tenacity results for virgin and recycled duvet pellets at same DTex

Spun Sample	Polymer flow		Drawing		Draw Ratio	Actual yarn dTex	Tenacity (cN/tex)
	Metering pump capacity (ml/rev)	Metering pump speed (rpm)	Godet speed 1 (mpm)	Godet speed 3 (mpm)			
First Comparison							
Virgin (V5, 2.75)	2.5	5.0	400	1100	2.75	146.3	17.14
R5, 550/1100	2.5	5.0	500	1100	2	140.27	10.09
R5, 550/1100	2.5	5.0	500	1100	2.75	80.15	18.30

Figure 141: Polyester Spinning Trial 5 analysis: Yarn tex and tenacity results for virgin and recycled duvet pellets at same draw ratio

Appendix 2: Wool

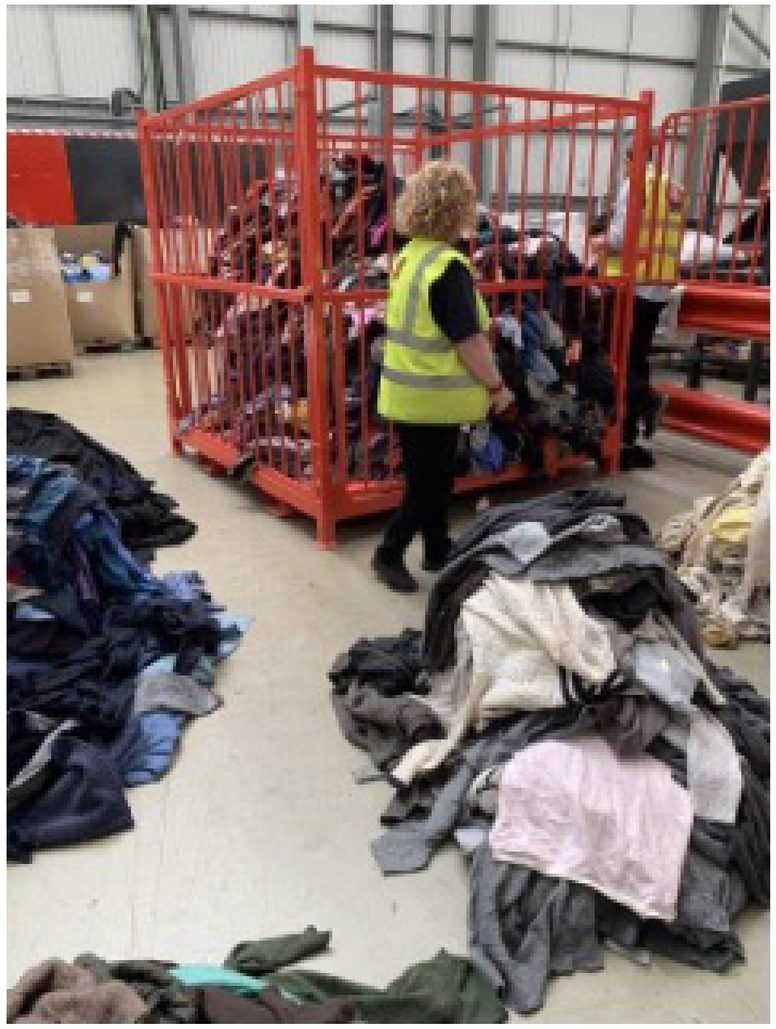


Image 37: Sorting post-consumer garments by colour



Image 38: Fibre recycling



Image 39: Recycled yarns

Colourfastness to light: (ISO 105-B02:2014, method 3, Xenon-arc lamp, modification: exposure up to contrast of greay scale 4)			
	Grey	**Blue**	
Rating (numerical mean)	4-5	4-5	/
*Remark			
Colourfastness to perspiration: (ISO 105-E04:2013, multifibre DW/ multifibre TV/ single adjacent fabric)			
	Acid	**Alkaline**	
Colour change	4-5	4-5	/
Self-staining	4-5	4-5	/
Colour standing on acetate	4-5	4-5	/
Colour standing on cotton	4-5	4-5	/
Colour standing on polyamide	4-5	4-5	
Colour standing on polyester	4-5	4-5	
Colour standing on acrylic	4-5	4-5	
Colour standing on wool	4-5	4-5	
Colourfastness to rubbing: (ISO 105-X12:2016/BS EN ISO 105-X12-2016)			
	Lengthwise	**Widethwise**	
Dry	4-5	4-5	/
Wet	4-5	4-5	/
*Remark			

Figure 142: Physical performance tests and results

Test	**Result**	**Pass/Fail**
Alkylphenol (AP) And Alkylphenol Ethoxylates (Apeos), Including All Isomers	Not Detected	Pass
Azo-Amines And Arylamine Salts	Not Detected	Pass
Chlorophenols	0.13 PPM – Not Detected	Pass
Extractable Heavy Metals	Not Detected	Pass
Ph Value	5.6	Pass
Formaldehyde Content	23 mg/kg	Data

Figure 143: Chemical performance tests and results

Chapter 6:

The business case for advanced textile sorting and pre-processing facilities

Exploring an ATSP facility via a cost model



CONTENTS

Introduction
- Current NRT profiles

Methodology: Creating an ATSP model
- ATSP value chain configurations
- ATSP technology landscape
- ATSP customer requirements
- ATSP customer landscape
- ATSP potential locations

Results: ATSP assumptions & cost model
- ATSP operational assumptions
- ATSP transition period
- ATSP capital expenditure requirements
- ATSP staffing requirements
- ATSP material and quality sensitivity
- Cost model scenarios
- Cost of goods sold and operating expenditure

Discussion
- Business case recommendations
- Key enablers recommendations
- Circle-8 Textile Ecosystems opportunities

Appendix
- Appendix 1: NRT profile methodology
- Appendix 2: Current & future recycling capacity overview
- Appendix 3: ATSP cost model assumptions

1. INTRODUCTION

Non-reusable textiles (NRT) resources remain underutilised due to the challenges faced at the sorting stage for recycling. The current post-consumer textile (PCT) value chain is not yet equipped to cater to emerging recycling solutions that require consistent, reliable feedstock that meets specific requirements.

As we have seen in earlier chapters, a potential solution is to build Advanced Textile Sorting and Pre-processing (ATSP) facilities, and Figure 144 shows how ATSP facilities have been mapped onto an ambitious vision for a circular textiles ecosystem.

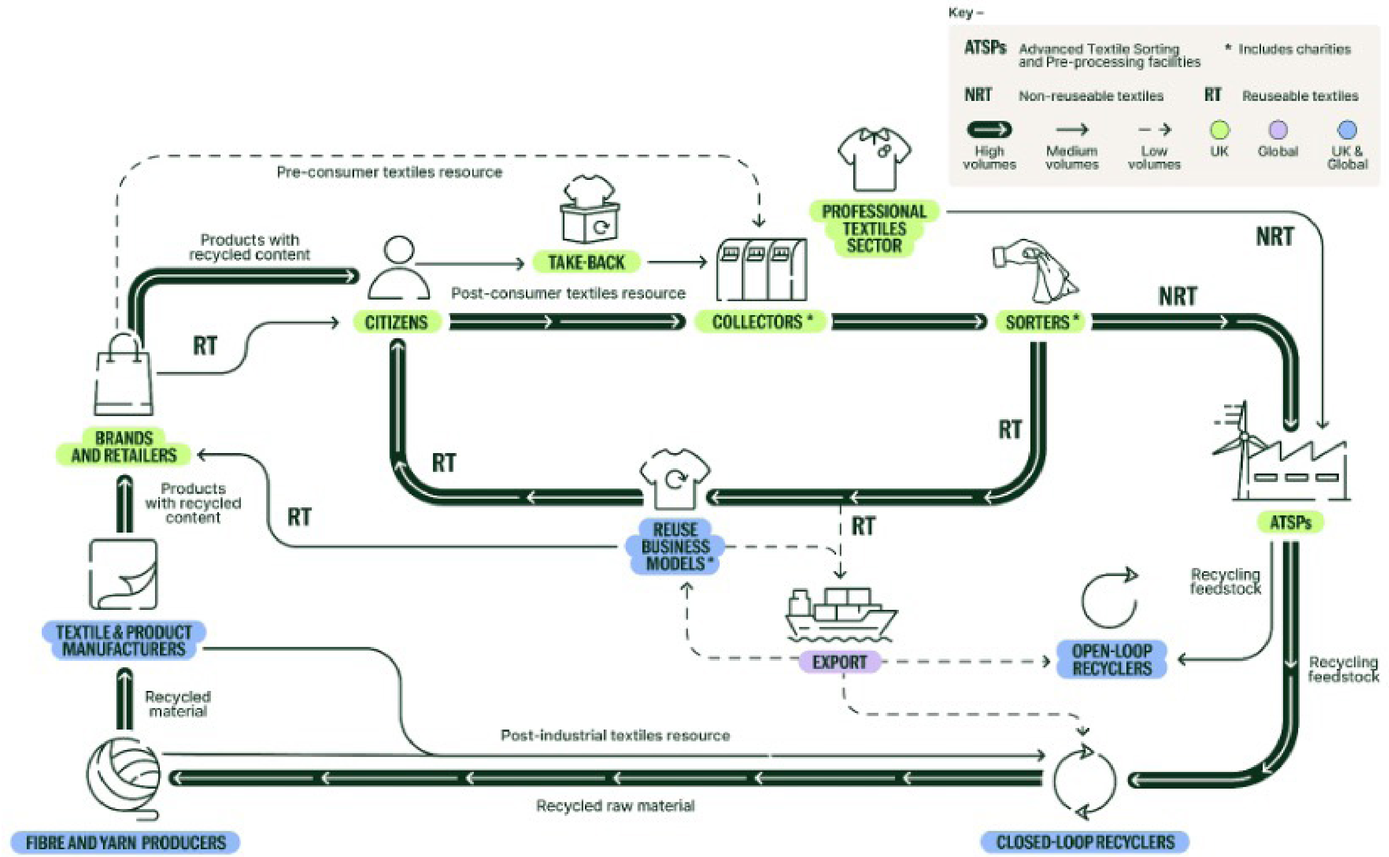


Figure 144: Diagram of an ATSP integrated circular textiles value chain vision including key stakeholders and movement of RT/NRT

This chapter consolidates research on the feasibility and viability of implementing a standalone ATSP facility. It also presents the business case for an ATSP, highlighting the challenges and opportunities within the current NRT system, and examining the business-as-usual cost model, volumes of NRT, and material flows. It reviews the ATSP landscape, covering potential ATSP configurations and technologies, and assesses the UK and EU textiles recycling market and optimal facility locations. This research underpins the establishment of an ATSP cost model to test its economic viability, outlining key assumptions and costs, such as capital expenditure (CAPEX) and labour (please note that in the ATSP cost model, costs of colour sorting are excluded, and met by mechanical recyclers).

The chapter also highlights the potential of ATSP circular textiles infrastructure and concludes with recommendations and opportunities to refine and adapt the cost model to create a profitable operating business proposition. It also emphasises the crucial role of key enablers such as government, green investors, brands, and retailers in supporting ATSP facilities and makes recommendations to implement the necessary market dynamics to establish effective recycling markets. Finally, this chapter summarises Circle-8 Textiles Ecosystems' business case, demonstrating how ATSP facilities can seize opportunities to meet industry demands.

1.1. Current NRT profiles

To establish a business case for ATSP facilities, it is important to conduct a market analysis of NRT in the UK, estimating what proportion they represent of total textile waste, and exploring the cost model of the current system. By conducting a survey (see Appendix 1 for details) to explore the landscape of textile collectors and sorters within the UK, an NRT profile was built that revealed the huge volumes of NRT currently not being captured and underutilised. This highlighted the material's potential as an ATSP input, which is explored in the following three sections (1.1.2, 1.1.3, 1.1.4).

1.1.2. NRT flows in the UK

Figure 145 displays the annual NRT volumes arising in the UK and onward flows, as well as key stakeholders collecting material. The main findings are[35]:

NRT total: An estimated 744,000 tonnes of NRT are discarded annually in the UK.

Residual waste: The majority (52%; 387,000 tonnes) of total NRT is disposed of via residual waste streams by citizens, where it is destined for incineration or landfill. Capturing this would increase volumes of potential ATSP input material. However, this would require substantial changes in citizen disposal behaviour and an optimised PCT collections system.

Collected: 206,000 tonnes of NRT is collected by the existing value chain.

Exported: A significant portion of collected NRT is exported as a resource for manual sorting (77%; 158,000 tonnes). Of these exports, the majority (92,000 tonnes) is sent to Pakistan for remanufacturing or mechanical recycling. Additionally, 44,000 tonnes are sent to the United Arab Emirates, where the textiles will be further sorted.

Recycled: Only a small fraction of collected NRT is currently recycled domestically and abroad, with 27,000 tonnes going to open-loop recycling in the UK and Europe and just 1,000 tonnes going to closed-loop recycling.

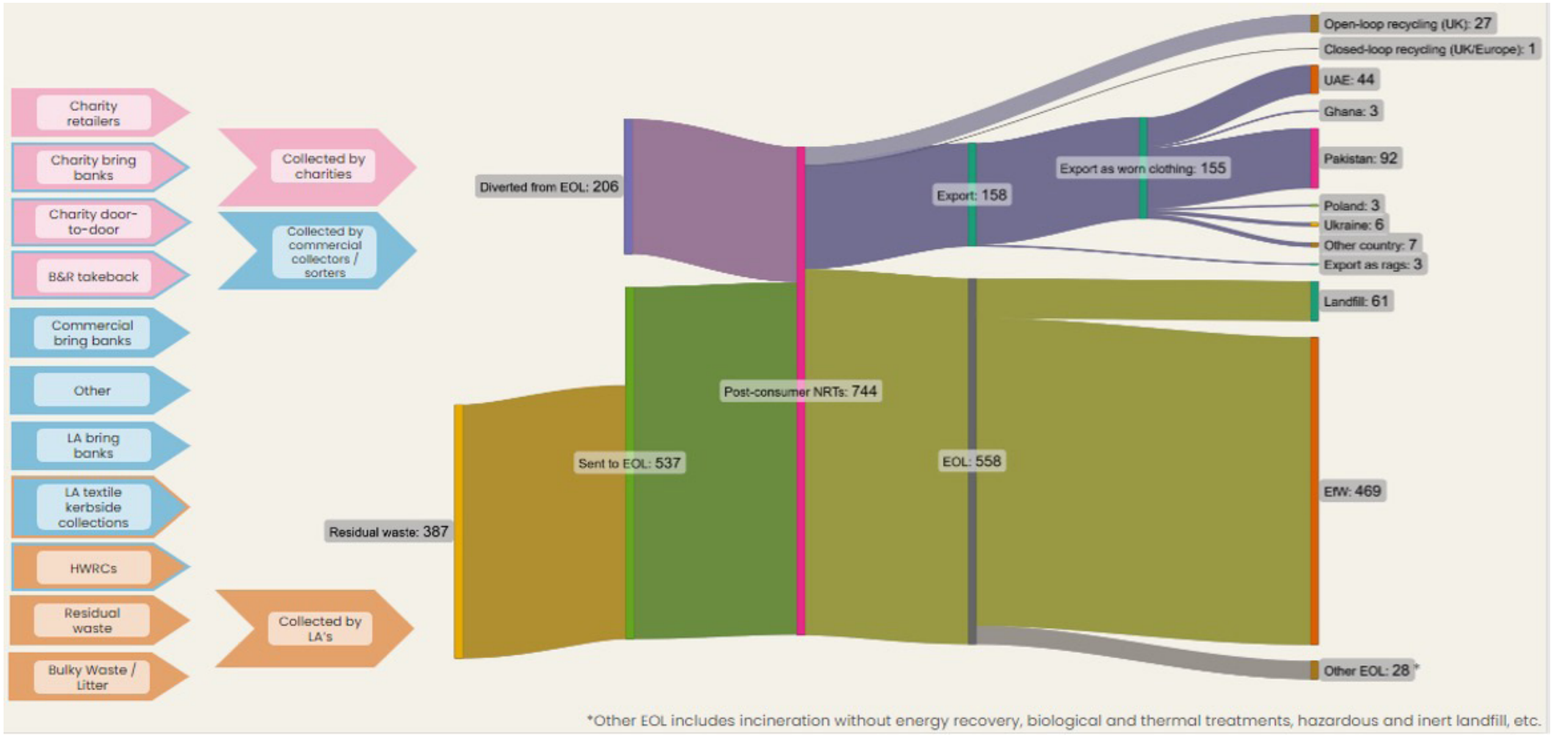


Figure 145: Current NRT flows annually in UK. All numbers are expressed in 1000s of tonnes. Quantities are not disaggregated for most collections to avoid double-counting

1.1.3. Potential NRT ATSP input material

By 2035, the potential material input to ATSP facilities could reach 335,000 tonnes[36]. This projection is based on the most likely scenario, which assumes that compared to 2024 levels:

- PCT volumes remain stable
- Collection rates see moderate increases
- Citizens continue to dispose of textiles in residual waste bins at current rates

To process this volume of non-recycled textile material, 14 ATSP facilities would be required, each handling 25,000 tonnes annually. For further reading on scenarios that investigate the potential landscape for NRT inputs in the future (2035), please read Chapter 8, 'Transitioning To a UK Circular Textiles Ecosystem'[37].

Although professional textiles were outside the scope of the ACT UK project, they could be utilised as immediate inputs to ATSP facilities as they scale up. ATSP facilities provide a possible path for professional textiles moving up the resource hierarchy, bypassing end-of-life (EOL) routes that are common due to business sensitivities and health and safety standards. Additionally, professional textiles have uniform characteristics such as material composition and colour, allowing for more streamlined processing at ATSP facilities.

1.1.4. Current NRT cost model

Under current processes, sorters incur average costs of £526 per tonne[38] for collections, transport, logistics, and manual sorting of standard textile flows (see Figure 146). When this material is sold at the typical NRT[39] value of £100 per tonne, the NRT stream generates a loss of £426 per tonne (see Figure 147). Given that 206,000 tonnes of NRT is collected in the UK annually, this represents a total sorting cost of approximately £88million[40].

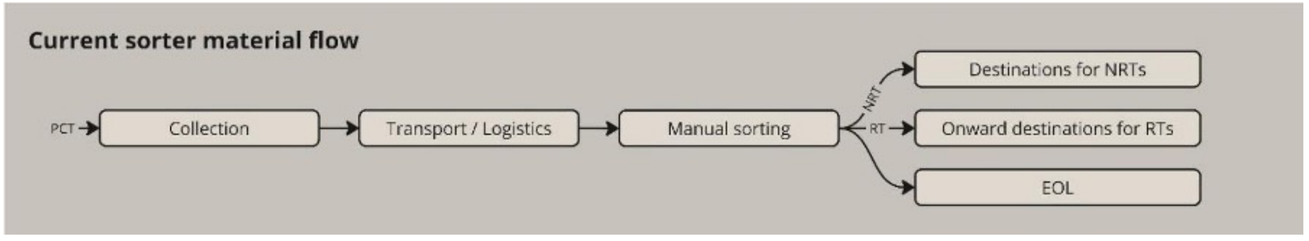


Figure 146: Current material flow of PCT

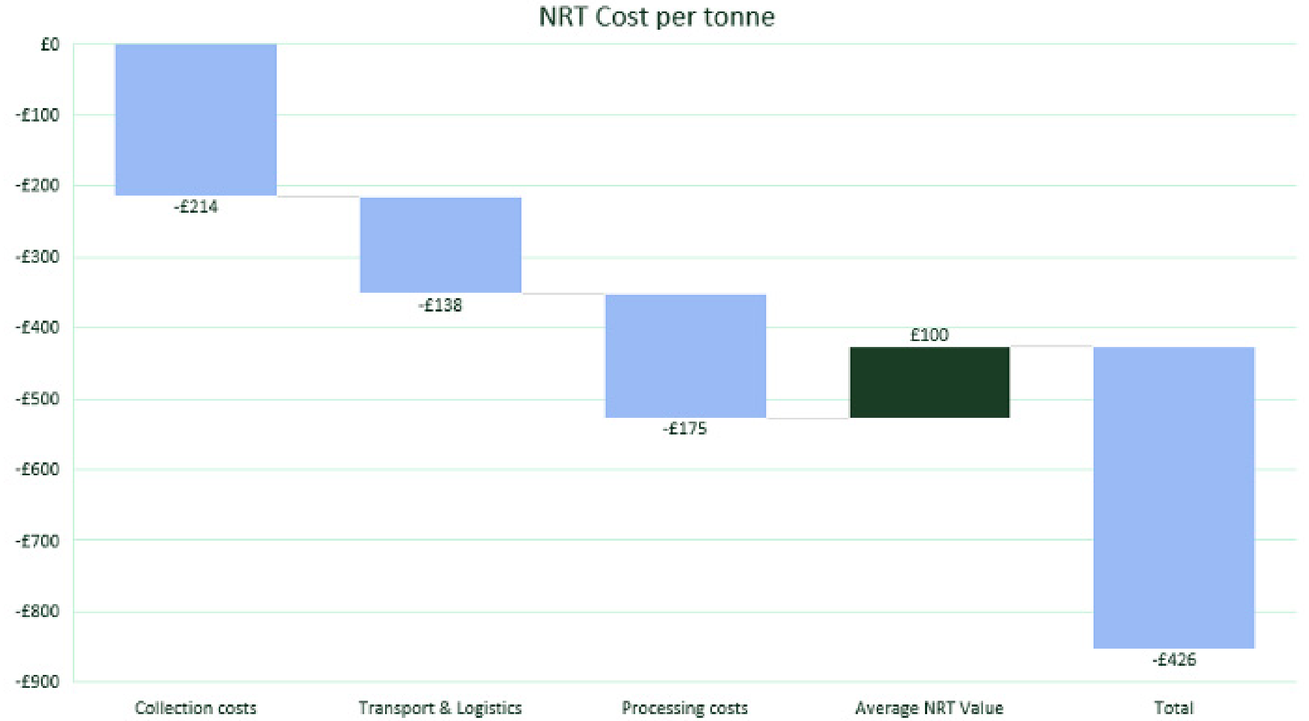


Figure 147: Current NRT cost overview under manual sorting

Although RT sales have historically generated enough revenue to offset NRT losses, industry experts warn that declining RT values and volumes are placing increasing financial pressure on sorters. These challenges in the RT market emphasise the need for new business models, particularly focusing on NRT processing and ATSP facilities.

2. METHODOLOGY: CREATING AN ATSP MODEL

To create a cost model for a stand-alone, for-profit ATSP facility, it is important to explore the role they can play in embedding circular systems. Therefore, this section examines the possible configurations, technology options, and potential locations for facilities, as well as reviewing the current recycling market and recycler requirements.

2.1. ATSP value chain configurations

ATSP facilities are not confined to a specific configuration or business model. This flexibility represents an opportunity to utilise diverse ATSP configurations to suit the different business needs and various future visions of stakeholders in the textiles value chain.

Figure 148 presents a non-exhaustive list of ATSP configurations, with ‘sorter’ referring to any stakeholder that conducts the sorting of textiles. This can include, but is not limited to, collectors, charities, waste management companies, brands, and retailers.

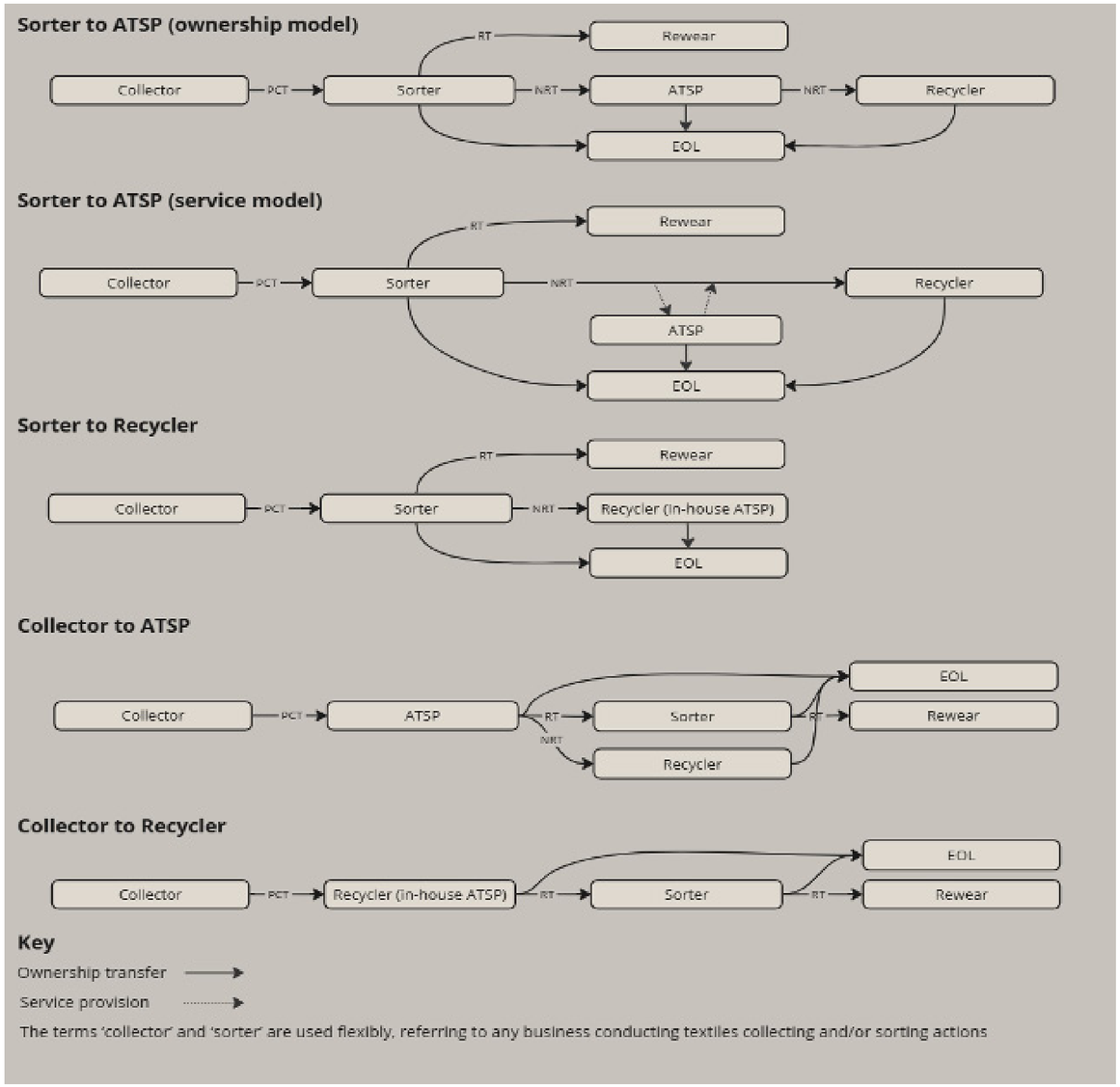


Figure 148: Possible value chain configurations

Configuration: Sorter to ATSP (ownership model):
The cost model created in section 3 is based on a generic, standalone, 'Sorter-to-ATSP' ownership model, as outlined in Figure 148. Therefore, it follows specific assumptions relating to transport and logistics, operating costs, and CAPEX of a single facility. In the ownership model, textiles are purchased by the ATSP facility at a cost and become its direct responsibility. The ownership model is sensitive to market fluctuations such as recyclable feedstock demand, input and output prices, and the input quality provided by its suppliers.

Configuration: Sorter to ATSP (service model):
A service model, as outlined in Figure 148, is far less sensitive to market fluctuations. In this model, the ATSP facility does not own the textiles processed but rather provides a service by sorting, processing, and sending the material to a recycler. The opportunities in the service model are covered in section 4.

Shared ownership could also optimise ATSP operations by integrating it into existing solution providers, such as sorters and recyclers. This would offer several opportunities to cost-share and combine resources on staffing, rent, utilities, and transport.

2.2. ATSP technology landscape

The table in Figure 149 compares six automated technology providers. All providers offer near-infrared (NIR) spectroscopy sorting solutions, sometimes coupled with image recognition solutions. All businesses can identify the most commonly recyclable fibres – cotton, polyester, and wool – and could expand fibre type given research and development funding.

Current technologies vary in their capacity. Two large commercial solutions are reported to handle between 2.5 to 12.5 tonnes per hour. A handheld technology listed in Figure 149 can process 100 kg per day per person, which can sort greater volumes than manual sorting (80 kg per day per person[41]). However, it should be noted that this chapter has not researched direct comparisons between manual and automated sorting capacity.

Regardless of manual versus automation assessments, NIR-scanned feedstock is an increasingly common requirement from textiles recyclers. Therefore, some level of automation technology will be necessary for sorting textiles for recycling.



Technology provider	Material composition sorting	Shape sorting	Colour sorting	Separation of disruptors	Material cutting	Technology specifications	Technology specifications Product offerings
ANDRITZ	Yes	Yes	Yes	Yes	Yes	NIR	Emerging technology
Matoha	Yes	No	No	No	No	NIR	Handheld devices
PICVISA	Yes	Yes	Yes	Yes	Yes	NIR & VIS	Handheld and large commercial solutions
REDWAVE RECYCLING & WASTE TREATMENT SOLUTIONS	Yes	Yes	Yes	Yes	Yes	Not specified	Emerging technology
TOMRA	Yes	Yes	Yes	Yes	Yes	NIR & VIS	Large commercial solutions
VALVAN	Yes	Yes	Yes	Yes	Yes	NIR & RGB camera	Small and large commercial solutions

Figure 149: Automated sorting technology due diligence (information as of September 2024)

NIR technology limitations

While NIR-based technologies enable efficient recognition of textile composition, accuracy limitations exist. These limitations can reduce the acceptance rates of input materials at ATSP facilities (acceptance rates are detailed in section 3.5):

- **Composition limitations:**
  - Blends: Often recognises up to two dominant fibre types.
  - Specific fabrics: NIR struggles with certain fabrics e.g., linen, leather. Limited in detecting elastane, which is common in textile blends.
- **Surface scan limitations:** Often only effective for monolayer garments as scanners and image-recognising technologies scan the top surface[42]. Thickness can also reduce accuracy.
- **Colour limitations:** Detection is more effective with light and single-coloured textiles colours but is less effective with darker textiles. It is also currently unable to recognise fibre composition dyed with carbon black ink.
- **Coatings/finishes limitations:** Presence can reduce accuracy e.g., polyurethane coated materials.
- **Moisture limitations:** Liquids interfere with NIR spectrum analysis, and wet textiles must be removed to prevent contamination and enable accurate NIR processing. Some technologies offer blower points that aid drying, while others remain reliable with a 0-2% moisture content[43].

Investment, innovation, and research and development in NIR and other automated sorting technologies are ongoing, creating opportunities for further advancements and optimisation.

2.3. ATSP customer requirements

Recyclers are currently the most likely primary customers of ATSP facilities. Therefore, they dictate the specifications of ATSP outputs.

Figure 150 presents common recycler requirements of mechanical and chemical (open and closed-loop) feedstock and details current specifications that can be used for ATSP output planning and revenue stream modelling.

Recycler requirements	Mechanical recycling (open and closed-loop)	Chemical recycling (open and closed-loop)
Material composition	Composition range dependent on recycling technology	Composition range dependent on recycling technology
Physical disruptors: Metal and plastic hardware	Removed for recycling	Removed for recycling
Physical disruptors: Other e.g., labels, embroidery	Recyclable	Recyclable
Physical disruptors:Coatings e.g., glitter, rubber, permanent press finishing	Non-recyclable	Non-recyclable
Chemical disruptors: e.g., optical brighteners, water-resistant finishing	Non-recyclable	Non-recyclable
Multi-colour	• Open-loop recyclable • Closed-loop non-recyclable	Colour range dependent on recycling technology
Multi-layers	Non-recyclable *Same composition recyclable	Non-recyclable *Same composition recyclable

Figure 150: Common recycler requirements for chemical and mechanical recycling (open and closed-loop) feedstock

2.4. ATSP customer landscape

Figure 151 displays all open and closed-loop recyclers listed in WRAP's Textiles Sorting and Recycling Database[44] in the UK and EU (find full table in Figure 163, Appendix 2). The volume, technology, and capacity of recyclers will grow if brands and retailers replace virgin material with recycled content to meet environmental targets, such as Textiles 2030[45] and net-zero[46], and follow minimum recycled content policies[47].

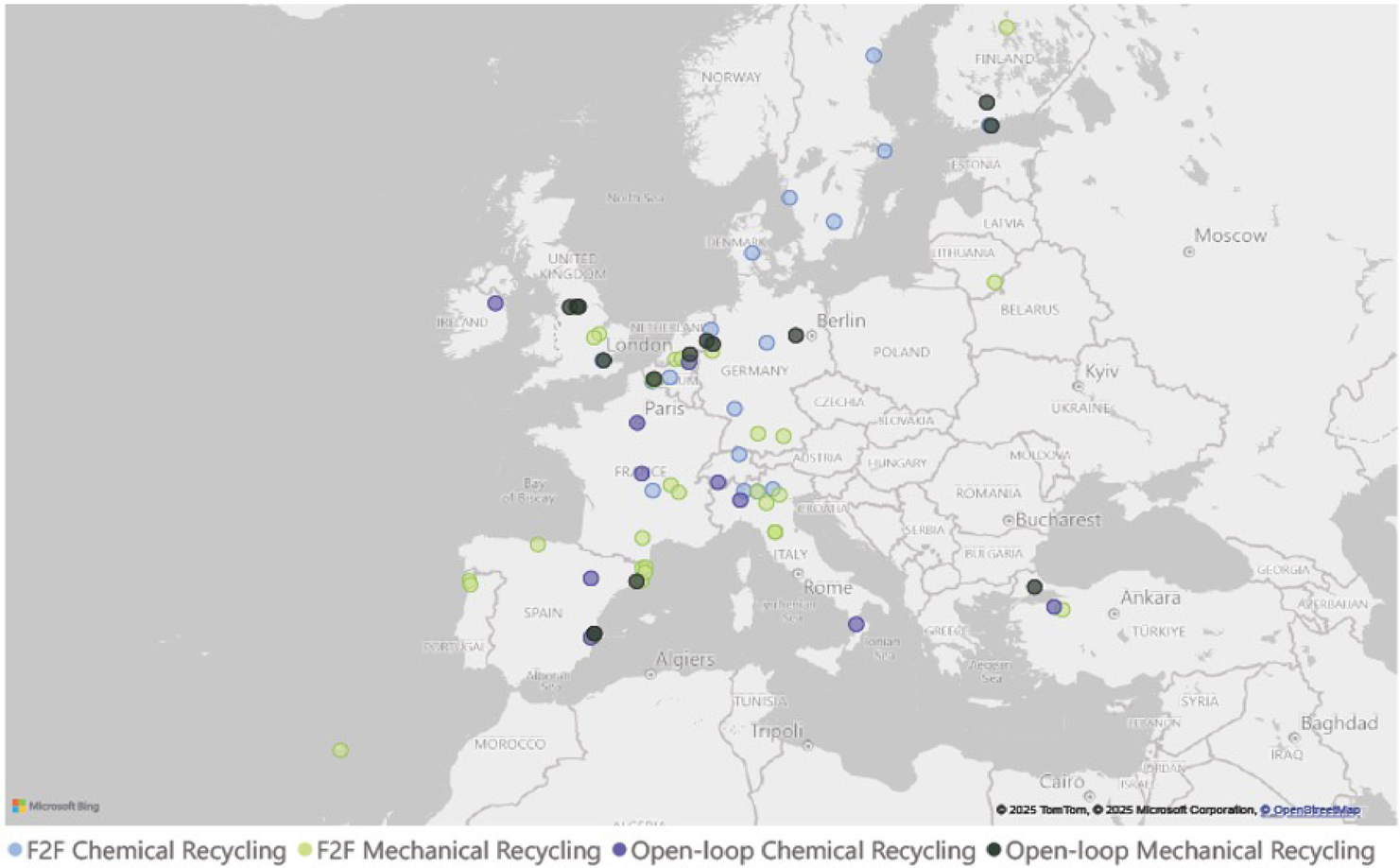


Figure 151: Map of all open/closed-loop recyclers broken down by recycling process listed in WRAP's Textiles Sorting and Recycling Database in the UK and EU. Find key in lower right corner

Capacity is a key indicator of potential ATSP market size, though the available data is poorly defined. In the EU, declared capacity runs at 871,400 T/a, and is expected to reach 1,142,600 T/a in 2030[48], a 23% increase. The forecasted increase further highlights the expected growth in the recycling sector and, subsequently, the need for feedstock.

	Open and closed-loop mechanical recyclers	Open and closed-loop chemical recyclers
Total recyclers	64	38
TRL level	27 At scale 3 Pilot/research	2 At scale 11 Pilot/research
Resource input	23 Post-industrial 18 Post-industrial/pre-consumer 1 Pre-consumer 10 Post-consumer 11 All inputs	10 Post-industrial 2 Post-industrial/pre-consumer 9 Post-industrial/post-consumer 8 Post-consumer 8 All inputs
Primary input material	Cotton	Cotton
Secondary input material	Wool/wool blends	Polyester

Figure 152: Information from WRAP's Textiles Sorting and Recycling Database on open and closed-loop mechanical and chemical recyclers in the UK and EU



2.5. ATSP potential locations

The location of an ATSP facility will have an integral bearing on its success. Optimising logistics, transport links, and proximity to primary stakeholders will enhance operational efficiency, minimise costs, and reduce environmental emissions.

Figure 153 displays potential ATSP facility locations close to ports, densely populated areas, and existing sorters. While the UK's 48 Special Economic Zones[49] are not mapped, their locations largely correspond to the identified hotspots. It should be noted that the cost of land has not informed research.

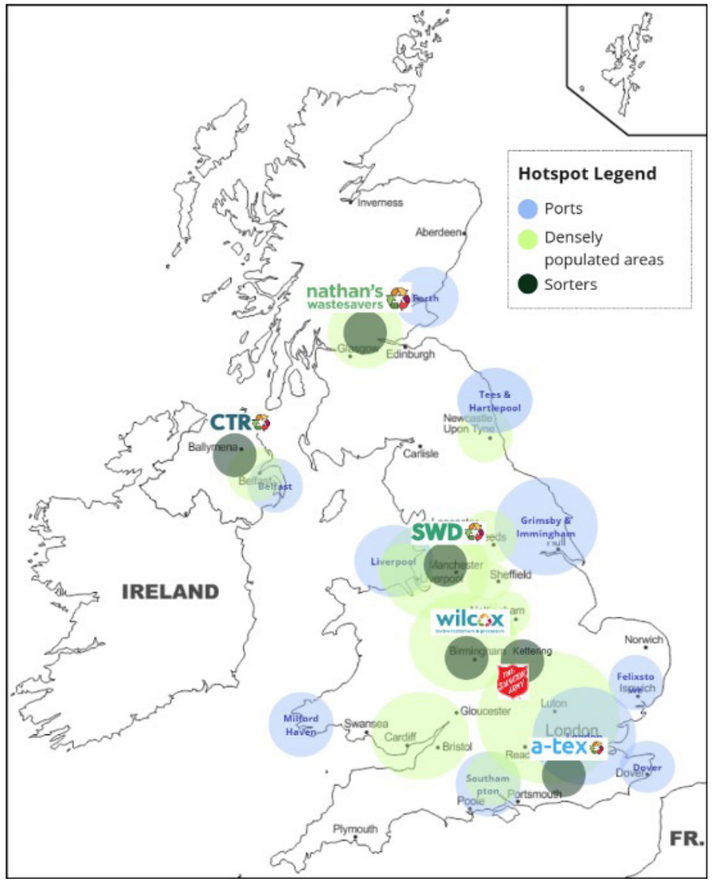


Figure 153: Map of potential ATSP locations within close distance to ports

The most plausible ATSP locations identified are:

1. Midlands: proximity to Birmingham and Nottingham
2. North West: proximity to Liverpool and Manchester
3. South: proximity to London.



3. RESULTS: ATSP OPERATIONAL ASSUMPTIONS & COST MODEL

To fully understand the operational and financial sensitivities and opportunities of an ATSP facility, a model has been created for a generic, stand-alone, for-profit facility. This section explores the forecasted outcomes of this model.

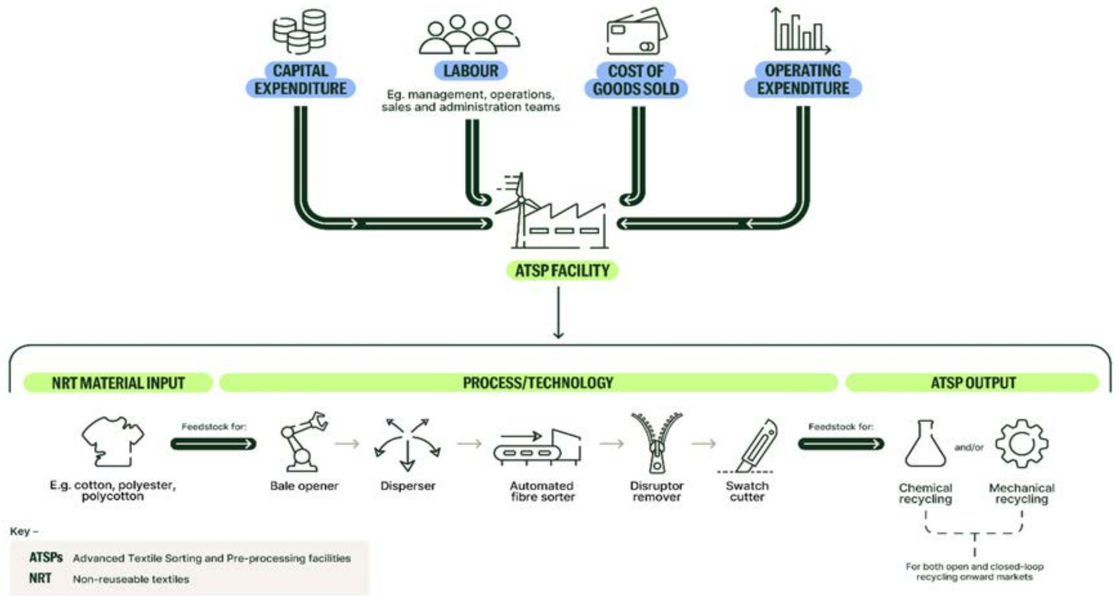


Figure 154: Key operational requirements and processes of a standalone, generic ATSP outlined in the cost model

3.1. ATSP operational assumptions

Accurate cost modelling requires realistic assumptions about how the ATSP business will actually operate. The assumptions can also inform decision-making and identify areas of uncertainty and risk.

Therefore, below is a list of the key cost and operational assumptions in the financial model of a generic, standalone, for-profit ATSP facility (see Figure 165 in Appendix 3 for further details). It is important to highlight that the cost model is based on a facility with no external financial support, such as grants, investment, or Extended Producer Responsibility (EPR) policy (there is no current UK textiles EPR policy, and its implementation remains uncertain).

Key input: Operational capabilities
Assumption: Fibre sorting, disruptor removal, and material size reduction.

Key input: Operating capacity
Assumption: Year 1 starting capacity: 10,000 T/a. Year 3 full capacity: 25,000 T/a.

Key input: Facility cost
Assumption: Rent, business rates, insurance, environmental monitoring, utilities, maintenance and repair.

Key input: Start-up cost
Assumption: Cost allocated to set up the facility in the first two years of its operations.

Key input: Staff and staffing schedule
Assumption: Staff year 1: 30 full-time employees. Staff year 3 (full capacity): 53 full-time employees. Staffing schedule: Three shifts, five days a week, 260 days, 52 weeks per year.

Key input: Transport cost structure
Assumption: Transport from a supplier to the facility covered by the ATSP facility. Transport from the facility to a customer not covered by the facility.

Key input: Input material prices
Assumption: Input prices are based on four different scenarios (detailed below in Figure 160).

Key input: Output product prices
Assumption: Product prices are split into seven product categories (detailed below in Figure 156)

Key input: Waste criteria
Assumption: Cutting waste from the disruptor removal process and materials that do not fit sorting criteria are diverted to EOL.

3.2. ATSP transition period

If the industry is to shift from existing NRT flows (see section 1.1.2) to a circular textiles ecosystem with a network of ATSP facilities operating at full capacity, the transition is expected to develop gradually. Because the modelled ATSP facility takes three years to reach a full capacity of 25,000 T/a, during this transition period, they will need to cater to intermediate markets.

In this transition phase, ATSP facilities should respond to market needs by marketing and selling to existing open-loop solutions, such as wipers and insulation. Figure 155 outlines that, in the model, 75% of products are sold to open-loop markets in year 1, reducing to 20% in year 3. Product prices for these NRT streams are lower than prices for closed-loop products (see Figure 156) but will serve to de-risk existing open-loop markets and enable ATSP facilities to build stable offtake agreements with emerging closed-loop recyclers.

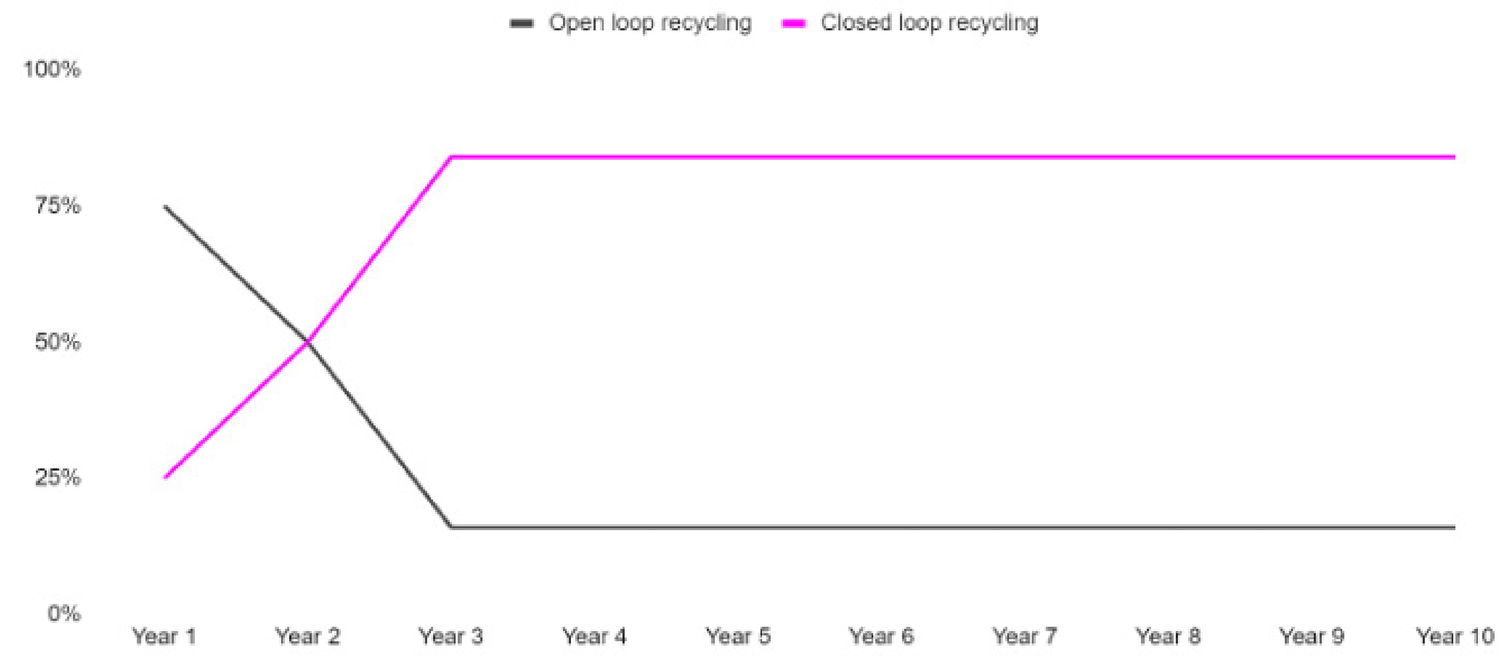


Figure 155: Indicative illustration of the transition from open to mainly closed-loop recycling product sales of an ATSP

ATSP output grade	Material composition sorting	Shape sorting	Colour sorting	Separation of disruptors
F2F Chemical Recycling - Polyester	≥95 polyester, <5% other fibres	No disruptor should be present	All	£200 per tonne
F2F Chemical Recycling - Polycotton	≥60% polyester, <40% cotton, <10% others	No disruptor should be present	All	£200 per tonne
F2F Chemical Recycling - Cotton	≥95% cotton, <5% other, no protein-based fibres	No disruptor should be present	All	£200 per tonne
F2F Mechanical Recycling – Cotton	≥80% cotton	Removable disruptors only	All monocolours	£400 per tonne
F2F Mechanical Recycling - Acrylic	≥95% acrylic	Removable disruptors only	All monocolours	£90 per tonne
F2F Mechanical Recycling - Wool	≥80% wool	Removable disruptors only	All monocolours	£1,200 per tonne
Open-loop recycling	Criteria that satisfy current open loop markets			£75-150 per tonne

Figure 156: ATSP proposed output grade information

3.3. ATSP capital expenditure requirements

ATSP facility capital expenditure mainly includes technology investments. A 20% CAPEX contingency has also been applied, following industry practice. Every five years, a CAPEX upgrade is scheduled at 20% of the initial CAPEX investment.

The total capital expenditure costs of all the machinery mentioned vary depending on the technology provider and ATSP configuration; this ranges between £15-22million.

3.4. ATSP staffing requirements

ATSP facility capital expenditure mainly includes technology investments. A 20% CAPEX contingency has also been applied, following industry practice. Every five years, a CAPEX upgrade is scheduled at 20% of the initial CAPEX investment.

The total capital expenditure costs of all the machinery mentioned vary depending on the technology provider and ATSP configuration; this ranges between £15-22million.

To operate effectively, the ATSP facility requires skilled staff. The modelled facility has four teams, with 30 full-time staff members in year 1, increasing to 53 full-time employees at full capacity. However, this number can vary greatly, particularly relative to an ATSP facility's business model configuration, capacity, and technology. Salary ranges apply to the skill levels required for each role (see Figure 165 in Appendix 3 for further detail).

Management team:

Team roles: 3
Team comprises: Managing Director, HR Manager, and Financial Controller.
Responsibility: Guiding the company's strategic direction and ensuring operational efficiency.

Operations team:

Team roles: 8
Team comprises: Production Manager (x3), production worker (x3), Warehouse Manager (x3), warehouse worker (x3), Environmental and Industrial Risk Advisor, Engineer, Bale Press Worker, and Logistics Manager.
Responsibility: Smooth and efficient running of the facility.

Sales team:

Team roles: 2
Team comprises: Sales Agent and the Business Development Manager.

Responsibility: Generating revenue and business growth.

Administration team:

Team members: 1
Team comprises: Bookkeeper
Responsibility: Recording and maintaining financial transactions for the business.

3.5. ATSP material and quality sensitivity

ATSP input material

Figure 157 shows the estimated NRT composition to be fed into an ATSP facility. All other fibres and blends account for 28% of incoming material, which includes compositions that are not included in Figure 157, such as non-recyclable fibre blends. Material composed of >95% pure cotton represents 24% of incoming material, while textiles made up of >95% polyester constitute 23% of the total material input. Materials with high compositions of cotton, wool, and polyester are at or near market for fibre-to-fibre (F2F) recycling (see section 2.4). These fibre types total 54% of overall ATSP input material, showing significant potential as F2F recycling feedstock.

Please note that the estimated composition is indicative only, based on a single facility and a relatively small sample size of five tonnes. It should not be considered representative of all NRT volumes. The material composition includes clothing and home textiles only, excluding accessories and shoes.

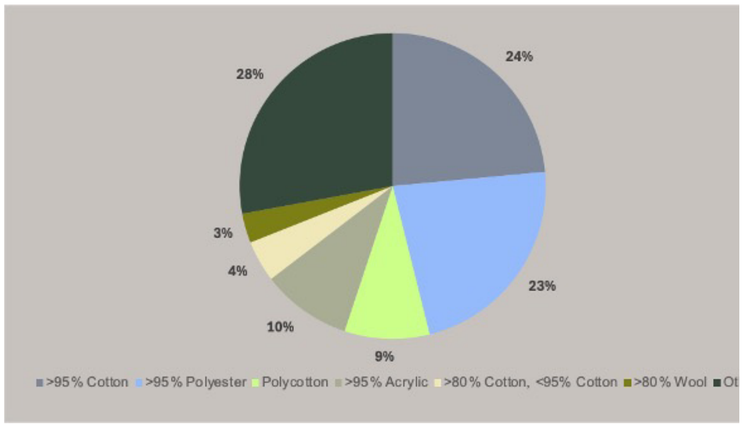


Figure 157: Indicative material composition of NRTs in the UK

ATSP output material

The ATSP facility has seven different output grades (see Figure 156). Three grades for chemical recycling, three grades for mechanical recycling, and one grade tailoring to open-loop recyclers. Note that output grades[50] are based on current and near-future recycler requirements and the material composition of NRTs in the UK.

Figure 156 also shows the estimated price at which ATSP outputs are expected to sell[51]. The range varies depending on the onward market and recycling process, from £75 per tonne for open-loop markets to £1,200 per tonne for mechanical wool recycling. These figures are indicative only because gathering specific price data from stakeholders is challenging due to the nascent closed-loop recycling landscape. Consequently, prices are not fully established, and prices can vary greatly. Additionally, data may also be considered business sensitive.



Acceptance rate

Figure 158 displays the ATSP material flows used in modelling[52]. The ATSP facility set-up includes opening (bale opener), evening out (dispenser), and sorting materials automatically by fibre composition (automated fibre sorter). NRT is sent to processing lines for four of the seven output grades presented in Figure 156 (note that output grades are used as examples only to showcase where material is lost).

A proportion of ATSP input material will not meet recycler feedstock criteria and will be rejected, and this percentage is known as the 'acceptance rate'. Figure 154 above visualises and outlines the percentages at each stage of the process where textiles may be rejected from an ATSP facility. Multi-layered textiles are assumed to make up 15%[53] of total NRT, while NRTs with disruptors present could amount to 40%.

The financial performance of ATSP facilities is heavily reliant on acceptance rates. This is because significant revenue losses can occur if volumes are lost and onward markets cannot be found, resulting in material being directed to EOL processing. Despite this challenge, acceptance rates can be improved by:

- Establishing offtake agreements with suppliers to define desired quality standards for NRT material
- Selecting high-accuracy sorting equipment as technology improves

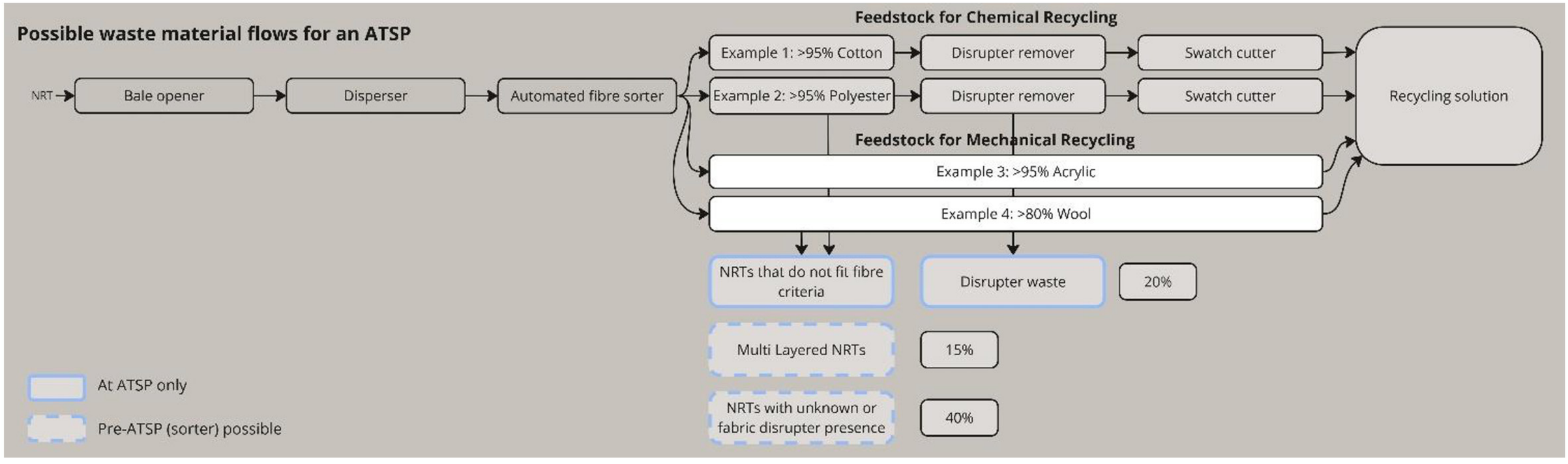


Figure 158: ATSP NRT material flows and rejected volumes

3.6. Cost model scenarios

To test and scope the financial performance of an ATSP facility, the cost model employs four scenarios, as displayed in the table below, Figure 159. In each case, ATSP facilities are responsible for transportation costs of input material only.

	Scenario 1: All NRT as revenue	Scenario 2: All NRT as cost	Scenario 3: Single layered NRT	Scenario 4: Single-layered NRT with removable/no disruptors present
Transport costs (per tonne)	£138	£138	£138	£138
NRT price (per tonne)	£100	£100	£120	£150
EfW gate fee	£112	£112	£-4,998,017	£112
Multi layers present	Yes	Yes	Yes	Only removable ones
Acceptance rate (% of total volume that is recyclable NRT)	46%	46%	54%	58%

Figure 159: NRT input costs per NRT input quality and its anticipated acceptance rates.

3.7. Cost of goods sold and operating expenditure

The cost of goods sold (COGS) includes costs for start-up, input feedstock transport, feedstock purchase, labour, and EOL treatment. It is assumed that all disruptor-removal waste and all textiles that do not fit the sorting criteria will be sent to EOL treatment. Operating expenditure comprises overhead (non-COGS allocated) and facility costs such as ground rent, utilities, insurance, repairs, and maintenance.

Following the assumptions laid out, none of the scenarios described in the table below, Figure 160, create positive EBITDA (earning before interest, tax, depreciation, and amortisation). Losses range from £7.6million to £2.6million annually at full capacity (see Figure 161), with the range dependent on an operating plan that includes staffing, transport costs, EOL costs, quality, and availability of input feedstock, input material price, output feedstock price, demand for output feedstock, and the acceptance rate.

While the negative figures highlight the evident need for financial support, the cost model highlights several strategies and recommendations to enhance the financial viability of the business case, which are discussed in section 4.

	Scenario 1: All NRT as revenue	Scenario 2: All NRT as cost	Scenario 3: Single layered NRT	Scenario 4: Single-layered NRT with removable/no disruptors present
Revenue	£ 3,786,169	£ 3,786,169	£ 4,454,316	£ 4,820,075
Cost of goods sold	£-4,131,809	£-9,131,809	£-9,452,333	£-10,104,084
Gross Profit	£-345,640	£-5,345,640	£-4,998,017	£-5,284,009
Operating expenditure	£-2,250,211	£-2,250,211	£-2,250,211	£-2,250,211
EBITDA	£-2,595,852	£-7,595,852	£-7,248,228	£-7,534,221

Figure 160: Annual financial results of an ATSP at full capacity based on four scenarios

	Scenario 1: All NRT as revenue	Scenario 2: All NRT as cost	Scenario 3: Single layered NRT	Scenario 4: Single-layered NRT with removable/no disruptors present
Revenue				
>95% cotton	£ 1,110,563	£ 1,110,563	£ 1,306,544	£ 1,413,829
>95% polyester	£ 1,005,084	£ 1,005,084	£ 1,182,452	£ 1,279,547
polycotton	£ 378,221	£ 378,221	£ 444,965	£ 481,503
>95% acrylic	£ 143,316	£ 143,316	£ 168,608	£ 182,453
>80% cotton	£ 293,109	£ 293,109	£ 344,835	£ 373,150
>80% wool	£ 624,944	£ 624,944	£ 735,228	£ 795,600
Other	£ 230,932	£ 230,932	£ 271,685	£ 293,994
Total	**£ 3,786,169**	**£ 3,786,169**	**£ 4,454,316**	**£ 4,820,075**
Cost of goods sold				
Transport costs	£-3,442,500	£-3,442,500	£-3,442,500	£-3,442,500
Purchase of input material	£-2,500,000	£-2,500,000	£-3,000,000	£-3,750,000
Labour	£-1,406,340	£-1,406,340	£-1,406,340	£-1,406,340
EOL treatment	£-1,782,969	£-1,782,969	£-1,603,493	£-1,505,244
	£-4,131,809	**£-9,131,809**	**£-9,452,333**	**£-10,104,084**
Gross profit	**£-345,640**	**£-5,345,640**	**£-4,998,017**	**£-5,284,009**
Operating expenditure				
Overheads	£-634,725	£-634,725	£-634,725	£-634,725
Facility Costs	£-1,111,486	£-1,111,486	£-1,111,486	£-1,111,486
Repairs & Maintenance	£-504,000	£-504,000	£-504,000	£-504,000
	£-2,250,211	**£-2,250,211**	**£-2,250,211**	**£-2,250,211**
EBITDA	**£-2,595,852**	**£-7,595,852**	**£-7,248,228**	**£-7,534,221**

Figure 161: Annual financial results of an ATSP at full capacity based on four different scenarios as described above

4. DISCUSSION

To create a cost model for a stand-alone, for-profit ATSP facility, it is important to explore the role they can play in embedding circular systems. Therefore, this section examines the possible configurations, technology options, and potential locations for facilities, as well as reviewing the current recycling market and recycler requirements.

4.1. Business case recommendations

Based on the research set out in this chapter, it is clear that an ATSP facility must meet two primary objectives to ensure long-term viability and support textiles circularity:

- Raising capital investment to purchase the necessary technology and machinery.
- Raising financial support to break even and run operations while ATSP facilities are in their infancy, pursuing open-loop recycling while the closed-loop recycling market develops and matures.

To achieve these objectives, the business case must be strengthened, particularly as the modelled ATSP facility does not generate positive earnings at full capacity. While the scenarios modelled are limited to available data and well-considered assumptions, pain points in the model highlight opportunities to leverage and build a strong, positive business case, outlined in the following nine recommendations:

- **4.1.1. Recommendations: Logistics and transport costs:** Streamline logistics, improve data, and utilise logistics from existing business operations (see ATSP configurations in section 2.1).
- **4.1.2. Recommendations: Location**: Position ATSP facilities strategically to leverage key NRT suppliers, feedstock buyers, and transport infrastructure, e.g. ports.
- **4.1.3. Recommendations: Staffing**: Form synergies with existing solution providers, upskill, and further automate the workforce.
- **4.1.4. Recommendations: Facility equipment:** Optimise set-up for sorting accuracy and capability. Select technologies that overcome low acceptance rates relating to multi-layers and disruptors.
- **4.1.5. Recommendations: Acceptance rate and input material**: Request offtake agreements with suppliers that specify desired quality standards.
- **4.1.6. Recommendations: Output material:** Respond to recycling market needs. This includes both open and closed-loop recycling.
- **4.1.7. Recommendations: Rejected volumes:** Find alternative onward markets to EOL for volumes rejected by ATSP facilities to avoid gate fees and landfill tax and gain revenue from other markets.
- **4.1.8. Recommendations: Unlocking ATSP configurations:** Integrate an ATSP into existing facilities or develop ATSP partnerships to utilise NRT supply, lower transport costs, staffing, and CAPEX.
- **4.1.9. Recommendations: Service business models:** Consider a service business model (see section 2.1). Costs relate to operations only e.g. labour, maintenance, repair, facility. ATSP facilities must charge customers an estimated minimum of £163 per tonne to break even.

4.2. Key enablers recommendations

Under the current cost model, ATSP facilities cannot cover costs even when operating at full capacity without external financial investment. Given the significant opportunity to support a circular textiles ecosystem and bridge the gap between NRT supply and textile recycling, support from key enablers is essential.

Enablers can signal the demand for textiles recycling and therefore sorting for recycling, vitally de-risking investments and accelerating implementation. The ACT consortium has outlined four critical areas of support:

- **4.2.1. Recommendations: Government support:** Textile policy will support the successful implementation of ATSP facilities (see Chapter 8, ‘Transitioning to a UK Circular Textiles Ecosystem’ for policy recommendations). In particular, appropriate EPR fees could relieve operational costs. Government grants, public funding, and regional subsidies can help ease the CAPEX bill. CAPEX grants can also incentivise private investors to engage in fundraising rounds.
- **4.2.2. Recommendations: Green investment:** Investment in ATSP technology and infrastructure by impact investors, private equity, and venture capital can substantially reduce upfront costs and encourage further investment in the landscape. Investment is expanded upon in Chapter 8, ‘Transitioning to a UK Circular Textiles Ecosystem’.

- **4.2.3. Recommendations: Commercial partnerships:**
  - Brands and retailers have ambitious environmental targets to achieve, and recycled content is a key route to reach these targets. However, the level of recycled content required to meet these targets[54] is highly ambitious and unrealistic without strategic, bold, and impact-led commercial partnerships. Forming direct supply partnerships that meet desired quality standards and contribute to the cost of NRT handling can reduce ATSP facility costs for pre-processing materials. Partnerships will help to ensure a steady supply of recycled content, mitigate risk in recycled content strategies, and minimise textile volumes reaching landfill and incineration.
  - Brands and retailers can also support ATSP facilities by creating effective take-back schemes with charities and collectors to guarantee NRT streams to the facilities, ensure demand for recycled content through offtake agreements and letters of intent with recycling suppliers, and by designing products for recyclability, thereby supporting the textiles ecosystem across the value chain.
- **4.2.4. Recommendations: A supportive wider textiles ecosystem:** The success of an ATSP network requires every part of the value chain to work collaboratively with the shared aim of creating a circular textiles ecosystem that is effective and future-proof. Textile collections must be fit for purpose to increase NRT collected, divert EOL, and foster positive citizen disposal behaviours, ensuring ATSP facilities secure reliable and quality input material. Please read Chapter 7, ‘The Next Phase of UK Manufacturing’, which spotlights collections as an emerging area for innovations in textiles circularity.

4.3. Circle-8 Textile Ecosystems opportunities

Circle-8 Textile Ecosystems is an ACT UK consortia member that has committed to developing a comprehensive, market-ready, and investible business case for the first UK 25,000 T/a ATSP facility. In addition to the above recommendations, Circle-8 has set out a series of key points to establish a successful ATSP facility:

Plant design:

- Circle-8 is planning to build a fully automated facility designed to sort and pre-process NRT, to deliver feedstock for chemical and mechanical recycling.
- TOMRA sorting technology will be combined with other sorting and processing equipment as part of the full design layout for cutting, shredding, and removal of seams, zippers, and metals to enable ‘pure textile output fractions’ as feedstock for recyclers.

Supply, offtake and logistics:

- A blended post-use supply approach, combining post-use commercial, business-to-business textiles and PCT, with RT and NRT pre-sort partnerships.
- Committed ATSP outputs of sorted and pre-processed cotton, polyester, and polycotton for chemical and mechanical recycling in the UK and globally.
- Greater emphasis in initial years on existing UK and EU open-loop recyclers as chemical recycling scales.
- Partnerships to support bringing down logistics costs and bringing up environmental efficiencies to NRT materials flows.

Brand engagement:

- Major UK brand commitments to engage in supply via advanced collection systems and in-direct sales demand for recycled content.
- Exploring collaborative commitments to contributing to NRT handling through a gate fee to provide ecosystem investment before EPR, gaining a competitive advantage for pro-active brands and retailers in the process. To be phased out as EPR comes into effect.
- A key principle is that ATSP facilities will not take on the cost burden of low-value, unrecyclable fractions.
- As mechanical and chemical recycling industries mature, the gate fee is adjusted to reflect the supply of increased value of recyclable materials in relation to the costs of non-recyclable materials.

Financial:

- £15-22million CAPEX.
- Automation at scale, high volumes, and industry-wide continued cooperation to achieve ecosystem economics is needed to incentivise the involvement of all parties.

APPENDIX

Appendix 1: NRT profile methodology

Surveys and interview scope

A survey[55] was conducted as part of the ACT UK project to inform the profile of NRT flows in the UK. This included both online surveys (7) and extended telephone interviews (5) facilitated by the Textile Recycling Association (TRA).

The survey explored the landscape of textile collectors and sorters within the UK to understand capacity, costs, impacts and capabilities, particularly in terms of NRT flows. The survey specified interest in NRTs and any aspects of textile collection and sorting, including RTs, which could affect NRT logistics, flows and costs.

Respondents: 12 respondents were part of the sample, including commercial collectors (used textiles, bank and charity retail, working with retailers), commercial sorters (including grading), pre-processors, used textile sellers (e.g. charity retailers), remanufacturers (repair, reuse and recycling), transportation, and destruction.

Textiles scope: Clothing, workwear, footwear, home textiles, industrial textiles (hospitality, hotels, commercial etc.), accessories, other.

Question design: The survey included, but was not limited to, questions surrounding:

- The selling and buying of NRTs, both sorted and unsorted
- Collection methods and grading for sorted NRTs
- Source and onward destination of textiles handled
- Whether businesses sort in the UK
- The approximate annual tonnage of used textiles handled by organisations
- The types of textile collected by an organisation
- Costs and observations associated with logistics, operations, transportation, and overheads

Limitations and assumptions: There are uncertainties around the percentage of NRT vs RT in many of these streams. In some cases, an approximation has been made based on qualitative information and/or a proxy used.

This chapter is based on several informed assumptions due to a lack of robust data in these areas:

- NRT fibre composition is the same composition as textiles sold in the UK in 2019
- Assumes 15% of cotton and polyester blends, and 50% of wool is within blends, that are not recyclable by F2F recycling
- All post-consumer textiles sold to the UK public through charity retailers, peer-to-peer reuse organisations and used textile retailers are RTs
- Diverted from EOL and those collected by commercial collectors/sorters/charities are 34% NRTs
- 75% of textiles sent for EOL via residual waste are NRTs
- Household Waste Recycling Centres, kerbside, and bring banks sent for EOL by local authorities are 60% NRT
- All rags and those sent for recycling are NRTs

Sensitivity analysis

There are several factors contributing to the uncertainty in NRT and RT split within residual waste:

- Very limited available data
- Subjective nature of determining NRT or RT after it has been contaminated in residual waste
- Uncertainty in condition of textiles before entering residual waste stream.

In addition, a large proportion of PCT enters residual waste, and therefore there is a large potential for this to become feedstock for an ATSP facility and F2F recycling system. It is therefore important to check the sensitivity of the NRT flows to changes in the % NRT in residual waste assumption.

% of NRT in total residual waste	Total NRTs generated by citizens 1000 tonnes/ yr
50	585
75	743
85	851
90	889
95	927

Figure 162: Sensitivity analysis on % NRT in residual waste, resulting NRT tonnes generated and approximate total NRT with fibre-to-fibre recycling potential

Appendix 2: Current and future recycling capacity overview

	Mechanical	Chemical
	Based on information from 64 recyclers	Based on information from 38 recyclers including 3 recyclers both mechanical and chemical
Current Capacity	• 3 at pilot scale; • 3 at scale with post-industrial waste and piloting post-consumer waste; • 27 at scale (no capacity given); • For the rest, the capacity at scale ranges from 50 T/a to 780 000 T/a or 136,000 T/a of waste processed	• 4 recyclers did not provide scale; • 4 demo plants; • 11 pilot/research scale; • 12 at scale (no capacity given); • For the rest, the capacity ranges from 264 T/a to 60,000 T/a
Future Capacity (2025 - 2030)	• 2 recyclers intend to maintain their capacity • 15 recyclers have provided future capacity which ranges from 800 T/a to 36,000 T/a	• 11 recyclers have provided future capacity which ranges from 5,000 T/a to 500,000 T/a
Input (post-industrial pre-consumer post-consumer)	• 23 recyclers of post-industrial • 18 recyclers of post-industrial and pre-consumer • 11 recyclers of all inputs (including mattresses and footwear) • 10 recyclers of post-consumer • 1 recycler of pre-consumer	• 10 recyclers of post-industrial • 2 recyclers of post-industrial and pre-consumer • 8 recyclers of all input types • 8 recyclers of post-consumer • 9 recyclers of post-consumer and post-industrial • 1 did not specify
Fabric structure	Only 8 recyclers indicated the types of fabric structures accepted • 4 recycling all structures (including shoes) • 1 recycling only knits • 3 recycling knits and wovens (including the recycler with the largest current capacity volume)	Only 8 recyclers indicated the types of fabric structures accepted • 5 recycling all structures • 1 recycling only their own products • 2 accepting knits and wovens
Materials recycled (input)	• 38 list cotton as the primary material • 12 list wool as the primary material • 21 recyclers are highly specialised and accept only one material type: down, leather, wool, acrylic, aramid, cashmere, cotton, polyamide, or polyester • 18 recyclers accept blends (acrylic polyester, acrylic polypropylene, cotton blends, polycotton blends, poly elastane blends and more) • 1 focused only on footwear	• 12 list cotton as the primary material • 11 list polyester as the primary material • 22 recyclers are highly specialised and accept only one material type: cotton, elastane, leather, nylon 6, nylon 6.625, polyester • 7 recyclers accept blends (mainly cotton blends and polycotton) • 5 did not indicate materials

Figure 163: Summary of closed-loop recycling capacities as indicated in WRAP's Textile Recycling Database (status: 2023)

Appendix 3: ATSP cost model assumptions

Item/Metric	Input	Source	Notes
TEXTILE HANDLING COSTS			
Collection costs	£214 per tonne	Textile Market Situation Report, p.25[56]	
Transport & Logistics	£138 per tonne	Aggregated Sorters Survey Data[57]	
Processing costs	£175 per tonne	Aggregated Sorters Survey Data[58]	
Total UK sorter volume	469,000 tonnes	Textile Market Situation Report, p.20[59]	
Estimated split of NRT in current collections	32%	Aggregated Sorters Survey Data[60]	
Average NRT Value	£100 per tonne	Aggregated Sorters Survey Data[61]	
EfW gate fee	£112 per tonne	WRAP's 17th Gate Fees Report[62]	
Non-hazardous Landfill gate fee	£24 per tonne	WRAP's 17th Gate Fees Report[63]	
Non-hazardous Landfill tax (£ per tonne)	£104 per tonne	Landfill Tax Rates[64]	
MATERIAL INPUT PRICES			
Scenario 1 - input material is a revenue stream, all quality accepted	£100		
Scenario 2 - input material is a cost, all quality accepted	£ (100)		
Scenario 3 - input material is a medium cost, only single layered quality	£ (120)		

continued...

Item/Metric	Input	Source	Notes
Scenario 4 - input material is a high cost, only single layered quality and disrupter criteria	£ (150)		
CAPEX			
Total Capital Expenditure	£ 7,000,000	Valvan	
CAPEX contingency	20%	Industry standard	
CAPEX upgrade	20%	Industry standard	
FACILITY COSTS			
Ground rent	£8.30 per sq ft per year		Industrial facility average ground rent based on Circle-8 site cost analysis
Security deposit	£ 373,500	**Legal Foundations**	6 months of rent
Stamp duty	£ 48,500	**Stamp Duty Land Tax**	Set by the government
Maintenance & repair	5% of RAV (Replacement Asset Value)	**Upkeep.com**	
Business Rates	£3 per year		Based on Circle-8 site cost analysis for WP 6
Environmental monitoring	£8,000 per year	**Costs for Municipal Waste Management in the EU**	MRF UK (no textiles) for a capacity of 42,000 tonnes

continued...

Item/Metric	Input	Source	Notes
Gas needs	30,000 kWh	**Average business gas and electricity bills explained**	Low-end usage for a medium-sized business
Gas Price	£0.08 per kWh		Price for a medium-sized business
Gas standing charge	£0.48 per day		Price for a medium-sized business
Electricity needs	25,000 kWh		Low-end usage for a medium-sized business
Electricity price	£0.254 per kWh		Price for a medium-sized business
Electricity standing charge	£0.88 per day		Price for a medium-sized business
Water usage	50 cubic meters per employee		
Water costs	£2 per cubic meter	**Business Water Rates 2024/25**	
Wastewater costs	£2 per cubic meter		
Insurance	£20,000 per year	**Key Expenses in Recycling**	From discussions with sorters
Miscellaneous other costs	£0.19 per sq ft per year		From discussions with sorters

continued...

Item/Metric	Input	Source	Notes
OPERATING INPUTS			
Starting capacity	10,000 tonnes		First years capacity
Maximum capacity	25,000 tonnes	Circle-8	From interview with Circle-8
Depreciation term	15 years		Standard depreciation term
Ramp up period	3 years		Currently assumed ramp up time
Start-up costs	£250,000 per year		Extra costs to incur during the ramp-up process, such as training, travel, and project management, from discussions with sorters
Year 2 start-up cost vs Year 1	50%		
Shifts	3 shifts per day		From discussions with sorters
Warehouse size	40,000 sq ft		Based on Circle-8 site cost analysis for WP 6
Total line size	50,000 sq ft		Valvan
Number of lines	7	**Sorting for Circularity Europe (2022)**	Based on 6 recycling grades: Chemical Recycling: Polyester, Chemical Recycling: Polycotton, Chemical Recycling: Cotton, Mechanical Recycling: Cotton, Mechanical Recycling Acrylic, Mechanical Recycling: Wool, Variable line

continued...

Item/Metric	Input	Source	Notes
Total disruptor removal line	5		Based on 6 recycling grades: Chemical Recycling: Polyester, Chemical Recycling: Polycotton, Chemical Recycling: Cotton, Mechanical Recycling: Cotton, Mechanical Recycling Acrylic, Mechanical Recycling: Wool, Variable line
Shift hours	1920 hours per shift per year		Assuming 40 hours per week, 48 weeks per year
Operating days per year	260 days		Assuming operations 5 days a week all year round

Figure 164: ATSP cost model assumptions

Job title	Team	Job Description	Number	Base salary
Managing director	Management	Directs and controls the company's operations and gives strategic guidance and direction to the board to ensure that the company achieves its mission and objectives	1	£ 63,000
Production manager	Operations	Ensures that the production starts and finishes within budget and on time and ensures all products meet the required quality standards	3	£ 42,000
Production worker	Operations	Responsible for the automated sorting process from bale opening to disrupter removal (full flow). This includes machine operations and quality assurance and quality control procedures	3	£ 29,000
Warehouse manager	Operations	Responsible for organising deliveries, storage and despatches of goods in the warehouse, oversees the warehouse team	3	£ 45,000

continued...

Job title	Team	Job Description	Number	Base salary
Managing director	Management	Directs and controls the company's operations and gives strategic guidance and direction to the board to ensure that the company achieves its mission and objectives	1	£ 63,000
Production manager	Operations	Ensures that the production starts and finishes within budget and on time and ensures all products meet the required quality standards	3	£ 42,000
Production worker	Operations	Responsible for the automated sorting process from bale opening to disrupter removal (full flow). This includes machine operations and quality assurance and quality control procedures	3	£ 29,000
Warehouse manager	Operations	Responsible for organising deliveries, storage and despatches of goods in the warehouse, oversees the warehouse team	3	£ 45,000
Environmental and industrial risk advisor	Operations	Providing environment and industrial risk compliance support for all areas of the business	1	£ 36,000
Engineer	Operations	Provide planned and reactive maintenance for all areas of plant, making sure plant installations and modifications meet the latest standards and regulatory requirements	1	£ 37,000
Warehouse worker	Operations	Loading and unloading of freight, picking and packing products, parcel sorting, baling, general warehouse duties	3	£ 27,000
Bale press worker	Operations	Managing the bale press, general warehouse duties	1	£ 27,000
Sales agents	Sales	Responsible for selling products and meeting customer needs while generating feedstock volumes through existing and new channels	1	£ 34,000
Business development manager	Sales	Develops, manages and maintains a pipeline of new buy/sell business opportunities, works on innovative projects	1	£ 48,000

continued...

Job title	Team	Job Description	Number	Base salary
HR manager	Management	Manages talent, compensation and benefits, training and development, compliance, and worker safety	1	£ 37,000
Logistics manager	Operations	Oversees and plans the movement and storage of supplies within the facility	1	£ 48,000
Financial controller	Management	Maintaining internal controls over financial reporting, presenting financial reports to an executive team and overseeing the preparation of budgets	1	£ 55,000
Bookkeeper	Administration	Responsible for recording and maintaining business financial transactions, such as purchases, expenses, sales revenue, invoices, and payments	1	£ 28,500

Figure 165: Staff required to operate the ATSP as a stand-alone facility

Chapter 7:

The next phase of UK manufacturing

Bridging capacity and other challenges for sustainable growth



CONTENTS

Introduction
- The current landscape of UK consumption, PCT volumes and fibre types
- An overview of UK fibre production
- A functioning textile supply chain

Methodology: Interviews
- Research limitations

Results: Interviews
- Infrastructure and technology: Insights and challenges
- Technical: Insights and challenges
- Skills and workforce: Insights and challenges
- Economic viability: Insights and challenges

Discussion
- Recommendations: Infrastructure and technology
- Recommendations: Technical
- Recommendations: Skills and workforce
- Recommendations: Economic viability
- Recommendations: General

Appendix

Trial questions

1. INTRODUCTION

This chapter provides a strategic overview of the role UK manufacturing must play to unlock and scale a workable domestic textile recycling ecosystem. Focusing on post-consumer textile (PCT) waste, this chapter explores how the manufacturing of recycled yarn can become a crucial link in a supply chain that works with the unified purpose of collecting textile waste, sorting and pre-processing it, recycling it, and manufacturing it for closed-loop and open-loop applications that deliver socio-economic benefits to the UK.

Automated sorting and pre-processing, and recycling technologies for the main consumable textiles, such as polyester, cotton, and wool, as well as different material mixes and compositions, are evolving in the UK and worldwide. The status of UK manufacturing within the textile recycling sector reveals both emerging opportunities and persistent challenges, yet remains insufficiently examined in existing research.

Therefore, this chapter sets out to identify the current status of UK manufacturing capacity and explores whether the existing manufacturing infrastructure is able to meet the demand for locally made recycled yarn and fabric. This chapter will also explore opportunities for manufacturing that support innovation, sustainability, and growth, aligned with the wider circular ambitions of the UK fashion and textile industry.

The key objectives of this chapter are as follows:

- To examine the current state of UK textile manufacturing within the textile recycling ecosystem and explore existing gaps in infrastructure and technology, technical, skills and workforce, economic viability, and, ultimately, capacity.
- To incorporate industry insights and expert viewpoints highlighting challenges and opportunities in manufacturing recycled content in a textile-to-textile recycling landscape in the UK.
- To offer a vision and actionable recommendations to advance the next phase of UK manufacturing for industry stakeholders, government and policymakers, including investment priorities, technological upgrades, closed-loop and open-loop innovation, and collaborative initiatives.

1.1. The current landscape of UK consumption, PCT volumes, and fibre types

1.1.1. UK fashion industry

It is important to understand the current state of the UK fashion and textile industry before exploring the challenges and opportunities for the next phase of UK manufacturing.

Admired globally, the UK fashion and textile industry is one of the country's largest sectors, generating a significant economic impact. A 2023 report[65] by UKFT with Oxford Economics found that in 2021, the industry supported:

- £62 billion in gross value-added contributions to GDP
- 1.3 million jobs
- £23 billion in tax payments to the UK government

These figures tell us that one in every 25 jobs in the UK is within the fashion and textile industry, generating £1 in every £34 of all gross value-added contributions. This success is down to the industry supporting multiple businesses and economic activities across its wide-ranging supply chain, from product development to growing crops and from education to retail. Among these activities, the UK has historically been a global leader in the manufacturing of fibres, textiles, and apparel. However, today, the manufacturing of fibres and textiles is more limited than the manufacturing of fashion and textile goods. While manufacturers of fashion and textile goods created an estimated 3.6bn gross value-added contribution to UK GDP in 2021, manufacturers of fibres and textiles generated a combined £980million.

While the gap is considerable, these figures also show that the manufacturing of fibres and textiles already contributes to the growth of the UK economy. While the existing manufacturing capacity is limited, it provides a valuable foundation for growth and represents an opportunity to consider the significant role this stage of the supply chain could play in a domestic textile recycling ecosystem in the UK.

1.1.2. UK apparel and textile consumption and PCT volumes

Let's take a closer look at the volume of textiles consumed in the UK and where those textiles end up post-consumer.

Consumers in the UK buy more clothes than any other country in Europe[66], and a 2023 report[67] states that in the UK, the annual textiles consumption is over 25kg per person, which is two to three times above the global average. However, only 262 kilotonnes of textiles are reused in the UK annually, with the remaining textiles split between being incinerated or sent to landfill (382kt), reused abroad (214kt), or disposed of abroad (435kt).

Additionally, a recent progress report[68] by the global Waste and Resources Action Programme (WRAP) found that people in the UK generate almost 1.5 million tonnes of used textiles per year, with 49% ending up in landfill or are incinerated. WRAP's report outlines the challenge this waste culture presents: "Textile waste is increasing, recycling infrastructure remains insufficient, and export markets are increasingly limited. WRAP's evidence shows that the UK market price for used textiles has plummeted, with a 57.5% reduction in price per tonne over the last 10 years for textile bank donations and a 41% reduction for charity shop donations, without accounting for inflation." Ultimately, this trend threatens economic sustainability across the value chain.

Therefore, while the UK fashion and textile industry is important economically on an industrial level, the amount of waste it generates presents a serious and immediate challenge. This challenge presents an opportunity for the UK to take the lead on embracing domestic circularity.

1.1.3. Fibre production composition and PCT flows

To find solutions to reduce textile waste, it is important to explore and understand the key fibre compositions.

Textile Exchange's 2024 Materials Market Report[69] revealed that in 2023 there were 124 million tonnes of fibre produced globally, with synthetics dominating. Noteworthy percentages of market share include:

- Polyester (synthetic fibre): 57.2%
- Cotton (plant fibre): 19.9%
- Viscose (man-made cellulosic fibre): 5%
- Nylon (synthetic fibre): 5.3%
- Wool (animal fibre): 0.9%

Since the mid-to-late 2000s, polyester has replaced cotton as the world's most widely used fibre. Between them, polyester and cotton account for 77.1% of the global market share, figures similarly replicated in the UK. The same report predicts that fibre production will increase from today's 124 million tonnes to 160 million tonnes in 2030, which would be an increase of 102 million tonnes per year since the start of the century.

However, the global market share of recycled fibres is down, decreasing from 7.9% in 2023 to 7.7% in 2023. Furthermore, 7% of that 7.7% figure was recycled polyester made from plastic bottles, which means less than 1% of the global fibre market was closed-loop recycling.

Breaking down the market share[70] of recycled fibres in each category paints a stark picture:

- Polyester: 12% recycled
- Wool: 6% recycled
- Cotton: 1% recycled

These figures clearly demonstrate the importance of exploring solutions to improve fibre recycling rates.

A significant barrier to increasing recycling rates is the proliferation of blended textiles produced for the market. Recycling post-consumer blended textiles requires separating the various fibre types, which is labour-intensive. *A Waste and Resource Management* study[71] of a large sample of post-consumer clothing in the UK found that 36.2% of the items consisted of a blended mixture of two or more fibres, with the remaining items made from single fibre types.

This tells us that, alongside exploring recycling methods for polyester and cotton, as well as other fibres, solutions are needed to streamline the process of recycling blended textiles for manufacturers to utilise.

1.1.4. Policy landscape

The textiles policy landscape is evolving to reflect a greater urgency for recycling and manufacturing recycled textiles.

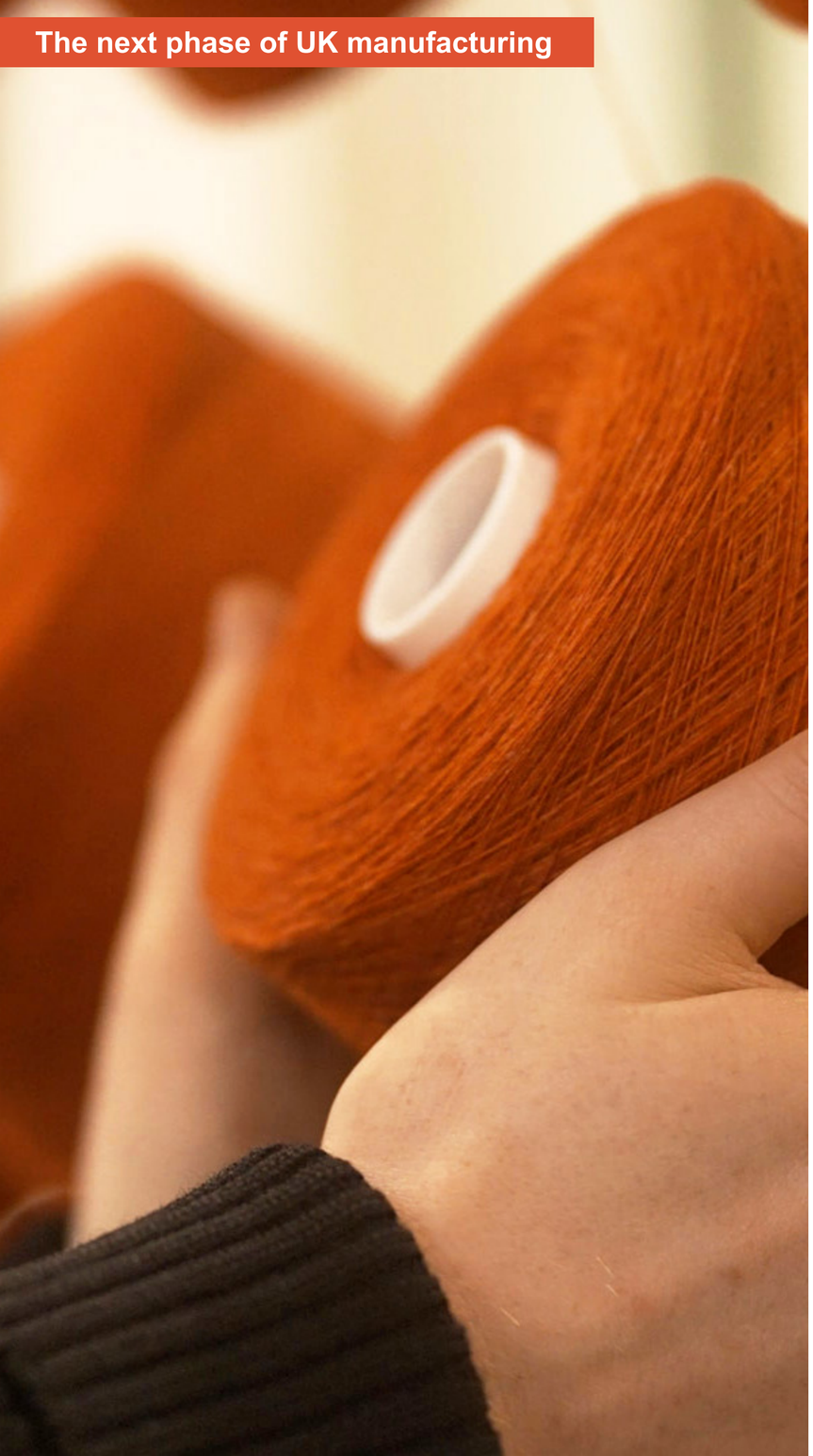
For example, the EU's Strategy for Sustainable and Circular Textiles (2022) directly addresses the production and consumption of textiles, while recognising the importance of the sector. Implementing the commitments of the European Green Deal, the Circular Economy Action Plan and the European Industrial strategy, the strategy examines the lifecycle of textile products and proposes coordinated actions to change how countries within the EU produce and consume textiles. A cornerstone of the strategy is exploring solutions to increasing textile-to-textile recycling in the industry, representing a significant shift in the EU's textile collection rules to reduce waste and create a more circular economy.

All EU member states had to implement systems for the separate collection of textile waste by January 2025. The purpose of this is to decrease the number of textiles that households are discarding in general waste, reducing contamination, establishing improved sorting, reuse and recycling, and increasing feedstock. The knock-on impact of this is the larger availability of PCT volumes, and the need for more recycling and manufacturing capacity to find applications for recycled textiles globally.

Critically, the EU has also introduced its Ecodesign for Sustainable Products Regulation (ESPR). Entered into force in July 2024, the ESPR policies set ecodesign requirements for almost all categories of physical goods, including textile products. The ESPR makes increasing the amount of recycled content a priority for brands and retailers, a clear indication that the manufacturing of recycled content is seen as a long-term priority area.

Additionally, in Europe, governments are establishing Extended Producer Responsibility (EPR) schemes. These are designed to incentivise industry stakeholders to create products that are, among other things, more durable or simpler to recycle and reuse by making them financially responsible for the collection, sorting, and recycling of waste. As an example, producers will have to pay more fees to EPR schemes if their products use virgin materials, but they will pay less if they use recycled materials. As a result, this will create funds that can be reinvested in the industry to stimulate a circular economy. Consequently, producers will demand higher recycled content rates, and there will be funds to redistribute throughout the circular economy ecosystem.

In the UK, policy development regarding textile waste collection systems, ecodesign, and EPR schemes could follow a similar path to Europe, which in turn could lead to greater opportunities for UK manufacturing.



1.2. An overview of UK fibre production

When exploring the landscape of UK fibre production and textile manufacturing in the UK and whether the manufacturing of recycled fibres is achievable at scale in the UK, a mixed picture emerges.

Section 1.1.1 showed that manufacturers of fashion and textile goods in the UK created an estimated 3.6bn gross value-added contributions to UK GDP in 2021, but manufacturers of fibres and textiles generated a combined £980million[72]. The same report also found that manufacturers of fibres and textiles created 19,000 jobs in the UK in 2021, compared to the 75,000 jobs created by manufacturers of fashion and textile goods.

It wasn't always this way. During the Industrial Revolution, the British textile manufacturing industry was a global pioneer. A series of innovations, from spinning mules to power looms, meant the UK grew, processed, and manufactured fibre in vast quantities and dominated the textile trade worldwide. Between 1800 and 1860, the UK's cotton exports increased from £5.4million to £46.8million, and Britain was responsible for producing almost half of the world's cloth[73].

Today, while the UK fashion sector remains very strong, production of fibres and textiles is in decline, with the majority outsourced. A 2019 House of Commons Environmental Audit Committee[74] stated: "Since the 1980s, many leading Western fashion retailers have been 'chasing the cheap needle round the planet' and sourcing their clothes from countries with low labour costs."

There is a clear disconnect between the fibre types found in the majority of PCT waste – typically cotton-rich and synthetic blends such as polyester – and those used within the UK's remaining manufacturing base, which is largely geared towards high-end textiles. Much of the current capacity focuses on animal fibres like wool and cashmere, with limited infrastructure to process polyester, viscose, or acrylic blends and no capacity to spin cotton. Where polyester processing does exist, it is largely confined to small-scale or research-focused operations rather than commercial production.

When it comes to the manufacturing of recycled textile waste in the UK, it is currently highly dominated by the processing of low-grade PCT into the open-loop wiper market. Therefore, reshoring the manufacturing of recycled content could present an opportunity for the UK manufacturing sector to stay ahead of the circular transition while boosting socio-economic opportunities. Reshoring can create jobs and power regional economies. It also aligns with sustainable production approaches, offering benefits such as reduced transportation costs and emissions, access to non-virgin raw materials that are not typically available to the UK, such as cotton, increased supply chain resilience, and more agile production systems that respond quickly to market demands.

However, there are real challenges to increasing the manufacturing of recycled textile content in the UK.

First, expanding domestic manufacturing capacity to meet reshoring and circular supply chain goals would require substantial investment in machinery, infrastructure, people, technology, and innovation. As stated by the *Reshoring UK Garment Manufacturing with Automation report*[75], "The fashion manufacturing sector in the UK urgently needs to modernise, optimising production and supply chains to meet net-zero and global sustainability challenges."

Improving skills and the workforce is also critical to increasing manufacturing capacity. A recent UKFT report[76] that explored skills levels in UK fashion and textile manufacturing through workshops with industry stakeholders stated: "Perceptions of factory work are still negative and there is perceived to be a huge skills shortage across the whole fashion and textiles industry.

An additional critical challenge is creating a unified textile-to-textile supply chain in the UK. This challenge is explored in further detail in the following section, 1.3.

While the UK textiles sector can't return to the heights of the Industrial Revolution, the right investment in infrastructure, technology, and skills could potentially elevate it towards a brighter future.

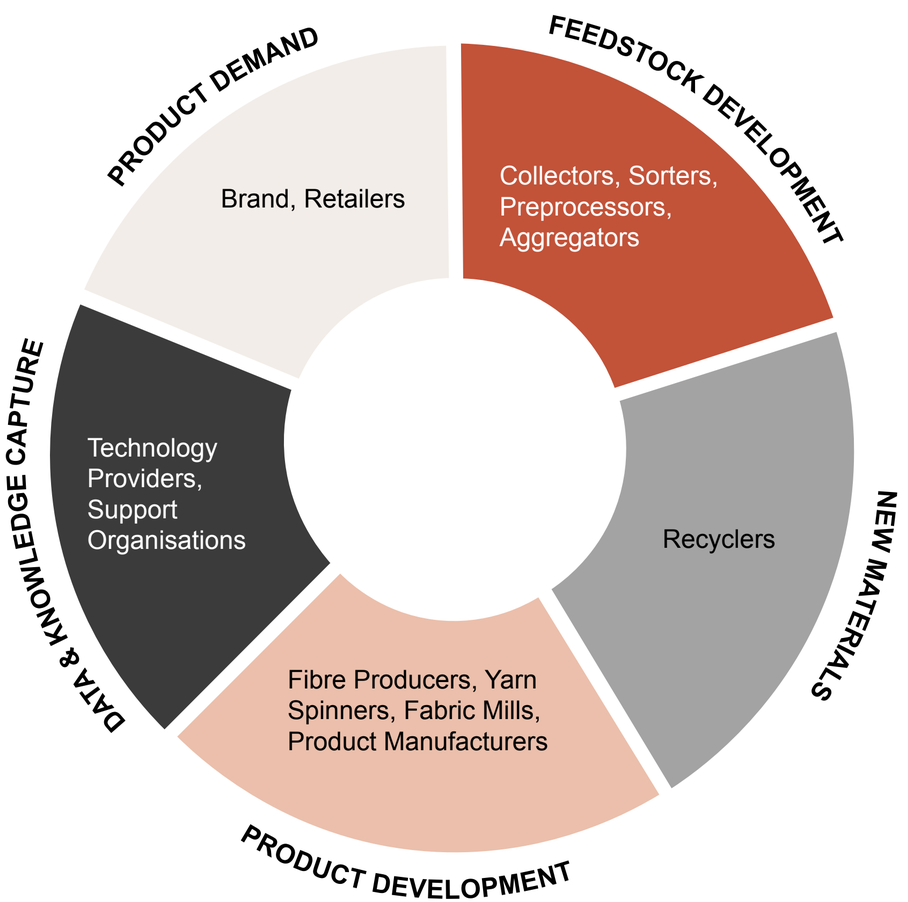
1.3. A functioning textile supply chain

1.3.1. A textile recycling supply chain

Before exploring the various types of technologies and the UK's current capacity, it is crucial to consider the current supply chain capabilities of creating a textile-to-textile recycling system.

Research and Mapping:

Accelerating Circularity identified end users and supply partners for a full spectrum of Post-Industrial (PI) and Post-Consumer (PC) textiles based on detailed textile-to-textile stakeholder mapping. Within this framework, we identified stakeholder engagement chllenges at various levels.



While new solutions and technologies in textile recycling will be critical to scaling a circular ecosystem, the current supply chain and value chain must also be integrated if the sector is to successfully enhance sustainability and socio-economic viability. A 2024 report[77] defines the textile-to-textile recycling supply chain as "a process of material recovery of pre- and post-consumer textile waste into yarns for new fabrics.", incorporating all the stages from feedstock supply to product demand.

One of the central challenges of the current textile recycling supply chain is that the key stakeholders, from recyclers to retailers and from fibre producers to manufacturers, are fragmented and operate separately within a linear set-up, making it difficult to close the loop. Only by unifying the supply chain and bringing all key stakeholders together under one system can the UK begin to effectively scale the manufacturing of recycled content.

While textile-to-textile recycling is in its infancy, this presents opportunities to expand quickly and create a joined-up and functioning supply chain. A 2022 McKinsey report[78] exploring supply chain capabilities notes that: *"The current landscape is changing rapidly and European textile recycling practices are 'characterised by fast-paced innovation and a race towards scale'."*

In Europe, McKinsey forecasts that textile-to-textile recycling could reach 18-26% of gross textile waste by 2030. McKinsey predicts this would create 15,000 new green jobs across the supply chain and abate 4 million tons of carbon emissions[79]. So while textile-to-textile recycling remains immature, its rapid global growth and its positive socio-economic outlook imply that it is key to building new manufacturing supply chains – and integrating within existing manufacturing supply chains – capable of manufacturing recycled content. This is an incentive for the UK fashion and textile sector to grasp the opportunity to build manufacturing capacity to produce recycled content, and further expand the circular domestic supply chain in the UK beyond the current manufacturing of new fashion and textiles goods.

1.3.2. Textile-to-textile recycling processes and output

Yarn manufacturing varies significantly across different fibre types, each requiring unique production processes. Therefore, it is important to understand the current technical advancements and output capabilities of the various recycling technologies. This section focuses on the four key textile recycling solutions: mechanical, thermomechanical, chemical, and biological.

Mechanical recycling:
- Consisting of a process where textiles are cut, shredded and opened into fibres, mechanical recycling is currently the most common recycling method
- **Pros:** Relatively cost-efficient, doesn't change material's chemical structure[80], high energy efficiency[81]
- **Cons:** Low-to-medium quality output, with a fibre-length reduction of up to 40%[82] (although technologies are emerging that can achieve fibre-length reduction of 10-15%[83]), requires automatic sorting solutions[84]

Thermomechanical recycling:
- Consists of a process that combines pressure and heat to enable polymer recovery from synthetic textiles
- **Pros:** Relatively high energy efficiency, good quality output[85]
- **Cons:** Can't be used for natural fibres such as cotton or wool[86]

Chemical recycling:
- Consists of processes that break down fibres to polymer or monomer level
- **Pros:** Good quality output[87], can help solve the issue of complex textile blends
- **Cons:** In its infancy, more expensive than mechanical recycling, and low energy efficiency[88]

Biological recycling:
- Consists of processes that use enzymes in biomechanical reactions and microorganisms in biological transformations[89]
- **Pros:** Enables recycling of contaminated textiles
- **Cons:** Nascent in textile-to-textile recycling

These recycling technologies diverge in many ways – processes, energy consumption, feedstock, input and output requirements – and they are progressing at varying speeds. Each technology operates uniquely and targets specific textile types, making a unified approach to textile-to-textile recycling and manufacturing of recycled content challenging. For example, mechanical recycling results in lower quality fibres compared to chemical recycling. These fibres, therefore, usually require mixing with virgin content during yarn production. Manufacturers need to consider each fibre type, recycling process and output recycled fibre to produce quality recycled yarn.



1.3.3.Textile-to-textile recycling processes and output

As explored above, because of the many fibre types, there is no one-size-fits-all approach to textile-to-textile recycling technologies and the manufacturing of recycled content. Each fibre performs very differently in terms of its properties and characteristics, which affects end-user requirements[90]. Consequently, recycled output fibres must meet target specifications that allow for industry-standard fabric developments. Therefore, the different fibres must be considered.

Synthetics recycling:

Polyester: Section 1.1.3 highlighted that polyester dominates the market share of global fibre production, at 57.2%. Therefore, the potential of developing textile-to-textile recycling and manufacturing capacity for polyester is a significant opportunity.

Currently, polyester is recycled through thermomechanical and chemical processes. While polyethylene terephthalate is the most common type of polyester in the fashion industry and is the prevalent polyester used in recycling, other types of polyester, such as polybutylene terephthalate and polytrimethylene terephthalate, must also be used as feedstock at a greater scale[91]. More solutions must also be developed to enable the recycling of polyester that is blended with other fibres, a process which is very much in its infancy.

Nylon: Section 1.1.3 showed that nylon only has a 5.3% market share of global fibre production. So, while it doesn't represent a large share, nylon remains prevalent in underwear and sportswear. Nylon is also a significant pollutant[92], accounting for around 10%[93] of the greenhouse gas impact of global fibre production – a significant difference between market distribution and impact. Therefore, improving nylon recycling solutions is critical for creating a circular system and reducing environmental impact.

However, because nylon is a lower-volume fibre, there is less availability of feedstock for recycling. Additionally, there are two prevalent nylons – nylon 6 and nylon 66 – in the textile industry, and they must be separated because they are recycled through different processes, which adds further challenges. Nylon 66 has greater mechanical strength and greater resistance to heat and wear and is mostly mechanically recycled, while most nylon 6 is chemically recycled. Therefore, a range of solutions across a range of locations must be sought to recycle existing nylon products as well as future nylon products, with hubs for collection, sorting, and fibre recycling established.

Cotton recycling:

As presented in section 1.1.3, cotton ranks second to polyester in global fibre production, at 19.9%. However, with only 1% recycled, there is a clear opportunity to significantly boost the recycling rates of this popular fibre.

There has already been significant research into the scope of recycling cotton waste in open-loop applications such as nonwovens for thermal and acoustic insulation, automotive applications of thermoset composites[94], cellulose fibres and nanocrystals, adsorptive materials, flexible electronic devices, and even biofuels[95]. Over the last few years, post-consumer closed-loop cotton recycling has developed but remains nascent.

Cotton is most commonly mechanically recycled because it is low-cost and has the benefit of not needing chemical treatment. However, one of the key challenges of mechanical cotton recycling is that the colour of the output mirrors the colour of the input. As a result, if the cotton isn't sorted accurately into the right colour, it will have a detrimental impact on the output, reducing the amount of recycled cotton available for manufacturing. Additionally, today's yarn manufacturing process allows for a limited percentage of post-consumer recycled cotton to be incorporated and needs to be mixed with post-industrial and virgin cotton. Solutions must be explored to increase this percentage.

Wool recycling:

The process of wool recycling started in the UK in 1813[96], and as explored in section 1.1.3, its current market share in the global production of fibres stands at only 0.9%. However, 6% is recycled, a comparatively high percentage compared to other fibres. Post-industrial wool clothing has been recycled mechanically for 200 years and has found common use in nonwovens, composites, and clothing[97].

Today, there are clusters of major recycled wool production centres in Italy, India, and China, as well as some facilities in the UK. Wool could thrive if a PCT recycling process is established because it is a high-quality fibre with a long and active lifespan that aligns with circularity principles[98], enabling zero-waste processing. However, there are challenges to ensuring that care is taken to minimise the deterioration to fibre length and tensile properties during the pulling process in low-impact mechanical recycling.

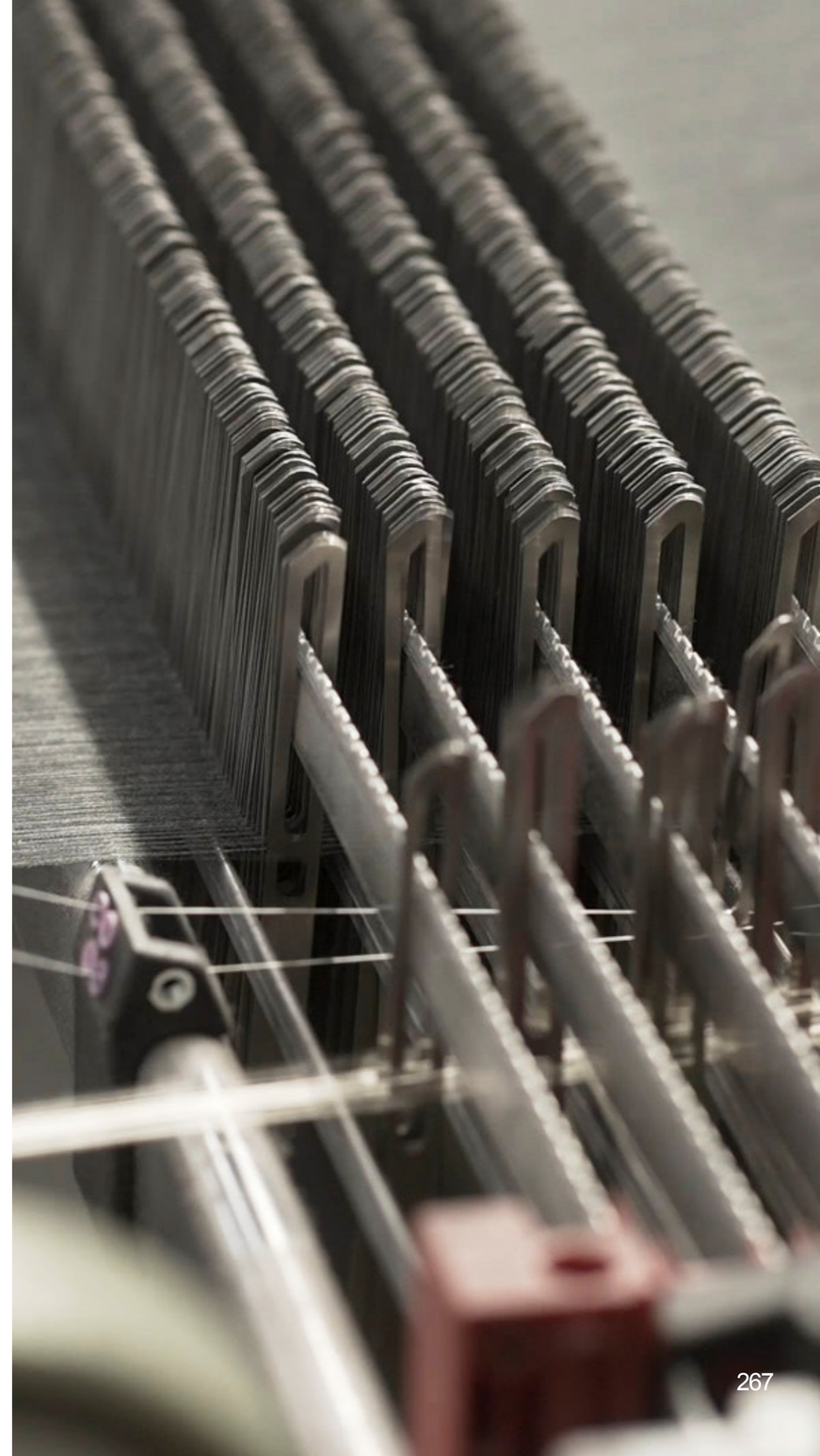
The diverse array of fibre types – as well as technologies covered in section 1.3.3 – means that the effective manufacturing of recycled content will require a flexible and adaptable approach to developing a textile recycling supply chain. In fact, McKinsey's Scaling Textile Recycling in Europe — *Turning Waste Into Value* report[99] calls for the manufacturing sector to increase its pace of innovation to create a supply chain that is fit for purpose.

Successfully spinning PCT fibres into yarn requires quality input. However, there are challenges posed by a number of common imperfections in recycled textile fibres, which can cause problems with the quality of output for yarn. Here, it is important to define exactly what is meant by textile fibre. This chapter uses the following definition: *"A textile fibre is a unit of matter, either natural or manufactured, that forms the basic element of fabrics and other textile structures. Specifically, a textile fibre is characterised as having a length at least 100 times its diameter and a form that allows it to be spun into a yarn or made into a fabric by various methods[100]."*

As highlighted in Chapter 5, 'Textile Recycling Supply Chain Trials', imperfections such as reduced tensile strength leading to fibre slippage during processing and inconsistent fibre lengths affecting yarn uniformity mean the industry must develop pre-processing and recycling solutions that can overcome these inherent limitations to produce recycled yarn that matches the performance characteristics of virgin materials. Only then can the industry start to create commercially viable closed-loop recycled textile content.

However, producing high-quality recycled yarn requires significantly more research and development to better understand what the optimal manufacturing of recycled content looks like across all fibre types, because the answer is currently unknown. For example, a 2023 study[101] into recycled cotton found: *"The effect of the spinning system on yarn unevenness, number of thin places, number of thick places, number of nep values, and yarn hairiness were found to be significant for all blends."*

Going forward, manufacturers should be involved in further testing of how different yarn counts, various recycling ratios, and diverse spinning methods affect the physical properties of yarn, to help support the adoption of recycled fibres.



1.3.4. Current textile-to-textile recycling capacity in the UK

Section 1.3.1 demonstrated how nascent the textile-to-textile recycling industry is. This is particularly evident in the UK in comparison to global markets.

WRAP's 2024 report[102], *Textiles Reuse and Recycling Definitions*, sets out the maturity levels of post-consumer non-reusable textile recycling solutions in three markets: UK, EU, and the rest of the world. While mechanical recycling for open-loop recycling is 'mature' in the UK, EU and the rest of the world, mechanical closed-loop recycling is classified as 'emerging' in all three markets. The UK is lagging behind in thermomechanical recycling, chemical polymer recycling, and chemical monomer recycling. For these three recycling technologies, the UK's maturity level is classified as 'piloting', while the EU and the rest of the world have been classified as 'emerging' – a step ahead of this country.

A closer look at WRAP's Recycler's Database[103] clearly demonstrates that the UK's textile-to-textile recycling system is less established than other major markets. An overview of around 100 PCT waste recyclers worldwide shows that most closed-loop textile recycling advancements are based in North America, Europe, and Asia.

However, there are a few projects in the UK that point the way to a brighter future:

Project Re:claim (Project Plan B x Salvation Army):

- **Recycling method:** Thermomechanical
- **Materials:** Polyester
- In January 2024, the Salvation Army launched a first-of-its-kind project to recycle polyester clothing and textiles into pellets that can be spun into new yarns and used in other relevant applications. Working with Project Plan B, a UK-based ecodesign and textile-to-textile polyester recycling specialist, Salvation Army Trading Company (SATCoL) is using the new technology at its reprocessing centre in Kettering, Northamptonshire. The initiative, called Project Re:claim, intends to process up to 5,000 tonnes of post-industrial and post-consumer waste textiles each year.

Iinouiio:

- **Recycling method:** Mechanical
- **Materials:** Wool
- A family-run, Yorkshire-based wool recycler, Iinouiio has partnered with Camira, a global fabric manufacturer, to install the first wool and luxury fibre recycling line in the UK, in Huddersfield. Funded by WRAP and Business of Fashion, Textiles & Technology (BFTT), the initiative aims to develop a scalable and replicable process for textile-to-textile wool recycling.

Epoch Biodesign:

- **Recycling method:** Biological
- **Materials:** Nylon 66, Nylon 6, Polyester
- London-based Epoch Biodesign develops processes capable of transforming blended textiles and plastics into sustainable drop-in molecules for existing textile supply chains. Epoch utilises AI to engineer enzymes that selectively depolymerise blended textiles at low temperatures to produce virgin-quality recycled outputs. Its technology unlocks fibre-to-fibre recycling for the most complex materials.

While these projects point the way forward, they are rare examples in the UK. This further highlights the gap in textile-to-textile recycling technologies, which is currently limited to mechanical for wool, the recent emergence of thermomechanical for polyester, biological for nylon, and none for cotton. This clearly demonstrates that investment is an urgent requirement to accelerate the capacity of recycling plants in the UK. Without investment, it will be a challenge to build the business case for recycled manufacturing yarn production in the UK, and without recycled manufacturing yarn production, it would be impossible to create a circular supply chain.



2. METHODOLOGY: INTERVIEWS

While the above sections provide background to the current status of UK manufacturing in a textile-to-textile recycling context, this section will explore the potential of the next phase of UK manufacturing.

To examine the upcoming opportunities and challenges in UK manufacturing, in December 2024 and January 2025 UKFT conducted in-depth interviews with:

- 4x leads from the ACT UK recycling trials following their completion (University of Leeds; Iinouiio; SATcol; WRAP)
- 1 x supplier of machinery for yarn and textile production in the UK (FET UK)
- 1x UK-based textile manufacturing expert (Wooltex)
- 3x Europe-based textile recycling and manufacturing experts (Vilarrasa; Technitiger; Recover)

The objective of the interviews was to gain insights into the potential for incorporating recycled yarn production in the UK's textile manufacturing sector within the current textile-to-textile recycling outlook, by better understanding gaps in infrastructure and technology, technical, skills and workforce, and economic viability, and how these gaps can be filled to increase manufacturing capacity.

The interview constructs were backed up by desk research using existing academic literature and grey literature. You can read the questions for trial partners and other manufacturers in the Appendix.

2.1. Research limitations

The interviews were rigorous and provided robust foundations for a comprehensive series of recommendations. However, it is important to acknowledge unavoidable limitations in this area of research:

- Supply chain capabilities weren't included in ACT UK's research scope, so trials did not necessarily include yarn production. However, this did not prevent the interviewees from offering expert insight into the potential implications, challenges, and impact of yarn manufacturing;
- The current textile-to-textile recycling capacity in the UK – and globally – is in its infancy. As such, it is a nascent research area, limiting the depth of understanding of UK recycled yarn production;
- Because the manufacturing of post-consumer recycled textiles remains in a research and development/trial stage in the UK and globally, desk research into its implications, challenges, and impact is limited to very few papers and studies;
- The complexity and fragmentation of fibre types, recycling types, and yarn production timescales means covering all possible scenarios in the available timeframe for the trials was not possible, and equally, not possible for this chapter;
- Commercial scaling know-how and expertise are currently absent due to the very limited manufacturing of recycled yarn in the UK.

Despite these limitations, the interviews and desk research provided comprehensive and in-depth insight into the state of play of textile-to-textile recycling in the UK and the manufacturing of recycled content, as well as the challenges and opportunities of bridging the existing gaps.

The results of these interviews and ACT UK's subsequent recommendations will be explored in the following two sections.

3. RESULTS: INTERVIEWS

As set out in the methodology, this results section is based on interviews with leading UK stakeholders and Europe-based textile recycling and manufacturing experts.

The following sections explore the results of the interviews, adding expert insights to the research covered in sections 1.1, 1.2, and 1.3. The results are set out across the four key areas that address the manufacturing capacity gap: infrastructure and technology, technical, skills and workforce, and economic viability.

3.1. Infrastructure and technology: Insights and challenges

The UK's textile manufacturing sector has the potential to be transformed. There is an opportunity to modernise infrastructure and advance technology solutions to compete effectively in the global market.

Automated sorting and textile recycling:
The supply chain must be able to accommodate automated sorting and recycling to enable the manufacturing of recycled content. However, an Automated Textile Sorting and Pre-processing (ATSP) facility remains in the development phase, with most sorting still done manually, limiting the potential for consistent feedstock for recycling and, consequently, for the manufacturing of recycled yarn.

Additionally, there is very little textile recycling infrastructure in the UK. A polyester recycling plant is in development, but the UK has no cotton recycling plant. As covered in section 1.1.3 of this chapter, polyester and cotton have the largest market share of produced fibres, so having little-to-no recycling infrastructure for both materials is a major barrier to manufacturing recycled content.

While a wool recycling plant exists in the UK, wool represents a limited proportion of materials placed on the market.

Manufacturing:
The UK currently lacks any infrastructure for cotton spinning and produces very limited polyester filament or staple yarn. While wool manufacturing possesses the most developed infrastructure within the UK, existing machinery limitations hinder the utilisation of post-consumer fibre.

More broadly, current UK manufacturing machinery is generally not designed for the high-volume yarn production characteristic of more modern equipment used in other global manufacturing centres.

While European countries such as Spain and Italy have more advanced manufacturing infrastructure than the UK, they still haven't advanced beyond the research and development phase of manufacturing post-consumer waste recycled content.

> **"The infrastructure in the UK has declined to such an extent that it makes it more difficult, but it doesn't make it impossible.**

3.2. Technical: Insights and challenges

The UK faces several technical challenges if it is to scale the manufacturing of high-quality recycled yarn in the near future.

Recycled fibres supply:
As explored in section 1.3.2, the automated sorting and recycling sector remains in the nascent stages of exploring the technical feasibility of processing diverse material types. The most significant disadvantage of post-consumer textiles is that they contain different fibres and materials. Technical issues persist in the recycling of certain materials, which can affect the quality and characteristics of the output material. These challenges include limitations in fibre length and strength, which subsequently present a significant obstacle for manufacturers. For instance, if the recycled output comprises short fibres or is contaminated, existing machinery will likely be unsuitable to produce quality yarn. Moreover, a key challenge is the consistency in volume feedstock supply for chemical recyclers.

Trials:
A significant limitation of current recycling trials is that many are lab-based. Lab-scale trials cannot fully replicate the processes required for industrial-scale recycling and, hence, industrial-scale manufacturing. Therefore, the results of lab-based trials may not be readily scalable to real-world industrial settings, may not reveal potential technical and commercialisation challenges, and are not yet at the stage where they can effectively inform or replicate the development of real-life manufacturing of recycled content scenarios.

> **“As long as the feedstock is of a good quality, we can get better quality outcomes**

Recycled yarn manufacturing:
Currently, the vast majority of textile waste being utilised for recycled yarn production comes from post-industrial waste. Therefore, manufacturers in the UK and Europe face the challenge of increasing the focus on and development of using post-consumer textile waste. In fact, the use of post-consumer recycled fibre remains largely confined to research and development initiatives. While companies are actively developing this technology and may offer limited product lines incorporating post-consumer waste, such products constitute a very small proportion of their overall output. Where post-consumer waste is used, it is currently necessary to mix post-consumer and post-industrial recycled fibre, or virgin fibre, to achieve the required properties and performance of the yarn.

> **“I’m towards the end of my career and there’s nobody left that’s had a lifetime in it. All that historical knowledge will be lost… [We need] younger people to learn and keep all those skills.**

3.3. Skills and workforce: Insights and challenges

The development of a circular supply chain depends on a skilled manufacturing workforce, particularly in relation to the manufacturing of recycled content.

Big picture:
A dual skills gap is challenging the UK’s manufacturing future. Firstly, traditional manufacturing skills are declining, compounded by a lack of young talent entering the sector, limiting growth potential. Secondly, the industry currently lacks the digital, innovative, and circularity skills necessary for a modern, sustainable manufacturing ecosystem. A recent report[104] exploring the skills shortage in UK manufacturing found that 97.5% of manufacturers agree that hiring and retaining skilled labour poses a significant challenge to their business, while 81% agree that digital skills are harder to acquire because of competition from other sectors.

Europe:
When it comes to skills in relation to the manufacturing of recycled content in the UK, the skills remain limited, and several European countries have more experience and knowledge of processing post-consumer textiles and manufacturing of recycled content than the UK. However, this experience and knowledge is mostly applied to post-industrial waste, with a skills gap in recycling post-consumer content.

Both the UK and Europe face the same issues of recruiting a skilled workforce. While a challenge, this presents an opportunity to build a new supply chain that can deliver green jobs and create training and education pathways to attract talent.

3.4. Economic viability: Insights and challenges

Because yarn manufacturing mostly occurs outside the UK, it would take significant investment to develop a robust UK manufacturing supply chain. Therefore, it is important to consider whether domestic textile-to-textile recycling and manufacturing of recycled content is economically viable enough to justify significant investment.

Brand and retailer demand:
If the UK were to develop sufficient capacity to manufacture recycled content, there still is no guarantee of commensurate demand from brands and retailers, as recycled content currently carries a significant cost premium for retailers.

Cost competition:
Even if recycled yarn was produced in the UK, it would still face competition from global production countries that can produce recycled yarn more cost-effectively due to comparatively high manufacturing costs in the UK.

Viable end markets:
Recyclers do not currently foresee the UK as a viable short-term end-market for their recycled output. Exporting the outputs from a recycling process to well-established, volume manufacturing hubs, particularly in Southeast Asia, presents a more economically attractive proposition for many.

> **One of the big missing pieces of the puzzle currently is how can we secure that buy-in and uptake from brands and retailers.**

> **We're under no illusion about the scale of the challenge but this report shows that change is possible. The UK has a genuine opportunity to modernise its textile manufacturing infrastructure and build a circular, resilient supply chain. While investment, innovation and collaboration are still urgently needed, the foundations being laid today across sorting, recycling and skills can unlock long-term potential for sustainable growth.**
>
> - Adam Mansell, CEO of UKFT

4. DISCUSSION

This section outlines a series of recommendations in four key areas to set out a vision for the future of UK recycled content manufacturing capacity:

- Infrastructure and technology
- Technical
- Skills and workforce
- Economic viability

4.1. Recommendations: Infrastructure and technology

Transition to an automated sorting process: This is critical to ensure consistent feedstock for textile recyclers, and, ultimately, consistent feedstock for manufacturers to invest in recycled content production.

Scale textile-to-textile recycling: Support the continued development of mechanical, thermomechanical, chemical, and biological recycling technologies to ensure high volumes of recycled fibre can be inputted into manufacturing.

Invest in manufacturing capacity: It must be acknowledged that establishing a workable textile recycling supply chain will require significant investment in the manufacturing capacity of cotton and polyester, so initial steps should be taken immediately to lay the groundwork for this long-term objective.

Modernise machinery and infrastructure: Existing machinery and infrastructure aren't capable of achieving the manufacturing volume required to create a commercially viable supply chain. Consequently, if the UK is to create its own recycled yarn, investment is required to upgrade manufacturing and infrastructure capabilities to internationally competitive standards.

Twin with neighbouring infrastructure: Explore the viability of expanding the UK's manufacturing capacity of recycled content by leveraging the more advanced infrastructure of European countries, such as Spain.

Consider short-term advances: A full transition to a circular economy will take time, so it is important to pave the way by exploring short-term open-loop opportunities for the manufacturing of recycled content to convert post-consumer textile waste into value-added products with enhanced functional properties.

4.2. Recommendations: Technical

Accelerate research and development trials: As highlighted in Chapter 5, 'Textile Recycling Supply Chain Trials', research and development trials must overcome the technical barriers of post-consumer textile recycling and focus on finished product marketability. Additionally, because research and development trials often end at the recycling stage, the scope of these trials must expand to incorporate manufacturing insights.

Conduct further testing to raise the percentage of recycled content in the manufacturing of recycled yarn: More particularly, there is an opportunity to increase the percentage of recycled content in yarn production. The UK should conduct further research and development and collaborate with and learn from countries with advanced expertise in this area.

Acknowledge the limitations in the current performance and quality of post-consumer recycled content: Be open to opportunities to mix post-consumer recycled content with post-industrial recycled content and virgin content at the yarn production stage.

4.3. Recommendations: Skills and workforce

Build expertise in recycled content production: It is essential to develop comprehensive manufacturing skills for recycled content. To support the manufacturing transition, opportunities to upskill and educate workers through training programmes must be provided.

Develop expertise for ATSP operations and recycling: The quality of feedstock is fundamental to producing high-quality yarn. Therefore, the specialised skills needed to create superior input materials must be developed. Additionally, existing recycling skills, such as in wool manufacturing, must be preserved and enhanced through structured training programmes to facilitate knowledge transfer and continuous improvement.

Learn from European and global partners: The UK can't do this in isolation. Facilitate skills-sharing with countries in Europe and globally that have significantly more experience and knowledge of processing recycled fibre and manufacturing recycled content.

4.4. Recommendations: Economic viability

Build a compelling business case: To scale textile-to-textile recycling and the manufacturing of recycled yarn in the UK, a comprehensive business case must be developed to assess the economic viability of investing in yarn manufacturing infrastructure within the UK. This analysis should encompass factors such as capital expenditure requirements, operational costs, potential revenue streams, market demand, and risk mitigation strategies, as well as environmental impact savings. A cost-benefit and environmental analysis of relocating manufacturing operations to the UK should also be conducted to evaluate onshoring potential.

Undertake cost comparisons: The various cost scenarios and implications of manufacturing recycled content in the UK must be compared against the costs of manufacturing recycled content elsewhere. Additionally, it is important to explore how UK-made recycled products can be marketed to compete with overseas-made recycled products.

Assess open-loop end-markets: Conduct a thorough cost-benefit evaluation of the potential for utilising recycled fibres in non-fashion sectors.

Explore international market development: Investigate all potential export channels for recycled output.

4.5. Recommendations: General

Communicate and collaborate across all stakeholders: To ensure comprehensive representation across the textile-to-textile recycling supply chain, active engagement with all stakeholders – local and global – is essential. This includes facilitating the meaningful participation of manufacturers in research initiatives, policy discussions, and decision-making processes.

Push for greater legislative support: Advocate for the implementation of eco-design regulations and EPR schemes to accelerate the adoption of recycled content within the textile industry. These policies should be designed to effectively incentivise both retailers and consumers to prioritise recycled materials, enabling the business case for domestic textile recycling and manufacturing to be built.

Gather manufacturing practitioner insights: Understanding the practical challenges and solutions from a manufacturing practitioner's perspective has emerged as a potential research gap which must be addressed through greater research and development in this area.

APPENDIX

Methodology: Questions for recycling trial partners interviews:
Questions varied slightly depending on the trial scope (e.g. fibre type, recycling method, trial partners). However, all questions followed a framework to elicit conversations about the relevant topics:

1. Please give a brief introduction to the trial and the process steps that were followed. Was yarn produced from the recycled fibre?
2. Did the recycling process influence the fibre quality and, as a consequence, the quality of the yarn that was spun? Were any other technical challenges, in terms of fibre characteristics and properties, encountered relating to the output feedstock of the recycling trial?
3. What opportunities are there for improving the quality of the recycled output, to ensure quality yarn production?
4. To what extent can the machine settings at various stages of production influence or improve the quality of the recycled yarn produced?
5. Do you think it is technically feasible that yarn with a high recycled content will be able to compete with virgin yarn in terms of performance in the short term (e.g. tensile properties, abrasion, pilling etc)?
6. To what extent is the current UK textile manufacturing sector set up for processing recycled fibre into quality yarn?
7. Will investment in new machinery be necessary for manufacturing recycled yarn at scale, or can this be achieved with the right knowledge/settings etc?
8. What machinery would we need to manufacture recycled yarn at scale?
7. What is the plan for a textile recycler regarding their end market? Do you envision a potential end market/partnership in the UK?
10. Regarding investment in machinery/infrastructure, what are the main risks and challenges to scaling the manufacture of recycled yarn in the UK?
11. Regarding commercial opportunities/demand, what are the main risks and challenges to scaling the manufacture of recycled yarn in the UK?
12. What are the next steps for making quality recycled yarn in the UK?

Methodology: Questions for other manufacturers' interviews:
Questions varied slightly depending on whether they were a UK or European manufacturer and relevance depending on the business type. However, all questions followed a framework to elicit conversations about the relevant topics:

1. Can you provide a brief overview of your business and the type of product or material that you make?
2. Do you currently manufacture any of your products using recycled fibre?

   If yes,

a. Where do you source the recycled fibre from? Is it pre- or post-consumer?
b. What technical challenges have you encountered when using recycled fibre/yarn?
c. How does the technical performance compare to virgin yarn?
d. What other challenges have you encountered?

If no,

e. Have you ever trialled the use of recycled fibre? Why or why not?
f. What have been the main barriers to using recycled fibre?
g. Do you have any plans to introduce recycled fibre into your products? Why or why not?

3. To what extent is the current UK (or European) textile manufacturing sector set up for processing post-consumer recycled fibre into quality yarn at scale?
4. Regarding investment in machinery/infrastructure, what are the main risks and challenges to scaling the manufacture of recycled yarn?
5. Regarding commercial opportunities/demand, what are the main risks and challenges to scaling the manufacture of recycled yarn?
6. Regarding workforce/skills, what are the main risks and challenges to scaling the manufacture of recycled yarn?
7. What are the next steps for making quality recycled yarn in the UK, from both a technical and capacity perspective?

Chapter 8:

Transitioning to a UK circular textiles ecosystem

The business case for the implementation of a circular textiles ecosystem in the UK



CONTENTS

Introduction
- Current challenges and opportunities

Mapping a future vision
- Material inputs
- Scale of opportunity
- Future outputs
- The vision

Economic challenges and opportunities
- As-is scenario
- NRT value
- Opportunities

Enablers
- Enabler: Policy
- Enabler: Environment
- Enabler: Social

Discussion
- Stakeholder recommendations: Policymakers
- Stakeholder recommendations: Investors
- Stakeholder: Current and future textiles value chain
- General recommendations

Appendix

1. INTRODUCTION

This report has explored the ACT UK project's aims of establishing an Advanced Textile Sorting and Preprocessing (ATSP) facility in the UK, with the goal of transforming the management of non-reusable textiles (NRTs) to support a fully circular textiles ecosystem. Chapter 6, 'The Business Case for Advanced Textile Sorting and Pre-processing Facilities', consolidated research on the feasibility of implementing a standalone ATSP facility, examining the challenges and opportunities within the current NRT system.

This chapter now focuses on the viability of an ATSP network that supplies and feeds fibre-to-fibre (F2F) recycling, detailing the challenges, enablers, and opportunities inherent in this systemic shift (see Figure 166). The chapter aims to address the critical gap in transitioning from the UK's current textiles ecosystem to one where NRTs are efficiently collected, sorted, and sent for F2F recycling.

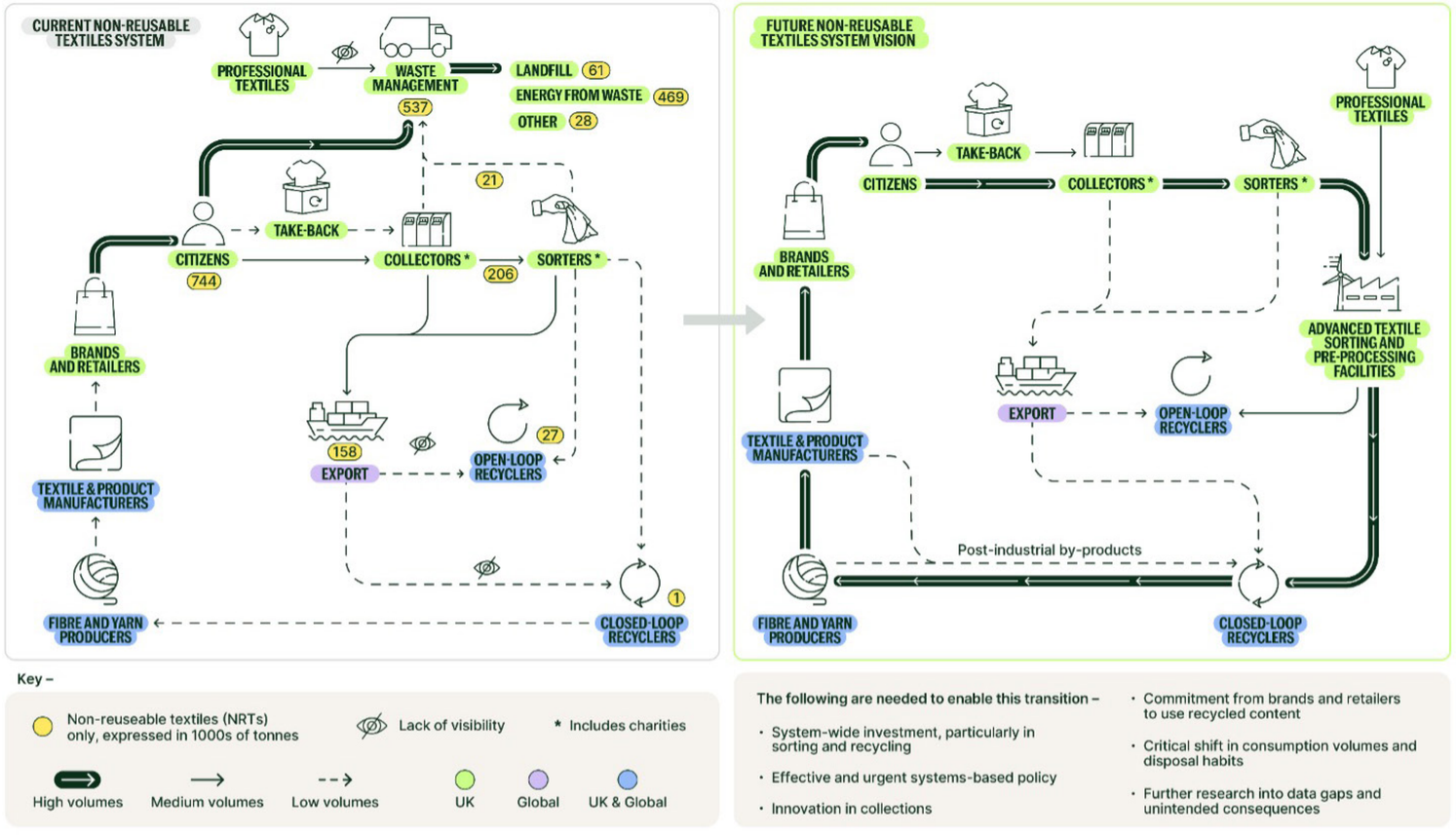


Figure 166: Transition from the current non-reusable textiles ecosystem to the vision for a future ecosystem, including key enablers.

Developing a circular textiles ecosystem by 2035 hinges on the used textiles value chain accelerating modernisation. This level of transformation requires the industry to align on a clear vision that effectively realises the potential economic, environmental, and social benefits of moving from a linear ecosystem to a circular ecosystem. Therefore, section 2 explores this future vision by assessing the challenges and opportunities across material inputs, scale of opportunity, and potential future outputs.

The transformation requires a viable business case, so section 3 looks at several economic scenarios. These range from the costs of failing to act and leaving the current post-consumer textiles (PCT) value chain as it is, to the opportunities – and challenges – created by implementing a circular ecosystem. Three clear enablers emerge – policy, environmental, and social – that are critical to an economically viable transition. Section 4 looks at how these enablers could support the economic case for a network of ATSP facilities. Finally, section 5 crystallises the research and lessons learned throughout this chapter and provides a clear set of recommendations to support and drive the transition to a circular textiles ecosystem.

However, to assess the potential benefits and impacts of moving to a circular textiles ecosystem, it's crucial to first understand the problems it aims to solve. Therefore, the following section (1.1) briefly presents a situational analysis of current sector challenges and highlights opportunities for positive change.

1.1. Current challenges and opportunities

The UK's PCT industry is well-established. Traditionally, businesses such as collectors and sorters relied on textile quality and partnerships to pass on used textiles for reuse, remanufacture, recycling, and repair, both domestically and internationally[105]. However, recent years have seen increased costs, labour shortages, and a rapidly evolving, high-risk market. There are also growing environmental concerns at the point of disposal, driven by increased consumption and global textile waste.

The effects of fast and cheap fashion, particularly the shift to synthetic, lower-cost materials and lower-quality manufacturing tailored for short-lived micro-trends, have exacerbated these challenges. Consequently, volumes of low-value and quality NRTs are rising, placing the collectors and sorters who have historically managed these materials under severe economic pressure.

Recent reports have highlighted urgent concern over the immediate future of the global PCT sector, particularly for collectors and sorters:

- In April 2024, the Textile Recycling Association (TRA) – which represents over 75% of the UK's used textile sorters and collectors – reported[106] the risk of an imminent collapse of the textile recycling sector. TRA attributed this threat to global market challenges, including shipping disruptions caused by the ongoing Red Sea crisis, increased taxation in African and Asian markets, and rising operational costs driven by the global influx of low-quality textiles
- In the UK, high collection and transport costs combined with the low price of sorted NRTs are resulting in sorters currently losing between £350-£430[107] per tonne of sorted NRTs
- Germany-based textile sorter and recycler SOEX Group, which is one of Europe's major operators, began insolvency proceedings and filed for bankruptcy in October 2024, putting additional pressure on UK operators
- Also in October 2024, the European Recycling Industries' Confederation echoed concerns in the UK about the unprecedented challenges facing the industry, with similar factors contributing to this pressure, as well as the war in Ukraine
- Also in October 2024, the European Recycling Industries' Confederation echoed concerns in the UK about the unprecedented challenges facing the industry, with similar factors contributing to this pressure, as well as the war in Ukraine

Collectively, these reports paint a concerning picture of the immediate future of the PCT sector, with urgent action required.

So, what action can be taken to tackle these problems?

Other chapters in this report have highlighted the significant disparity between the vast amount of used textiles being discarded in the UK and the comparatively small volume that is reprocessed into new textile products. While this disparity demonstrates the scale of the current system's challenges, it also highlights the huge potential for a future, more efficient value chain.

To support the shift from a linear to a circular textiles ecosystem, F2F recycling must displace virgin material production. This will maximise the utilisation of valuable resources within existing textiles and reduce the dependency on virgin materials. Although current levels of F2F recycling globally are relatively low, investment in recycling technology over the past decade has highlighted that optimised sorting is required to drive economic viability and meet quality and cost requirements[108]. For F2F recycling to be scalable, there must be a consistent, reliable stream of input material in the form of sorted and pre-processed NRTs.

This sorting stage, which is currently done manually, is the main bottleneck between the substantial potential supply of NRTs and the substantial potential for F2F recycling. While innovation across different aspects of automated sorting and pre-processing has been increasing, investment in implementation and scaling up is urgently needed to optimise sorting while ensuring short-term and long-term economic stability for the industry.

A potential solution to these significant challenges is establishing ATSP facilities to automate sorting and pre-processing in preparation for F2F recycling (as well as for open-loop recycling as F2F scales up). If successful, this would enable the value chain and recyclers to operate more efficiently, keep jobs and industry within the UK, reduce reliance on virgin resources, develop an export market for recycled materials to be sold to overseas manufacturers, and reduce textiles going to landfill and incineration.

2. MAPPING A FUTURE VISION

As explored throughout this report, the UK's NRTs are often lost to residual waste streams or exported to regions with lower labour costs, where it's difficult to track whether they are ultimately reused or recycled. In response, F2F recycling can displace the use of virgin resources, enable the traceability of used textiles to reduce the volume ending up in waste management, and support the textile industry in meeting its net-zero targets. However, the existing used textiles value chain is not currently optimised to supply these recycling processes.

Therefore, for the UK to realise the potential economic, environmental, and social benefits of a functioning textiles ecosystem, the vision for the future of textiles over the next 10 years must be one of true materials circularity. It must be a vision where collections, sorting, and F2F recycling enable materials to be fed back into textiles production, with ATSP facilities ideally suited to bridge the gap between collections and F2F recycling.

To support this vision, this section explores the feasibility of establishing a circular textiles ecosystem by 2035. It does this by examining the challenges and opportunities across:

- Material inputs
- Scale of opportunity
- Potential future outputs

2.1. Material inputs

Several scenarios have been developed to investigate the potential landscape for NRT inputs into a circular textiles ecosystem by 2035.

These scenarios are based on possible changes in the volumes of PCT generated in the UK, as well as collection rates[109]. Reusable textiles diverted for local reuse or export, as well as those sent to end-of-life (EOL) by sorters due to contamination, are excluded, with the remaining NRT assumed to be feedstock for ATSP facilities. Therefore, the remaining NRT could also be for F2F recycling, depending on fibre composition and disruptors present (please refer to 'Future scenario data' in the Appendix for detailed assumptions and the data employed).

Firstly, scenarios were varied depending on future potential PCT generation:

- The base scenario is based on current volumes of textiles discarded per person per year (21kg/person). This is compared to:
  - The low scenario, which represents 33% lower volume of textiles discarded per person vs the current state (14kg/\ person)
  - The high scenario, where there is an increase of 33% in the volume of textiles discarded per person (29 kg/person)

For PCT collection rates:

- The low scenario represents the current collection rate, which is 50% (which accounts for the percentage of total PCT diverted from EOL, including peer-to-peer resale)
- The high scenario represents an aspirational collection rate based on a saturated industry comparison (glass; 90%)
- The base scenario is an average of the low and high, where collections have increased but not been maximised (70%)

The resulting nine potential future scenarios are shown in Figure 167.

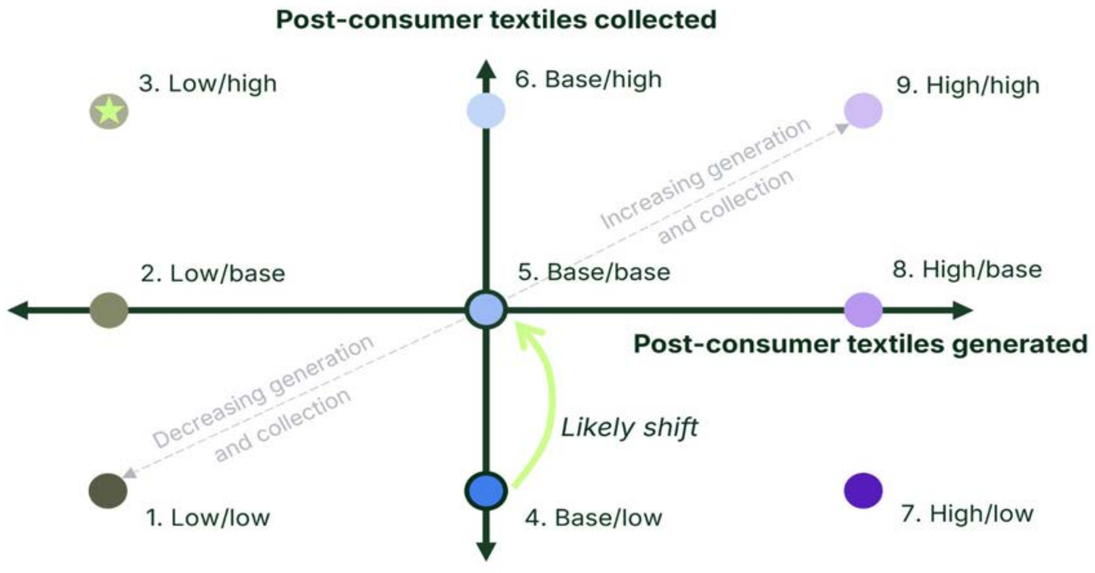


Figure 167: Nine scenarios considered as potential future scenarios where post-consumer textile generation and collection rates vary[110]

Notable reflections of these nine scenarios include:

Scenario 4: This represents the current situation, characterised by base PCT generation levels and 'low' collection rates.

Scenario 3: This scenario, characterised by high collection rates and low PCT generation, is considered the 'North Star', intended to guide the industry towards systemic change. In this scenario, circularity would function effectively, with more textiles being utilised through circular business models (such as resale, rental, swapping, etc.) and for longer periods due to enhanced durability.

Scenario 5: Based on WRAP's and Circle Economy's consultations with industry stakeholders, this scenario was identified as the most likely future outcome. It envisions collection rates moderately increasing to 70% while the volume of PCT generated per person remains unchanged (with absolute volumes rising only in proportion to population growth). The data points used in this scenario are presented in Figure 168. The scenario's assumption relies on increased efficiencies in collections, as well as increased citizen engagement with this. This would result in approximately 363 kilotonnes (kt) of PCTs collected annually. Processing this volume would require around 14 ATSP facilities at current throughput estimates (25 kt/yr), though fewer facilities might be needed if throughput capacity is increased.

	Unit	Past	As is	Transition	Future
Scenario 5 Base/Base					
PCT total	Tonnes		1,453,000	1,505,700	1,541,400
PCT (decrease) / increase	Percentage		n/a	n/a	n/a
PCT per person	kg		21	21	21
Collected textiles	Tonnes	600,000	733,000	908,472	1,082,428
Collection rate	Percentage		50%	60%	70%
Local Resale	Tonnes	186,000	276,000	342,071	407,572
Local resale rate	Percentage	31%	38%	38%	38%
Exported textiles	Tonnes		421,000	353,640	286,280
Export rate	Percentage		57%	39%	26%
EOL from collected textiles	Tonnes		36,000	44,618	53,162
EOL from collected textiles rate	Percentage		5%	5%	5%
Open & Closed loop recycling	Tonnes		34,000	168,143	335,415
Total	Tonnes		767,000	908,472	1,082,428
ATSPs required	Quantity		n/a	7	14

Figure 168: Data used in Scenario 5, future vision

Scenario		Post-consumer textiles generated		
		Low	Base	High
Post-consumer textiles collected	High	11	21	32
	Base	6	14	19
	Low	1	7	14

Figure 169: Number of ATSPs required to handle PCTs collected in the UK, assuming an ATSP throughput of 25kt/yr by year 3

Figure 169 shows the number of ATSP facilities required in all scenarios.

In practice, systemic change is slow and uncertain. Therefore, it could be a gradual shift towards, or through, various scenarios. This is why understanding the challenges and opportunities across the entire value chain, not just within sorting, is crucial to this transition. After all, PCT generation may decline over time as the textiles industry acknowledges and addresses rising production and consumption levels, expands the use of circular business models, and improves durability. In contrast, businesses in the current textiles collection sector may struggle due to the existing challenges they face, leading to a potential decrease in collection rates.

2.2. Scale of opportunity

The vast quantities of post-consumer NRTs in the current ecosystem pose a significant opportunity for positive change. However, several uncertainties exist in estimating the scale of this opportunity.

Firstly, while the NRT volume figures[111] used in this report were based on research and informed assumptions developed in collaboration with the industry, the distinction between RT and NRT is inherently subjective. It may vary by organisation, region or country due to different grading systems, end markets, and tolerance levels. There is a similar subjectivity in assessing reusable and re-sellable textiles. This means that estimates of NRT volumes represent a close approximation but are not absolute values.

Secondly, there has been very little large-scale research into the fibre composition and potential recyclability of UK NRTs, especially for those currently disposed of in residual waste. However, the Sorting for Circularity Europe project[112] studied 21 tonnes of PCTs for composition, with promising results for recycling potential. Current F2F recycling technologies require suitable feedstock not only in terms of fibre composition (and tolerance to other non-target fibres), but also in structure (single, multi-layered, etc.), absence of disruptors (zips, buttons, prints, etc.), colour, and lack of contamination (e.g., moisture, chemicals[113]). Every recycler has different feedstock specifications, which may change over time as technology develops, making it difficult to map the potential recyclability of NRTs, even if fibre composition is known.

Despite these uncertainties, there is little doubt that the scale of NRT generation is vast and presents an equally vast opportunity for actors within the value chain. Figure 170 shows the current estimation of annual NRT generation mapped onto F2F requirements, although it's likely that not all would fit the desired output criteria[114]. These estimations result from a material analysis conducted at a single facility twice in one year on a moderate sample (below 5 tonnes in total) within the Sorting for Circularity Europe study by Fashion for Good and Circle Economy (2022). Please note that this overview of the material composition of the NRTs in the UK can be used as an indication, but it should be recognised that it is not representative of all the sorters in the UK at all moments in time.

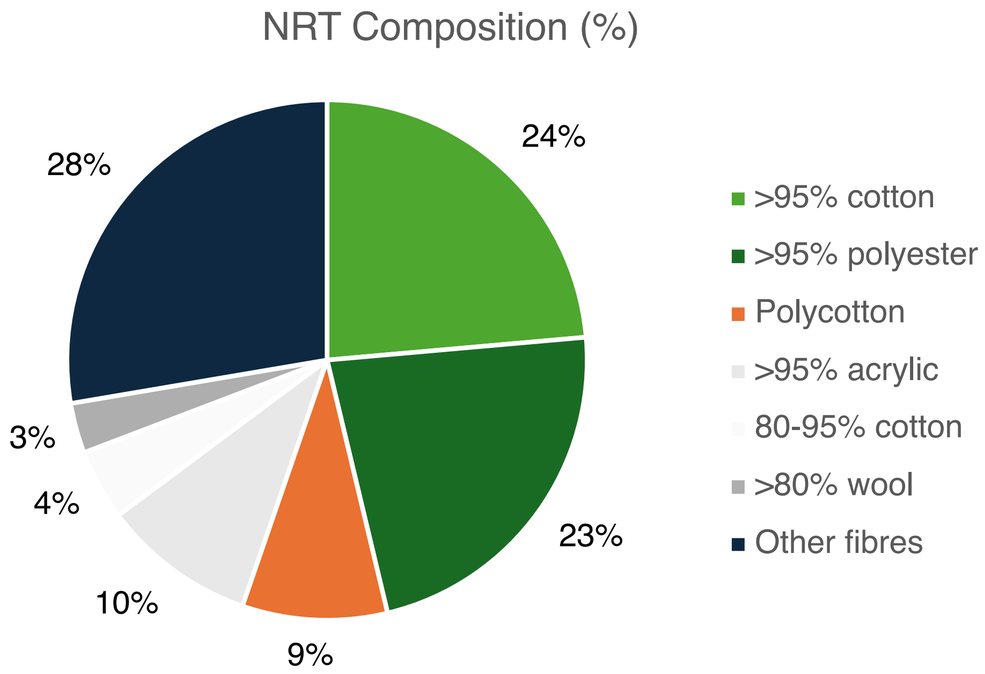


Figure 170: Estimated fibre composition of the 744,000 tonnes of NRTs generated annually in the UK, as ATSP outputs, split by F2F recycling fibre composition specifications.

2.3. Future outputs

While the input scale is important, it is equally vital to consider the demand for an ATSP facility's output materials and what this could mean for future outcomes.

As brands and retailers strive to achieve climate targets, recycled fibres will become increasingly important. The carbon and water savings associated with recycled fibre use, primarily due to a reduction in virgin fibre production, could create a heightened demand for these products. Therefore, as recycler demand increases, greater volumes of high-quality, consistent feedstock will be necessary for recyclers to produce high-quality fibres, and an ATSP network could be ideally positioned to fulfil this demand. This will be crucial for both open-loop and closed-loop recycling, with open-loop recycling being particularly significant as an ATSP onward market, especially while closed-loop – and, therefore, demand from these recyclers – scales up.

So, what could this look like in practice?

In 2021, Textiles 2030 proposed[115] an ambitious scenario to achieve a 50% reduction in carbon and a 30% reduction in water by using 40% mechanically recycled cotton, 100% closed-loop recycled polyester, and 50% recycled man-made cellulosic fibres (MMCF). If the current market fibre composition doesn't dramatically change, an estimated future demand for these recycled fibres can be calculated. For UK brands and retailers, this would produce an estimated demand of over 250,000 tonnes per year of mechanically recycled cotton, almost 445,000 tonnes of closed-loop recycled polyester, and just under 45,000 tonnes of recycled MMCF[116].

A second ambitious, but more realistic, WRAP-defined scenario, developed through consultation with the Closing the Loop Textiles 2030 Working Group in 2025, proposes 23% for cotton, with MMCF remaining at 50% and polyester shifting to 70% open-loop, and 30% closed-loop. This would revise the demand to 144,000 tonnes per year of mechanically recycled cotton and 134,000 tonnes per year of closed-loop recycled polyester.

However, if closed-loop recycled fibre production continues at the current rate, only a fraction of what is required will be available by 2030 (see Figure 171), with a shortfall of 107,000 tonnes of mechanically recycled cotton and 311,000 tonnes of closed-loop recycled polyester.

Therefore, to meet targets such as these, urgent change and significant scale-up are required, driven by innovation in collections, sorting, and recycling.

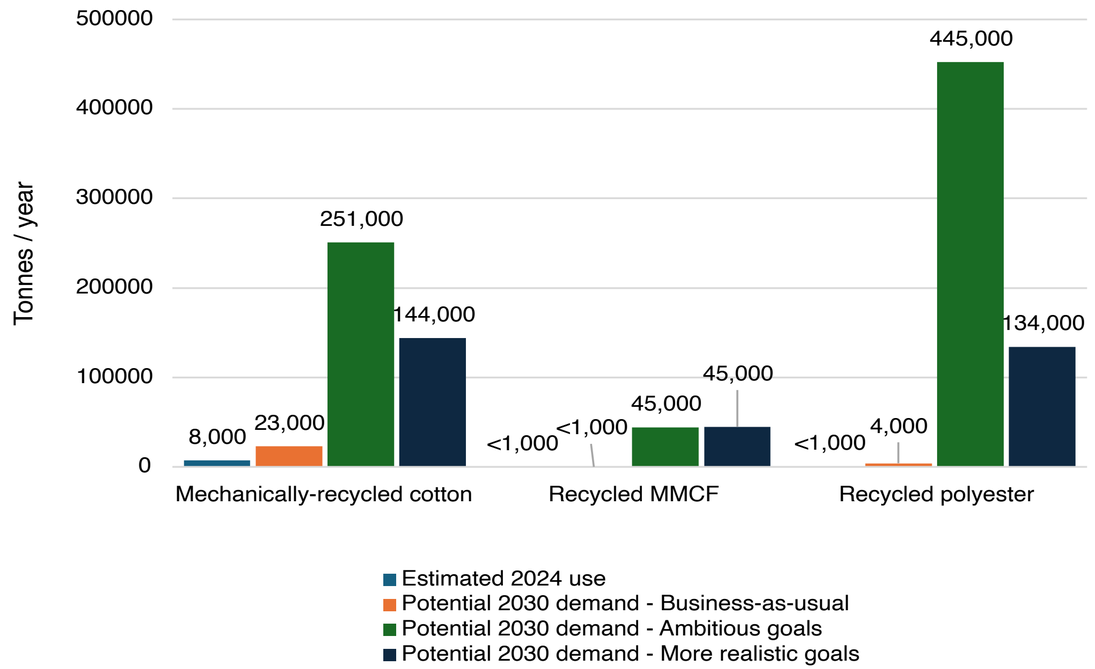


Figure 171: Closed-loop F2F recycled content currently used (estimated) by UK brands and retailers, potential 2030 use if business as usual continues uptake at current rate, and potential 2030 use if recycled content increased to meet ambitious and more realistic climate targets[117]

2.4. The vision

The 2035 vision for the future of textiles is a circular ecosystem in which waste is prevented and minimised, resource use is maximised, and materials remain within the textiles value chain for as long as possible.

To do this, the vision must support the UK sorting sector in overcoming current challenges and adapting to new operating methods by reducing risk and uncertainty in the industry. The intended outcomes of supporting UK sorting sector include:

- Decreased reliance on virgin materials for new textile production
- Reduced environmental footprint of the textiles sector
- Increased social and economic benefits across the UK through job creation and investment

While the Circle-8 ATSP demonstrator, currently in development as part of the ACT UK project, will be based in the UK, the future vision must consider the entire value chain when planning the locations and operational set-up of ATSP facilities within the full system.

Because UK materials circularity also depends on international collaboration and global circularity, it is essential to include manufacturing, recycling, and used textile end-market regions when considering where to locate ATSP facilities. This approach would support reuse end markets when textiles reach the end of their useful life.

Therefore, the configuration and location of ATSP facilities are likely to depend on the local and international context. For example:

- An ATSP facility located at, or close to, a recycling or manufacturing region may make economic, environmental, and social sense
- An ATSP facility located at, or close to, a large-scale recycler may be set up to provide feedstock to the specifications of that recycling process
- An ATSP facility located at, or close to, a collection hotspot may be set up to handle a wider range and higher volume of materials with multiple onward destination options
- To avoid unintended consequences, ATSP facilities outside of the UK should also be considered an important part of the future vision

Further analysis of the potential location of ATSP facilities in the UK can be found in Chapter 6, ‘The Business Case for Advanced Textile Sorting and Pre-processing Facilities’.

Figure 172: Diagram of an ATSP integrated circular textiles value chain vision including key stakeholders and movement of RT/NRT

3. ECONOMIC CHALLENGES AND OPPORTUNITIES

This section explores the economic challenges and opportunities in achieving the vision of transitioning to a circular textiles ecosystem. It analyses the current financial costs to the NRT sector, compares the 'as-is' scenario with a potential ATSP network, and identifies six key economic opportunities to support a financially sustainable circular textiles ecosystem.

3.1. As-is scenario

As set out in section 1.1, the cost to the current sorting sector is estimated to be between £350-£430 per tonne of NRTs sorted, with an average of £426. Considering that 206,000 tonnes of NRT are currently sorted in the UK per year[118], this suggests that the cost to sorters could be around £88million per year. Previously, this was offset by the high-value RTs. However, this is becoming increasingly challenging to balance out. Therefore, with the sector's collapse a very real threat[119], the economic impact of not acting must be considered and assessed.

In this scenario, it is assumed that all commercial textile collection banks and partnerships would disappear. As a result, the volume of textiles would overwhelm charities. They would either have to pay to dispose of what they cannot sell, which would reduce revenue going to charitable causes and add additional strain on their operations and resources, or they would have to export directly themselves.

Additionally, with fewer options for citizens to dispose of used textiles, such as collection banks, there would inevitably be significantly more textiles going to residual waste and being fly-tipped. This would increase costs to local authorities and government, which may be passed onto taxpayers. Additionally, with the UK's Emission Trading Scheme likely to expand in 2028 to cover energy from waste (EfW) and incineration, the increased volume of textile materials in residual waste will be a further financial burden on local authorities[120].

If the sorting sector collapsed today, and all PCT generated went to residual waste (excluding those sold through peer-to-peer resale), this could result in:

- An increase of around 95,000 tonnes of textiles in landfill each year
- An increase of almost 555,000 tonnes of textiles to EfW per year

Based on a median EfW gate fee of £112 per tonne for residual waste (excluding bulky Persistent Organic Pollutants waste) and a median non-hazardous landfill gate fee of £24 per tonne, this could add up to an additional £64million in gate fees per year to local authorities and charities, as well as brands and retailers that offer take-back schemes. It would also likely cause additional operational costs[121]. Against a baseline of around £73million in gate fees for landfill and incineration currently, this is an increase of 88%.

Extrapolating this to 2035, the total gate fee costs could range from £146million (if PCT generation increases only with population growth) to £200million (if PCT generation increases by 33%).

3.1.1. As-is scenario compared to ATSP ecosystem

It is important to understand how this as-is scenario compares to an ecosystem that is utilising ATSP facilities.

Given current assumptions on the operations of a single, generic ATSP facility, it is estimated that it could operate at a loss of between £2.6million and £7.6million annually when at full capacity (further details can be found in Chapter 6, 'The Business Case for Advanced Textile Sorting and Pre-processing Facilities'). While these initial estimates are concerning, they should be viewed against the annual loss which the sector could experience if it remains as it is.

Looking to 2035, if the sector sorts 363,000 tonnes of NRT annually and operations remain the same as today (i.e., without ATSP facilities), the cost to the sector could be £77million per year. In comparison, an ATSP network of 14 UK facilities handling the same amount of textiles could cost £38million, which is a 51% reduction in loss (see Figure 172). Therefore, this potentially poses a significantly better economic situation.

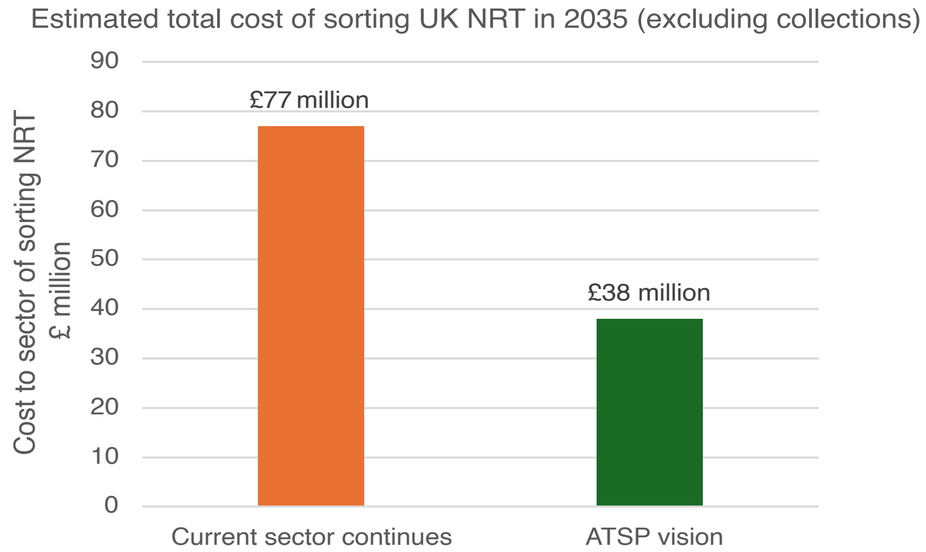


Figure 173: Estimated cost of sorting NRT (363,000 tonnes) to the UK sector in 2035 – excluding collection costs, as it is expected that collections would be required in both scenarios. Compares if operations continued as they do today with a 14 ATSP system.

There is also a range of factors that can improve this business case financially, particularly when considering a system that works collectively towards circularity. Factors for improving the ATSP business case include:

- Ensuring good quality input material
- Increased efficiency in logistics and operations
- Responding to recycling market needs
- Optimising locations with respect to off-takers or suppliers
- Considering grants, subsidies, and commercial partnerships with brands and retailers

When looking at the full system economics, there is potential for success given the scale of the opportunity. In some cases – such as for Circle-8 – a positive business case has been developed, utilising these and other levers to demonstrate investment opportunities. However, successful implementation may still be challenging without additional financing, policy levers, and incentives, such as Extended Producer Responsibility (EPR) and brand and retailer support, which are explored throughout section 4.

3.2. NRT value

Currently, when textile materials move from being products to becoming ‘waste’, their inherent value is reduced. This must change to drive an economically viable circular ecosystem.

When the current linear ecosystem reconnects to form a circular ecosystem, it will have two halves in terms of value, as shown in Figure 174. These two halves are:

- High-value (products)
- Low-value (waste)

Currently, the system loses value at the citizens stage, with the percentage loss based on the quality of and demand for the used textile item. At the other end, the value is increased again at the recycling stage, where the material returns to being a product.

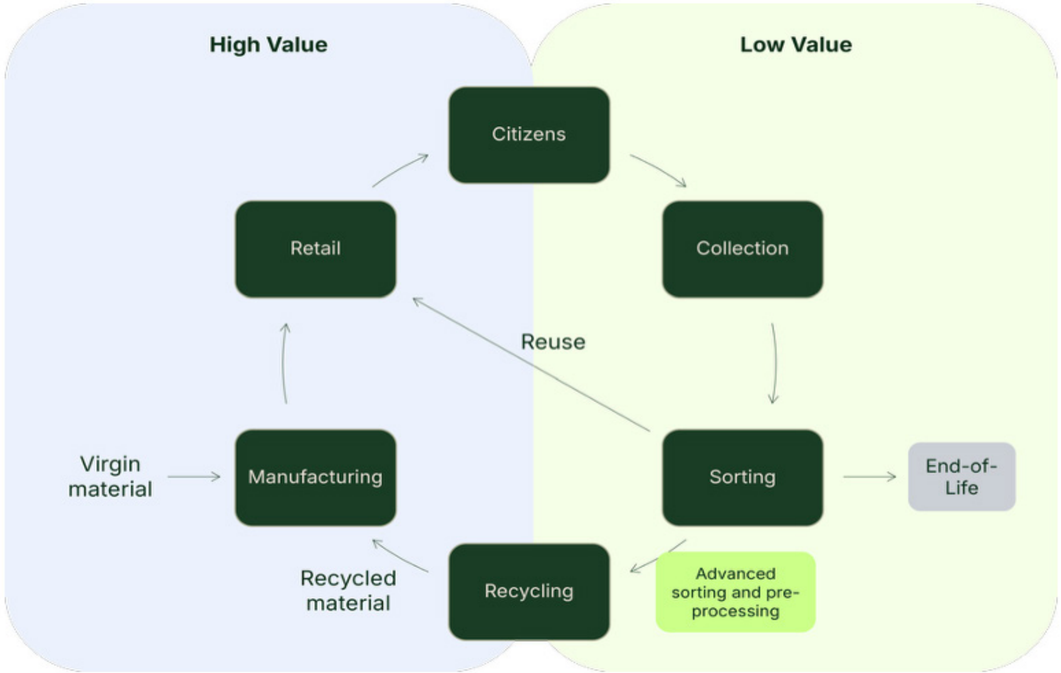


Figure 174: Circular textiles ecosystem split by value of material flowing

Therefore, if the circular textiles ecosystem is to be an economic success, 'waste' textiles must be seen as a reusable resource to increase the value of the low-value half.

This perception shift is relevant not only to textiles but is critical to all aspects of a future circular economy. However, this transformation requires substantial systemic change and adaptation, as it cannot occur within the constraints of the current linear ecosystem.

Collaboration between sorters and recyclers is also essential to address the current 'chicken and egg' situation, where recyclers require suitable feedstock to scale up, but sorters lack sufficient demand or competitive prices from recyclers operating at a small scale. Additionally, recyclers require commitment from brands and retailers to scale up their operations, but retailers require a reliable source of recycled materials that meets their requirements to be able to commit. Collaboration is also key throughout the textiles ecosystem. It must be recognised that no single company alone can transform the entire supply chain, so new commitments and long-term partnerships are needed between brands and retailers, collectors and sorters, ATSP operators, recyclers, and the rest of the value chain to scale the next generation of the textiles ecosystem.

Additionally, the ATSP facility's demand for input material may compete with the low-value reuse market if the value of lower reuse qualities aligns with the value of NRT. If the ATSP network increases NRT value, then sorters may prefer to send lower reuse quality textiles to the ATSP facility instead. The ATSP facility could also provide a solution for businesses with stock they cannot sell due to global market challenges and oversupply.

Providing these solutions can prevent these used textiles from ultimately becoming waste by harnessing their resources if they are not likely to be reused.

3.3. Opportunities

Based on the economic landscape explored above, the following six opportunities have been identified as key levers to support the implementation of an economically sustainable circular textiles ecosystem:

Opportunity: Brand and retailer commitment:
Brands and retailers can assume greater responsibility for products introduced to the market by building partnerships with ATSP facilities. By doing so, they actively support a positive business case and guarantee the supply of recycled content to meet environmental targets.

Additionally, brands and retailers can aid ATSP facilities by:
- Reinforcing the demand for recycled content through offtake agreements and letters of intent with recycling suppliers
- Establishing effective take-back partnerships with charities and collectors that secure direct NRT streams to ATSP facilities
- Designing all products for circularity

Opportunity: Impact investment:
Impact and sustainable investing have increased and are widely practised in the UK. Interventions that focus on climate mitigation and climate adaptation are enticing offers to investors who are looking for long-term success and low volatility and can often be more profitable[122] in the long run.

Social value and the Just Transition are also becoming increasingly important to this type of investor. While the current generic cost models developed in this project do not present a system where ATSP facilities can be profitable in the short term, financial returns are not the only metric many investors use to assess potential investments. Social and environmental benefits are also considered.

Opportunity: Public funding:
The UK government has established various funds, such as the National Wealth Fund, to mobilise private investment needed for the nation's green transition and to support SMEs and micro-businesses in this journey. Additionally, the government's newly announced Invest 2035 initiative aims to drive growth by supporting net-zero objectives, regional development, and economic security – all areas where a circular textiles ecosystem could naturally align.

Opportunity: NRT value:
Currently, there are inconsistencies in perceptions of when NRT becomes waste, with reports providing a wide range of apparent 'waste' within exported used textile bales. This is inherently subjective, and what may be seen as waste from a UK perspective could be seen as a product in another region and vice versa. Similarly, individuals and businesses may have different views on whether something is waste or not. As the perception of 'product' and 'waste' is so critical to the materials' value, learnings could be taken from international markets on retaining value in NRT through a participatory approach, taking broader social dynamics and the psychological value of products and waste into account, in addition to material properties.

Opportunity: Other markets for ATSP outputs as a stopgap:
While closed-loop textile recycling technologies are scaled up, diversifying the customer base for ATSP outputs may offer a critical financial stopgap for the industry. Open-loop recycling is a proven approach that could utilise an ATSP's outputs and produce useful products for other sectors. This would provide recyclers with the necessary time to scale up while ensuring there is a consistent feedstock available, thereby reducing risk for investors.

Opportunity: Other sources of ATSP inputs:
As NRT collection rates rise, diversifying the input stream may provide a temporary solution for ATSP facilities to operate and facilitate the scaling up of F2F recycling. PCTs currently destined for open-loop recycling and incineration due to contractual restrictions could serve as a stopgap, though ideally, contractual agreements would be amended to permit reselling. In the future, however, there may be a legal prohibition against the destruction of unsold textiles and footwear in the EU through ESPR (Eco-design for Sustainable Products Regulation), with proposals currently including closed-loop recycling within destruction, which could potentially be replicated in the UK[123].

In the long term, professional textiles could be an important source because they often comprise large quantities of mono-material and, therefore, provide quality feedstock for ATSP facilities and F2F recycling. Additional longer-term sources could include faulty or damaged PCTs otherwise destined for landfill and incineration, accessed through partnerships with brands or destruction organisations.

Opportunity: Economies of scale:
The scale-up of automatic sorting and recycling capacity will create efficiencies, fostering more favourable conditions for economic gain. In the short term, this will require coordinated efforts across the entire value chain and from policymakers to position the industry for success and guide it toward self-sufficiency.

4. ENABLERS

While the six opportunities outlined in the previous section focus on the economics of establishing a circular textiles ecosystem, they share three clear themes that are vital to the transition and will underpin the economic case:

- Policy
- Environmental
- Social

These three key enablers are explored in greater detail.

4.1. Enabler: Policy

As identified in the economic analysis, policy measures could support a circular textiles ecosystem in the UK, as well as in the EU and, in some cases, globally.

First, it is important to explore the current policy landscape.

In recent years, the stance of the UK government's Department for Environment, Food and Rural Affairs (Defra) on textiles policy has changed. EPR has come in and out of consideration, leading to uncertainty in the sector. However, in July 2024, Labour won the UK General Election and subsequently appointed a minister responsible for circular economy. This has presented an opportunity for the UK government to support the textiles industry and address the imbalance in finances and security across different sector areas.

This opportunity is crucial because, previously, UK policy on textiles has mostly been voluntary or directed by EU and international policy. It has focused on the production and retail side of the value chain, working towards sustainable production and clear communication with the public. In contrast, in the EOL stage of the value chain, textiles have often been considered within general waste policies. For example, targets to reduce biodegradable municipal waste going to landfill sites would have impacted textiles.

Current UK and EU policies include:

EU's Waste Framework Directive: Launched in 2008 and later updated in 2018 and 2023, the directive established a waste hierarchy and outlined basic waste management principles, prioritising prevention and reuse over recycling and, finally, recovery or disposal.

Sustainable Clothing Action Plan (SCAP): SCAP is a voluntary agreement that brings together fashion retailers, charity retailers, and textile recyclers to reduce the impacts of clothing consumed in the UK[124]. Launched in 2012, it focuses on reducing carbon and water footprints as well as waste from brands and retailers.

European Green Deal: Launched in 2019, the EU's Green Deal fed into a range of textiles-focused policies throughout the Continent, including the EU's 2022 Strategy for Sustainable and Circular Textiles in 2022. Other international projects that continue to look at this area and inform governments on developing used textile policy include the G7 Berlin Roadmap on Resource Efficiency and Circular Economy (2022-2025) and the UN Environment Programme's Circularity and Used Textile Trade project (2023-2025).

Textiles 2030: Launched in 2021, Textiles 2030 is the UK's leading voluntary initiative supporting businesses and organisations within the fashion and textile industry to transition to more sustainable and circular practices by 2030.

Unfortunately, since 2021, textiles policy activity in the UK has not developed significantly, failing to meet the challenges of the used textiles sector. This is despite several proposed policy options[125] around the management of textile waste and the release of the government's Maximising Resources, Minimising Waste strategy in 2023.

Since 2022, there has been a proliferation of EPR scheme proposals worldwide, highlighting a solution that connects the system by incentivising textile producers to manufacture more sustainably while also offering the PCT sector financial support. However, despite urgent calls from the industry, no commitment has been made to implement textiles EPR in the UK.

Additionally, while the UK government has not included textiles within its 2025 Simpler Recycling legislation, the upcoming implementation of the UK Emissions Trading Scheme (ETS) in 2028 means that local authorities could be charged a levy for disposing of textiles in residual waste streams, with the intention of also including charges for incineration and EfW. However, the recent establishment of the UK government's Circular Economy Taskforce in November 2024 may provide an opportunity to accelerate textiles policy in the UK in the coming years[126].

While establishing the Circular Economy Taskforce is an encouraging development, research has highlighted that a whole systems approach is essential for building an effective circular textiles ecosystem. Avoiding a siloed approach and focusing on addressing the root causes of the current market failures can only be achieved by working collaboratively with a shared goal of reducing virgin textile consumption, designing for circularity, replacing virgin materials, investing in the NRT landscape, and implementing thought-out policies with a systems lens, all of which current policies are not adequately addressing in the UK.

However, there is a clear range of policy options that could be used within a systems approach to enable the implementation of a circular textiles ecosystem in the UK. These policy recommendations are shown in Figure 175, and a full description of these and their intended effects on the system are available in 'Policy Recommendations' in the Appendix.

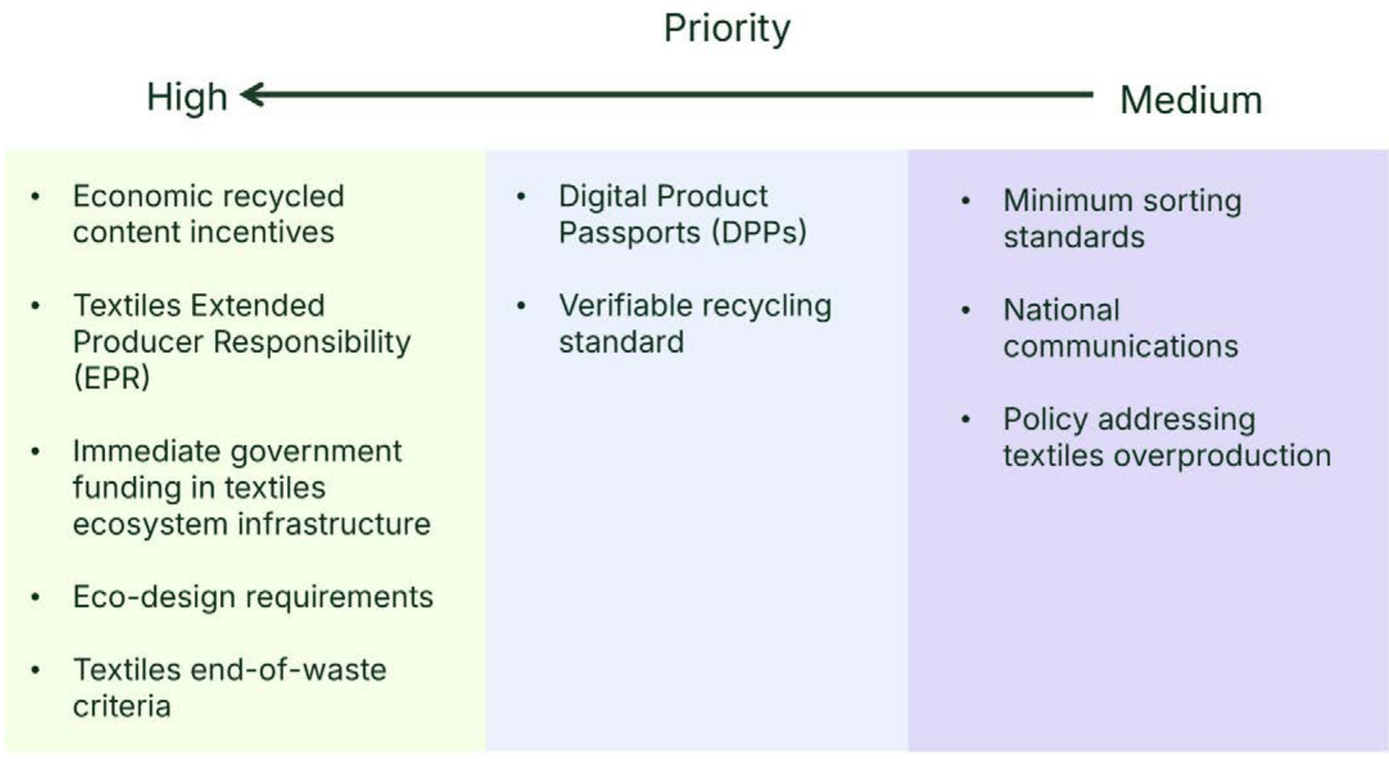


Figure 175: Policy recommendation suite for supporting the development of an ATSP network in the UK.

4.1.1. Priority policies

The sector's immediate risk is the challenging economic environment, so this situation must be addressed to implement the full system.

Three of the five high-priority policies in Figure 175 cover economic support and incentives. Therefore, immediate funding and investment are required to relieve the critical pressure on the UK's used textiles sector, with the government ideally situated to provide this. Following this alleviation of immediate risks, longer-term economic support should be seriously considered.

This support could come from eco-modulated EPR schemes, addressing the imbalance in the value of material throughout the ecosystem, and helping to create a sustainable ecosystem long-term. For example, an ATSP facility handling 25,000 tonnes of textiles per year, with an average item weight of 300g, incurs a loss of £2.6 to £7.6million. This translates to a cost of £0.03 to £0.09 per item. Including this cost in an EPR fee could support the used textile value chain and reduce financial strain on the sector. Therefore, EPR schemes must be a priority policy.

It is important to state that no single policy measure alone will achieve all objectives. Complementary priority policies, either integrated into EPR eco-modulation or implemented separately, are needed to support and strengthen the system. For example, economic incentives for brands and retailers to use recycled content can allow demand commitments to be made, enabling ATSP facilities and recyclers to scale up. Additionally, eco-design requirements covering designing for recyclability and disassembly can work towards a feedstock which is suitable for recycling and requires less processing to prepare for this, reducing costs.

Finally, digital product passports offer supply chain and feedstock traceability, optimise post-collection handling, and increase visibility across the value chain, thereby encouraging collaboration for used textile treatment.

4.1.2. Supporting policies

Other supporting policies could include standards such as end-of-waste criteria (defining the transition between 'used' and 'waste') for textile recycling, minimum sorting guidelines, and a verifiable recycling standard. These measures would improve transparency throughout the supply chain and promote best practices in all areas. As identified in section 3.2, the transition point where textiles change from 'products' to waste' is particularly crucial for economic viability. Therefore, clear end-of-waste criteria would help materials move more efficiently to global recyclers by eliminating subjectivity, supporting systemic change, and preserving value in NRT.

Additionally, citizen-facing communications, including consistency in separate textile collections and associated messaging, could help to divert textiles from the residual waste stream and towards an ATSP network. However, significant citizen behaviour change would be required for meaningful diversion to occur, and therefore, government intervention is likely to be required. Yet, findings from 'The ACT UK Trials Spotlight: Innovations in Post-consumer Textile Collection' show that there is public appetite for an avenue to be able to responsibly dispose of clothing and textiles[127].

4.1.3. Policy summary

Policy can play a central role in enabling the UK's circular textiles ecosystem, but it requires a collective effort – and will.

This research recommends immediate financial support to the used textile sector in the UK, followed by an effective EPR system where eco-modulation is added to support systems change. A healthy and effective system requires all actors within it to operate sustainably, and to create this, a holistic and systems-based policy is essential. Policy measures must not consider one aspect of the value chain in isolation. Instead, they must work to support the entire system to make the required step change.

4.2. Enabler: Environment

Currently, carbon emissions from the textiles sector account for 8-10% of total global emissions[128], and around 20%[129] of global clean water pollution from dyeing and finishing products. To ensure that the UK achieves the reductions required to meet the limit agreed in the UN's Paris Agreement[130], it has been estimated that UK brands and retailers need to reduce their absolute carbon footprint by 50% and water use by 30% by 2030[131].

Against this backdrop, it is estimated that recycled fibre use could contribute around 12% to the required carbon savings and 18% to the water savings[132]. A circular textiles ecosystem, including ATSP facilities, can support these targets by providing the critical infrastructure to bridge the current gap between the generation and recycling of NRTs.

4.2.1. Environmental assessment

Demonstrating the potential environmental benefits of transitioning to a circular textiles ecosystem is crucial. It helps to attract impact investors, reassures brands and retailers looking to switch to improved fibres, and provides evidence to governments considering new investment and policy measures.

There are several factors which contribute towards the circular ecosystem being more environmentally favourable than the linear ecosystem. The most significant is the reduced demand for virgin materials, because recycled content requires less water and carbon than virgin materials production.

Secondly, the diversion of textiles away from landfill and incineration and towards recycling can have environmental benefits, despite losing the energy produced from incineration. This is particularly true in the UK, where EfW is dominant for textiles in residual waste. This also aligns with the principles of the waste hierarchy, making the most of the resources and keeping them in circulation for as long as possible[133].

It should be noted, however, that the circular ecosystem will also create an environmental footprint. Some parts of the sector are relying on the development of chemical recycling processes to produce F2F recycled content at the quality required. However, it's possible that chemical recycling processes will initially have higher environmental impacts than mechanical due to higher energy requirements and the use of chemicals. Currently, this is difficult to estimate due to a lack of data on chemical recycling processes[134]. While it's expected that these processes should become more efficient over time, and, therefore, have lower environmental impacts, this should be monitored and not relied upon as the only solution.

Findings from the full ecosystem Life Cycle Assessment (LCA) have suggested that producing mechanically recycled cotton and thermomechanically recycled closed-loop polyester from NRTs through the ATSP network both have significant environmental benefits (see Figure 176; please note that, as of March 2025, the LCA has not yet been through a peer review process outside of ACT UK partners. A journal paper is being prepared for submission, where a peer review process will be conducted, and the final output published publicly).

However, in this LCA, and using the limited data available at the time based on small-scale trials, producing chemically recycled closed-loop MMCF from NRT in the same system had adverse environmental impacts. The demand for recycled MMCF could be around one-tenth of the demand for recycled cotton due to MMCF not always being able to directly replace cotton, mainly because of performance and property requirements[135]. Given this, and the impacts associated with chemical cotton closed-loop recycling (as per current data), it may be more beneficial to divert more cotton NRTs towards mechanically recycled closed-loop cotton rather than chemically recycled (closed-loop cotton) MMCF to meet recycled cotton demands and minimise environmental impacts.

In the future, however, as chemical cotton recycling develops and becomes more efficient and outputs improve in performance and quality, recycled MMCF could be used in place of virgin cotton, providing substantial water savings. However, this may depend on brand and product requirements.

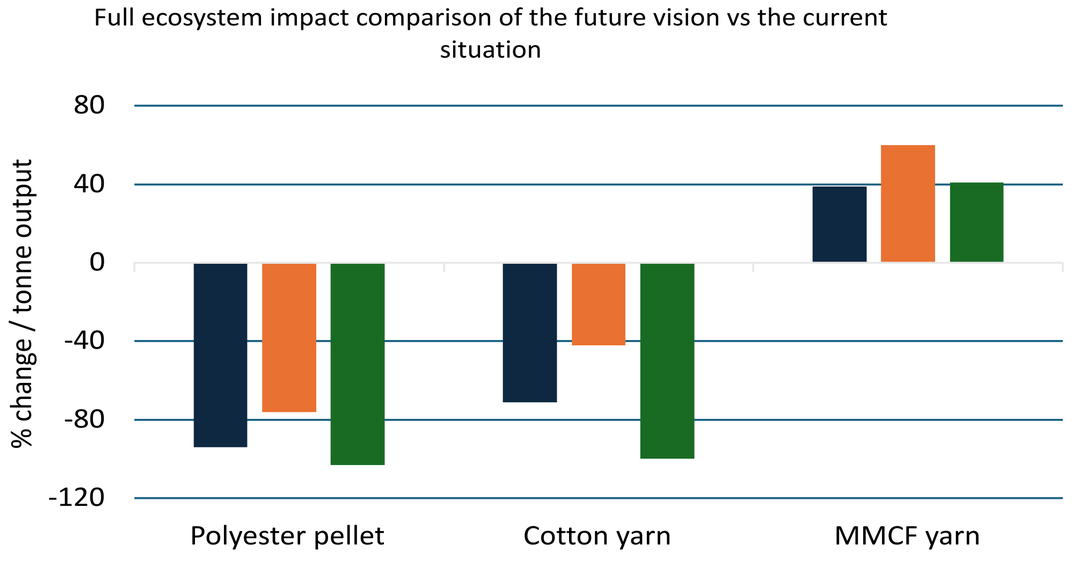


Figure 176: Estimated change in climate change impacts, fossil resource use and water use when switching from the current situation to future vision, per tonne of output[136].

Considering the future potential for lowering the impacts of recycling MMCF over time and the fact that polyester and cotton currently make up the majority of fibre usage in the UK, the environmental benefits are clear. This can support the economic case to potential investors by demonstrating how investment can support climate goals.

See 'Life Cycle Assessment' in the Appendix for LCA limitations, and Figure 182 for a full assessment of the data source types used and where more data and research is urgently needed.

4.2.2. Role of climate targets

Understanding the volume inputs and outputs – and therefore supply and demand – is critical since this is a vital component of overall impacts and is closely linked to brand and retailer climate targets.

Given future scenario modelling, it is assumed that 363,000 tonnes could be collected and sorted annually in the UK. Given estimates of fibre composition, waste and multilayered material rates, disruptor removal rates, and recycling efficiency assumptions used in the LCA, this would produce 30,000 tonnes of 50% recycled MMCF yarn, 63,000 tonnes of 23% mechanically recycled cotton yarn, and 209,000 tonnes of 70% closed-loop (with 30% open-loop) recycled polyester yarn (see Figure 177).

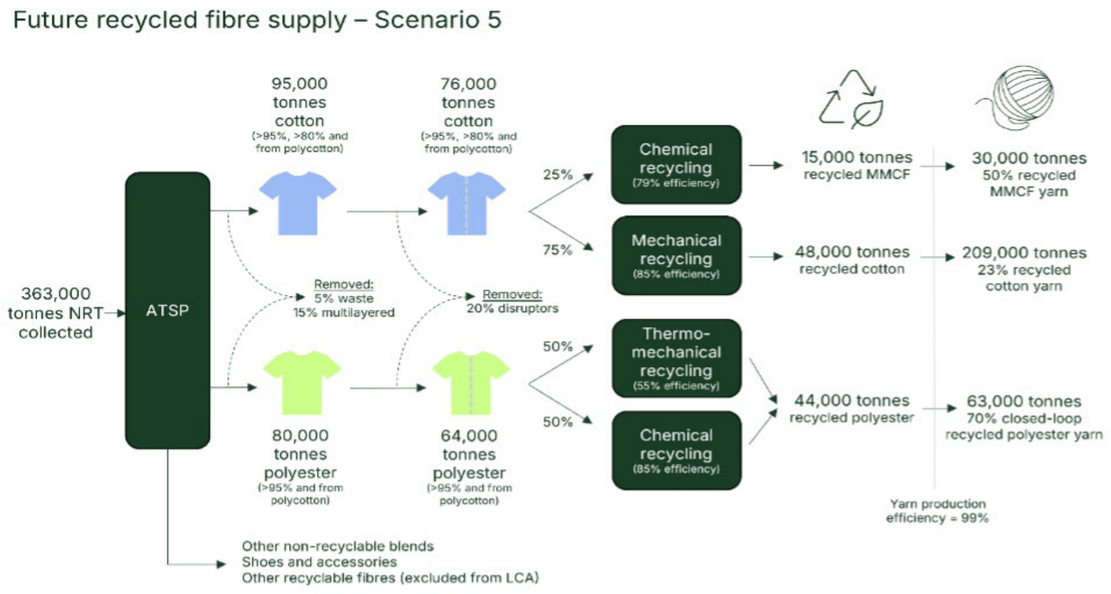


Figure 177: Future (2035) scenario NRT inputs and recycled fibre outputs

Due to uncertainty in brand and retailer growth rates from 2030 to 2035 and uncertainty around recycled content targets, it is most useful to compare this to potential demand in 2030 (transition state). In this state, 292,000 tonnes of NRT would be collected, producing 24,000 tonnes of 50% recycled MMCF yarn, 168,000 tonnes of 23% mechanically recycled cotton yarn, and 51,000 tonnes of 70% closed-loop (with 30% open-loop) recycled polyester yarn.

Comparing this (Figure 178: B) to the potential future demand from brands and retailers who are Textiles 2030 signatories (Figure 178: A), depending on the commitment from brands and retailers to meet their climate goals, there is potential for this amount of recycled cotton and polyester produced from UK NRTs to be insufficient to meet demand. Supply will exceed demand if business-as-usual continues and the current, slow uptake rate continues. However, urgent and significant increases in recycled content use are required to meet climate targets if brands continue to increase production volumes at the current rate, and already retailers are committing to increasing recycled content. As demand increases, it has the potential to outweigh supply in 2030. While this is concerning, it does provide a positive economic opportunity for those within the ATSP and recycling sector, as demand outweighing supply often creates higher value and more positive economic circumstances as long as recycled fibres can meet quality and performance requirements.

Looking at opportunities to meet these demands, let's consider a scenario where all 745,000 tonnes of NRT are collected. Even with current waste (5%), multilayer (15%), disruptor (20%), and recycling efficiency (55-85%) assumptions, this would meet potential demand for cotton and MMCF, but not polyester (Figure 178: C). This is because of the higher recycled content target for polyester, and the volume of polyester NRT being lower than cotton.

Another scenario looks at the potential to reduce losses throughout the polyester value chain by increases in efficiencies, aiming to establish what would be required to meet demand. Assuming waste remains at 5% due to unavoidable contamination, design for recyclability leads to there being 0% non-recyclable multilayers and disruptors, and polyester recycling processes increase to 99.5% efficiency, which would be very close to meeting demand (Figure 178: D). If similar efficiency increases were also made for cotton, there could be export potential from supply outweighing UK demand.

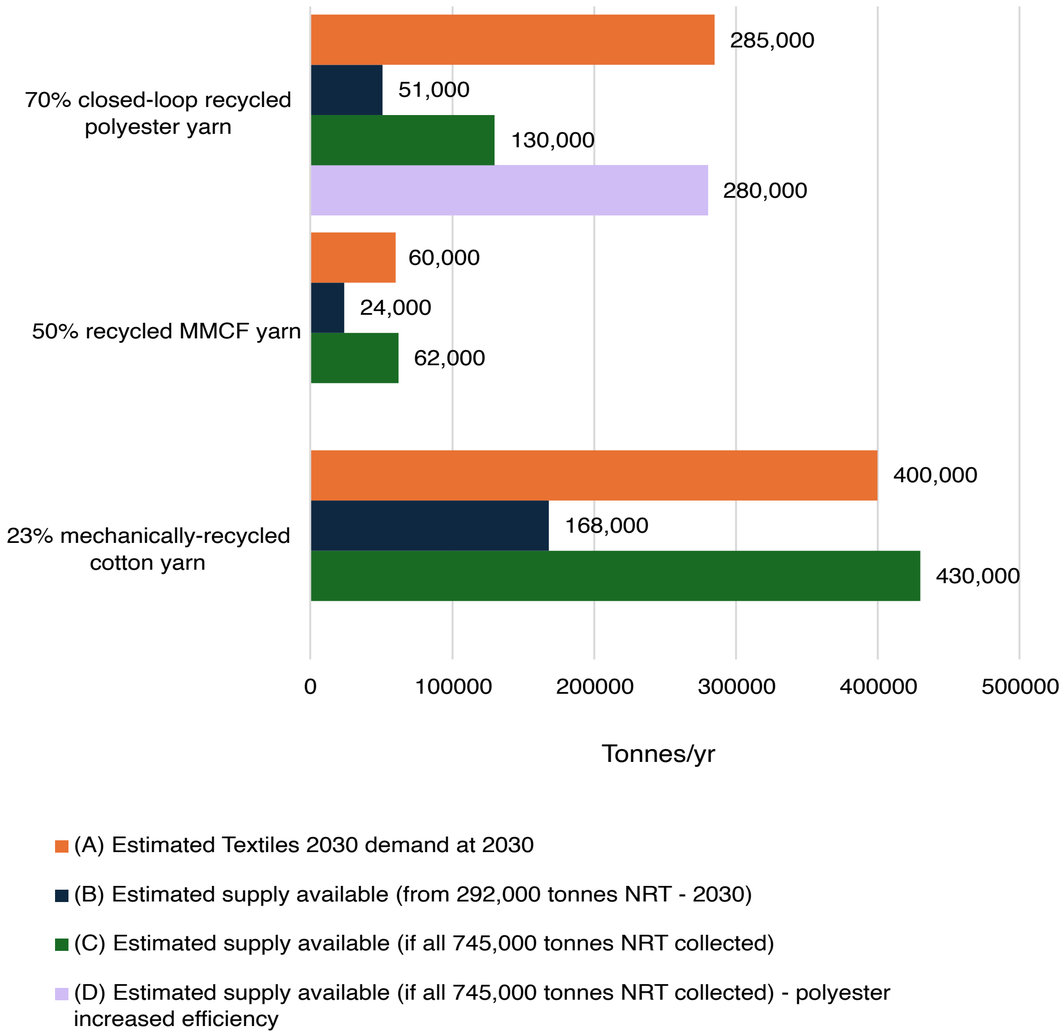


Figure 178: Estimated future (2030) supply and demand of recycled fibres by brands and retailers who are Textiles 2030 signatories (~62% market share) in a circular UK textiles ecosystem (not BAU). The future is modelled as 2030 (Scenario 5 transition state) rather than 2035 due to uncertainty in growth rates and recycled content targets for brands beyond 2030

The above analysis shows that by the end of the decade, it would be possible to meet Textiles 2030 signatory demand for recycled fibres if three conditions are met:

- All NRT is collected and sorted
- Polyester garments are designed with recyclability in mind
- Polyester recycling processes become more efficient

However, looking ahead to 2035, if garment production continues to increase and/or recycled content targets become more ambitious, additional feedstock sources beyond UK NRT may be required. These could include open-loop recycled materials, imported NRT and/or NRT from other sectors, such as workwear.

It should be noted that these scenarios would still require significant behaviour change to divert NRT from residual waste, which is highly challenging, expensive, and slow. Additionally, as Textiles 2030 signatories only make up around 62% of the UK textiles sector, there is likely to be additional demand from other brands and retailers.

4.2.3. Environmental impact of current sector collapse

As explored in sections 1.1 and 3.1, the current sector is at risk of collapsing. Therefore, as well as comparing the current and future vision systems, it is important to examine the environmental impact of this worst-case scenario.

In this scenario, no PCT would be collected, and citizens would have no option other than to put their used textiles in residual waste. If all 1.45 million tonnes of currently generated PCT were sent to residual waste (except the 83,000 tonnes which are peer-to-peer reused) this would result in an increase of almost 2.5 million tonnes of CO2e. This increase is equivalent to just under 20% of the total, whole lifecycle, carbon footprint of products placed on the market by Textiles 2030 signatories for 2023/24, totalling 13.3 million tonnes of CO2e[137].

4.2.4. Environment summary

This research has shown that significant behaviour change is required to divert NRT from residual waste, and is a key enabler to recycled content demands being met. However, there are many barriers to this, which means it cannot be relied upon as the solution. Therefore, while a circular textiles ecosystem would undoubtedly contribute towards the UK's net-zero commitments, it should not be understated that the UK cannot recycle its way out of the climate crisis. Urgently addressing increasing consumption and production relating to virgin material use will also be key.

Textiles 2030 results have so far indicated that carbon and water savings from improvements in preferred fibre use and other circular innovations have been wiped out by increasing production tonnages[138], demonstrating that this effect is already being seen. This increase, above a reasonable level relating to population increase, is not sustainable, and climate impacts will continue to go up if this outweighs the contributions made by recycling and circular activities.

4.3. Enabler: Social

As the effects of climate change have begun to emerge, it has become even more apparent that a Just Transition is required to ensure that those most affected by the impacts are brought along on the journey and prioritised to ensure minimal unintended consequences. This is also the case within the UK, where rising energy prices and the cost of living disproportionately affect those within low-income households.

Therefore, to build a truly sustainable textiles ecosystem in the UK and beyond, it must be socially sustainable as well as environmentally sustainable. Addressing social issues will be critical, and understanding the gaps can enable these to be filled when designing and implementing a sustainable future system. In addition to creating opportunities to solve issues in the current system, the circular textiles ecosystem would provide opportunities to make new connections and build a new, better system that works for all.

4.3.1. Citizens

In recent years, there has been a shift in citizen behaviour towards increased consumption of new, lower-quality products[139]. The economic crisis in the UK may have exacerbated this behavioural shift and contributed to a need for low-cost clothing.

While it is critical that people still have access to the clothing they need, this shift towards lower-quality products has likely increased the percentage of NRT within PCTs and will continue to do so. This poses a social challenge of balancing overconsumption and social responsibility with providing access to clothing.

As citizens are key to both the demand for new products and the supply of NRT, they must be brought along on the journey of creating a circular textiles ecosystem. While significant behaviour change is required to overcome overconsumption and the diversion of used textiles from residual waste streams, other actors within the system, such as brands and retailers, have a social responsibility to empower and enable citizens to do so.

For example, brands and retailers can support people to make sustainable purchasing choices by making this the default option and driving diversion from residual waste through offering take-back schemes. Collectors and sorters can help enable this diversion by providing an efficient and convenient system for citizens to dispose of their used items.

4.3.2. Collectors and sorters

The current crisis within the current sorting and collecting sector is a major and urgent social issue impacting the textiles industry.

Sorting and collecting businesses face enormous economic pressure, potentially risking the wellbeing of those working within them. Many of these businesses are historically family-owned firms, and the social impacts of the UK losing this heritage and the jobs and skills within this ecosystem should not be underestimated. Building a circular ecosystem, with ATSP facilities central to it functioning successfully, provides an opportunity to support and complement the sector, providing future economic stability.

Outside of the UK, communities in the Global South are flooded with increasingly poor-quality used textiles, drastically limiting the economic value they can recover from them. These local communities rely on this industry for income, and the UK has a social responsibility to recognise its role in this. While it is important to ensure that RTs are kept in use for as long as possible, and that NRT is managed appropriately, any unintended consequences on the communities managing the UK's used textiles globally must be considered and mitigated.

A circular textiles ecosystem with a network of ATSP facilities could provide job generation and skill development opportunities. Each ATSP facility would create new, skilled jobs both directly (such as engineering, equipment operation, and technicians) and indirectly (such as equipment design, engineering, data analysis, AI, and machine learning). Chapter 6, 'The Business Case for Advanced Textile Sorting and Pre-processing Facilities', details ATSP operational assumptions, but depending on the ATSP business model and configuration, there could be a total of 18-53 full-time employees per facility. It is estimated that around 20 jobs could be created for every 1,000 tonnes of textiles collected for reuse[140]. This could create up to 120,000 jobs within the EU, a proportion of which could be within the UK.

It should be noted that ATSP facilities will utilise automation and may directly employ fewer people than a conventional, manual sorting facility. However, the new markets for higher-quality outputs could increase overall job numbers. Additionally, manual sorting jobs have declined in the UK due to high labour costs resulting in sorting being exported, so automatic sorting would bring these new jobs back to the UK.

Considering current assumptions, each ATSP facility could provide an additional total economic benefit to employees of between £575,000 and £2million per year[141]. If there are 14 ATSP facilities in the UK, this could total £8-28million per year earned by UK citizens, in addition to the current sorting jobs in the industry[142].

4.3.3. Recyclers

Currently, the majority of recycling of NRTs from the UK happens overseas. High UK labour costs drive textile exports, where materials are primarily processed through open-loop recycling in global markets. However, due to limited traceability, some of these materials may ultimately end up in informal landfill sites. It is a similar case with closed-loop recycling, which has emerged mostly in Europe, the US, and the Asia-Pacific region, rather than focused in the UK.

This approach is logical within the current linear ecosystem, as maintaining recycling in areas outside the UK – where NRTs are sorted and manufacturers utilise recycled content – mitigates both the economic and environmental impacts of transporting the material. However, sending non-recyclable fractions and trims alongside the material increases costs and environmental impacts.

Therefore, implementing a circular ecosystem with strategically located ATSP facilities would facilitate the pre-export removal of non-recyclable fractions and trims. To minimise transportation distances, and thus reduce financial and environmental burdens, facilities could be located near the source of NRT in the UK, near the recyclers who utilise the sorted NRT (primarily in Europe), or a combination of both.

Locating ATSP facilities within the UK offers several advantages. It could provide incentives and security for recyclers establishing or operating in the UK by guaranteeing readily available feedstock. This, in turn, could encourage the on-shoring of fibre and yarn production and manufacturing, boosting the UK economy and creating new jobs.

Furthermore, the UK has a social responsibility to manage its used textiles. Therefore, maintaining a significant portion of the value chain within the UK, including UK-based open-loop recyclers, can help fulfil this responsibility.

Strategically locating different stages of the value chain is crucial to minimise transportation distances and costs. And, as recyclers emerge globally, particularly in traditional manufacturing regions, locating ATSP facilities within these regions could prove beneficial, given that NRT is generated worldwide. This approach could also create additional skilled jobs in manufacturing regions and, with lower labour costs, potentially be more profitable than in the UK. Therefore, global collaboration is necessary to further research this and to establish how an international circular textiles ecosystem would integrate with the UK system, as well as to identify and mitigate any unintended consequences.

4.3.4. Brands and retailers

Brands and retailers hold a social responsibility to their customers to mitigate their climate impacts, and increasing the use of recycled materials is one effective way to achieve this. However, beyond the environmental benefits, the social consequences of inaction are also undeniable.

The reduction in the use of virgin material by UK brands may negatively impact the income of raw material producers worldwide, such as cotton growers in Pakistan, from which the UK imported around £33million worth in 2023[143]. However, global demand for virgin materials is unlikely to drop off imminently, affording material producers time to adapt, while current targets will still require a majority of virgin cotton.

It is crucial, however, that the UK engages raw material producers in this transition and provides support for shifting towards other preferred virgin materials, such as regenerative or organic cotton. However, this would depend on the pressure to produce conventional virgin cotton easing due to the increased use of recycled content.

Additionally, virgin material producers have often been the most exposed to the real-world impacts of climate change, such as extreme weather events, floods, and droughts. Across all cotton-growing locations, the northern regions of the sub-Saharan countries, specifically across Senegal and southern Mali, are predicted to be the worst affected by climate hazards. Brands and retailers can both play their part in minimising this risk for their supply chains, and diversify their feedstock to protect against future raw material crises by urgently investing in recycled content.

Brands and retailers also have a social responsibility to support F2F recyclers, who have faced significant economic challenges in recent years. A key contributing factor to these financial pressures is the lack of commitment and off-take agreements from brands and retailers to utilise recycled content, which are vital for securing investment.

Finally, current product design often neglects recyclability. Eventually, all textiles become NRT and potential feedstock for F2F recycling. Therefore, to ensure efficiency and improve the acceptance rate through ATSP facilities, which is essential for their economic viability, textile products must be designed for disassembly and recycling. For a truly circular ecosystem, a substantial increase in textiles designed for circular processes is essential.

5. DISCUSSION

The previous sections have outlined both the challenges and enablers when considering the shift to a circular textiles ecosystem through the lens of automatic sorting and F2F recycling. To provide a clear overview, a set of recommendations has been developed to realise these opportunities to support and drive the transition.

The recommendations have been compartmentalised into four groups of enabling stakeholders:

- Policymakers
- Investors
- Value chain
- General

5.1. Stakeholder recommendations: Policymakers

UK government, EU policymakers, global policymakers

Opportunity: The recent change of UK government provides an opportunity for review
Recommendation: Urgently review textiles policy and the inadequacy of current measures to meet net-zero for UK textiles, with a systems-based approach. Additionally, reform textile trade codes to be fit for purpose for the circular ecosystem, facilitating the movement of recycler feedstock globally.

Opportunity: Support the current sorting and collecting sector, which is facing crisis
Recommendation: Immediate funding and investment are required to relieve the critical pressure on the UK textiles sector, with the government ideally situated to provide this and support this UK industry. Investment and support for ATSP facilities can also help alleviate the critical pressure on current collectors and sorters and provide long-term support.

Opportunity: Long-term economic stability for the UK textiles sector
Recommendation: Implement EPR with eco-modulation, with economic incentives for brands and retailers to commit to recycled content purchases, and to take responsibility for their NRT by providing economic support to the organisations dealing with textiles that would otherwise end up in waste management.

5.2. Stakeholder recommendations: Investors

Impact investors, government investors, private equity and venture capital, brands and retailers, trusts and foundations

Opportunity: Scale-up of F2F recycling
Recommendation: Urgently invest in recyclers, and ATSP facilities providing F2F feedstock, to enable scale-up, both in direct investment and commitments to use recycled content produced.

Opportunity: Social and environmental benefits associated with circular textiles ecosystem
Recommendation: Invest in all parts of the circular textiles ecosystem (collections, behaviour change, sorting, recycling, durability, and recyclability) in a systems-based approach, including careful considerations outside of the UK to minimise unintended consequences.

Opportunity: Support the UK in reaching net-zero
Recommendation: Invest in areas of the circular textiles ecosystem that can lead to carbon and water savings, contributing to the UK's meeting climate commitments.

5.3. Stakeholder: Current and future textiles value chain

Brands and retailers, collectors, sorters, recyclers, manufacturers

Opportunity: Futureproof supply chains
Recommendation: Brands and retailers can pre-emptively mitigate against climate risks to their virgin material supply chains by investing in recycled content. The recycled content supply chain can be future-proofed through investment in recyclers and sorting.

Opportunity: UK can be the global leader in circular textiles
Recommendation: Creating a circular textiles ecosystem which is truly sustainable long-term could result in the UK becoming world-leading in this area. Exporting sorted textiles or recycled materials to manufacturing countries can drive economic growth in the UK.

Opportunity: Balancing chemical and mechanical/ thermomechanical recycling
Recommendation: Until technologies develop further and more data is available, a careful balance should be maintained between chemical and other F2F recycling processes to ensure there are no increased environmental impacts.

5.4. General recommendations

Beyond the above recommendations, which relate to developing an ATSP network, additional recommendations have emerged from this chapter that will need addressing to enable the full circular ecosystem to work effectively.

The ATSP network should not be considered in isolation, as a full systems change is needed to create the full circular ecosystem, with innovation in all aspects of that required almost simultaneously. Alongside the development of NRT sorting and pre-processing, the following have been identified as key development areas:

Collections: Behaviour change:
Considering the significant amount of textiles entering the residual waste stream directly from citizens, and the challenges seen in the collection trials when relying on citizens to pre-sort RT and NRT, further research is needed in this area. Considering that research has shown that there is public appetite for solutions to discarding NRT, a people-centric approach should be taken in this research to optimise behaviour change and understand the current challenges citizens face so that effective solutions can be designed. The upcoming expansion of the Emissions Trading Scheme in 2028 means that local authorities could be charged a levy for the disposal of textiles in residual waste streams. This charge could be passed onto citizens via increased tax, meaning behaviour change to divert textiles from residual waste will become increasingly important. Learning from other sectors and citizen behaviour campaigns could provide useful insights that can be harnessed to tackle this challenge.

Collections: System optimisation:
Once the citizen angle is understood, an effective system can be designed for collections. Currently, collections lack operational coordination and are disparate in their messaging to citizens, leaving room for improvements in collection efficiency. Making collections convenient, consistent, and straightforward for citizens will be key, and optimising the logistics of this will ensure that this is economically and environmentally sustainable – as has been investigated in preparation for Simpler Recycling for other materials. Further pilots and demonstration trials, supported by robust evaluation, will be needed to optimise collection systems. Additionally, commercial sorters and collectors can optimise the logistics and location of collections, reducing emissions and contamination using technology.

Separating RT and NRT with artificial intelligence:
Citizens did not successfully separate RT and NRT in the ACT UK citizen pre-sorting trials, meaning that a pre-sorting stage will still be required to remove RT before sorting NRT by fibre type can be done. Innovation in AI to allow quick and automatic pre-sorting, supporting the highly skilled manual labour currently doing this, could ensure consistency in sorting and increase throughput, therefore driving down sorting costs. This could also be built into an ATSP system to minimise transportation and increase efficiency. In the UK, this sortation of RT from NRT is currently done manually by skilled and experienced professionals, so work would need to be done to ensure that there are no unintended consequences of moving away from this and towards automation with AI, and that AI is supporting the sector rather than replacing it.

Scaling F2F and open-loop recycling:
While this project has focussed on sorting NRTs for F2F recycling, in reality there is a lot of work to be done for F2F to be fully scaled. ATSP facilities will have to also provide feedstock for open-loop recycling, which will be an important part of the future recycling landscape and can produce useful products which equally displace virgin materials in other sectors. There are durability challenges with F2F recycled fibres that need further investigation and further innovation to overcome. Given the current high impacts of chemical recycling, there will be a need to balance chemical and mechanical/thermomechanical F2F recycling to minimise negative impacts on the environment. The sector should not rely on just one technology or answer, and considering diverse solutions will mitigate risk to all stakeholders.

In summary, it is clear that no part of the value chain should be considered in isolation, and that interventions must consider the entire system to be effective and play its key role in the transition to the new system. Policy needs to economically incentivise the transition to ensure that it happens at the pace required, and that the economic imbalance within the value chain is addressed to prevent sections of the industry collapsing. More data is needed for both open- and closed-loop recycling processes, which will be key to understanding the potential environmental impacts of the future system. To minimise risk and unintended consequences on investments, people and the environment, maintaining and encouraging a diversity of solutions should be prioritised.

Equally, recycling should not be seen as the answer to all current issues. Overproduction and overconsumption need urgently addressing to ease the pressure on the sector working at the EOL.

APPENDIX

Future scenario data:

Data point	Description	Past (2019)	Current (2024)	Future (2035)	Source name and link
UK population	The population of the United Kingdom		67,600,000		Office for National Statistics
UK population	The population of the United Kingdom			73,400,000	Office for National Statistics
ATSP Capacity	Planned annual ATSP facility capacity (tonnes)			25,000	Circle-8
PCT total	Total post consumer textiles generated in the UK annually (tonnes)		1,453,000		WRAP Textiles Market Situation Report 2024
PCT per person	Total post consumer textiles generated in the UK annually per person (kg)		21		WRAP Textiles Market Situation Report 2024
Collected textiles	Total post consumer textiles collected separately in the UK annually, this includes textiles sold on peer to peer platforms (tonnes)	600,000	733,000		WRAP Textiles Market Situation Report 2019 & 2024
Collection rate	The highest possible collection rate for textiles			90%	The European container Glass Federation, 2023
Local Resale	Total volume of textiles sold by charity and P2P platforms to the UK public (tonnes)	186,000	276,000		WRAP Textiles Market Situation Report 2024
Exported textiles	Total volume of textiles exported outside of the UK for resale (tonnes)		421,000		WRAP Textiles Market Situation Report 2024
EOL from collected textiles	Total volume of separately collected textiles going to EOL treatment (tonnes)		36,000		WRAP Textiles Market Situation Report 2024
EOL from collected textiles rate	The % of separately collected textiles going to EOL treatment		6%	6%	WRAP Textiles Market Situation Report 2024

Continued...

Data point	Description	Past (2019)	Current (2024)	Future (2035)	Source name and link
Open & closed loop recycling	Textiles suitable for open and closed loop recycling (tonnes)		34,000		**WRAP Textiles Market Situation Report 2024**
UK textile manufacturing size	Total production volume of the textile and garment manufacturing industry in the UK (tonnes)		142,000		**A material flow analysis of the UK clothing economy (after UKFT)**
PIT %	Post Industrial Textile waste generation rate, as a percentage of total production volume		35%		**Vyas, Creating the Vogue through Sustainability, 2022**

***Figure** 179: Table of data for scenario modelling*[144]

	Unit	Past	As is	Transition	Future
Year	Year	2019	2024	2030	2035
UK population	n/a		67,600,000	71,700,000	73,400,000
Generic ATSP Capacity			25,000	25,000	25,000
UK textile manufacturing size	Tonnes		142,000		
PIT %	Percentage		35%		
PIT	Tonnes		49,700		

Continued...

	Unit	Past	As is	Transition	Future
SCENARIO 1 LOW/ LOW					
PCT total	Tonnes		1,453,000	1,252,389	1,051,777
PCT (decrease) / increase	Percentage		n/a	(14%)	(33%)
PCT per person	kg		21	17	14
Collected textiles	Tonnes	600,000	733,000	631,797	530,594
Collection rate	Percentage		50%	50%	50%
Local Resale	Tonnes	186,000	276,000	237,893	199,787
Local resale rate	Percentage	31%	38%	38%	38%
Exported textiles	Tonnes		421,000	353,640	286,280
Export rate	Percentage		57%	56%	54%
EOL from collected textiles	Tonnes		36,000	31,030	26,059
EOL from collected textiles rate	Percentage		5%	5%	5%
Open & Closed loop recycling	Tonnes		34,000	9,234	18,468
Total	Tonnes		767,000	631,797	530,594
ATSPs required	Quantity		n/a	1	1

Continued...

	Unit	Past	As is	Transition	Future
SCENARIO 2 BASE/ LOW					
PCT total	Tonnes		1,453,000	1,252,389	1,051,777
PCT (decrease) / increase	Percentage		n/a	(14%)	(33%)
PCT per person	kg		21	17	14
Collected textiles	Tonnes	600,000	733,000	755,635	738,597
Collection rate	Percentage		50%	60%	70%
Local Resale	Tonnes	186,000	276,000	284,523	278,107
Local resale rate	Percentage	31%	38%	38%	38%
Exported textiles	Tonnes		421,000	353,640	286,280
Export rate	Percentage		57%	47%	39%
EOL from collected textiles	Tonnes		36,000	37,112	36,275
EOL from collected textiles rate	Percentage		5%	5%	5%
Open & Closed loop recycling	Tonnes		34,000	80,360	137,934
Total	Tonnes		767,000	755,635	738,597
ATSPs required	Quantity		n/a	4	6

Continued...

	Unit	Past	As is	Transition	Future
SCENARIO 3 HIGH/ LOW					
PCT total	Tonnes		1,453,000	1,252,389	1,051,777
PCT (decrease) / increase	Percentage		n/a	(14%)	(33%)
PCT per person	kg		21	17	14
Collected textiles	Tonnes	600,000	733,000	879,473	946,599
Collection rate	Percentage		50%	70%	90%
Local Resale	Tonnes	186,000	276,000	331,152	356,428
Local resale rate	Percentage	31%	38%	38%	38%
Exported textiles	Tonnes		421,000	353,640	286,280
Export rate	Percentage		57%	40%	30%
EOL from collected textiles	Tonnes		36,000	41,245	46,491
EOL from collected textiles rate	Percentage		5%	5%	5%
Open & Closed loop recycling	Tonnes		34,000	153,436	257,401
Total	Tonnes		767,000	879,473	946,599
ATSPs required	Quantity		n/a	7	11

Continued...

	Unit	Past	As is	Transition	Future
SCENARIO 4 LOW/ BASE					
PCT total	Tonnes		1,453,000	1,505,700	1,541,400
PCT (decrease) / increase	Percentage		n/a	n/a	n/a
PCT per person	kg		21	21	21
Collected textiles	Tonnes	600,000	733,000	759,586	777,595
Collection rate	Percentage		50%	50%	50%
Local Resale	Tonnes	186,000	276,000	286,010	292,792
Local resale rate	Percentage	31%	38%	38%	38%
Exported textiles	Tonnes		421,000	353,640	286,280
Export rate	Percentage		57%	47%	37%
EOL from collected textiles	Tonnes		36,000	37,306	38,190
EOL from collected textiles rate	Percentage		5%	5%	5%
Open & Closed loop recycling	Tonnes		34,000	82,630	160,333
Total	Tonnes		767,000	759,586	777,595
ATSPs required	Quantity		n/a	4	7

Continued...

	Unit	Past	As is	Transition	Future
SCENARIO 5 BASE/ BASE					
PCT total	Tonnes		1,453,000	1,505,700	1,541,400
PCT (decrease) / increase	Percentage		n/a	n/a	n/a
PCT per person	kg		21	21	21
Collected textiles	Tonnes	600,000	733,000	908,472	1,082,428
Collection rate	Percentage		50%	60%	70%
Local Resale	Tonnes	186,000	276,000	342,071	407,572
Local resale rate	Percentage	31%	38%	38%	38%
Exported textiles	Tonnes		421,000	353,640	286,280
Export rate	Percentage		57%	39%	26%
EOL from collected textiles	Tonnes		36,000	44,618	53,162
EOL from collected textiles rate	Percentage		5%	5%	5%
Open & Closed loop recycling	Tonnes		34,000	168,143	335,415
Total	Tonnes		767,000	908,472	1,082,428
ATSPs required	Quantity		n/a	7	14

Continued...

	Unit	Past	As is	Transition	Future
SCENARIO 6 HIGH/ BASE					
PCT total	Tonnes		1,453,000	1,505,700	1,541,400
PCT (decrease) / increase	Percentage		n/a	n/a	n/a
PCT per person	kg		21	21	21
Collected textiles	Tonnes	600,000	733,000	1,057,358	1,387,260
Collection rate	Percentage		50%	70%	90%
Local Resale	Tonnes	186,000	276,000	398,132	522,352
Local resale rate	Percentage	31%	38%	38%	38%
Exported textiles	Tonnes		421,000	353,640	286,280
Export rate	Percentage		57%	33%	21%
EOL from collected textiles	Tonnes		36,000	51,930	68,133
EOL from collected textiles rate	Percentage		5%	5%	5%
Open & Closed loop recycling	Tonnes		34,000	253,656	510,496
Total	Tonnes		767,000	1,057,358	1,387,260
ATSPs required	Quantity		n/a	11	21

Continued...

	Unit	Past	As is	Transition	Future
SCENARIO 7 LOW/ HIGH					
PCT total	Tonnes		1,453,000	1,778,277	2,103,554
PCT (decrease) / increase	Percentage		n/a	22%	33%
PCT per person	kg		21	25	29
Collected textiles	Tonnes	600,000	733,000	897,094	1,061,187
Collection rate	Percentage		50%	50%	50%
Local Resale	Tonnes	186,000	276,000	337,787	399,574
Local resale rate	Percentage	31%	38%	38%	38%
Exported textiles	Tonnes		421,000	353,640	286,280
Export rate	Percentage		57%	39%	27%
EOL from collected textiles	Tonnes		36,000	44,059	52,118
EOL from collected textiles rate	Percentage		5%	5%	5%
Open & Closed loop recycling	Tonnes		34,000	161,608	323,215
Total	Tonnes		767,000	897,094	1,061,187
ATSPs required	Quantity		n/a	7	13

Continued...

	Unit	Past	As is	Transition	Future
SCENARIO 8 BASE/ HIGH					
PCT total	Tonnes		1,453,000	1,778,277	2,103,554
PCT (decrease) / increase	Percentage		n/a	22%	33%
PCT per person	kg		21	25	29
Collected textiles	Tonnes	600,000	733,000	1,072,933	1,477,193
Collection rate	Percentage		50%	60%	70%
Local Resale	Tonnes	186,000	276,000	443,408	664,737
Local resale rate	Percentage	31%	38%	41%	45%
Exported textiles	Tonnes		421,000	353,640	286,280
Export rate	Percentage		57%	33%	19%
EOL from collected textiles	Tonnes		36,000	52,695	72,550
EOL from collected textiles rate	Percentage		5%	5%	5%
Open & Closed loop recycling	Tonnes		34,000	223,189	453,626
Total	Tonnes		767,000	1,072,933	1,477,193
ATSPs required	Quantity		n/a	9	19

Continued...

	Unit	Past	As is	Transition	Future
SCENARIO 9 HIGH/ HIGH					
PCT total	Tonnes		1,453,000	1,778,277	2,103,554
PCT (decrease) / increase	Percentage		n/a	22%	33%
PCT per person	kg		21	25	29
Collected textiles	Tonnes	600,000	733,000	1,248,772	1,893,199
Collection rate	Percentage		50%	70%	90%
Local Resale	Tonnes	186,000	276,000	474,533	719,416
Local resale rate	Percentage	31%	38%	38%	38%
Exported textiles	Tonnes		421,000	353,640	286,280
Export rate	Percentage		57%	28%	15%
EOL from collected textiles	Tonnes		36,000	61,331	92,981
EOL from collected textiles rate	Percentage		5%	5%	5%
Open & Closed loop recycling	Tonnes		34,000	359,267	794,522
Total	Tonnes		767,000	1,248,772	1,893,199
ATSPs required	Quantity		n/a	15	32

Figure 180: Table of detailed scenario modelling of nine future (2035) scenarios[145]

Policy recommendations:

Priority	Policy recommendation	Aims for circular textiles ecosystem
High	Immediate government funding in textiles ecosystem infrastructure	• Immediate economic support and infrastructure investment • De-risk and facilitate the shift towards circular economy and supply chain • Ensure infrastructure meets market needs • Incentivise private investment in NRT infrastructure and scaling
	Textiles Extended Producer Responsibility (EPR)	• Long-term economic support and infrastructure investment for NRT collectors, sorters, recyclers • Make businesses across the supply chain understand and leverage NRT flows • Optimise collection and processes post • Reduce textile waste in landfills/incineration • Reduce environmental impacts • Shift financial responsibility to producers • Accelerate innovation
	Economic recycled content incentive: - Eco-modulated fee on recycled content (subsidy/tax) and/or - Minimum recycled content	• Increase demand and use of recycled fibres through incentivising replacing virgin • Incentivise private investment in NRT infrastructure and scaling • Economically incentivise recycled content • Reduce environmental impacts • Accelerate innovation
	Eco-design requirements: - Design for recycling - Design for disassembly - Design for durability	• Design in products of value to recycling market and optimise ATSP process • Design in products of value to reuse market • Design out textile waste • Incentivise private investment in NRT infrastructure and scaling • Incentivise recycled content • Reduce environmental impacts
	Digital product passports (DPP) *Developed in line with eco-design requirements	• Optimise processes following collection • Ensure supply chain traceability and transparency downstream and upstream • Support and promote eco circular design • Incentivise private investment in NRT infrastructure and scaling • Citizen behaviour change

Continued...

Priority	Policy recommendation	Aims for circular textiles ecosystem
Medium-high	Textiles end-of-waste (EoW) criteria - Textiles resource hierarchy - Preparation for reuse definition - Preparation for recycling definition	• Provide clear legal framework on textiles waste/reuse/recycling • Ensure supply chain traceability and transparency • Ensure reuse/recycling best practice • Ensure exports and imports support circularity
	Verifiable recycling standard *Developed in line with design for recycling	• Regulating processes to enhance and increase sorting in UK • Facilitate trade in ATSP volumes • Increase demand and use of recycled fibres through incentivising replacing virgin • Incentivise investment in NRT infrastructure and scaling • Mitigate reputational risks
Medium	Minimum sorting standards	• Ensure supply chain traceability and transparency downstream and upstream • Facilitate trade in ATSP volumes • Ensure supply chain traceability and transparency downstream and upstream • Ensure reuse/recycling best practise
	National communications - Consistency in collections	• Divert textiles from residual bin for ATSP feedstock • Collaboration and alignment across stakeholders • Citizen behaviour change • Reduce environmental impacts
	Policy addressing textile overproduction	• Economically support sorters • Design in products of value to recycling and reuse market • Design out textile waste • Reduce environmental impacts • Citizen behaviour change • Lower consumption rates • Support reuse markets

Figure 181: Table of policy recommendations ordered by priority

Life Cycle Assessment

However, there are limitations with the LCA conducted, mainly due to limited data availability for some processes. Some primary data used was sourced directly from stakeholders. Other data was from secondary sources, databases, literature sources and informed assumptions. While all data used was assessed and deemed accurate enough for inclusion, there is room for improvement, and some areas critically need further data gathering. In particular, data on recycling processes is difficult to obtain, especially for scaled-up processes. Recycling impact data is often for small-scale trials, and impacts would likely change when scaled up. Additionally, this data can be commercially sensitive to recyclers, who cannot always share it with external organisations. However, this LCA was conducted using conservative assumptions as opposed to generous assumptions, and therefore, it is expected that environmental savings could, in reality, be greater than estimated here.

Figure 178 shows a full assessment of the data source types used and where more data and research are urgently needed. This work would build on it to enable future LCAs to be more accurate and to enable robust decisions. Additionally, the LCA focused only on the cotton and polyester NRT fractions because these fibres are most commonly used, but other fibres should also be considered in future research to understand the environmental impact of other recycling processes.

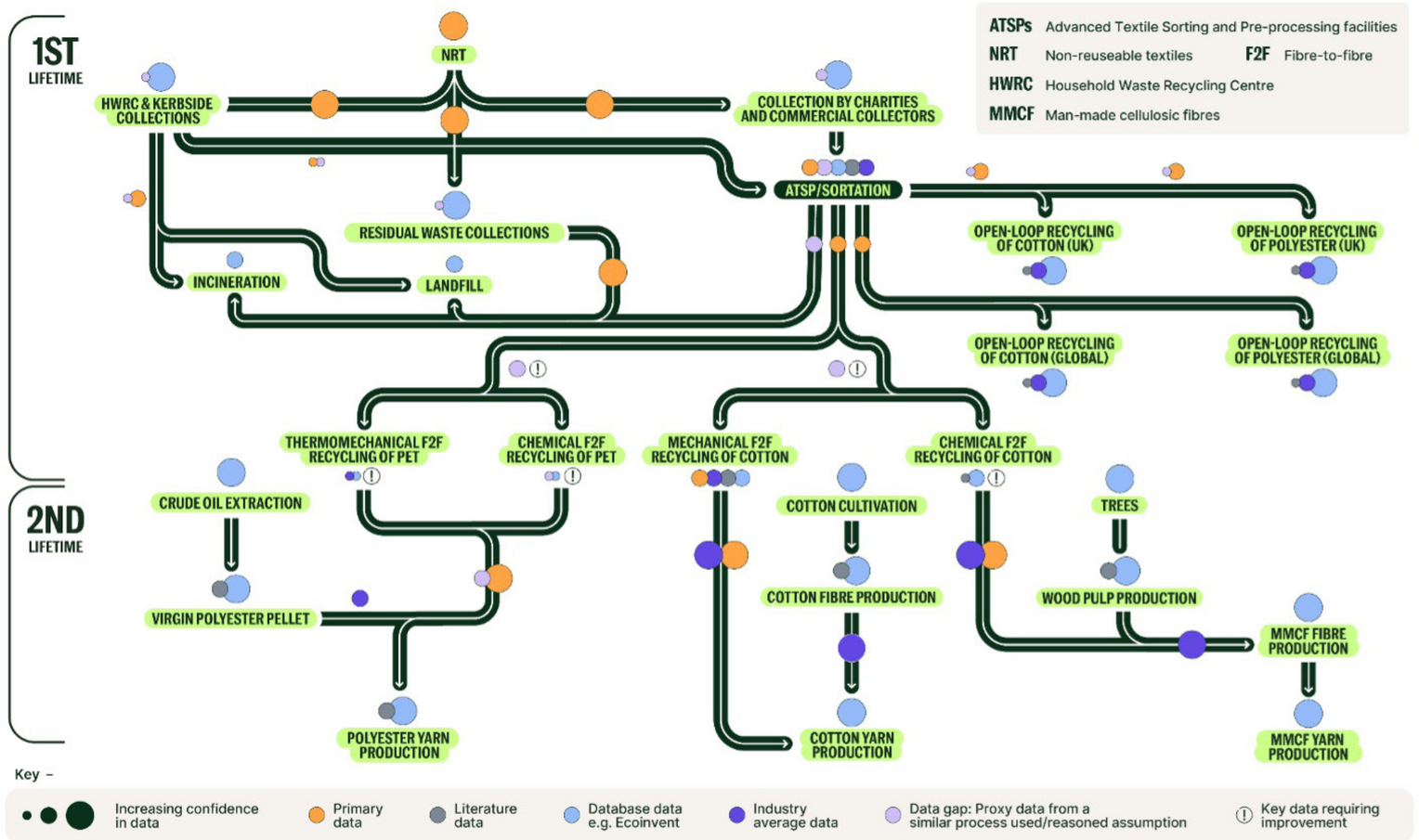


Figure 182: System boundaries used in life cycle assessment of the full system, including data sources and data confidence

Conclusion and priority recommendations



Conclusion and priority recommendations

The UK fashion and textile industry has an opportunity to help create a more sustainable ecosystem that delivers socio-economic value to the UK. Despite the formidable challenges the sector faces, this is a watershed moment to reimagine post-consumer non-reusable textiles (NRT) management.

By shifting towards a circular system that yields economic, social, and environmental benefits through enhanced collection, sorting, and recycling processes, the UK can unlock new revenue streams, foster innovation, drive economic growth, generate new green jobs, and affect sustainable change. In response to Innovate UK's challenge to develop and demonstrate closed-loop recycling for the fashion and textile sector at scale, UKFT created the ACT UK consortium to establish an Advanced Textile Sorting and Pre-processing (ATSP) facility to enable post-consumer NRT to be recycled back into textiles or alternative products at scale.

In support of ACT UK's objective, this report has explored the opportunities, challenges, and, ultimately, the feasibility of developing a blueprint for a commercially sustainable ATSP facility. However, while the ACT UK project has looked at the textiles system through the lens of one intervention – automated sorting and pre-processing for fibre-to-fibre (F2F) recycling – the results of this 20-month long project has made it increasingly clear that a full systems-based approach to policy, people, and planet is required to secure a sustainable future for all. The transformation of the entire value chain and establishment of a new circular ecosystem cannot be achieved by any single entity, organisation, or policy in isolation.

The findings in this report make it clear that a network of ATSP facilities holds significant potential as a catalyst for a more sustainable future for the UK fashion and textile industry. However, the successful and economically viable implementation of ATSP facilities will hinge on realising new government policies and attracting significant upfront investment to address both immediate and future commercial challenges.

Recognising that an ATSP facility's long-term profitability is contingent on maximising the volume of sorted NRT that can be sent for recycling, a holistic approach, starting at the very point of design, is both critical and urgently required. This necessitates a fundamental shift towards creating inherently recyclable textiles. Such a proactive strategy will not only enhance resource efficiency but also secure the economic viability of future textile recovery streams.

This, when coupled with robust policy interventions – encompassing both immediate short-term funding and longer-term eco-modulated Extended Producer Responsibility (EPR) policy together with minimum recycled content legislation – as well as strategic investment in the sorting and collection infrastructure, can forge a resilient economic foundation for a circular textiles ecosystem and stimulate innovation in F2F recycling.

Also key to a successful transition is shifting attitudes and behaviours towards sustainability, both at a business level and among the public. Businesses are developing robust strategies to achieve net-zero objectives, and recycled content will be a key element in supporting these ambitions. However, to effectively meet this future demand for recycled content, significant efficiency enhancements will be necessary across the entire value chain, encompassing collections, sorting, and recycling processes. Therefore, it is encouraging that this report has demonstrated a public appetite for embracing sustainable solutions to divert used textiles from residual waste towards recycling – although more effective public communication and messaging will be essential to fully capitalise on this willingness. To harness this growing public appetite, an ATSP network can provide the requisite increase in sorting efficiency, empowering citizens to dispose of their used textiles responsibly and, in turn, support the growing volumes of F2F recycled content that the industry requires.

When an industry stands at a pivotal moment, it is always worth considering the outlook if the alternative path is taken. This report has demonstrated that if the UK and global fashion and textile industries were to continue as is, the sector faces rapidly escalating challenges. This scenario would be economically and environmentally disastrous, with local authorities, charities, brands, and retailers facing pronounced increases in waste management costs, a burden which, in turn, could be passed on to consumers. Simply, a textiles ecosystem with a network of ATSP facilities would operate at a significantly lower cost overall to the UK than continuing with the sector as it currently is.

While this report paints an optimistic picture, it is also realistic about the challenges of building a network of economically viable ATSP facilities. At present, a reliable assessment of feasibility remains unattainable due to significant uncertainty and incomplete data. To establish a comprehensive and meaningful conclusion regarding feasibility, further investigation is essential, particularly concerning recycling impacts, collection systems, and economic considerations across the entire framework.

Therefore, the following section has consolidated the recommendations from each chapter to present the priority recommendations for the next steps on the journey towards advanced textile sorting and pre-processing. While there is an inevitable crossover between some priority recommendations, they are fundamental to successfully implementing an ATSP facility and, ultimately, to advancing the UK's fashion and textile sector towards a more sustainable future.

PRIORITY RECOMMENDATIONS

Post-consumer textile collections and logistics

Priority recommendations to develop innovative approaches to PCT collection and logistics:

1. Divert end-of-life textiles from general waste through further targeted research into citizen behaviour and proactive engagement to overcome barriers to participation.

2. Standardise collection messaging across all stakeholders and standardise the coordination of municipal waste collections to simplify the process for citizens.

3. Brands and retailers should embrace recyclability design, embed circularity principles into product development, and collaborate with the industry to facilitate the transition to cost-effective and sustainable automated sorting.

4. Actively lobby the government to establish supportive textiles policies, including strategically allocating Extended Producer Responsibility (EPR) funds.

5. Seek green investment and lobby the government to provide grant mechanisms and funding to accelerate and de-risk innovation in collection, automated sorting, and F2F recycling technologies.

Textile sorting and pre-processing technology

Priority recommendations to advance technology solutions for sorting and pre-processing:

1. Mandate structured cross-sector collaboration between recyclers and technology providers to align feedstock needs with equipment capabilities and potential technology solutions.

2. Select an experienced plant designer and systems integrator for ATSP facilities to achieve optimal layout and combination of equipment.

3. Further innovation is required to address size reduction limitations across diverse F2F processes, while automating item singulation with finger grippers paired with vision systems is key for precise control over the textile material feeding mechanism.

4. Accelerate disruptor removal technology solutions to significantly improve yield and accuracy to achieve industrial scalability.

5. Establish an industry-agreed feedstock standard with certificates of conformity from the ATSP facility to enhance recycler confidence and streamline the supply chain.

Site selection and engineering design of an ATSP facility

Priority recommendations to select optimal sites to host an ATSP facility:

1. Key site requirements include sufficient floorspace, height, existing B2 use, and transport and logistics costs.

2. Minimise deposits through improved financial standing or a guarantor and apply early for relevant permits to avoid lengthy delays.

Priority recommendations to optimise the engineering design of an ATSP facility:

1. Establish strategic collaborations to secure supply and optimise NRT handling.

2. Standardise incoming NRT supply by establishing clear ATSP Supply Specifications Guide.

3. Develop robust customer relationships for future products and outputs to streamline the transition to a steady state for F2F recycling.

Conclusion and priority recommendations

Textile recycling supply chain trials

Priority recommendations determined by the key findings of the recycling supply chain trials:

1. Establish a standardised industry-wide approach to designing for recyclability and integrating circularity components to enhance traceability and provide clarity on processing feedstock.

2. Introduce guidelines per product category to consistently identify trims and target categories to maximise material for recycling.

3. Further research is required into sanitation and hygiene best practices and the volume of soiled NRT.

4. Consider standardised feedstock colour offerings or the investigation of on-site colour removal technologies to enhance both sorting and recyclability.

5. Explore solutions to improve data on chemical content.

The business case for ATSP facilities

Priority recommendations to secure and sustain the economic viability of ATSP facilities:

1. Seek capital investment and initial operational funding.

2. Seek external support from the government through policy and EPR fees to de-risk investments and stimulate demand.

3. Streamline logistics, improve data management, and leverage existing transport networks to strengthen the ATSP business case.

4. Consider optimising ATSP facility locations with strategic site selection near NRT suppliers, buyers, and infrastructure. Additionally, explore viable routes for exporting outputs to scaled recycling plants overseas.

5. Engage with the demands of open-loop and closed-loop recycling market needs, and proactively seek alternative markets for rejected volumes to avoid disposal costs.



Conclusion and priority recommendations



The next phase of UK manufacturing

Priority recommendations to unlock and scale a workable domestic textile recycling ecosystem:

1. Explore avenues to attract significant investment to expand manufacturing capacity and seek collaborations with European partners.

2. Advocate for greater legislative support to implement eco-design regulations and EPR schemes that incentivise retailers and consumers to prioritise recycled materials.

3. Accelerate research and development trials that focus on marketability and incorporate manufacturing insights, alongside further testing to increase recycled content in yarn production.

4. Scale training programmes to upskill and educate workers to develop expertise in recycled content production.

5. Facilitate the meaningful participation of manufacturers in research initiatives, policy discussions, and decision-making processes to ensure comprehensive representation across the textile-to-textile recycling supply chain.

Transitioning to a UK circular textiles ecosystem

Priority recommendations to effectively transition to a circular textiles ecosystem:

1. Policymakers should review and reform textile policies and trade codes and implement Extended Producer Responsibility policies with eco-modulation to incentivise recycled content use and producer responsibility.

2. Investors should scale up investment in F2F recycling technologies and ATSP infrastructure, with a clear prioritisation of investments demonstrating the potential for carbon and water footprint reduction.

3. The entire textiles value chain, including brands, retailers, collectors, sorters, recyclers, and manufacturers, should future-proof supply chains by investing in recycled content and infrastructure.

4. Enable holistic systems change by driving innovation in collections through changing citizen behaviour, applying AI for efficient sorting, and scaling both F2F and open-loop recycling technologies.

5. Address overproduction and overconsumption to alleviate pressure on end-of-life management.

List of figures and tables

Figure 1: Total textile volumes collected
Figure 2: Monthly volume and percentage change of total NRT collections
Figure 3: Monthly volume and percentage change of total RT collections
Figure 4: Monthly volume and percentage change of control site totals
Figure 5: Tesco x SATCoL bring bank split post-sorting
Figure 6: Bags sent versus bags returned
Figure 7: Average postal donation
Figure 8: Post-sorting category splits
Figure 9: Comparison of donated weights and sorted weights
Figure 10: Reskinned average number of pieces per bag
Figure 11: Reskinned take-back items compared to sorted items
Figure 12: Reskinned post-sorting category split
Figure 13: Reskinned NRT subcategorisation
Figure 14: TRI RT and NRT collection volumes compared to control sites
Figure 15: TRI monthly volume and percentage change of total RT collections
Figure 16: TRI monthly volume and percentage change of total NRT collections
Figure 17: TRI monthly volume and percentage change of control site collections
Figure 18: TRI trial site locations.
Figure 19: Control site locations
Figure 20: TRI post-sorting category splits
Figure 21: Dunelm post-sorting category splits
Figure 22: Crisis post-sort category splits
Figure 23: Current textile recycling landscape
Figure 24: General requirements of current market players
Figure 25: Scope of market review
Figure 26: Technology requirements, conveyance
Figure 27: Analysis of gripper types
Figure 28: Technology requirements, fibre identification and sorting
Figure 29: Fibre identification and sorting equipment summary table
Figure 30: Technology requirements, size reduction
Figure 31: Tearing machine schematic
Figure 32: Size reduction equipment summary table
Figure 33: Technology requirements, disruptor removal
Figure 34: Size reduction for ballistic operators
Figure 35: Exemplary textile waste conditioning system’
Figure 36: Disruptor removal equipment summary table
Figure 37: Fibre ID to size reduction
Figure 38: Size reduction to disruptor removal
Figure 39: ATSP facility’s place in the recycling ecosystem
Figure 40: ATSP engineering methodology
Figure 41: Overview of ATSP operations
Figure 42: Effect of target throughput increase to number of units per machine type
Figure 43: Effect of B2B ratio increase to number of units per machine type
Figure 44: Effect of target throughput increase to machine electricity consumption
Figure 45: Effect of B2B ratio increase to machine electricity consumption
Figure 46: Effect of target throughput increase to machine working utilisation
Figure 47: Effect of B2B ratio increase to machine working utilisation
Figure 48: The 2D layout and flow of the generic system
Figure 49: System yield profile for the baseline (S2.1)
Figure 50: Individual machine utilisation profiles for the baseline (S2.1)
Figure 51: System yield profile for the baseline (S3.1 and S3.2)
Figure 52: System yield profile for S4.1 and S4.2 compared to baseline
Figure 53: Total electricity cost and cleaning time for S4.1 & S4.2 compared to baseline
Figure 54: System yield profile for St-5.2 compared to baseline
Figure 55: Product purity profile for S5.2 (2-shift, 50:50 blend) compared to baseline
Figure 56: System yield profile for study 6 compared to baseline
Figure 57: Product purity profile for S6.1 – S6.4 (2-shift, 50:50 blend) compared to baseline
Figure 58: System yield and cleaning time values for study 7 compared to the baseline
Figure 59: System level utilisation
Figure 60: Maximum system yield profile for St8.1 - St8.4 (with constraints)
Figure 61: Maximum system yield for St8.5 – St8.8 (without constraints)
Figure 62: Importance weighting of full criteria
Figure 63: Expression of interest outline brief
Figure 64: Single-site ATSP solution
Figure 65: Dual-site ATSP solution
Figure 66: Permit summary table
Figure 67: Table of cotton recycling supply chain partners
Figure 68: Table of cotton feedstock specification
Figure 69: Table of cotton recycling trials
Figure 70: Table of Cotton yarn trials
Figure 71: Cotton trial output per kg
Figure 72: Cotton trial time taken per kg
Figure 73: Tensile strength between virgin and recycled blend yarns at 10Ne, 20Ne, and 28Ne
Figure 74: Table showing common trims per category
Figure 75: Table of polyester recycling supply chain partners
Figure 76: Table of polyester feedstock specification
Figure 77: Table of spinning trials
Figure 78: Table of melt blow trial
Figure 79: Polyester trial output per kg
Figure 80: Polyester trial time taken per kg
Figure 81: Tenacity and elongation at break for spun PET multifilaments
Figure 82: Table of Spinning Trial 4 yarn machine parameters
Figure 83: Table of Spinning Trial 5 yarn machine parameters
Figure 84: Table of Spinning Trial 5 tenacity comparison for yarns with comparable linear density
Figure 85: Table of Spinning Trial 5 tenacity comparison for yarns with comparable draw ratio
Figure 86: Table of wool recycling supply chain partners

Figure 87: Table of wool feedstock specification
Figure 88: Wool trial output per kg
Figure 89: Wool trial time taken per kg
Figure 90: Table of wool yarn performance
Figure 91: Cotton fibre analysis: Composition
Figure 92: Cotton fibre analysis: Mean fibre lengths
Figure 93: Cotton fibre analysis: Upper half mean length
Figure 94: Cotton fibre analysis: Short fibre content
Figure 95: Cotton fibre analysis: Strength
Figure 96: Cotton fibre analysis: Elongation
Figure 97: Cotton spinning trial: Fibre properties
Figure 98: Cotton spinning trial: Fibre composition
Figure 99: Cotton spinning trial: Yarn tensile strength
Figure 100: Cotton spinning trial: Yarn elongation at max force
Figure 101: Cotton spinning trial: Yarn unevenness
Figure 102: Cotton spinning trial: Yarn CVM results
Figure 103: Cotton spinning trial: Yarn imperfection index results
Figure 104: Cotton spinning trial: Yarn hairiness
Figure 105: Cotton spinning trial: Chemical analysis
Figure 106: FTIR spectrum for bottle flake rPET pellets and PCT duvet rPET pellets
Figure 107: FTIR spectrum of 150 micron unwashed duvet pellets, 50 micron unwashed white duvet pellets, and 50 micron washed white PCT pellets
Figure 108: DSC analysis: Results for five batches of rPET pellets following a heating cooling cycle at a rate of 10 degrees C/min: Bottle flake rPET pellets
Figure 109: DSC analysis: Duvet rPET pellets
Figure 110: DSC analysis: 150 micron unwashed duvet rPET pellets
Figure 111: DSC analysis: 50 micron unwashed white PCT pellets
Figure 112: DSC analysis: 50 micron washed white PCT pellets
Figure 113: TGA analysis: Thermograph for bottle rPET pellets
Figure 114: TGA analysis: Thermograph for duvet rPET pellets
Figure 115: TGA analysis: Thermograph for 150 micron unwashed duvet pellets
Figure 116: TGA analysis: Thermograph for unwashed white PCT pellets
Figure 117: TGA analysis: Thermograph for 50 micron washed white PCT rPET pellets
Figure 118: Polyester Spinning Trial 1 properties
Figure 119: Polyester Spinning Trial 1 analysis: Weight
Figure 120: Polyester Spinning Trial 1 analysis: Tensile strength
Figure 121: Polyester Spinning Trial 2 analysis: Multifilament yarn count
Figure 122: Polyester Spinning Trial 2 analysis: Multifilament tensile strength
Figure 123: Polyester Spinning Trial 3 analysis: Multifilament tensile strength
Figure 124: Polyester Spinning Trial 3 analysis: DSC for virgin PET pellets
Figure 125: Polyester Spinning Trial 3 analysis: DSC for duvet pellets (no additives)
Figure 126: Polyester Spinning Trial 3 analysis: DSC for duvet pellets (0.25% additives)
Figure 127: Polyester Spinning Trial 3 analysis: DSC for duvet pellets (0.5% additives)
Figure 128: Polyester Spinning Trial 3 analysis: TGA for duvet pellets (no additives)
Figure 129: Polyester Spinning Trial 3 analysis: TGA for duvet pellets (0.25% additives)
Figure 130: Polyester Spinning Trial 3 analysis: TGA for duvet pellets (0.25% additives)
Figure 131: Polyester Spinning Trial 4 analysis: Draw ratios for virgin tarns
Figure 132: Polyester Spinning Trial 4 analysis: Yarn tex for virgin filaments spun at various draw ratio at 5rpm
Figure 133: Polyester Spinning Trial 4 analysis: Tensile strength for spun virgin filaments at different draw ratios
Figure 134: Polyester Spinning Trial 4 analysis: Tensile strength for spun virgin filaments at different draw ratios at metering pump speed of 5rpm
Figure 135: Polyester Spinning Trial 4 analysis: Elongation at break for spun virgin filaments at different draw ratios
Figure 136: Polyester Spinning Trial 5 analysis: Draw ratios for recycled yarns
Figure 137: Polyester Spinning Trial 5 analysis: Tenacity and elongation at break for recycled yarns
Figure 138: Polyester Spinning Trial 5 analysis: MFI results for virgin and recycled duvet pellets
Figure 139: Polyester Spinning Trial 5 analysis: Tenacity results for virgin and recycled duvet pellets at same DTex
Figure 140: Polyester Spinning Trial 5 analysis: Yarn tex and tenacity results for virgin and recycled duvet pellets at same DTex
Figure 141: Polyester Spinning Trial 5 analysis: Yarn tex and tenacity results for virgin and recycled duvet pellets at same draw ratio
Figure 142: Physical performance tests and results
Figure 143: Chemical performance tests and results
Figure 144: Diagram of an ATSP integrated circular textiles value chain vision including key stakeholders and movement of RT/NRT
Figure 145: Current NRT flows annually in UK. All numbers are expressed in 1000s of tonnes. Quantities are not disaggregated for most collections to avoid double-counting
Figure 146: Current material flow of PCT
Figure 147: Current NRT cost overview under manual sorting
Figure 148: Possible value chain configurations
Figure 149: Automated sorting technology due diligence (information as of September 2024)
Figure 150: Common recycler requirements for chemical and mechanical recycling (open and closed-loop) feedstock
Figure 151: Map of all open/closed-loop recyclers broken down by recycling process listed in WRAP’s Textiles Sorting and Recycling Database in the UK and EU. Find key in lower right corner
Figure 152: Information from WRAP’s Textiles Sorting and Recycling Database on open and closed-loop mechanical and chemical recyclers in the UK and EU
Figure 153: Map of potential ATSP locations within close distance to ports
Figure 154: Key operational requirements and processes of a standalone, generic ATSP outlined in the cost model
Figure 155: Indicative illustration of the transition from open to mainly closed-loop recycling product sales of an ATSP
Figure 156: ATSP proposed output grade information
Figure 157: Indicative material composition of NRTs in the UK
Figure 158: ATSP NRT material flows and rejected volumes
Figure 159: NRT input costs per NRT input quality and its anticipated acceptance rates.
Figure 160: Annual financial results of an ATSP at full capacity based on four scenarios
Figure 161: Annual financial results of an ATSP at full capacity based on four different scenarios as described above
Figure 162: Sensitivity analysis on % NRT in residual waste, resulting NRT tonnes generated and approximate total NRT with fibre-to-fibre recycling potential
Figure 163: Summary of closed-loop recycling capacities as indicated in WRAP’s Textile Recycling Database (status: 2023)
Figure 164: ATSP cost model assumptions
Figure 165: Staff required to operate the ATSP as a stand-alone facility
Figure 166: Transition from the current non-reusable textiles ecosystem to the vision for a future ecosystem, including key enablers.

Figure 167: Nine scenarios considered as potential future scenarios where post-consumer textile generation and collection rates vary
Figure 168: Data used in Scenario 5, future vision
Figure 169: Number of ATSPs required to handle PCTs collected in the UK, assuming an ATSP throughput of 25kt/yr by year 3
Figure 170: Estimated fibre composition of the 744,000 tonnes of NRTs generated annually in the UK, as ATSP outputs, split by F2F recycling fibre composition specifications.
Figure 171: Closed-loop F2F recycled content currently used (estimated) by UK brands and retailers, potential 2030 use if business as usual continues uptake at current rate, and potential 2030 use if recycled content increased to meet ambitious and more realistic climate targets
Figure 172: Diagram of an ATSP integrated circular textiles value chain vision including key stakeholders and movement of RT/NRT
Figure 173: Estimated cost of sorting NRT (363,000 tonnes) to the UK sector in 2035 – excluding collection costs, as it is expected that collections would be required in both scenarios. Compares if operations continued as they do today with a 14 ATSP system.
Figure 174: Circular textiles ecosystem split by value of material flowing
Figure 175: Policy recommendation suite for supporting the development of an ATSP network in the UK.
Figure 176: Estimated change in climate change impacts, fossil resource use and water use when switching from the current situation to future vision, per tonne of output
Figure 177: Future (2035) scenario NRT inputs and recycled fibre outputs
Figure 178: Estimated future (2030) supply and demand of recycled fibres by brands and retailers who are Textiles 2030 signatories (~62% market share) in a circular UK textiles ecosystem (not BAU). The future is modelled as 2030 (Scenario 5 transition state) rather than 2035 due to uncertainty in growth rates and recycled content targets for brands beyond 2030
Figure 179: Table of data for scenario modelling
Figure 180: Table of detailed scenario modelling of nine future (2035) scenarios
Figure 181: Table of policy recommendations ordered by priority
Figure 182: System boundaries used in life cycle assessment of the full system, including data sources and data confidence

List of images

Image 1: SATCoL trial bring banks, Tesco carpark
Image 2: M&S x Oxfam sorting information
Image 3: Reskinned donation page, specifying either ‘Rewear’ or ‘Recycle’
Image 4: Reskinned items specification page allowing the subcategorisation of NRT items
Image 5: TRI bring banks
Image 6: Dunelm trial communication
Image 7: Crisis Instagram reel defining RT and NR
Image 8: Tomra Autosort NIR VS
Image 9: Pellenc ST Mistral Connect
Image 10: Valvan Fibresort
Image 11: Picvisa Ecosort Textil Optical Sorter’
Image 12: Twin-shaft shredder, Proshed 800
Image 13: Schematic of guillotine cutting
Image 14: TRM rotative cutting machine
Figure 15: Tearing machine schematic
Image 16: Zigzag Air Classifier, provided by trial partner Impact Air Systems
Image 17: Hyperspectral System
Image 18: Automatic collection of 100 spectral samples
Image 19: Automatic collection of 100 spectral samples
Image 20: SWIR Camera Setup
Image 21: Matoha FabriTell Desktop
Image 22: Cotton feedstock
Image 23: Cotton spinning trial yarn outputs
Image 24: Polyester Spinning Trial 1 PET pellets (left); Spinning Trial 1 hollow PET pellets (right)
Image 25: Polyester spinning trial 2 yarns
Image 26: Polyester spinning trial 3 yarns
Image 27: Laboratory-scale Laroche Cadette tearing machine (left) and Mesdan carding machine (right)
Image 28: Recycled cotton yarns
Image 29: Polyester trial PET pellets
Image 30: Mortan dryer (left) and FET multifilament spinning line (right)
Image 31: Cross sections of unwashed post-consumer duvet pellets
Image 32: Polyester Trial 2: Pellets
Image 33: 85% virgin polyester 15% recycled yarn extrusion, no master-batch
Image 34: Spinning Trial 3 yarns
Image 35: Spinning Trial 4 & 5 yarns
Image 36: Melt-blown samples
Image 37: Sorting post-consumer garments by colour
Image 38: Fibre recycling
Image 39: Recycled yarns

List of references

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