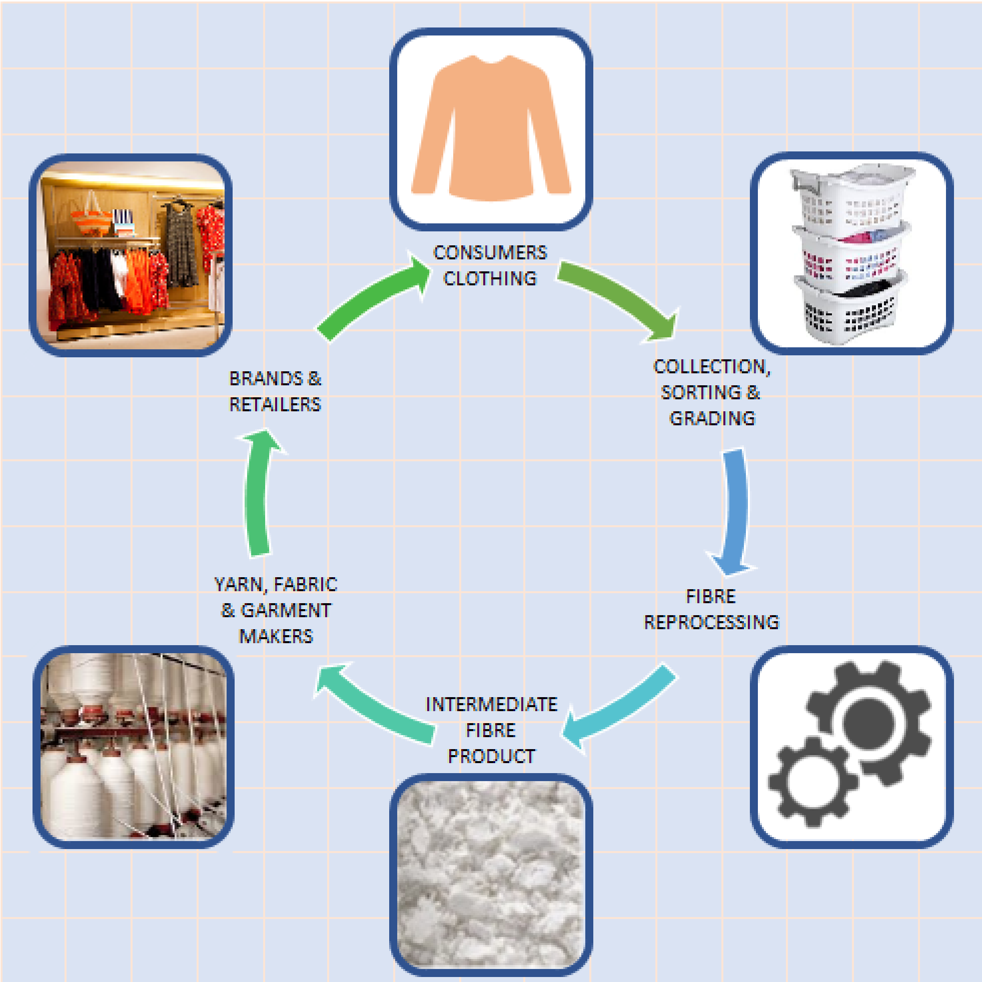
Final Report



Fibre to fibre recycling:
An economic & financial sustainability assessment

Identification of and recommendations to overcome barriers to the development of post-consumer, closed loop clothing recycling in the UK

Project code: PRR104-101

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Front cover photography: Simplified F2F Lifecycle Diagram – AP Benson Graphic

Executive summary

Global clothing consumption is on the rise. While demand for raw materials is expected to triple by 2050, a deficit of five million tonnes for cotton – the UK's most commonly-used fibre – is predicted by 2020.

Meanwhile, an estimated £140 million-worth of clothing is sent to UK landfill each year. WRAP has published work designed to extend the life of clothes and encourage re-use. However, in order to meet future demand for clothing, and to minimise the environmental impacts of manufacturing new clothing, there will be a need for alternative sources of fibre including, potentially, recycled fibres. This report focuses on post-consumer clothing and textiles, and the potential for capturing these materials in the UK for use in fibre to fibre (F2F) recycling. It also reviews F2F recycling methods in research, development, pilot and commercialisation stages, and presents financial models to explore the viability and potential of chemical and mechanical F2F processes.

The research suggests that chemical F2F recycling of polycotton blends, with recovery of two outputs, could be financially viable. This is governed by potential increases in feedstock costs, reductions in the sales price of dissolving pulp, and/or the value paid for polymer pellets needed for processes that recover both dissolving pulp and polymer pellets from polycotton feedstock. The findings are limited, by the relative immaturity of the processes and the consequent lack of detail available from chemical F2F process developers on process detail, investment requirements and associated costs.

The financial viability of mechanical F2F recycling of cotton is highly dependent on the final price yarn producers will charge for recycled yarn, and must include the cost of any carrier fibres added in the final, recycled yarn. Recent ECAP trials on the use of mechanically-recycled cotton recovered from post-consumer jeans show that mechanical F2F recycling may be financially viable if subsequent yarn, fabric and garment production costs are carefully monitored.

The report identifies a series of potential barriers to F2F recycling in the UK and sets out possible measures to overcome those barriers. These include:

- Potential for an extended producer responsibility regime to facilitate F2F recycling.
- Improvements in post-consumer textiles collection and sorting processes.
- Introduction of automation to increase accuracy and decrease costs in the sorting process. Although still in development, automation may also lower garment preparation costs (removal of zippers, etc.).
- Development and communication of feedstock specifications through collaboration between textile merchants and F2F recycling process developers.
- Supply chain integration and work to foster demand (pull) from brands, retailers and consumers.

- Support for, and by, F2F recycling process developers and those in the textile merchant supply chain, in securing finance for process scale-up and commercialisation.

Further work is needed to refine economic and financial models, as more data on costs and prices in the F2F recycling value chain and in F2F recycling processes is made available. This report references two models – one chemical recycling process, and one mechanical recycling system. With a greater depth of data, this modelling exercise could be expanded to reflect a wider range of techniques and systems and explore the potential for financial viability further.

Contents

Figures & Tables

Glossary

Cellulosic fibres	Fibres made, usually, from plant-derived (wood, cotton, hemp etc.) cellulosic materials. Examples include natural cellulosics like cotton, linen, hemp etc. and chemically-derived materials such as viscose and Lyocell.
F2F chemical recycling	Fibre to fibre chemical reprocessing techniques for recovery of cellulosic and synthetic fibres rely on selective dissolution of those fibres using solvents that target either the cellulosic or synthetic content of the textiles. The recovered synthetic fraction is processed into pellets, which can re-enter the yarn manufacturing process, or can be used in other applications. Cellulosic fibres are dissolved into a product similar to wood-derived 'dissolving pulp' used in the production of viscose-like materials.
Closed-loop F2F recycling	Fibre to fibre recycling into the same application.
Downcycling	Post-consumer textile recycling processes that result in a lower value or lower quality output than the originating product.
ECAP	[European Clothing Action Plan.](#)
EfW	Energy from waste.
F2F	Fibre to fibre.
Feedstock	In this report, 'feedstock' refers to the post-consumer textiles required by F2F recyclers as raw material for their recycling process.
Fibre composition/ fibre type	The chemically distinguishable composition of the fibre and the proportion of fibre types found in a fabric.
Garment preparation (also called 'cleaning' or 'pre-processing')	Removal of non-textile components (hard points, embellishments etc.) and textile contaminants for the recycling processes (i.e. seams, labels, linings etc.).
F2F mechanical recycling	Fibre to fibre mechanical reprocessing techniques refine existing techniques in which garments are broken down, through a chopping and pulling process, into shredded fragments until recovered fibres are obtained. The process suffers from the disadvantage of producing shortened fibres that, as a result, do not perform as well as virgin fibres, both during manufacture and in use.
NIR	Near-infrared (spectroscopic technique used to chemically identify fibre content from its unique, chemical, near-infrared spectrum).

Original	Term used for post-consumer clothing and textiles in the form in which they are collected from consumers (charity shop donations, clothing/textile recycling banks etc.). May also refer to post-consumer textiles and clothing from which waste – i.e. non-textile items and soiled textiles – have been removed.
Post-consumer textiles	Clothing materials that have been discarded.
Polycotton	Fabrics and yarns containing blended polyester and cotton fibres.
F2F recycling process developers/reprocessors	Closed-loop, fibre to fibre recycling process developers.
Re-use	Re-use refers to the wearable fraction of post-consumer clothing sold as second-hand clothing.
Scale-up cost	The cost of implementing plant with increased capacity, sufficient to support a new level of production volumes.
Synthetic fibres	Synthetic fibres include chemically-manufactured fibres from non-renewable oil sources, including nylon, acrylic and polyester.
Textile waste	Refers to non-textile items or soiled textiles in the post-consumer textile stream.
Transfer price	The monetary value (sales price) attached to internal transactions for a good or service.

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Bristol Textiles Recycling Limited	UK	Aimee Campanella, Senior Account Manager
British Heart Foundation	UK	David Roman, Waste & Recycling Manager
Aalto University	Finland	Professor Herbert Sixta, Head of Department, Chemical Pulping Technology, Chemical Engineering, Department of Bioproducts and Biosystems
C.L.A.S.S. (Creativity Lifestyle Sustainable Synergy) and Re.Verso™	Italy	Giusy Bettoni, CEO Founder, C.L.A.S.S.
Recovertex	Spain	Hélène Smits, Business Development Manager Alfredo Ferre, Managing Director Hilaturas Ferre
Lawrence M Barry & Co	UK	Ross Barry, Managing Director Ian Woods, Business Development Manager
Leger des Heils "ReShare" (equivalent to UK's SATCOL)	Netherlands	Simon Smedinga, Operational Director
Oxfam	UK	Lorraine Needham-Reid, Manager
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1.0 Introduction

1.1 Background

Annual global clothing production currently utilises 98 million tonnes of raw materials, with growth in consumption expected to drive this figure to 300 million tonnes by 2050.[1] In order to meet future demand for clothing, and to minimise the environmental impacts associated with production, there will be a need to source alternative fibres, including taking full advantage of the potential of recycled fibres.

The current textile market is largely dominated by cotton and polyester.[2] Retailers in the UK continue to use more cotton than other fibres and, for many, cotton garments make up more than half of the outfits sold.[3]

Current global annual production of cotton is static at around 25 million tonnes, and is subject to market control by source nations.[4] There is, therefore, little prospect for growth in annual production and cotton is likely to develop into an increasingly premium and costly product. However, in its 2030 fibre strategy (supply and price), global denim brand Levi's®, has identified cotton as the most significant risk, and a deficit of five million tonnes is predicted globally by 2020. It is, therefore, expected that demand for alternative products will rise significantly; these may include cotton-like materials produced through fibre to fibre (F2F) reprocessing of post-consumer cotton textiles, which also offer environmental benefits including reduced water consumption.[5]

Polyester is currently the dominant fibre on the market. It is a synthetic, non-renewable, petroleum-based fibre made using a carbon-intensive process[6] that requires more than 70 million barrels of oil each year. Polyester represents 55% of the market share[7] and production is rising year-on-year. As use of polyester grows, there is an opportunity to increase the input of recycled polyester to help minimise carbon emissions.[8]

The greatest potential is for closed loop recycling, where material is designed and captured for fibre to fibre recycling.[9] Reprocessing of textiles has existed in some form

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[1] *See: https://www.ellenmacarthurfoundation.org/assets/downloads/publications/A-New-Textiles-Economy_Full-Report_Updated_1-12-17.pdf*

[2] https://www.ivc-ev.de/live/index.php?page_id=87

[3] *WRAP, Valuing our Clothes: the cost of UK fashion, 2017*

[4] *See:* https://www.ivc-ev.de/live/index.php?page_id=87

[5] *Spathas, T. (2017) The Environmental Performance of High Value Recycling for the Fashion Industry. Chalmers University of Technology, Gothenburg, Sweden*

[6] *See: https://www.forbes.com/sites/jamesconca/2015/12/03/making-climate-change-fashionable-the-garment-industry-takes-on-global-warming/#382322ec79e4*

[7] *https://www.ellenmacarthurfoundation.org/assets/downloads/publications/A-New-Textiles-Economy_Full-Report_Updated_1-12-17.pdf*

[8] *WRAP, Valuing our Clothes: the cost of UK fashion, 2017*

[9] *WRAP, Valuing our Clothes: the cost of UK fashion, 2017*

for many years – mechanical recycling processes for recovery of post-industrial textile waste and offcuts, for example, have a pedigree of more than 100 years. However, the fibres produced from mechanical recycling have typically been of a lower quality than virgin fibres. More recent F2F recycling developments have focussed on the production of higher-quality recycled fibres suitable for yarn and fabric production.

Issue	Constraints
Recycling	• Fibre blends contained in textiles. • Costs of sorting and logistics. • Presence of contaminants in mixed textiles (metals, plastics, dyes, etc.).
End markets for recycled textiles	• Lack of demand for recycled textiles. • Lack of demonstrable economic viability of textile sorting. • Lack of demonstrable economic viability of textile recycling. • Low incentives for investment. • Costs associated with trying to achieve single fibres free of dyes, metals and other contaminants.
Recycling and sorting technologies	• Relative immaturity of chemical recycling technologies. • Similar relative immaturity of automated textile sorting needed to increase volumes of appropriate textiles available for fibre to fibre recycling. • Low investment in automated textile sorting technologies. • Quality limitations in mechanical recycling processes for processing post-consumer textiles (fibre length reduction), and the limited availability and evidence for the effectiveness and scalability of chemical recycling.

Table [2.2] Barriers to F2F recycling as reported by Mistra Future Fashion (2016) [10]

This study explores the potential economic viability of producing higher-quality recycled fibres for yarn and fabric production, in order to better understand the nature of these barriers. The results will inform the SCAP (Sustainable Clothing Action Plan) Re-use & Recycling Programme, and contribute to a roadmap towards a circular economy for clothing and textiles in the UK.

[10] *Mistra Future Fashion: Critical Aspects in Design for F2F recycling of textiles,* and *Mistra Future Fashion: The Use of Recycled Fibres in Fashion and Home Products, Karen K. Leonas.*

1.2 Project objectives

The aims of this project are:

- to review the feasibility of developing fibre to fibre (F2F) recycling as a destination for low grades of post-consumer clothing and textiles arising in the UK;
- to review the economic and financial conditions under which recycling might be feasible;
- to identify barriers to the development of recycling; and
- to recommend how these barriers might be overcome.

2.0 Methodology

The methodology adopted for the work is set out in table 1.1. This involved research into existing F2F recycling initiatives. These are predominantly based in Europe.

The research used for the analysis includes published, secondary-source material, and primary research gathered from the post-consumer textile value chain and from F2F recycling process developers.

Eighteen UK, European and North American developers of F2F recycling technologies and other potential stakeholders – including charities and textile merchants – have participated in the research. The information was provided on a confidential basis and has been aggregated to provide an overall view of the development of F2F recycling.

Respondents are classified as follows:

- Chemical F2F recycling process developers.
- Mechanical F2F recycling process developers.
- Charity, post-consumer textile collectors.
- Textile merchants.
- Research consortia (interdisciplinary/multi-country EU projects).
- NIR-enabled sorting technology developers.

In addition to this study, several other projects are currently exploring the financial sustainability of F2F recycling processes. Driven by the opportunity to generate value from the growing quantities of post-consumer textiles not fit for re-use, a number of EU projects (e.g. Fibersort, Trash2Cash and Resyntex) are exploring F2F and other recycling opportunities.

Most of these projects, including those being undertaken by F2F recycling process developers themselves (which will be a primary source for economic data), are not expected to report for two to three years; there is, therefore, a paucity of complete and reliable operational information. Review of the current information from published sources also revealed that reliable, detailed and complete data on a number of the metrics required for the development of financial models was not readily available at the time of writing.

Due to these limitations, it has not been possible to establish complete information on costing and volume requirements. Once additional data becomes available, the economics of the F2F recycling supply chain will become clearer. Developments in the economic assessment of sorting and recycling technologies will follow over the next two to three years, beginning with economic assessments of operational, automated sorting, as financial data becomes available during 2019.

Table 1.1 Methodology for the research reported in this document

Research	Review published documentation and reports. Complete research with existing F2F recycling initiatives.
Textile identification	Identify categories of textile fibres that provide greatest potential for F2F recycling, based on considerations of: • overall volume of textile fibre types in the supply chain; • cost of sorting, preparation and processing of post-consumer clothing and textiles; • demand and value of different fibre types in accessible, fibre to fibre recovery marketplaces; • practical considerations associated with collection of post-consumer textiles; • availability of sustainable supplies; and • technical requirements (feedstock composition and presentation) required by F2F recyclers.
Textile availability for F2F recovery	Assess the availability of post-consumer textiles that have the highest potential for F2F recovery, based on: • volumes of post-consumer textiles from alternative sources, such as kerbside collection, charities, retailer take-back schemes, or from aggregators which collect and ship post-consumer textiles abroad; and • sustainability of supply of appropriate textiles for F2F recovery. Establish fibre composition of post-consumer textiles collected from different sources (charities, recycling firms etc.) in order to support yield calculations for financial and economic models.
Supply and value chain analysis	Develop supply and value chain diagrams that explain the process of textile collection, sorting and recovery in some detail and, therefore, demonstrate where costs arise. Identify prices and other financial factors for financial investment and economic analysis.
Capital investment and incremental costs	For each investment option, assess the investment required in plant and infrastructure, (i.e. the scale of investment required to develop an optimally functioning plant able to process a specified volume of feedstock), and to establish the plant required for F2F recycling, including: • capital cost; • capacity, processing volumes and operating efficiencies of processing equipment; • operating costs of the processing equipment, including the total operating costs (including some items such as consumables, maintenance, insurance etc.); • incremental costs of plant operation (for the different capital investment options), including managerial costs, surplus textiles, and waste disposal costs;

- any incremental delivery costs associated with collection and customer delivery of recovered fibres; and
- scale-up costs – in order to arrive at an indication of the potential of the investment.

Information used in the models has been sourced from a number of respondents, each with processes at varying stages of development and commercialisation. As a result, each respondent has provided some of the information types listed above, but this has often been provided in aggregate, or in a form that is not directly comparable, or is incomplete.

Financial and economic assessment

Establish the factors that underpin the analyses, including:

- the weighted average cost of capital appropriate to the investment decision;
- interest, cost inflation and depreciation rates;
- taxation and investment allowance rates; and
- output prices, costs of sale.

Develop models to describe, and rationalise the results, for each investment proposition:

- net present value using discounted cash flow techniques for cash flows;
- return on investment;
- internal rate of return; and
- payback periods,.

3.0 Feedstock

3.1 Current arisings

Around 650,000 tonnes of post-consumer textiles are collected annually, based on reported 2014 figures.[11] Cotton and polycotton textiles represent the bulk of textiles put on the market.

These materials pose practical limitations to the availability of feedstocks for some F2F recycling technologies requiring a pure feedstock. For example, one of the purest cotton feedstocks from post-consumer clothing is material from denim jeans, once zippers, studs, rivets and buttons have been removed in a pre-processing preparation step. However:

a. Denim jeans represent only between 3% and 5% of the overall waste fraction received by sorters.
b. The volume of denim jeans required to feed a 50,000-tonne plant is more than 82 million pairs annually (a pair of jeans weighs in the region of 0.6 kg). A UK-based plant would need to access feedstocks that greatly exceed the volume of jeans available in the UK, and the resulting transportation costs would significantly increase the tonnage cost.[12]

[11] *Textiles Market Situation Report, WRAP Spring 2016*

[12] *Interview with research respondent*

Other attractive feedstocks include items such as post-consumer and post-commercial cotton bedsheets and pillow cases. The majority of these will be polycotton and would not require pre-processing preparation.

3.2 Destination of sorted textiles

The majority of post-consumer textiles flow through textile merchants. As a result, merchants are likely to be the optimal point in the post-consumer fibre supply chain for capture of feedstock suitable for F2F recycling.

Collected textiles are sorted into graded fractions and routed into re-use (domestic or export), recycling, residual waste for landfill, or to fuel energy from waste (EfW) plants. Maximising re-use grades is the primary focus for textile merchants, as this generates the greatest income.

Post-consumer clothing and textiles that are exported for re-use or recycling are generally sold into:

- Eastern Europe. Some charity shop operators currently report that around 15% of all collected or donated post-consumer textiles are sent to Poland (ex-works);
- Asia. Low-grade materials are exported, often through intermediaries (free on-board); and
- Africa. UK textiles help to satisfy a high demand for light summer clothes.

The value chain that describes the flow of post-consumer textiles from the point when they are discarded by consumers, through recycling, re-use and waste disposal is set out in Figure 3.1. The diagram illustrates the process of collection and sorting that results in separation of textiles suitable for re-use, and for low-grade textiles destined for recycling.

A proportion of the recycling grades could be captured for higher-quality F2F recycling. The potential point of capture, highlighted in the diagram, follows the first sorting, by article type, undertaken by textile merchants.

High-quality grades for re-use in the UK or overseas will follow current routes for resale and are unlikely to be diverted for F2F or other recycling (subject to the discussion in Section 4.2).

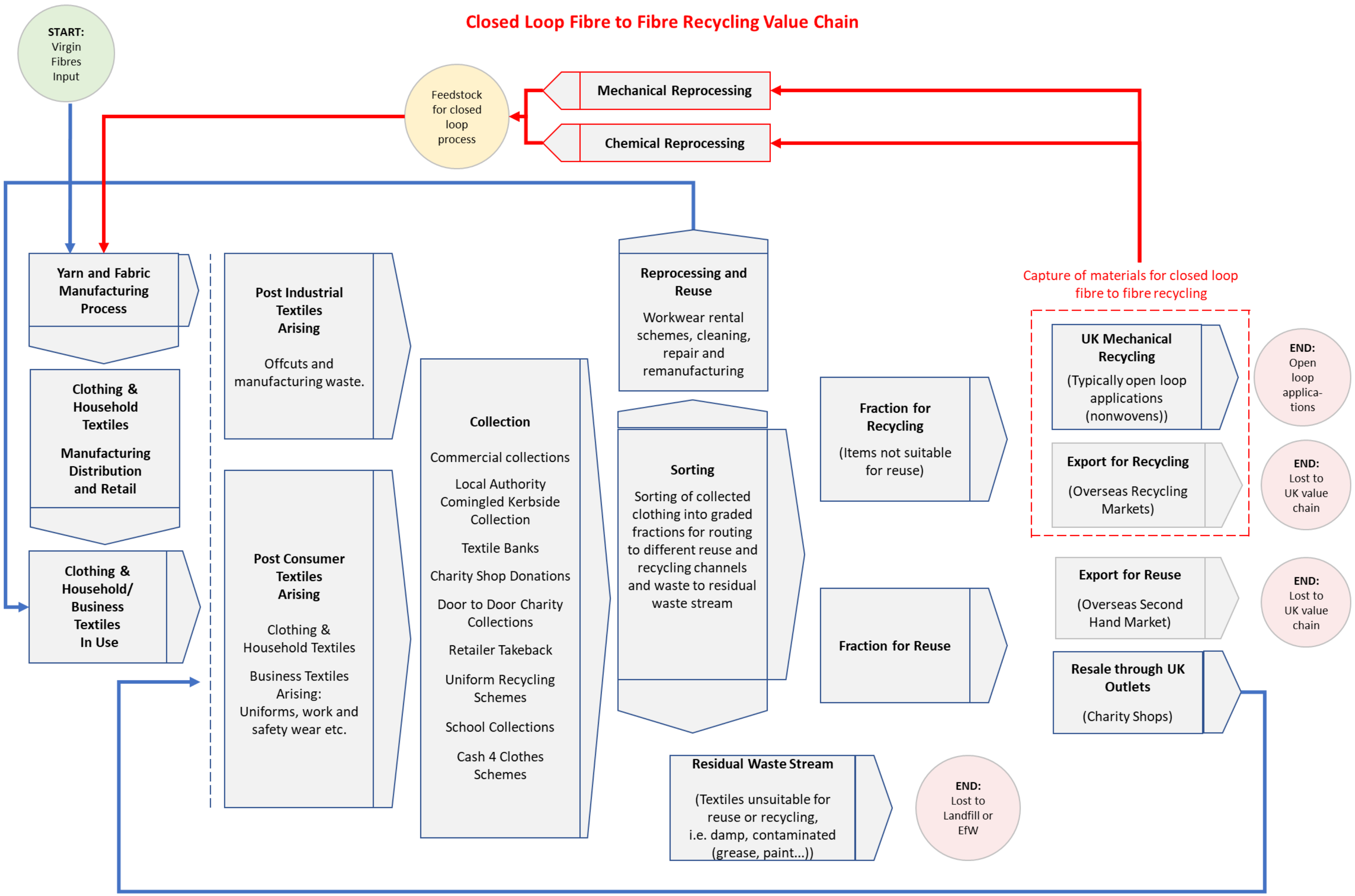

Figure 3.1 Post-consumer textiles value chain (illustrating capture of fibre for closed loop reprocessing)

4.0 Market Trends

4.1 Sorting and grading

Prices for original feedstock from clothing banks and charity shops have fluctuated in the period July 2013 to January 2018. They range from £180 to £410, and £225 to £475 per tonne respectively.[13] Some UK textile merchants have reported rises over 2017 in prices paid for collected, unsorted post-consumer textiles, led by aggressive competition eager to drive out other merchants.

While there is pressure on prices, driven by merchants who are still sorting in the UK, falling margins mean that they are unwilling to undertake anything other than a limited sort. Having extracted the high-value, re-usable fraction and non-textile waste, the remainder is baled, unsorted, and exported (to Eastern Europe, the Middle East and Africa).[14] Some merchants report that a number of African buyers, and those in Dubai, are now specifying limited sorting on the basis that it is cheaper if it takes place in these markets.

The reported willingness of F2F reprocessors to pay premium prices, provided that they can source the recycled fraction, may present an opportunity for textile merchants to revive and invest in their local sorting capabilities (including potential investment in automated sorting technologies, see Section 6.1.1). The location of sorting depends on a variety of factors, including transportation costs and sustainability of demand, but is likely to be geographically close to the reprocessing facility. There is, however, a risk that the re-use market could be cannibalised in order to meet this demand.

4.2 Post-consumer textile market trends which support F2F recycling

Textile merchant and charity respondents reported the following trends, based on their current experience:

- The profit margin for textile merchants on post-consumer textiles is reported to have been falling in the UK since 2016, due to an increase in the prices demanded for feedstock from participants in an earlier position in the post-consumer textiles value chain. Higher prices for feedstock demanded by charities were specifically cited.[15]
- Overseas demand (at the time of the interviews carried out for this report) for some re-use grades has fallen, driven by a greater requirement for quality clothing, particularly in Africa. This could potentially cause a grading shift from re-use to recycling.[16]

[13] *WRAP, Materials Pricing Report 2017*

[14] *Textiles Market Situation Report, WRAP Spring 2016*

[15] *Interview with research respondent*

[16] *Interview with research respondent*

- Merchants may be willing to support recycling, given that a number receive only £100 per tonne for wiper cloths derived from cotton recycling grades.[17]
- Wage increases on the Indian subcontinent are challenging shoddy producers.[18] If overseas markets, such as India, reduce their demand this could, in turn, reduce the incentive to collect and recover post-consumer textiles. An alternative outlet, such as fibre to fibre recycling in the UK may, therefore, be attractive.
- Demand for clothing in the UK is rising, indicating an increase in volumes of post-consumer textiles.

These factors may result in increased availability of post-consumer textiles suitable for F2F recovery, although it is also worth noting the potential for competition for feedstocks currently used in open loop, non-woven applications.

5.0 Fibre Types Providing Greatest F2F Recycling Potential

The fibre types providing the greatest F2F recycling potential are, currently, cotton and polyester, in mono-fibre fabrics and polycotton blends. These are the most commonly used in clothing and household textiles – three-quarters of post-consumer recycling grades contain polycotton blends,[19] so the developers of F2F processes have focussed on improving the technical expertise to reprocess this feedstock economically.

Both chemical and mechanical F2F recycling processes rely on a supply of feedstock that is sorted accurately and efficiently, and which has been prepared to meet their individual processing requirements.

Each of the processes reviewed results in the production of a common currency, semi-finished product (e.g. dissolving pulp or polymer pellets for the chemical process, or pulled fibres for the mechanical process) that can be used in yarn spinning, fabric weaving, knitting and garment manufacturing processes, and which closes the clothing lifecycle loop, as illustrated in Figure 3.1.

Those respondents to the research which were developing chemical F2F recycling technologies were primarily engaged in early research and development (R&D) stages to develop cellulosic F2F reprocessing. Table 5.2 shows chemical processes that are known to have been developed or to be in development.[20] These developments range from laboratory-scale work and scaled-up batch production, to development of pilot plants. Production scale has only been achieved for 100% pre-consumer cotton waste. At the time of writing this report, no commercial scale, post-consumer cellulosic fibres reprocessing has yet been launched, although projects are scaling up to full production and are now close to market.

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[17] *Pricing for wiper cloths quoted by research respondent*

[18] *www.bbc.co.uk/news/business-40352910*

[19] *Research respondent communication*

[20] *Mistra Future Fashion – Critical Aspects in Design for F2F recycling of textiles (with additions)*

Further detail on chemical recycling processes is included in section 6.1.

Input	Process	Steps	Output	Main technologies
Cotton	Cellulosics recovery	Pre-processing, dissolution, wet spinning	Cellulosic fibres	Lenzing, Austria Reloopingfashion, Finland
Polyester, cotton and polyester/cotton blends	Cellulosics and synthetics recovery	Pre-processing, dissolution	Dissolving pulp for new cellulosic fibres; pelletised polymer for open and closed loop applications	Worn Again, UK HKRITA Blend Re:wind, Sweden
Cotton, viscose, lyocell – pre-and post-consumer	Cellulosics recovery	Pre-processing, dissolution	Dissolving pulp for new cellulosic fibres	Re:newcell, Sweden Evrnu, USA Saxion, Netherlands Aalto University, Finland VTT, Finland
Polyester or polyester/cotton blends (max 20% cellulosics)	Synthetics recovery	de-polymerisation to monomer, polymerisation melt-spinning	Polyester fibres	Teijin, Japan Swerea, Sweden VTT, Finland Toray, Japan

Table 5.2 Chemical recycling processes in production or development

6.0 F2F Reprocessing Techniques

6.1 The chemical F2F recycling process

Chemical F2F reprocessing techniques targeting cotton and polycotton textiles rely on selective dissolution of cellulosic and/or synthetic fibres, using solvents or enzymes.

- Some processes target only cellulosic fibres and tend to favour either pure cotton or high cotton content, polycotton textiles. These processes have been developed over the last 10 years.
- Far East developers of chemical, F2F recycling processes have focussed on the recycling of synthetics. Teijin in Japan has developed a chemical polyester F2F recycling process requiring feedstock with at least 80% polyester fibre content. It has recently begun to develop processes for natural fibres, similar to those being developed in Europe.[21]

Cellulosic fibres are reprocessed into a product similar to wood-derived, dissolving pulp used in the production of viscose, which can be used directly in yarn wet spinning. It is reported that the same cellulosic fibres can be reprocessed between three and four times before they begin to degrade into sugars.

[21] *Mistra Future Fashion: Critical Aspects in Design for F2F recycling of textiles,* and
Mistra Future Fashion: The Use of Recycled Fibres in Fashion and Home Products, Karen K. Leonas.

Recycled cellulosic dissolving pulp must meet standard technical specifications for dissolving pulp including, for example, optical brightness.

It is important to note that chemically-recycled cellulosic material will no longer be cotton although, depending on the production processes used, fabrics made from this material may have many similar properties to those made from virgin cotton.

Synthetics are typically processed into polymer pellets which can be sold for use in open and closed loop applications, i.e. yarn production. Since reprocessed synthetics also degrade, there are limitations on the number of closed recycling loops (estimated at four to five) through which the same fibres can be passed.

However, since recovered fibres are usually blended with newer, unprocessed feedstock, the generational degradation issue can be mitigated.[22]

6.1.1 Chemical F2F processing feedstock requirements

Chemical F2F reprocessing requires feedstock that is carefully sorted by fibre type.

Since dyes are removed in the chemical process, colour sorting is not necessary but, as dyes such as vat dyes or reactive dyes are still a challenge to remove, some F2F chemical recycling processes prefer white, pure mono-fibre feedstock. However, this type of feedstock is available only in relatively low volumes. For most chemical F2F recycling processes, dyes like indigo – which is used to dye jeans – can be removed and disposed of with the waste fraction if not recovered.

6.1.2 Chemical recycling process stages

The diagram shown in Figure 5.1 traces the process for the conversion of input feedstock textiles sourced from charities and textile merchants, through to production of common currency feedstock which can be used in conventional yarn production processes.

In common with other recycling processes, key prior stages include:

- **material sorting**: an additional sort by fibre type may be required to ensure that graded textiles meet the specification of F2F recyclers; and
- **garment preparation**: as chemical reprocessing requires that garments are rendered into millimetre-sized fragments, it is necessary to remove all non-textile elements and any known contaminants (hard points, seams etc.) that may interfere with fragmentation or with later stages in the process. This step could be performed by either the sorter or the recycler. Where this process occurs is currently the subject of negotiation between these parties (see Section 12.1). In the model detailed in this report (see Sections 10 and 11), it is assumed that this operation is performed by the sorter.

[22] *Personal communication with F2F process developer*

The chemical F2F recycling process comprises:[23]

- **Feedstock preparation**: this involves processes such as shredding or fragmentation, which reduce the feedstock textiles into particles of fabrics that can be readily transferred into the dissolving process.
- **Dissolving fibres**: the key to the chemical process is selective solubility/degradation of cellulosic and/or synthetic fibres in one or more proprietary solvents. Where two outputs are recovered, two solvents are used – one per fibre type for each of the polyester and cellulosic fractions. It is this element of the process that represents key intellectual property for the developers of chemical F2F recovery processes. Developers are therefore unwilling to share specific details on this step.
- **Fibre separation**: where the process has been developed to recover both synthetic and cellulosic fibre types from polycotton blends, separate solvent fractions may be recovered for each, for subsequent recovery. Some processes target either synthetics or cellulosics recovery and, in these cases, a single solvent containing the target fibre may be recovered. A waste fraction is also recovered.
- **Synthetics recovery process**: the process involves depolymerisation in the dissolving process – recovery requires repolymerisation followed by onward processing, usually into polymer pellets. Pellets are a common currency that can be sold on to be processed into open and closed loop applications. End applications depend on the solvents used. For example, specific applications will be required where food grade solvent is used.
- **Cellulosics recovery process**: cellulosic fibres are recovered as dissolving pulp, which may be used directly in a wet yarn spinning process or dried for sale to regenerated yarn producers. It is important to note that cellulosics recovery produces viscose-like fibres and does not return the material to a state equivalent to virgin cotton.[24]
- A waste fraction also results from the chemical process. This may contain any fibre types not targeted by the F2F recycling process, and other materials, including finishing chemicals, dyestuffs, etc. Black dyes in clothing can represent up to 6% of the garment by weight and this would, currently, be disposed of in the waste fraction.[25] Waste is sent to EfW or landfill. Most developers have reported that they are seeking to recover dyestuffs from the process.
- Some developers have reported that reactive and vat dyestuffs may survive their dissolution process, remaining chemically bonded to the fibre recovered through the selective solvent process.[26] Processes may require repeated cycles of

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[23] The Swedish EPA report of 2015 (ibid) gives details of polymer chemistries, out of scope in this report, used in chemical F2F recycling, included in their report for the purposes of LCA. This report also highlights the opportunity to develop enzymatic methods for polymer breakdown and recovery as a longer term R&D prospect.

[24] Performance in yarn and fabric production is reported to be as good as or, more often, better than the equivalent virgin (man-made cellulosic) fibre in some chemical F2F processes.

[25] F2F process developer respondent, personal communication

dissolution and recovery to increase the purity/quality of the recovered fibres, by fully removing contaminants.

For environmental and cost reasons, chemical processes have been designed to capture and conserve solvents, and to minimise waste and emissions. Solvent loss is reported to be as low as between 0.6% and 1% per cycle in batch processing. Loss rates in continuous processing are not yet known or have not been disclosed.

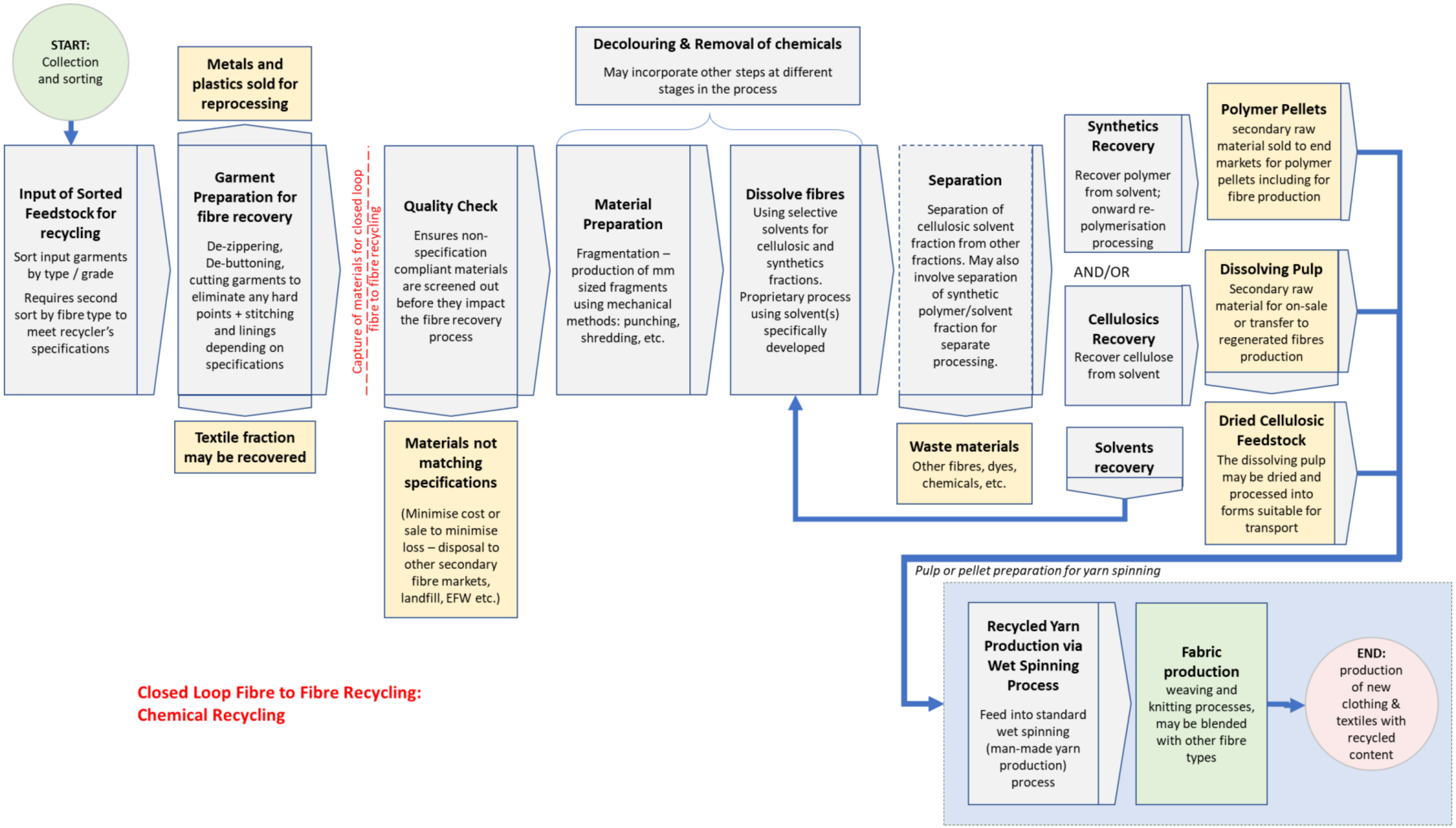

Figure 5.1 The chemical F2F recycling process (for recovery of cellulosics & synthetics)

6.1.3 Market readiness

Cellulosic, chemical F2F recycling initiatives are generally several years away from full commercialisation, while commercial initiatives using pre-consumer cotton have already been deployed.

The earliest chemical F2F recycling technologies to reach production volumes require 100% cotton feedstock. Feedstock for these processes is primarily being sourced in-house, as post-industrial feedstocks from yarn and fabric manufacture, rather than from post-consumer textiles.

The tolerance for non-cellulosic content in feedstock appears to increase proportionately for processes whose expected launch date is further into the future. Systems which are closer to market, or at the point of scale-up, are able to tolerate 2% non-cotton content; some have already been tested at between 98% and 90% in the laboratory.

Future cellulosic-only chemical recycling processes are expected to reduce the minimum required cellulosic content to 80% (allowing up to 20% of other fibre types which are separated out as waste) and anticipate sourcing material from the post-consumer textiles value chain, mainly via textile merchant partners.

Some F2F reprocessors can separate and reprocess polycotton fabrics into both cellulosic pulp or fibre and synthetic pellets, so it may prove economic to process lower cotton and higher synthetic blends. One such chemical process developer expects to be able to process 50:50 polycotton and, potentially, an even higher level of polyester content blends. Production of both dissolving pulp and polymer pellets supports the economic viability of the process.

Several chemical F2F processes developed by respondents will come to market over the next three to six years. As a result, the volume of recycled materials, in the form of cellulosic dissolving pulp and/or polymer pellets, available to yarn manufacturers will increase over this time. It is expected that these processes will be increasingly tolerant of polyester (and other non-cellulosic) content in polycotton blends. Some processes developed have already been shown to be tolerant of other synthetics mixed with cotton, including elastane. Other fibres are, however, usually disposed of as part of the waste fraction.

Some chemical F2F recycling processes currently work best for undyed, pure white textiles, or for textiles that have been dyed with dyestuffs that are not chemically-bound to the cellulose fibres (e.g. jeans indigo). Others are being developed that are better able to deal with dye and with the chemical content of feedstock.

Times to market are heavily influenced by factors such as demonstrable outputs from current and intended pilots and trials, and the ability to raise funds, both of which could delay target deployment dates. Whilst pilot plants and trials are processing volumes below those needed to feed the full capacity of some larger yarn production lines, scale-up to meet high capacity yarn mill demand would be the next stage of development. This might be assumed to be another two to three years away. Even if recyclate volumes are not sufficient to fully meet the demand of a yarn production line, partial displacement of virgin feedstock still represents a desirable outcome.

6.2 The mechanical F2F recycling process

6.2.1 Mechanical F2F processing feedstock requirements

Mechanical recyclers prefer homogenous, or near homogenous, feedstock in terms of fibre type as well as colour, since mechanical recycling does not include any intrinsic decolouration.

The feedstock might include a combination of post-industrial and post-consumer cotton. For post-consumer clothing, colour-sorted jeans and T-shirts are the favoured feedstock for F2F mechanically-recycled cotton. Hard points and non-cotton materials must be removed before the material is recycled into fibres.

6.2.2 Mechanical F2F recycling process stages

Mechanical reprocessing techniques involve breaking down garments by chopping into shredded fragments and then utilising a pulling process to produce shoddy. Methods have gradually been refined to produce fibres of sufficient quality to be regarded as closed loop, F2F processing rather than downcycling. Historically, there has been a focus on recovery of high-value, long staple fibres such as wool and cashmere. The current emphasis is on improvement of F2F reprocessing for cotton and polycotton blends.

The mechanical recycling process suffers from the disadvantage of producing shortened fibres that, as a result, do not perform as well as virgin fibres either during yarn and fabric production, or in use. As a result, mechanical reprocessing through multiple closed loop cycles is not likely to be viable due to the serial degradation of fibre lengths in each cycle. The more refined, mechanical F2F processes are reported to deliver cotton fibre staples only 25% to 30% shorter than virgin fibres (c. 21mm vs. 25mm), and allow the production of quality yarn and fabrics.

Current systems in development all seem to be refinements of the process set out in Figure 5.3. The diagram traces the process for conversion of input feedstock textiles, from collection and sorting through to production of recycled fibres for use in conventional yarn production processes and new clothing production.

The initial stages of the mechanical process, prior to the recycling step, are similar to those described in Section 5.3.1 in relation to the chemical processes:

- **Material and colour sorting**: an additional sort by fibre type and colour is likely to be required to ensure that textiles received from textile merchants meet feedstock specifications. A sort will usually be required to ensure conformance to material type and quality standards, although the recovery process may be less stringent/more tolerant of non-conformant material in comparison with the chemical processes already described.

- **Garment preparation**: the process requires rendering of garments into small fragments using a chopping and pulling process. Elements that might interfere in the recycling process, such as hard points, are removed.

Following the recycling process, material will require:

- **Carding**: the process of aligning fibres using a combing process, so that they can be spun.
- **Blending**: recovered fibres are combined with carrier fibres (virgin or regenerated cellulosic, synthetic or other fibres) to improve the properties of the final, recycled yarn.
- **Spinning**: a yarn production process.
- **Weaving:** high-speed weaving may be problematic; slower/gentler weaving may be required. Resulting fabrics may contain blended recycled and virgin content.

Recent ECAP F2F recovery pilots are trialling mechanical reprocessing techniques targeting polycotton blends and cotton (particularly denim to denim).[27] The trials indicate that the recycled fibre content may only represent a useful, but small, fractional displacement of virgin fibre use.[28]

[27] *www.ecap.eu.com*

[28] *Information received verbally from a third party on the progress of ECAP F2F trials*

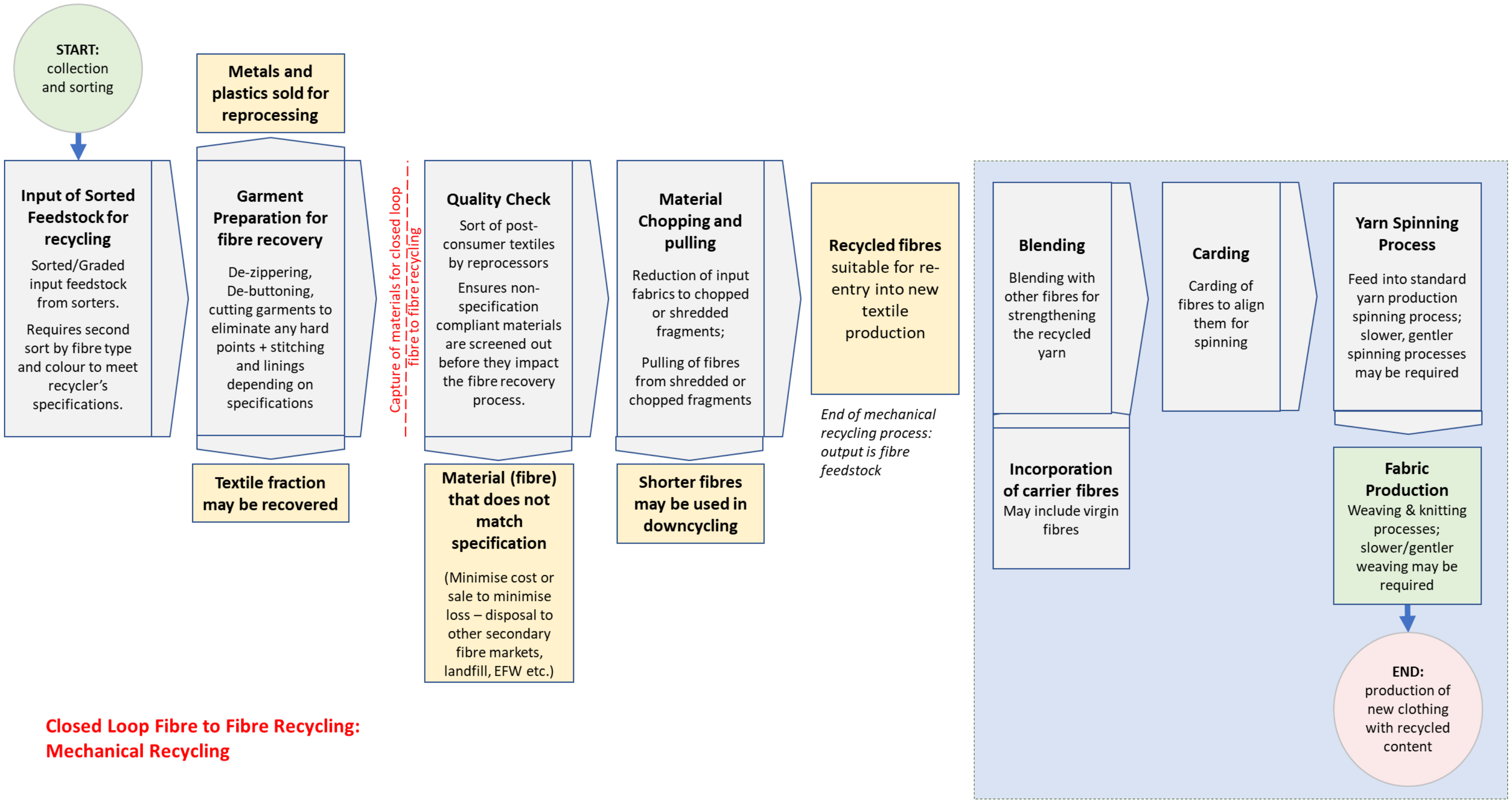

Figure 5.3 The mechanical F2F recycling process

7.0 Feedstock Requirements and Specifications

7.1 Sorting by fibre type

Manual sorting, consisting of fibre composition identification by reading garment care labels, is currently the only option. Research respondents reported, however, that 25-30% of garments have washed out, missing or otherwise inaccurate care labels. Recent near-infrared (NIR) textile identification work has also highlighted concerns about label accuracy.

As a consequence, manual sorting is felt to be insufficiently accurate to produce feedstock matching the requirements of some F2F chemical reprocessors. This is especially true where chemical processes are optimised to deal with only very low levels of contaminants, as is common with early implementers. As processes that recover both cellulosic and synthetic (polyester) fractions are rolled out, they are likely to become more tolerant, but may continue to require more precise sorting than manual methods can offer.

Automation of sorting is expected to improve sorting accuracy and reduce sorting-related costs. One such process, Fibersort, developed by Valvan Baling Systems in Belgium, uses NIR spectroscopy to accurately identify the fibre content of textile recycling grades after manual sorting of the re-use grades. Automated NIR sorting can also be used to sort by colour, although lower cost colour sensors or manual sorting may also be used for colour sorting.

Automated sorting using NIR fibre recognition is seen as an attractive option by F2F recyclers, although concerns remain over the cost/benefit considerations around introducing the machinery, and over the current sorting speed and capacity of the systems in development. Recyclers reported that the "*implementation of automated, efficient [fibre sorting technology] able to work at volume will be important to lowering costs and improving the economic feasibility/performance of F2F recycling*". Performance and quantitative data generated from Fibersort in real world use is expected to be available after its start in 2018; broader implementation at other sites may then follow.

While waiting for data – both from Fibersort and from competing NIR sorting systems – to become fully available, recyclers have factored in the cost of an additional sort, either at sorters' sites or an on-site sort at the recycling facility. In order to remove unnecessary costs from the value chain, recyclers and sorters need to work to develop trust relationships, and to agree standard specifications and realistic premiums for pre-processed feedstock that meets the specifications. Alternatively, F2F recyclers may need to invest in sorting capabilities, which will add cost but enable them to optimise on quality.

7.1.1 Volumes and availability

Availability of feedstock is not regarded as an issue, since widespread post-consumer textiles collection infrastructure already exists in the UK. However, the volumes of feedstocks required to support a F2F recycling plant of production scale are expected to be significant. One F2F chemical recycler targeting cotton recovery reported a need for 11.5 million pairs of post-consumer denim jeans to provide 7,000 tonnes of unprocessed feedstock (at c. 0.6kg per pair of jeans). Jeans are desirable for cotton fibre recycling because they represent a homogenous, cotton-rich feedstock. They can also be easily identified and sorted in garment form.

7.2 Textile merchants’ role in meeting feedstock requirements

Chemical F2F process developers expect to secure feedstock that has been sorted to meet specifications. Improved sorting by textile merchants, particularly through use of automated NIR sorting systems, may improve sorting quality and cost effectiveness. Textile merchants are also likely to add value to the sorted feedstock by undertaking garment preparation work.

A clear example is the preparation of post-consumer jeans or T-shirts for cotton recycling. These are cut into panels and any hard points, linings and seams are removed (to meet specifications). Garment preparation can add value to post-consumer jeans for F2F recycling, but this is balanced by an increase in labour costs to the operator.

8.0 Business Models Considered for F2F Recycling

A variety of different business models are being envisaged by both chemical and mechanical F2F recyclers:

i. **Owned-and-operated facilities**: scaling owned-and-operated facilities funded by investors, and close cooperation and licensing arrangements with brands, retailers, fashion designers, and manufacturers.
ii. **Collaboration**: collaboration through joint ventures with textile merchants/ sorters, yarn manufacturers and fabric mills, and through local/international partnerships with industry, brands, funders.
iii. **Leasing**: garment leasing has been implemented by a number of clothing manufacturers, particularly those in the professional workwear market. A ‘leasing molecules’ F2F model has been proposed by one recycling process developer. This would require consumers to return garments at the end of a specified lease period, thereby providing the F2F recycler with sustainable, quality-assured feedstocks.
iv. **Franchising**: external investment to support franchising of technology and process to third party investor/operators, yarn spinners, etc., or licensing of technology, with only the first plant owned and operated by the organisation.

Some F2F reprocessing methods are being developed by yarn manufacturers or partners which intend to co-locate, and may be integrated to feed product into existing yarn production lines, based on an internal transfer price mechanism. Other F2F reprocessing developers are working more independently and plan to sell recovered outputs to yarn manufacturers. Most F2F process developers stated a preference to be located close to yarn producers, although others were developing their processes to produce transportable, dried dissolving pulp or pelleted synthetics. Logistics costs are cited as an important consideration in the economics of F2F reprocessing.

9.0 Financial & Economic Assessment

This assessment, subject to the caveats as set out below, is merely intended to be a potential guide for interested parties. The report includes two processing models which have been assessed for their economic and financial viability – although a number of systems and processes exist, with others still in development, it has only been possible to include one scenario for each type of system. For example, any type of fibre can be processed through a mechanical F2F system, but the model employed in the report refers to cotton feedstock. It will be up to potential stakeholders to substantiate and to determine the actual inputs based upon their own due diligence undertaken.

The chemical and mechanical F2F recycling financial models developed in the course of this work are enclosed as Appendix A and the assumptions that underlie the models appear as Appendix B. The financial models comprise four elements:

i. A **profit and loss projection** over a period of 10 years which, for the chemical recycling model, takes account of a two-staged investment in the production process – a Year One investment which produces an output of 30,000 tonnes per annum, and a Year Four investment to take annual production to 50,000 tonnes per year. This is considered to be the optimum output at which production efficiencies and, therefore, cost savings are achieved. Some F2F chemical recyclers believe that an annual production capacity of up to 100,000 tonnes can ultimately be achieved, but the level of production efficiencies available at this level are unknown.
   The mechanical recycling model comprises a single investment in annual capacity of 30,000 tonnes per annum. No data was provided during the research process for an increase in annual production.
ii. A **cash flow forecast** over the same period.
iii. A **projection of financial position** of the chemical and the mechanical F2F recycling processes.
iv. Calculations of **returns on investment** presented in four alternative ways, and assuming a weighted average cost of capital (WACC):
   a. The net present value (NPV). This is the future cash flow associated with the investment, discounted at the recycler's WACC to arrive at a net value at today's prices. An NPV which yields a positive value indicates a worthwhile investment project.
   b. The internal rate of return (IRR). The IRR is the rate of return of the investment project that would yield a zero NPV. Hence, an investment project for which the IRR is greater than the WACC would be a worthwhile investment.

c. The payback period. Expressed as a year, the payback period indicates the year in which the investment project would repay all of the investment.
d. The return on investment (ROI) is the simple return calculated as the ratio of total future cash flows (over the 10-year period) to the total investment.

The WACC for Lenzing A.G., a botanic cellulose fibres supplier, has been used as the basis for this model. However, since Lenzing is a large, established and diversified company for whom the chemical recycling process is a relatively small part of the business, a risk premium of 10% over its WACC has been assumed.[29] This compares with an average UK risk premium of 5.23% and is, therefore, considered appropriate for a higher risk start-up business.[30] A WACC of 15% and a pre-tax cost of debt of 9% imply a cost of equity of 33%, which is appropriate for a start-up with growing revenues.[31]

9.1 Significant limitations and assumptions in the financial models

Details of chemical and mechanical F2F recycling processes are considered proprietary, and developers have been reluctant to share information that would allow the full capital, processing and other operational costs to be understood. The paucity of information is also due to the relatively early stages of development of many of the F2F recycling processes. The ability to prepare more detailed financial models, and to draw conclusions on the financial viability and investment prospects of F2F recycling processes, has therefore been limited.

The financial models have been developed for one type of chemical F2F recycling process and for a generic, mechanical F2F recycling process, using data from a variety of sources. The processes modelled are those described in Section 5 of this report.

The models could be improved through further, longer-term engagement with F2F recycling process developers and post-consumer value chain stakeholders to obtain data on pilot operations, including real world experience on capital investment and the operating costs of the F2F recycling plants now in development. Although there are limitations in the data used and the assumptions made, the models are fairly representative of the commercial and technical issues associated with these processes, their sensitivity to various factors and, consequently, the areas of the post-consumer textiles value chain which must be addressed.

9.2 Technical architecture

In each case, since a detailed breakdown of the costs and equipment required has not been shared for this research, the capital expenditure and related data – such as processing capacities – are obscured. Consequently, data proxies have been used. For

[29] The Lenzing A.G. WACC is 4.23% (see: https://www.gurufocus.comper tonneerm/wacc/LNZNF/WACC/Lenzing%2BAG).

[30] https://www.statista.com/statistics/664734/average-market-risk-premium-selected-countries/

[31] https://www.jbs.cam.ac.uk/fileadmin/user_upload/research/centres/accelerate-cambridge/downloads/raising-financial-capital.pdf

example, an aggregate, per-tonne production cost for the chemical recycling of polycotton, including the following steps; (i) dissolution of fibres in solvent, (ii) separation, (iii) synthetics recovery, and (iv) cellulosics recovery.

9.3 Feedstock pricing

Current pricing information for sorted, post-consumer textiles supplied as feedstock into both processes is relatively easily available. It is, however, difficult to accurately assess the effect that future increased demand may have on prices. This is very much dependent on the type and, therefore, availability of textiles that are demanded, and the ongoing investment by collectors/sorters in better quality sorting (both manual and NIR-enabled sorting) and garment preparation work. In all cases, the sensitivity of the financial model to changes in input prices and costs has been established.

10.0 Chemical F2F Recycling Model

Although a number of chemical F2F recycling options have been developed, only one model has been highlighted in this report. The financial and economic assessment of the process is based on a composite view of the chemical F2F recycling of polycotton worn textiles producing two outputs (cellulosic pulp and synthetic pellets), against which input and processing costs and output values can be compared, using data from the research.

Table 7.1 sets out in summary the chemical F2F recycling process and maps the price/cost data obtained during the research to each process step. These costs have been used in developing the financial model of the process attached at Appendix A.

Data assumptions used for this scenario:

Feedstock: polycotton, worn textiles which have been collected, sorted for recycling grades and by fibre type, containing a minimum of 80% polycotton material within the mix. Three-quarters of all post-consumer textile recycling grades are suitable feedstock. Suitable sorted clothing requires a garment preparation step, whereas it is unnecessary for the vast majority of suitable home textiles.
The sorted, prepared, polycotton-rich feedstock is then transported and sold to the F2F chemical recycler. The price of this feedstock is estimated at an average of £150 per tonne, including transport.

Optional additional sort: An additional, on-site sort at the chemical recycling facility is not required given the feedstock is supplied, sorted and prepared to specifications by sorters. However, if an additional fibre type sort is required, manual or automated sorting arrangements would need to be factored in.

Reprocessing:

Process step	Feedstock acquisition	Reprocessing	Sale of recycled outputs to yarn spinners (or transfer pricing for vertically-integrated spinners)
Data reference	Feedstock costs 75% of textiles recycling grades, minimum 80% polycotton, sorted and prepared. Average cost of £150 per tonne	Processing costs (as a 'black box' process) £90 per tonne Solvent costs Initial solvent investment £2 million Loss/replacement rate: 1% Finalisation costs: PET pellets: £50 per tonne Cellulosics: £50 per tonne Disposal costs £103 per tonne (20% waste based on feedstock mix)	Sale prices Polymer pellets £700 per tonne Dissolving pulp £720 per tonne Expected yield balance between cellulosic and synthetic output products based on estimated feedstock mix 40% synthetics 60% cellulosics
Other costs	Salary costs 6 managers @ £30,000 and 15 staff @ £22,000 p.a. (plus employment costs) Incremental overheads £100,000 for rent and other operating costs Capital investment costs & plant capacity Plant 30,000-tonne @ £28 million; Increase to 50,000 tonne @ £18.6 million		

Table 7.1 Prices/costs for chemical F2F recycling of polycotton model

Sale prices: The sale price of the chemically-recycled outputs, polymer pellets and dissolving pulp are assumed to be £700 and £720 respectively.

Yield: For the particular instance of the chemical model presented in this report, it is assumed that the feedstock comprises a polycotton blend that is expected to yield 40% synthetics and 60% cellulosics. Waste from processing, including other fibre types than polyester and/or cotton, dyes (3% to 6%) and other chemicals, is estimated at 20%. Waste is assumed to be sent to landfill at a disposal cost of £103 per tonne.[32]

Cost and price inflation: Cost and price inflation figures based on the Office of Budget Responsibility Inflation Forecast December 2017 are included at 2%, and it is assumed that the recycler can increase absolute prices by 2% annually as demand for recycled fibres increases. The impact on the financial model of there being no increase in recycled fibre prices is to reduce the profitability of the chemical process.

Solvent(s) costs: The closed loop nature of solvent use is assumed to require replacement of solvents at the rate of 1% per annum, with an initial solvent investment

[32] *(£89 landfill tax and £14 per tonne gate fee) SOURCE?*

of £2 million for a plant with an annual 30,000-tonne throughput, rising pro-rata with production volumes.

Processing costs: Based on research conducted for this study, chemical processing costs are estimated at £90 per tonne (excluding labour) and represent primarily energy costs associated with (i) dissolution of fibres in solvents, (ii) separation, (iii) synthetics recovery, and (iv) cellulosics recovery.

The chemical process requires two further costs associated with the finalisation step of producing recycled polyester pellets and cellulosic dissolving pulp. This step is required to increase the intrinsic viscosity factor of recycled polyester pellets to an intrinsic viscosity (IV) suitable for subsequent yarn spinning. A similar process is expected for cellulosics, but has not yet been defined. This may, for example, involve rendering the dissolving pulp into a dried form for sale and transport to third party yarn spinners. Finalisation of recycled polyester pellets and cellulosic pulp is estimated at £50 per tonne. Within an integrated facility, costs may be lower.

Salaries and overheads: A 50,000-tonne chemical plant is assumed to require six supervisor level managers and 15 operatives, paid respectively £30,000 and £22,000 per annum (plus employment costs). The only other incremental overheads are estimated at £100,000 for rent and any other costs (such as sales and marketing). All costs are subject to annual inflationary increases. It is also assumed that only marginal changes are required in staffing levels for differences of a few tens of kilo tonnes. These factors have been obtained from the research.

Capital investment: Planned capital investment is based on plant capacity of 30,000 tonnes per annum, and pro rata for an increased 50,000-tonne plant in Year Four, in which efficiency gains can be achieved. There is insufficient experience in the sector of the gains possible, other than from similar sectors where cost savings of between 5% and 8% per year have been observed. The financial model therefore assumes a conservative 4% efficiency factor applicable from Year Four.

Working capital is calculated from the model as being the cash investment needed to ensure that the plant trades on a cash positive basis until profitable.

Capacity, kt p.a.	**30 kt**	**50 kt**
Capital investment in plant, £	£28m	+ c. £19m
Investment in working capital	£3.5m	+ £1m

Table 7.3 Chemical recycling processes' capital requirement

The working capital requirement depends on debtor and creditor days (estimated at 5% and 6% of year end balances), and an initial cash investment to meet running costs. Plant is depreciated over 10 years.

Plant capacity: The financial model assumes a 50% capacity utilisation in Year One, followed by 100% output thereafter, even after the second phase of investment at Year Four.

Environmental permitting: No costs are included to obtain an original permit. Current rules might allow such businesses to operate under an exemption; this would need to be taken into account.

Funding: It is assumed that investment in the plant would be funded by a combination of debt (70%) and equity (30%), and located within an existing facility at an annual rent of £100,000. The cost of debt is put at 9% p.a. throughout the projection phase. Additional capital investment can be represented in the model if a new facility/building is required, or rental costs could be built into the model.

10.1 Model outputs

The chemical processing financial model output is set out in Table 7.6. Under these assumptions, the model suggests that the F2F chemical recycling process is financially attractive, for the scenario modelled, given the positive return on all four measures:

Net present value	£16.9m
ROI	158%
IRR	29%
Payback	Year 6
Weighted average cost of capital	15%

Table 7.5 Chemical recycling payback

The above figures (and those presented in the model in Table 7.6) illustrate the potential for a very profitable process that can be cash generative, making the investment proposition highly attractive. However, the model makes various assumptions on price and costs that might not, in a new and volatile marketplace, be achievable. The factors to which the model is sensitive are explored further in the following sections.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Feedstock acquired, tonnes	37,500	37,500	37,500	62,500	62,500	62,500	62,500	62,500	62,500	62,500
Waste from processing inc. other fibres, dyes (3% to 6%) and other chemicals	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
Capacity utilisation	50%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Net annual production, tonnes	15,000	30,000	30,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Yield polymer pellets	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%
Yield dissolving pulp	60%	60%	60%	60%	60%	60%	60%	60%	60%	60%
Polymer pellets, tonnes	6,000	12,000	12,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
Dissolving pulp, tonnes	9,000	18,000	18,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000

	£'000	£'000	£'000	£'000	£'000	£'000	£'000	£'000	£'000	£'000
Revenue from two outputs	10,680	21,787	22,223	37,779	38,535	39,305	40,091	40,893	41,711	42,545
Direct costs	8,777	12,670	12,912	22,606	21,463	21,648	21,841	22,043	22,253	22,471
Gross profit	1,903	9,117	9,311	15,173	17,072	17,657	18,250	18,850	19,458	20,074
Overheads	100	102	104	106	108	110	113	115	117	120
EBITDA	1,803	9,015	9,207	15,067	16,963	17,547	18,137	18,735	19,341	19,955
Depreciation	2,800	2,800	2,800	4,667	4,667	4,667	4,667	4,667	4,667	4,667
EBIT	(997)	6,215	6,407	10,400	12,297	12,880	13,471	14,069	14,674	15,288
Interest on debt	1,985	1,786	1,588	2,628	2,306	1,983	1,661	1,339	1,016	694
EBT	(2,981)	4,429	4,820	7,772	9,991	10,897	11,810	12,730	13,658	14,594
Corporation Tax	0	1,301	1,448	2,325	2,785	2,957	3,131	3,305	3,482	3,660
Retained profit	-£2,981	£3,128	£3,372	£5,447	£7,206	£7,940	£8,679	£9,425	£10,176	£10,934
Increase/(decrease) in cash	£1,078	£3,401	£3,959	£7,335	£8,184	£8,997	£9,736	£10,481	£11,232	£11,990

Table 7.6 Chemical recycling 10-year cashflow model

The attractiveness of the investment is heavily dependent on certain key assumptions that can significantly alter the outcome. These are as follows, and have been determined by using a range of figures in the model, in order to determine the tipping points:

1. Feedstock price. The model has a base assumption that the average feedstock price will be £150 per tonne, including sorting by material type, garment preparation where required, and transport costs. The tipping point, being the price above which the model becomes unprofitable, is £232 per tonne.
2. Pulp sales price. The model is also sensitive to falls in the pulp sales price. Whilst profitable if the pulp sales price falls to £580 per tonne, a drop in price to £500 causes the process to become unprofitable.
3. Polymer sales price. The model is less sensitive to falls in the polymer sales price, which reflects the lower proportion of synthetics recovered from the process, compared to dissolving pulp (40% versus 60%). The process becomes unprofitable for falls in polymer pellets from £700 per tonne to £300 per tonne.

Sensitivity Factor	**Base Case**	**Feedstock Price Increase: £250 per tonne**	**Pulp Sales Price Reduction: £500 per tonne**	**Polymer Sales Price Reduction: £300 per tonne**
Base figures		£150 per tonne	£720 per tonne	£700 per tonne
NPV	£16m	(£4m)	(£5m)	(£10m)
ROI	158%	57%	51%	28%
IRR	29%	11%	10%	6%
Payback	Year 6	Year 8	Year 8	Year 9
WACC	15%	15%	15%	15%
	Profitable	**Negative returns**	**Negative returns**	**Negative returns**

Table 7.7 Chemical recycling economic sensitivity factors

A 30% increase in the chemical recycling processing costs – from £90 to £120 per tonne (but not above this level) – continues to support investment in the process. This appears to indicate that the process, as it undergoes any teething problems (reflected primarily in energy usage) in the start-up and subsequent scale-up phases, remains a financially worthwhile investment. An increase in the waste of solvent used in the chemical process from 1% annually to, say, 20% annually, only marginally affects the base outcome.

11.0 Mechanical F2F Recycling Process

Although a number of mechanical F2F recycling options have been developed, only one model has been highlighted in this report, which assumes a hypothetical plant scaled to 30,000 tonnes per annum. To produce an outline financial model, we have undertaken enquiries of operators in the field, analysed published, audited accounts and exercised our judgement in relation to specified inputs. The model is therefore only a guide, subject to specific unknowns, and not a statement of fact.

The modelling seeks to illustrate the potential for profitability under a range of assumptions. Many factors affect the actual performance and profitability of a plant. The model presented here is simply illustrative of the potential combined impact of the assumptions, some of which are substantiated, others which are not. An alternative set of assumptions would have yielded a different base case, and there is insufficient information to discriminate between the range of base cases that might be considered acceptable.

The model assumes that the mechanical F2F recycler sources post-industrial textiles (cotton) and post-consumer textiles (also cotton, in this case: denim jeans), which are 'cleaned' in the garment preparation step before being chopped and pulled to produce shredded fibres. These recovered cotton fibres are shorter and more brittle than virgin cotton fibres. The integrated yarn spinner then buys carrier fibres (here, virgin polyester), needed to provide mechanical strength and integrity to the final recycled yarn. The recovered cotton fibres are blended with the carrier fibres (dyed to match the colour of recovered cotton) and spun into yarn. The final product is the recycled yarn, here a blend of recycled cotton and polyester.

Feedstocks and garment preparation: The three main feedstocks are set out below. In addition to the cost of buying the feedstock, the post-consumer textiles (jeans) need to undergo a level of preparation before they can move on to the chopping and pulling stage. Garment preparation consists of removing hard points and any non-cotton materials, and is estimated here at £268 per tonne. The price assumptions for the post-consumer textiles, post-industrial textiles and the preparation cost assumptions are based on indicative values from existing operators. One UK textile merchant has confirmed that it would supply fully prepared, sorted feedstock at £250 per tonne.

The disposal cost is the same as in the chemical modelling, while the cost of the carrier fibres varies depending on the selected fibre (e.g. virgin or recycled polyester, lyocell, virgin cotton, etc.. Here, we have assumed the fibre to be virgin polyester). The price assumption for the virgin polyester was sourced from a commodity price website during the research phase of the project.

Feedstock	Price per tonne of buying the feedstock	Preparation	Preparation cost per tonne (and disposal cost per tonne)
Post-consumer cotton – the model assumes that the cotton feedstock is clean, sorted by garment type and basic-colour-sorted. The example given here is used blue jeans.	£134 per tonne	The jeans are cut to produce denim panels. The denim panels go on to the next stage and the remainder of the jeans (pockets, zipper, etc.) is assumed to be disposed of. This is a simplifying assumption – there is theoretical value in the remainder, but it would require further processing to attract buyers for the leftover metals and plastics.	Garment preparation: £268 per tonne. Disposal: £103 per tonne (35% waste estimated)
Post-industrial cotton – in this case blue cotton clippings	£446 per tonne	Not applicable	Not applicable
Carrier fibres – assumed for this scenario to be virgin polyester	£1,205 per tonne	Not applicable	Not applicable

Table 7.8 Feedstock type and price

The model assumes a ratio of 50:50 carrier to recycled fibres. This is a working assumption; changing that ratio affects the overall feedstock costs.

Based on enquiries with existing operators, the model assumes around 15% waste throughout the entire recycling and spinning process. The waste consists of dust which, for simplicity, is assumed to bear no disposal cost, since dust from mechanical recycling can be sold for downcycling applications.

Salaries and overheads: We have not been able to substantiate this area with any certainty and have, therefore, had to rely on i) the published accounts for existing operators, and ii) our judgement as to the economies and efficiencies that can be derived from a hypothetical, scaled-up plant of 30,000 tonnes per annum. These costs are assumed to be fixed (index linked) and are reflected as such in the model itself.

Inflation: the model assumes 2% annual inflation (as per the chemical modelling).

Planned capital investment: the model assumes planned capital investment of £10 million for a plant capacity of 30,000 tonnes per annum. This is indicative, extrapolated based on enquiries with existing operators.

Working capital is calculated from the model as being the cash investment needed to ensure that the plant trades on a cash positive basis until profitable. The working capital requirement depends on debtor and creditor days (adjusted in the model on an arbitrary basis), and an initial working capital cash investment to meet the running costs.

Plant depreciation and capacity: plant is depreciated over 10 years on a straight line basis. The financial model assumes an 85% production capacity of yarn.

Funding and rent: it is assumed that investment in plant itself will be funded by a combination of debt (70%) and, possibly, lease finance and equity (30%). The facility would be located within an existing building/footprint, at an annual rent/rates of £350,000 per annum. The cost of debt is put at 9% per year. All feedstocks and semi-finished product will be transferred at ex-works prices.

Recycled yarn sale price: the model assumes a selling price of £1,830 per tonne. This is at the lower end of a range of indicative yarn prices (across yarn types) provided by existing operators. The price will vary upon final properties (count, twist, colour) of the recycled yarn, and the ratio and nature of carrier fibres.

11.1 Model outputs

PROFIT AND LOSS										
(Designated in £'s Sterling)										
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Sales										
Sales of recycled yarn	**46,674,107**	**47,607,589**	**48,559,741**	**49,530,936**	**50,521,555**	**51,531,986**	**52,562,625**	**53,613,878**	**54,686,155**	**55,779,879**
Cost of sales - total	**24,782,787**	**25,278,443**	**25,784,011**	**26,299,692**	**26,825,685**	**27,362,199**	**27,909,443**	**28,467,632**	**29,036,985**	**29,617,724**
Gross Profit	**21,891,320**	**22,329,147**	**22,775,730**	**23,231,244**	**23,695,869**	**24,169,787**	**24,653,182**	**25,146,246**	**25,649,171**	**26,162,154**
Operating costs total	**6,500,000**	**6,630,000**	**6,762,600**	**6,897,852**	**7,035,809**	**7,176,525**	**7,320,056**	**7,466,457**	**7,615,786**	**7,768,102**
Operating Profit	**15,391,320**	**15,699,147**	**16,013,130**	**16,333,392**	**16,660,060**	**16,993,261**	**17,333,127**	**17,679,789**	**18,033,385**	**18,394,053**
Operating profit %	32.98%	32.98%	32.98%	32.98%	32.98%	32.98%	32.98%	32.98%	32.98%	32.98%
Overheads - total, incl. utilities, rents and rates, other	**13,084,821**	**13,346,518**	**13,613,448**	**13,885,717**	**14,163,432**	**14,446,700**	**14,735,634**	**15,030,347**	**15,330,954**	**15,637,573**
EBITDA	**2,306,499**	**2,352,629**	**2,399,681**	**2,447,675**	**2,496,629**	**2,546,561**	**2,597,492**	**2,649,442**	**2,702,431**	**2,756,480**
EBITDA %	4.94%	4.94%	4.94%	4.94%	4.94%	4.94%	4.94%	4.94%	4.94%	4.94%
Depreciation *(straight line)*	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
EBIT	**1,306,499**	**1,352,629**	**1,399,681**	**1,447,675**	**1,496,629**	**1,546,561**	**1,597,492**	**1,649,442**	**1,702,431**	**1,756,480**
EBIT %	2.80%	2.84%	2.88%	2.92%	2.96%	3.00%	3.04%	3.08%	3.11%	3.15%
Interest payable (*fixed rate presumed*)	630,000	630,000	630,000	630,000	630,000	630,000	630,000	630,000	630,000	630,000
Profit (loss) before tax	**676,499**	**722,629**	**769,681**	**817,675**	**866,629**	**916,561**	**967,492**	**1,019,442**	**1,072,431**	**1,126,480**
Add back depreciation (no Capital Allowances assumed)	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
Profit for Corporation Tax Purposes	*1,676,499*	*1,722,629*	*1,769,681*	*1,817,675*	*1,866,629*	*1,916,561*	*1,967,492*	*2,019,442*	*2,072,431*	*2,126,480*
Corporation Tax	318,535	327,299	336,239	345,358	354,659	364,147	373,824	383,694	393,762	404,031
Profit (loss) after tax	**357,964**	**395,329**	**433,442**	**472,317**	**511,969**	**552,415**	**593,669**	**635,748**	**678,669**	**722,449**

Table 7.9 Mechanical recycling, 10-year outline profit and loss model

Further information about the outline financial model and its assumptions can be found in Appendices A & B.

The model illustrates the potential for profitability under the assumptions presented.

Net Present Value	£86,617
ROI Gross	79%
IRR (based on excel function) *	12%
Payback	Year 6
Weighted Average Cost of Capital	15%

Table 7.10 Mechanical recycling payback
*capex included pre-trading in year 0

The model presented in Table 7.9 and figures from Table 7.10 illustrate a potentially profitable process that can be cash-generative, but this is subject to the financial model caveats and assumptions mentioned. The model makes various assumptions on price and costs that may not, in a new and volatile marketplace, be achievable.

The model yields a positive NPV of £86,617. The base case represents the combined impact of the assumptions. A different set of assumptions would have yielded a different base case, and there is insufficient information to discriminate between the range of base cases that might be considered acceptable.

Against this starting point, most – even small - adverse variations, such as an increase in the cost of feedstock or a decrease in the selling price of the recycled yarn, are sufficient to yield negative NPVs.

Sensitivity factor	Base case	Carrier fibres cost	Recycled yarn selling price	Ratio of carrier to recycled fibres
Starting assumption		£1,205 per tonne	£1,830 per tonne	50:50
Sensitivity assumption (+/-10%)		£1,326 per tonne	1,647 per tonne	60:40
NPV	£0.1m	(£6m)	(£13m)	(£8m)
WACC	15%	15%	15%	15%
	Profitable	**Negative returns**	**Negative returns**	**Negative returns**

Table 7.11 Mechanical recycling sensitivity to assumptions

For illustration purposes, table 7.11 shows the NPV when: some of the assumptions are moved adversely by 10%; when the cost of carrier fibres is increased by 10%; when the selling price is decreased by 10%; and when the proportion of carrier fibres relative to recycled fibres is increased. Conversely, the NPV would increase under reverse assumptions.

There are, therefore, high variations expected in final revenues, depending on the variety of orders and lot sizes of different types of recycled cotton yarns, blended with other fibres or types of cotton.

12.0 Options for Overcoming Barriers to F2F Reprocessing

Based on the research and analysis undertaken for this study, opportunities to overcome barriers to F2F reprocessing include:

12.1 Potential for extended producer responsibility to facilitate F2F recycling

As a systemic approach, the introduction of an extended producer responsibility (EPR) scheme, which could be similar to that adopted in France, could be used to raise funding to support initial investment in F2F recycling capacity in the UK. This might include incentivisation of improved collection and sorting activities – providing, for example, a matched funding offer for investment in improved and automated sorting systems. Similar support might also be offered to developers of F2F recycling facilities in the UK.

Alternatively, government could encourage the development of a self-regulated EPR scheme to encourage the development of F2F recycling, or may be able to use direct aid, subsidies, tax breaks or other similar instruments to support investment in the sector.

F2F process developers have made a strong case for the viability of F2F reprocessing in the UK without the assistance of an EPR incentive or government aid. Any modest aid that should become available – from organisations such as regional governments – to incentivise the location of F2F recycling plants may consequently prove effective in encouraging F2F recyclers to opt for particular locations for plant development. This might apply to the development of collection, sorting, clothing pre-processing or recycling process implementers.

12.2 Other regulations

F2F recycling developers (and sorters) cite that, if they needed to import feedstock to meet volume requirements, then movement of waste (post-consumer clothing) across borders may pose a potential cost or barrier to broader implementation of F2F recycling. They also refer to regulatory costs such as Environmental Permitting and REACH which, although secondary to existing high transportation costs, may still have a significant impact on project costs. Clarification and communication of current regulations may be required so that the industry properly understands the potential barriers and costs.

Changes in government and regional regulation – either in the UK, between the UK and the EU, or within the EU – may be needed to ease transport of (i) used textiles for F2F recycling, and (ii) F2F recycled material for input into recycled yarn production.

12.3 Engagement with brands and retailers

Some brands highlight concerns about human health (hygiene) and consumer perception of using post-consumer, mechanically recycled fibres in the manufacture of new clothing. However, an increasing number of brands are interested in creating closed loop processes, and are involved in mechanical F2F recycling trials, including those undertaken under ECAP.

Due to the nature of the recovery process used, in which the recycling method represents an effective decontamination process, chemical processes are likely to pose a negligible risk. Communication of the benefits of F2F recycling to the public, and to brands and retailers, should address and counter potentially negative perceptions.

Recyclers report difficulty in processing garments that incorporate high blends, a high content of elastane, and hard points. Opportunities to engage brands and retailers on the selection of dyes and trims, and on the limitation of problematic fibres within fabrics like elastane may increase the potential for recyclability of clothing.

The cost of innovation may also pose a barrier. Many F2F recycling process developers are collaborating with global leading brands and retailers on trials to support future investment with multi-year, recycled yarn purchasing commitments. A clear commitment from brands and retailers, in the form of supply contracts or commitments to purchase clothing with recycled fibre content on a scale that would support investment from recyclers, would support the development of this activity.

It is reported that up to one third of garments have washed out or missing labels. Although this implies that the majority of recycling grades could be sorted by care labels, some textile merchants report that labels do not always reflect the true material content, and that label inaccuracy is sufficient to prevent it being a completely reliable method. Improved labelling accuracy, and use of labelling techniques that survive garment use, could assist in manual care label sorting.

12.4 Increasing capture of recycling grades from charities

Relatively low overall volumes are processed through charities, even at central sorting sites, compared with the volumes handled by textile merchants. One option considered in the charity collection and sorting sector in Sweden and Finland is the creation of a shared sorting facility, developed as a collaboration between several charities.[33] It is worth mentioning, however, that there are fewer textile collectors and charities in these two countries than in the UK.

12.5 Optimising the cost of collection, manual sorting and garment processing

Textile merchants are unlikely to invest in additional capacity without a commitment from F2F recycling partners to purchase feedstock from them. Clarification of who is best-placed within the F2F supply chain to undertake sorting and garment preparation is needed. Reliable sorting and preparation by textile merchants, prior to sale to F2F

[33] *Respondent communication and www.diva-portal.org/smash/get/diva2:916826/FULLTEXT01.pdf ; www.researchgate.net/publication/312939659_Planning_a_Swedish_Collection_and_Sorting_Plant_for_Used_Textiles_A_Feasibility_Study*

reprocessors, is likely to be the most cost effective option, given that textile merchants will also be sorting and preparing garments for other markets.

The feasibility and relative immaturity of F2F recycling processes remain an issue, as does concern about fibre quality and consistency. For post-consumer textiles recovery, some yarn spinners report the need to charge substantially higher prices for recycled yarns than for virgin yarns. The costs associated with feedstocks are highly dependent on transport and distances travelled. As a result, the location from which feedstocks are sourced has a major impact on overall costs. However, recent ECAP fibre to fibre recovery trials have shown that innovative approaches to supply chain costs may be able to overcome this barrier. [34]

Manual sorting is labour intensive and this activity is currently configured for sale of garments for re-use. The cost of manual sorting (and garment processing) is a barrier to cost effective production of feedstock for the F2F recycling process, particularly in the UK, where used textiles prices are reported to be higher than in other countries. The requirement for a careful sort of post-consumer textiles, identifying fibre type, to meet F2F recycling specifications, is a necessity. The current UK post-consumer textile market, based on manual sorting, may face some challenges to deliver quantities of sorted and prepared feedstock at stable prices.

Greater sophistication in the sorting sector, including automation, would support the development of F2F reprocessing. Automated sorting, using near-infrared spectroscopy identification of textile content, may be a critical enabler, although the costs of capital investment and operation need to be considered in more detail. Maximum throughput is claimed by the manufacturer of the Fibersort machinery as one item per second. A manual sorter is able to sort a textile piece every six seconds, so the investment significantly increases the output of one operator, by a factor of six. The motivation behind automated NIR sorting is therefore the premise that the value of recycling grades increases with accurately identified fibre composition. This is still yet to be fully tested in the marketplace.

It may be possible to introduce a simpler, NIR-enabled, automated sorting system which would only distinguish conformant from non-conformant feedstock, and may allow F2F recyclers or feedstock suppliers to introduce the technology at a lower cost. Given that textile merchants are more likely to want to sort recycling grades of textiles into multiple categories, the fully-featured Fibersort system may prove to be a more popular option.

Automation of garment preparation steps may also reduce the combined sorting/preparation costs for production of feedstock suitable for F2F reprocessing. Research is ongoing in this area throughout Europe.

12.6 Communicating feedstock prices and specifications

Textile merchants intending to supply F2F recyclers will need to more fully understand the specifications and tolerances of the specific recycling process. As a result, potential

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[34] *Information received verbally from a third party on the progress of ECAP F2F trials*

suppliers to F2F recyclers are likely to welcome early distribution of feedstock specifications by recyclers, to allow them to invest in processes and capacity.

Policy developers and industry groups are likely to assist the development of the F2F marketplace by working on ways to ease communication of feedstock requirements, standard supply agreements and communication of pricing. The market would benefit from greater visibility of pricing data and pricing data fluctuations, through regular publication of this data from a trusted third party, or from the development of online trading platforms that make pricing data more visible.

Agreements to supply sorted materials with suitable pricing mechanisms might allow recyclers to rely on the supply of sorted and prepared materials that match specification to a greater degree. Alternatively, non-conformant feedstock might be rejected by the reprocessor and returned for re-sorting.

Work with the Textile Recycling Association and its members on the feasibility of, and value in, meeting the requirements of recyclers is likely to form a valuable element of a strategy for the development of F2F recycling in the UK.

12.7 Commercialising processes

Chemical F2F recycling processes are in various stages of R&D and most have stringent feedstock requirements (in terms of accepted fibre composition percentages). More tolerant recycling methods, able to accept a wider variety of feedstock types, are still several years from volume production; commercial-scale plants for chemical recycling are two to three years away. Full commercial capacity is, in most cases, five or six years away. F2F chemical recycling processes will need to continue to work to produce outputs that are able to compete with the prices of virgin equivalents.

Mechanical processes are already available and able to process commercial volumes of cotton textiles feedstock. The financial viability and take-up of these processes appears to be limited by production costs, although recent F2F trials conducted for the ECAP project suggest that F2F recycling may be financially viable as long as the recycled yarn, fabric and garment production costs are carefully monitored through optimised sourcing.

F2F reprocessors will benefit from participation in trials with potential purchasers of post-consumer textile recyclates (dissolving pulp, polymer pellets or mechanically-recovered fibres) and subsequent actors in the textile supply chain, to demonstrate the quality and the cost effectiveness of these recovered materials in final textile products.

Some yarn spinners have expressed doubts over the quality of the dissolving pulp produced by some of the cellulosic F2F chemical recyclers, and may have reservations about using this post-consumer cellulosic pulp in their yarn manufacturing process. Further engagement will be required to ensure confidence in quality.

12.8 Supply chain integration

Organisations that are vertically-integrated are less likely to be sensitive to small fluctuations in price, given investment in F2F recycling capability. Those that are not vertically-integrated will wish to seek long term agreements with feedstock suppliers and with purchasers of recovered fibre at reasonable, realistic and stable prices.

F2F recyclers may integrate as suppliers of fibres into the clothing supply chain and, specifically, with yarn manufacturers. There is potential for resistance, due to the reported conservatism of buyers – clothing manufacturers, brands and retailers – since processes have been developed, ostensibly, to fully integrate with current yarn manufacturing processes.

Continued work with brands and retailers to foster demand for garments featuring recycled content is also likely to be beneficial.

12.9 Transport costs

Respondents reported that transport costs for post-consumer textile feedstock between countries within the EU proved to be a prohibitive economic barrier to F2F recovery. Two options for overcoming this were proposed: development of F2F recycling facilities close to the source of post-consumer textiles, or in-country pre-processing of post-consumer clothing and textiles to produce feedstock sorted and processed to meet the needs of recyclers outside of the UK.

F2F reprocessing might produce output materials of sufficient economic value to warrant longer-distance transport costs. Transportation costs in the latter instance would, however, still potentially be subject to premiums associated with transfer of waste across borders. Transport of recycled fibres from mechanical recycling may also be subject to these issues.

Given the apparent viability of mechanical F2F reprocessing, it is possible that mechanical F2F recycling facilities in the UK could ship reprocessed materials to yarn producers in lower-cost countries and complete production there.

12.10 Consumer engagement

Potentially suitable feedstock is currently being sent to landfill, due to consumer failure to recycle through existing routes. A research respondent estimates that if around 20% of landfilled textile waste were recycled or re-used, this could increase annual volumes in the sector by around one third. Further improvements in consumer messaging, and separate collection infrastructure could influence the proportion of discarded clothing sent to landfill by the public.

Consumer behaviour also affects the quality of garments being received. Excessive washing or tumble drying at high temperature causes damage to clothing and affects the quality of the fibres recovered in mechanical reprocessing. The impact on the recovered fibre quality is reported as a key issue in mechanical recycling. Improved consumer messaging to reduce over-washing could address this issue.

12.11 Maintaining awareness of developments

Since many of the projects used to inform this research are in early stage development, benefit would be gained from updating the report as more detailed figures and information becomes available. This would include re-contacting F2F reprocessing developers in order to access more reliable cost data, as processes move from trial to scale-up and, finally, to production stage. The emergence of new entrants into the F2F reprocessing market should also be monitored, with a view to sourcing additional data. Improved modelling will continue to support the business case for investment by F2F reprocessors and their potential used textiles feedstock suppliers.

13.0 Conclusions

This study has focussed on the potential for the development of closed loop, F2F recycling using UK, post-consumer clothing and textiles as part of the feedstock.

13.1 Fibre types arising in the UK market with the most potential for F2F recycling

Cellulosic and polyester fibres (in pure cotton, polycotton blends and pure polyester garments) have the greatest potential for F2F recovery. Growing demand for cotton, and the potential for its displacement by F2F recycled cellulosic material, means that this material is likely to be able to sustain viable income levels for F2F recyclers. It is worth highlighting, however, that chemically-recycled cellulosic material will no longer be cotton, even though – depending on the production processes used – it may retain many similar properties. Mechanically-recycled cotton fibres, albeit shorter in length, remain cotton.

13.2 Viability of chemical F2F reprocessing (polycotton blends)

Although there is limited information on the financial aspects of the chemical process, the data available appears to demonstrate that it can be financially viable within certain cost and price ranges. The model indicates that the process, as it undergoes any teething problems (reflected primarily in energy usage) in the start-up and subsequent scale-up phases, remains a financially worthwhile investment. The financial viability of the process is, however, sensitive to (i) feedstock prices, (ii) the number of outputs produced, depending on what can be recovered from the process, and (iii) the sales price of the dissolving pulp and the polymer pellets.

13.3 Viability of mechanical F2F reprocessing (cotton)

The process/cost information available from mechanical F2F reprocessors is similarly limited. Based on the information available, financial viability of mechanical F2F recycling is highly sensitive to a number of factors. In particular:

(i) The final recycled yarn selling price, depending on the final yarn's properties (count, twist, colour) and lot size determined for production.

(ii) The selection (due to cost) and ratio of carrier fibres. Whilst this is a matter for the brand, or retailer, and yarn spinner, it is a key factor in the economics of the mechanically-recycled yarn.

This is in line with previous research.[35] Our research respondents reported that profitability depended on an ability to command a higher price for recycled yarns than for virgin yarns (which may be up to four times the current price of virgin yarns, depending on final yarn characteristics).

While mechanical F2F recyclers have demonstrated technical capability, financial viability remains doubtful unless purchasers are willing to pay premium (above virgin) prices for recycled cotton. That mechanical F2F recycling can be financially viable appears, however, to have been demonstrated by recent ECAP fibre to fibre trials.[36] Information from these trials, such as: (i) the prices paid for prepared feedstock for F2F recycling, (ii) the cost of processing, (iii) the final price of the recycled yarns and fabrics, etc. could be used to improve the predictive ability of the model.

[35] *"Closing the Loop for clothing: Closed loop fibre recycling-current status and future challenges." Oakdene Hollins Report: March 2013 . https://www.oakdenehollins.com/reports/2013/4/9/closing-the-loop-for-clothing*

[36] *Information received verbally from a third party on the progress of ECAP F2F recovery trials*

Appendix A: F2F Financial Model

Chemical Recycling Model

Profit and Loss Account	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
	£'000	£'000	£'000	£'000	£'000	£'000	£'000	£'000	£'000	£'000
Revenue										
Sale of Dissolving Pulp	6,480,000	13,219,200	13,483,584	22,922,093	23,380,535	23,848,145	24,325,108	24,811,610	25,307,843	25,813,999
Polymer Pellets	4,200,000	8,568,000	8,739,360	14,856,912	15,154,050	15,457,131	15,766,274	16,081,599	16,403,231	16,731,296
	10,680,000	**21,787,200**	**22,222,944**	**37,779,005**	**38,534,585**	**39,305,277**	**40,091,382**	**40,893,210**	**41,711,074**	**42,545,295**
Direct Costs										
Feedstock	2,812,500	5,737,500	5,852,250	9,948,825	10,147,802	10,350,758	10,557,773	10,768,928	10,984,307	11,203,993
Solvent	2,000,000	20,000	20,000	1,353,333	33,333	33,333	33,333	33,333	33,333	33,333
Second Sort	-	-	-	-	-	-	-	-	-	-
Processing Cost	1,687,500	3,442,500	3,511,350	5,735,205	5,620,501	5,508,091	5,397,929	5,289,970	5,184,171	5,080,488
Material Finalisation	750,000	1,530,000	1,560,600	2,653,020	2,706,080	2,760,202	2,815,406	2,871,714	2,929,148	2,987,731
Disposal of Waste Materials	386,250	787,950	803,709	1,366,305	1,393,631	1,421,504	1,449,934	1,478,933	1,508,511	1,538,682
Salaries	580,380	591,988	603,827	615,904	628,222	640,786	653,602	666,674	680,008	693,608
Maintenance Costs	560,000	560,000	560,000	933,333	933,333	933,333	933,333	933,333	933,333	933,333
	8,776,630	***12,669,938***	***12,911,736***	***22,605,926***	***21,462,903***	***21,648,008***	***21,841,311***	***22,042,886***	***22,252,812***	***22,471,168***
Gross Profit	***1,903,370***	***9,117,262***	***9,311,208***	***15,173,079***	***17,071,682***	***17,657,269***	***18,250,071***	***18,850,323***	***19,458,262***	***20,074,127***
Overhead Costs										
Rent and rates	100,000	102,000	104,040	106,121	108,243	110,408	112,616	114,869	117,166	119,509
Utilities	-	-	-	-	-	-	-	-	-	-
	100,000	**102,000**	**104,040**	**106,121**	**108,243**	**110,408**	**112,616**	**114,869**	**117,166**	**119,509**
EBITDA	**1,803,370**	**9,015,262**	**9,207,168**	**15,066,958**	**16,963,439**	**17,546,861**	**18,137,455**	**18,735,455**	**19,341,096**	**19,954,618**
Depreciation	2,800,000	2,800,000	2,800,000	4,666,667	4,666,667	4,666,667	4,666,667	4,666,667	4,666,667	4,666,667
EBIT	**- 996,630**	**6,215,262**	**6,407,168**	**10,400,291**	**12,296,772**	**12,880,194**	**13,470,788**	**14,068,788**	**14,674,429**	**15,287,951**
Interest on debt	1,984,500	1,786,050	1,587,600	2,628,150	2,305,800	1,983,450	1,661,100	1,338,750	1,016,400	694,050
EBT	**- 2,981,130**	**4,429,212**	**4,819,568**	**7,772,141**	**9,990,972**	**10,896,744**	**11,809,688**	**12,730,038**	**13,658,029**	**14,593,901**
Corporation Tax	-	1,301,136	1,447,718	2,325,374	2,784,951	2,957,048	3,130,507	3,305,374	3,481,692	3,659,508
Retained profit/(loss)	**- 2,981,130**	**3,128,077**	**3,371,850**	**5,446,768**	**7,206,021**	**7,939,696**	**8,679,181**	**9,424,664**	**10,176,337**	**10,934,394**

Cash Flow Forecast	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
	£'000	£'000	£'000	£'000	£'000	£'000	£'000	£'000	£'000	£'000
Retained Profit	- 2,981,130	3,128,077	3,371,850	5,446,768	7,206,021	7,939,696	8,679,181	9,424,664	10,176,337	10,934,394
Add Back:										
Depreciation	2,800,000	2,800,000	2,800,000	4,666,667	4,666,667	4,666,667	4,666,667	4,666,667	4,666,667	4,666,667
Movement in working capital:										
Change in Trade Debtors	- 534,000	- 555,360	- 21,787	- 777,803	- 37,779	- 38,535	- 39,305	- 40,091	- 40,893	- 41,711
Change in Trade Creditors	497,775	233,022	13,920	581,052	- 69,193	10,482	10,962	11,445	11,933	12,426
Change in Corporation Tax Liability	-	-	-	-	-	-	-	-	-	-
Cash flow from operating activities	***- 217,355***	***5,605,739***	***6,163,983***	***9,916,683***	***11,765,715***	***12,578,311***	***13,317,504***	***14,062,685***	***14,814,044***	***15,571,775***
Capital Expenditure	28,000,000	-	-	18,666,667	-	-	-	-	-	-
Financing										
Equity Introduced	9,450,000	-	-	5,900,000	-	-	-	-	-	-
Debt Raised	22,050,000	-	-	13,766,667	-	-	-	-	-	-
Debt Repaid	2,205,000	2,205,000	2,205,000	3,581,667	3,581,667	3,581,667	3,581,667	3,581,667	3,581,667	3,581,667
	29,295,000	***- 2,205,000***	***- 2,205,000***	***16,085,000***	***- 3,581,667***	***- 3,581,667***	***- 3,581,667***	***- 3,581,667***	***- 3,581,667***	***- 3,581,667***
Increase/(decrease) in cash	***£1,077,645***	***£3,400,739***	***£3,958,983***	***£7,335,017***	***£8,184,049***	***£8,996,644***	***£9,735,837***	***£10,481,018***	***£11,232,377***	***£11,990,108***

Balance Sheet	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
	£	£	£	£	£	£	£	£	£	£
Fixed Assets										
Capital equipment	25,200,000	22,400,000	19,600,000	33,600,000	28,933,333	24,266,667	19,600,000	14,933,333	10,266,667	5,600,000
	25,200,000	**22,400,000**	**19,600,000**	**33,600,000**	**28,933,333**	**24,266,667**	**19,600,000**	**14,933,333**	**10,266,667**	**5,600,000**
Current Assets										
Trade Debtors	534,000	1,089,360	1,111,147	1,888,950	1,926,729	1,965,264	2,004,569	2,044,660	2,085,554	2,127,265
Cash	1,077,645	4,478,384	8,437,366	15,772,383	23,956,431	32,953,075	42,688,913	53,169,931	64,402,308	76,392,417
	1,611,645	**5,567,744**	**9,548,513**	**17,661,333**	**25,883,161**	**34,918,339**	**44,693,482**	**55,214,592**	**66,487,862**	**78,519,681**
Current Liabilities										
Trade Creditors	497,775	730,797	744,717	1,325,769	1,256,575	1,267,058	1,278,019	1,289,465	1,301,398	1,313,824
Corporation Tax	-	-	-	-	-	-	-	-	-	-
	497,775	**730,797**	**744,717**	**1,325,769**	**1,256,575**	**1,267,058**	**1,278,019**	**1,289,465**	**1,301,398**	**1,313,824**
Net Current Assets	**1,113,870**	**4,836,947**	**8,803,797**	**16,335,564**	**24,626,585**	**33,651,281**	**43,415,462**	**53,925,127**	**65,186,464**	**77,205,857**
Liabilities falling due after more than 1 year										
Debt financing	19,845,000	17,640,000	15,435,000	25,620,000	22,038,333	18,456,667	14,875,000	11,293,333	7,711,667	4,130,000
Net Assets	**6,468,870**	**9,596,947**	**12,968,797**	**24,315,564**	**31,521,585**	**39,461,281**	**48,140,462**	**57,565,127**	**67,741,464**	**78,675,857**
Equity	9,450,000	9,450,000	9,450,000	15,350,000	15,350,000	15,350,000	15,350,000	15,350,000	15,350,000	15,350,000
Reserves	- 2,981,130	146,947	3,518,797	8,965,564	16,171,585	24,111,281	32,790,462	42,215,127	52,391,464	63,325,857
	6,468,870	**9,596,947**	**12,968,797**	**24,315,564**	**31,521,585**	**39,461,281**	**48,140,462**	**57,565,127**	**67,741,464**	**78,675,857**

Return on Investment Model	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
	£	**£**	**£**	**£**	**£**	**£**	**£**	**£**	**£**	**£**
Cash flow from operating activities	- 217,355	5,605,739	6,163,983	9,916,683	11,765,715	12,578,311	13,317,504	14,062,685	14,814,044	15,571,775
Add back interest on debt	1,984,500	1,786,050	1,587,600	2,628,150	2,305,800	1,983,450	1,661,100	1,338,750	1,016,400	694,050
Cash flow from operations	**1,767,145**	**7,391,789**	**7,751,583**	**12,544,833**	**14,071,515**	**14,561,761**	**14,978,604**	**15,401,435**	**15,830,444**	**16,265,825**
Less: Capex	28,000,000	-	-	18,666,667	-	-	-	-	-	-
Net Cash flow	**- 26,232,855**	**7,391,789**	**7,751,583**	**- 6,121,833**	**14,071,515**	**14,561,761**	**14,978,604**	**15,401,435**	**15,830,444**	**16,265,825**
Cumulative cash flows	**- 26,232,855**	**- 18,841,066**	**- 11,089,484**	**- 17,211,317**	**- 3,139,802**	**11,421,959**	**26,400,563**	**41,801,998**	**57,632,442**	**73,898,267**
Weighted Average Cost of Capital	**15.0%**									
Net Present Value, £	£16,852,602									
ROI	158%	at year 10								
IRR	29.01%									
PayBack	**-**	**-**	**-**	**-**	**-**	**Year 6**	**-**	**-**	**-**	**-**

Mechanical Recycling Model

PROFIT AND LOSS											
(Designated in £'s Sterling)											
		Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Sales											
Sales of recycled yarn		**46,674,107**	**47,607,589**	**48,559,741**	**49,530,936**	**50,521,555**	**51,531,986**	**52,562,625**	**53,613,878**	**54,686,155**	**55,779,879**
Cost of sales - total		**24,782,787**	**25,278,443**	**25,784,011**	**26,299,692**	**26,825,685**	**27,362,199**	**27,909,443**	**28,467,632**	**29,036,985**	**29,617,724**
Gross Profit		**21,891,320**	**22,329,147**	**22,775,730**	**23,231,244**	**23,695,869**	**24,169,787**	**24,653,182**	**25,146,246**	**25,649,171**	**26,162,154**
Operating costs total		**6,500,000**	**6,630,000**	**6,762,600**	**6,897,852**	**7,035,809**	**7,176,525**	**7,320,056**	**7,466,457**	**7,615,786**	**7,768,102**
Operating Profit		**15,391,320**	**15,699,147**	**16,013,130**	**16,333,392**	**16,660,060**	**16,993,261**	**17,333,127**	**17,679,789**	**18,033,385**	**18,394,053**
Operating profit %		32.98%	32.98%	32.98%	32.98%	32.98%	32.98%	32.98%	32.98%	32.98%	32.98%
Overheads - total, incl. utilities, rents and rates, other		**13,084,821**	**13,346,518**	**13,613,448**	**13,885,717**	**14,163,432**	**14,446,700**	**14,735,634**	**15,030,347**	**15,330,954**	**15,637,573**
EBITDA		**2,306,499**	**2,352,629**	**2,399,681**	**2,447,675**	**2,496,629**	**2,546,561**	**2,597,492**	**2,649,442**	**2,702,431**	**2,756,480**
EBITDA %		4.94%	4.94%	4.94%	4.94%	4.94%	4.94%	4.94%	4.94%	4.94%	4.94%
Depreciation *(straight line)*		1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
EBIT		**1,306,499**	**1,352,629**	**1,399,681**	**1,447,675**	**1,496,629**	**1,546,561**	**1,597,492**	**1,649,442**	**1,702,431**	**1,756,480**
EBIT %		2.80%	2.84%	2.88%	2.92%	2.96%	3.00%	3.04%	3.08%	3.11%	3.15%
Interest payable *(fixed rate presumed)*		630,000	630,000	630,000	630,000	630,000	630,000	630,000	630,000	630,000	630,000
Profit (loss) before tax		**676,499**	**722,629**	**769,681**	**817,675**	**866,629**	**916,561**	**967,492**	**1,019,442**	**1,072,431**	**1,126,480**
Add back depreciation (no Capital Allowances assumed)		1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
Profit for Corporation Tax Purposes		*1,676,499*	*1,722,629*	*1,769,681*	*1,817,675*	*1,866,629*	*1,916,561*	*1,967,492*	*2,019,442*	*2,072,431*	*2,126,480*
Corporation Tax		318,535	327,299	336,239	345,358	354,659	364,147	373,824	383,694	393,762	404,031
Profit (loss) after tax		**357,964**	**395,329**	**433,442**	**472,317**	**511,969**	**552,415**	**593,669**	**635,748**	**678,669**	**722,449**

DCF/NPV ANALYSIS (INDICATIVE ONLY)											
NB: VAT excluded	*Pre trading*	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
EBITDA		**2,306,499**	**2,352,629**	**2,399,681**	**2,447,675**	**2,496,629**	**2,546,561**	**2,597,492**	**2,649,442**	**2,702,431**	**2,756,480**
Adjusted for movement in working capital (arbitrary)		1,960,524	1,999,735	2,039,729	2,080,524	2,122,134	2,164,577	2,207,869	2,252,026	2,297,066	2,343,008
Operating Cashflow pre tax		**1,960,524**	**1,999,735**	**2,039,729**	**2,080,524**	**2,122,134**	**2,164,577**	**2,207,869**	**2,252,026**	**2,297,066**	**2,343,008**
Corporation Tax		318,535	327,299	336,239	345,358	354,659	364,147	373,824	383,694	393,762	404,031
Operating Cashflow post tax		**1,641,989**	**1,672,435**	**1,703,490**	**1,735,166**	**1,767,475**	**1,800,430**	**1,834,045**	**1,868,332**	**1,903,305**	**1,938,977**
Capex funded by equity	3,000,000										
Capex funded by debt (lease presumed)	7,000,000										
Net Cashflow *(before financing)*	-10,000,000	1,641,989	1,672,435	1,703,490	1,735,166	1,767,475	1,800,430	1,834,045	1,868,332	1,903,305	1,938,977
Cumulative Cashflow	**-10,000,000**	**-8,358,011**	**-6,685,576**	**-4,982,086**	**-3,246,920**	**-1,479,445**	**320,985**	**2,155,030**	**4,023,362**	**5,926,666**	**7,865,643**
NPV *(based on excel function)*	**86,617**										
IRR *(based on excel function)*	**12%**										
ROI *(gross based on Year 10 cumulative cashflow)*	**79%**										

Appendix B: F2F Model Assumptions

The following assumptions, based on the research, were made in the models:

General Assumptions	
Model factor	**Assumption**
Cost of transportation of feedstocks	The transportation cost of feedstocks into both the chemical and the mechanical recycling processes are included within the feedstock price. If feedstocks are required to be sourced from further afield – for example because of a lack of local availability – it is assumed that the additional transportation cost will be reflected in the feedstock price.
Cost of transportation of outputs	The recycling processes are a bolt-on to an existing yarn mill and located in the same building or adjacent to the yarn mill. The recycler will therefore incur no transportation costs.
Annual feedstock capacity	Both recycling processes will produce 30,000 tonnes per annum rising, in the case of the chemical process, to 50,000 tonnes in Year Four. There was insufficient information from the research to support a similar increase in mechanical process volumes.
Inflation factors	Inflation factors have been based on the Office of Budget Responsibility forecast from December 2017 and set at 2% for all cost and price factors.
Efficiency factor	The process cost savings, as a result of increases in overall production volumes in the chemical model, are assumed to be 4%, based on a rule of thumb applied in other sectors which expects cost savings of between 5% and 8% as volumes increase.
Cost of disposal of waste materials	It is assumed that unrecoverable waste materials from both processes are sent to landfill at a cost of £103 per tonne, representing a landfill tax of £89 and a gate fee of £14 per tonne. In the case of mechanical recycling, dust from processing is sent to downcycling at neutral cost.
Debt/equity	It is assumed that the process will be funded by 30% equity and 70% debt.
Weighted average cost of capital (WACC)	The WACC is estimated, from publicly available sources, at 15% and is based on that for a company such as Lenzing A.G., a botanic cellulose fibres supplier. Since Lenzing is a large, established and diversified company for whom the chemical recycling process is a relatively small part of the business, a risk premium of 10% over its WACC has been assumed. This compares with an average UK risk premium of 5.23% and is, therefore, considered appropriate for a higher risk, start-up business. A WACC of 15%, and a pre-tax cost of debt of 9%, imply a

	cost of equity of 33%, which is appropriate for a start-up with growing revenues.
Depreciation	Plant is assumed to have a useful life of 10 years and is therefore depreciated on a straight line basis at the rate of 10% annually.
Maintenance costs	Maintenance costs and spared held are assumed at the rate of 5% per annum of initial capex (index linked).
Working capital	The F2F working capital is not reflected in the mechanical financial model, as no cashflow forecast has been prepared. Additional factors that will need to be considered are i) the terms of trade negotiated with suppliers/customers; ii) the availability of invoice discounting; and iii) the initial level of working capital to be provided upfront as part of the project investment.

Additional Chemical F2F Recycling Model Assumptions	
Yields	The recycling process will yield 40% synthetic pellets and 60% cellulosics pulp for a polycotton feedstock of similar proportion.
Capacity utilisation	The plant will be utilised at the rate of 50% in Year One and 100% thereafter.
Feedstock price	The price of sorted, prepared polycotton feedstocks is £150 per tonne, inclusive of all other costs (e.g. transportation).
Solvents	The cost of solvents is £2 million for annual production volumes of 30,000 tonnes and higher, pro rata, as volumes increase. It is assumed that there is 1% solvent loss per annum that is replaced at a proportional cost.
Outputs prices	The sale price of polymer pellets and dissolving pulp is assumed to be, respectively, £700 and £720 per tonne.
Processing cost	The chemical processing cost, representing utility costs associated with (i) dissolution of fibres in solvents, (ii) separation, (iii) synthetics recovery, and (iv) cellulosics recovery, is assumed to be £90 per tonne.
Finalisation costs	Finalisation of polyester pellets is required in order to increase their intrinsic viscosity (IV) factor and is estimated at £50 per tonne. A similar process is expected for cellulosics but has not yet been defined. Therefore, a cost of £50 per tonne has been factored in to the model. This may, for example, involve rendering the dissolving pulp into a dried form, for sale and transport to third party yarn spinners.
Capital investment	Capital investment is £28 million for a 30,000-tonne plant and a further £19 million for an additional 20,000-tonne plant. Working capital investment generates a positive cash flow in the base model

	and so represents the equivalent of overdraft funding invested as equity or long term debt.

Additional Mechanical F2F Recycling Model Assumptions	
Carrier fibre	The carrier fibre is assumed to be virgin polyester.
Feedstock price	The price is assumed to be £134 per tonne for post-consumer cotton, £446 per tonne for post-industrial cotton, and £1,205 for carrier fibres.
Fibre ratio	The model assumes a ratio of 50:50 carrier to recycled fibres.
Garment preparation price	The cost for preparation of post-consumer cotton is assumed to be £268 per tonne.
Outputs prices	The sale price of recycled yarn is assumed to be £1,830 per tonne.
Capital investment	Capital investment is £10 million for a 30,000-tonne plant. Working capital investment generates a positive cash flow in the base model, and so represents the equivalent of overdraft funding invested as equity or long term debt.

Appendix C: Research Questionnaires

Copies of the two research questionnaire formats (blank) used in this project are included here:

Questionnaire: F2F reprocessors

Questionnaire: sorters & collectors