Working together for a world without waste

Technology review

A review of commercial textile fibre recycling technologies

A study to identify commercially viable textile fibre recycling technologies, to inform the development of a sustainable market within the UK for recycled fibres, including a high level business case for their operation in the UK.

Project code: MPD007-009
Research date: October-November 2012 **Date:** November 2012

WRAP's vision is a world without waste, where resources are used sustainably.

We work with businesses, individuals and communities to help them reap the benefits of reducing waste, developing sustainable products and using resources in an efficient way.

Find out more at www.wrap.org.uk

Written by: Dr Paul Thompson, Peter Willis and Nick Morley

OAKDENE HOLLINS
RESEARCH & CONSULTING

Front cover photography: Textiles pulling and recycling line – SOEX 2010

Executive summary

This report reviews commercially available textile fibre recycling technologies. Its purpose is to identify existing textile fibre recycling techniques, to inform the development of a sustainable textiles recycling market within the UK.

Technologies reviewed

The study reviewed a wide range of textile fibre recycling technologies including:

- textile sorting: manual and automated;
- mechanical recycling: flocking, nonwovens and shoddy manufacture;
- chemical recycling: polyester, nylon and polypropylene;
- carpet recycling: mechanical and chemical;
- mattress recycling: manual disassembly and;
- footwear recycling: shredding, blending and remoulding.

Wipers were excluded because they represent re-use rather than recycling to fibre.

Further work by WRAP will review developmental textile recycling technologies, but the focus of this study is on commercially available technologies.

Economic assessments

The report identified a variety of commercially available textiles technologies that could absorb additional collection volumes of used textiles, including grades of post-consumer textiles unsuitable for re-use. Further and complementary market research work is currently being undertaken by WRAP to measure the UK supply of rag and fibre.

Indicative economic assessments for UK-based operations were completed for seven different recycling technologies selected to represent the types of textiles that can be recycled. These technologies (Table 1) are the building blocks for the wider range of technologies and recycled products identified in the review.

The economic assessments highlight considerable diversity in terms of their total capital expenditure, number of employees, sales price and net profit margins. Details on the assumptions and methodology used to calculate these economic assessments can be found within the report. It is recommended, that any company considering investment in any technology should undertake their own due diligence on the technology and the financials.

Table 1 Summary of economic assessment for commercial viability in the UK of the fibre recycling technologies considered in this report

Technology	Throughput (tonnes/year)	Total capital expenditure	Number of employees	Sales price (£/tonne)	Net profit margin (%)
Automated sorting	10,000	£400,000	11	£325	11.5%
Flocking (stuffing)	5,000	£2,500,000	34	£600	6.6%
Shoddy blankets	6,000	£7,500,000	90	£2,000	3.4%
Nylon recycling	11,000	£28,000,000	35	£3,200	15.3%
Polyester recycling	10,000	£60,000,000	35	£2,500	-12.5%
Carpet shredding	10,000	£400,000	15.5	-£25	3.1%
Mattress recycling	400	£12,000	5.5	£55	2.2%

NB: The net profit margin figures are independent of automated sorting

Findings and conclusions

The findings of this report identify relatively few technical barriers for the uptake of the textile fibre recycling technologies apart from fibre to fibre systems, particularly with fibre blends. This reflects the fact that all of them are commercially available worldwide (with the exception of footwear recycling), with some already operating within the UK. Specific comments on each of the technologies are listed below.

Automated sorting

In the Netherlands, Textiles 4 Textiles has developed a technology for the automated sorting of used textiles. The technology was recently demonstrated, along with sample business cases. The technology review conducted here suggests that automated sorting is most appropriate for developing and supporting fibre-to-fibre recycling. This is because the outputs of the automated sorting process do not seem to match the feedstock specifications currently required by mechanical recyclers. Further technological and market development work of fibre-to-fibre recycling is required for its commercialisation.

Flocking and other nonwovens

Flocking and other nonwovens are both technically viable and are currently in UK operation. Particular applications include stuffing materials for mattresses and upholstery; insulation, felts and carpet underlay. The economic assessment conducted suggests that these markets are under commercial pressure, because of increasing feedstock prices and costs competition versus virgin fibres and other materials. Policy measures could be used to stimulate these markets for greater operation within the UK.

Shoddy blankets

Shoddy blankets are a large market for recycled textiles, including sourcing considerable feedstock from the UK. Manufacture is concentrated in developing countries, notably India, and is highly labour intensive. The economic assessment suggests that a more capital intensive model based in the UK is relatively marginal. In addition there is little demand in the UK for the low quality blankets that would be produced. An alternative business model, for the UK, is low volume re-spinning operations to produce niche clothing.

Chemical recycling

Two main types of chemical recycling of textile fibres were assessed in the report:

- Nylon recycling is considered to be commercially viable in a UK setting. Discussions should commence with Aquafil about bringing the technology to the UK market.
- Polyester recycling does not appear profitable using currently available technology, unless prices for the outputs well above market rates can be obtained.

Carpet shredding and mattress recycling

Carpet shredding and mattress recycling primarily focus on low value markets; notably energy-from-waste, and the separation and recycling of constituent materials. These operations and markets are relatively marginal and appear only exist because of the cost of the landfill tax. Higher value opportunities deserve greater exploration.

Contents

List of figures

List of tables

Glossary

$CaCO_3$	calcium carbonate
Closed-loop	Fibre to fibre recycling in the same application
DMT	dimethyl terephthalate
EfW	Energy from Waste
EPD	environmental product declaration
Flocking	stuffing materials for upholstery and mattresses
FYE	For Your Earth
HWRC	household waste recycling centres
LYF	Love Your Footprint
Mungo	low quality textile yarns and fabrics made from recycled fibres
NIR	near infra-red
PP	polypropylene
PUR	polyurethane (foam)
PVC	polyvinyl chloride
RDF	resource derived fuel
SBR	styrene-butadiene latex rubber
Shoddy	low quality textile yarns and fabrics made from recycled fibres
T4T	Textiles 4 Textiles
Thermoplastic	plastic that re-melts and can be remoulded

(Technical descriptions of the mechanical recycling processes can be found in Appendix 1)

Acknowledgements

We are grateful to the following organisations for assistance in the production of this report:

Allertex
Anglo Recycling
Axion Consulting
Carpet Recycling Group
Carpet Recycling UK (CRUK)
Desso
Edward Clay
EOL Recycling
Fretex International
Janesville Acoustics
JMP Wilcox
KICI Foundation
Le Relais
Loughborough University
Made-By
Nonwovens Innovation & Research Institute
Reeds Carpets
SOEX
Teijin
Textiles 4 Textiles
University College London
WE Rawson
Worn Again

1.0 Introduction and overview

1.1 Context

The growth in the quantity of textiles collected for recycling is expected to lead to a greater proportion of recycling grades which are not suitable for re-use, as lower quality textiles are discarded by consumers for collection by charities or commercial organisations. The recent WRAP report *Textiles flow and market development opportunities* estimated that around 660,000 tonnes of used textiles were being collected each year in the UK. Although most of this was being sold for re-use in the UK or overseas, an estimated 74,800 tonnes of clothing, carpets and mattresses were found to be recycled, much of it into fibres.[1]

The WRAP textiles flow report also identified around £238-£249 million worth of potentially re-usable or recyclable textiles in the UK currently discarded within the kerbside residual waste stream.[1] Capturing just an additional 10% of this resource would generate a potential sales value of almost £25 million, as well as making considerable volumes of material available for re-use and recycling. Although UK fibre recycling markets and technologies are often mature; there may be opportunities for new fibre recycling technologies, particularly those that can create new markets for recycled fibre. In addition, there is considerable retail and brand interest in fibre recycling technologies that can "close the loop", i.e. recycle fibre back to fibre that is suitable for the same product from which it came.

The purpose of this report is to identify existing textile fibre recycling technologies and to inform the development of a sustainable market within the UK for recycled fibres; to this end publicly available evidence on the available technologies and their business case for operation in the UK will be provided. This will help inform industry stakeholders (textile recyclers, waste management companies and others) of the infrastructure investment required to develop UK textile manufacturing markets or markets for recycled fibres. It is recommended, however, that any company considering investment in any technology should undertake their own due diligence on the technology and the financials.

1.2 Scope

The scope of this work includes:

- textile products: clothing, footwear, carpets, mattresses and household linens;
- textile fibres: cotton, wool, polyester, nylon, polypropylene and composites of these;
- commercially operational technologies only, i.e. not developmental technologies; and
- mechanical and chemical recycling techniques.

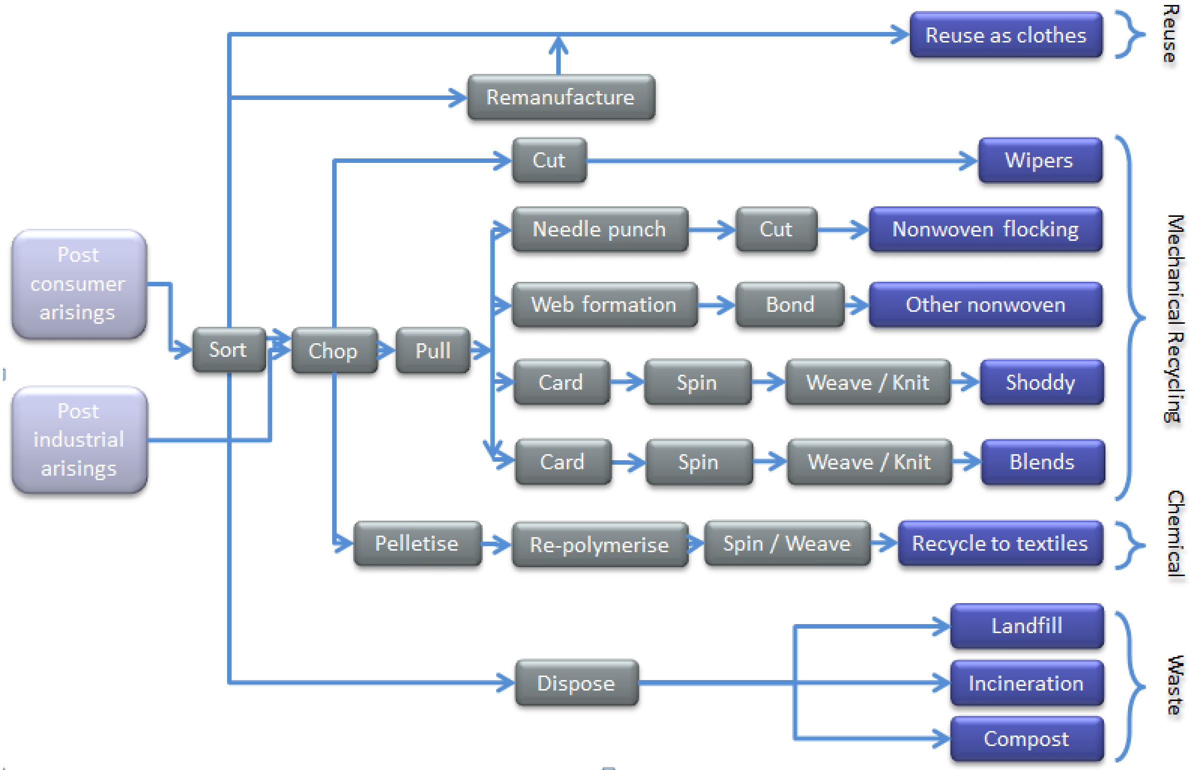
Figure 1 demonstrates textiles that can be reprocessed for re-use, be recycled, or, in the worst case, be disposed of. As the source of textiles can vary greatly (from post-production textiles, barely-worn to worn-out garments, and textiles used in upholstery or for mattresses or bedding) the physical condition of the textile will influence the potential end use. The diagram outlines the different approaches that are available. Table 2 provides further details, including a description of the materials.

In some instances the technologies used are based on well-established processes that were devised during the Industrial Revolution (approximately 1750-1850 AD); others have been developed to capture and use synthetic fibres. This review focuses on nonwoven flocking, other nonwovens, shoddy (from knitted fabrics – longer fibre lengths), mungo (from woven fabrics – shorter fibre lengths) and blends, and chemical recycling. In addition this review covers carpet, mattress and footwear recycling.

---

[1] *WRAP (2012), Textiles flow and market development opportunities in the UK; Oakdene Hollins*

Figure 1 An overview of textile re-use and recycling for post-consumer textiles



Source: Oakdene Hollins (2010), Studies on Recyclable Waste Textile; EC JRC-IPTS

Within the scope of the project, textile sorting has been included, where it affects the feedstock of the recycling operations. Wipers have been excluded from this report, on the basis that they are re-used rather than recycled to fibre.

Table 2 outlines the textile recycling technologies identified.

Table 2 Overview of the fibre recycling technologies considered in this report

Textile	Feedstock	Final Product	Company /Country	Processes
Flocking (stuffing)	Specific grades of post-consumer textiles (e.g. wool-rich) & post-industrial wastes	Upholstery stuffing and Mattress padding	WE Rawson, Edward Clay, John Cotton; UK	Chopping, pulling, needle-punching and cutting.
Other nonwovens	Recycled cotton and wool-acrylic with 15% virgin polyester fibre	Métisse (insulation)	Le Relais, France	Pulling, mixing with virgin polyester, bonding at 170 °C.
	Cotton denim fibres	Inno-Therm (insulation)	Recovery Insulation, UK	Pulling, mixing with low melt polyester, bonding.
	Production off-cuts, preferably wool-rich	Automotive felt	Autoneum, Germany; Janesville Acoustics, UK	Sorting, pulling, web formation and bonding.
	Off-cuts & fibres; post-consumer textiles	Carpet underlay; horticultural matting	Anglo Recycling, UK	Sorting, pulling, webbing and bonding.

Textile	Feedstock	Final Product	Company /Country	Processes
Other nonwovens	Post-consumer wool, cotton & polypropylene	Oil sorbent sheeting	Dafecor Oy, Finland	Shredding, sorting, crushing, treating with oil, pulling, carding, folding and needling, cutting.
Shoddy, mungo and blending	Post-consumer & post-industrial fibres, including some virgin	Shoddy blankets	Various, India	Pulling, carding, spinning, and weaving/ knitting.
Chemical recycling	Polyester rich garments and materials	Polyester fibre ECOCIRCLE™.	Teijin, Japan	Depolymerise polyester pellets using chemicals to the raw material dimethyl terephthalate (DMT).
	PVC coated polyester fibres	PVC granules & polyester fibres	Texyloop, France	Crushing and separating the PVC from the polyester fibres before re-granulating PVC.
	Nylon 6 fishing nets, carpets etc.	Caprolactam (precursor for Nylon 6)	Aquafil, Slovenia	Mechanical and chemical processing of nylon materials such as carpets.
Footwear	Used sport shoes	Nike Grind	Nike	Shredding, sorting.
	Used shoes	Soles	For Your Earth	Shredding, mixing with virgin rubber, moulding.
	Used flip-flops	Flip-flops	Okabashi, U.S.	Shredding, softening, remoulding.
Carpets	General carpet waste (sorted and unsorted)	Road construction, roofing, carpet backing/underlay, sports surfaces, horticultural matting, EfW,	Asmac Renovations, Carpet Recycling Group, ECO2 Enterprises, Anglo Recycling	Shredding
	Post-consumer nylon carpet	Nylon 6 and 6,6 Post-consumer carpet content 27%, Minimum total recycled content 61%.	Interface, U.S.	Separate yarn & backing Re-melt yarn, pelletised and extruded into fibre. Shred backing, form into pellets to create backing. Combine fibre and backing into recycled carpet.
	Post-consumer nylon carpet	Nylon 6; 25% post-consumer carpet.	Shaw, U.S.	Patented technology to convert post-consumer Nylon carpet back to caprolactam.
	Post-consumer nylon carpet	Carpet	Invista, U.S.	Antron® Lumena™ solution dyed Nylon with fibre technology. The TruBlend™ process is a work in progress.
	Polypropylene exhibition carpets	Dust bins, drain pipes, roof tiles	Reeds Carpets, UK	Cleaning, granulation, chemical recycling.
Mattresses	Used mattresses	Nonwovens, steel, carpet underlay chipboard etc.	Misc.	Manually disassembled. Steel compressed. Textiles baled and sent for nonwovens.

2.0 Textiles sorting

Textiles sorting is a crucial part of the textile fibre recycling supply chain as it provides much of the feedstock for the industry. Here commentary is provided for the conventional textiles sorting process, as well as for an innovative technology developed by Textiles 4 Textiles.

2.1 Conventional textiles sorting

2.1.1 Technology description

Post-consumer textiles are sorted according to the end application, although sorting processes vary widely in their sophistication. Clothes are sorted manually by skilled and experienced operators. Some processes use a degree of machinery, such as conveyor belts and weighing machines, but fundamentally the sorting processes are done by hand.

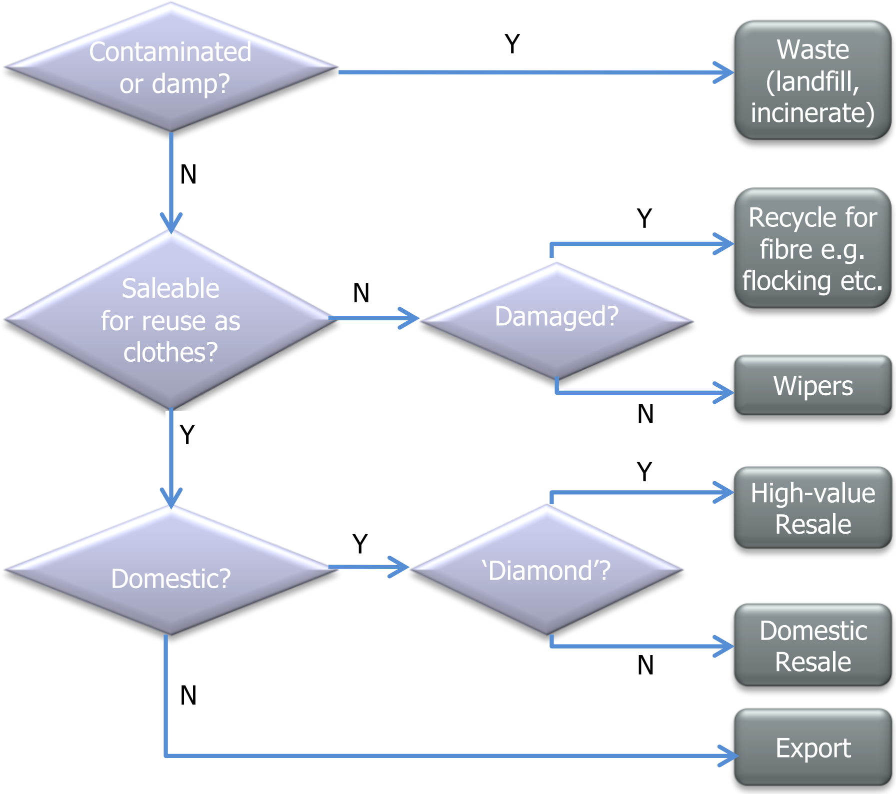
As a feedstock, textile sorting receives material from post-consumer such as charity shops, textile banks and door-to-door collection. Operators receive various types of textiles including clothing, household textiles and footwear. Unsuitable materials include damp or contaminated textiles and non-textile materials.

The sorting procedure for post-consumer textiles is: (Figure 2):

- Initial procedures remove unsuitable materials for disposal;
- The next stage is a rough sort into broad categories e.g. different types of clothing, carpets, blankets, wipers and recycling grades; and
- Finer sorting can separate these bulk categories further, in order to direct the textiles to the most suitable stream and their destination.

This finer sort uses subjective judgements of criteria such as style, weight and material type, based upon knowledge of the end markets through repeated transactions.

Figure 2 A sorting procedure for post-consumer textiles



As for outputs and markets, there is no standard list of grades as each sorter uses its own categories depending upon its customers, and, to a degree, their level of throughput. The main distinction is between grades suitable for re-use as clothing (or for wipers), and those for recycling. Grades are sold according to the input specifications of purchasers. More detail on the feedstock specifications for recyclers can be found later in each of the report in Sections 3.2, 4.2 and 5.2 respectively.

2.1.2 Economic assessment

Analysis of the economics of textile sorting revealed that the high value associated with sale of clothing for re-use accounts for 98% of a sorter's revenue, and profit margins are estimated at 5% at most for UK sorting.[2] This is in part due to the relatively high cost of labour in the UK. The marginal costs of UK textiles sorting are estimated to be at least £100 per tonne excluding transport costs.[3] This helps explain why textiles sorting is increasingly occurring overseas such as in Poland.

Recycling grades are of relatively limited value in comparison to re-use, although some revenue is generated and the costs of landfill are also avoided. Given that unsorted post-consumer textiles from charity shops, for example, cost in excess of £500 per tonne,[4] it is apparent that textile sorters make a significant loss on sorting these recycling grades. Therefore sorting for recycling is only sustained by cross-subsidisation using revenues obtained from the sale of re-use grades.

Conventional textile sorters are generally wary of receiving and sorting additional quantities of these recycling grades, and hence diluting the quality of textiles received. Consequently the proportion of recycling grades within unsorted post-consumer textiles is closely monitored. However, if unsorted textiles were to contain an increased proportion of recycling grades, perhaps as the result of increased collection of used textiles, the market price for post-consumer textiles could fall in response. One limiting factor in this market adjustment is the revenue generated for the sale of textile recycling grades versus the cost of UK sorting. Both of these are currently around the £100 per tonne level, and the cost of sorting is relatively fixed.

Sales prices for recycling grades have already risen to around £100 per tonne from £50 per tonne two years ago. This has been driven in part by the Indian market and the comparative cost versus cotton. The indications are that domestic textile recyclers are unwilling to absorb further feedstock price increases, making the UK textile sorting and recycling industries increasingly marginal in terms of their profitability. Increased textiles sorting overseas is possible due to the lower labour costs there, but this may affect the availability of textiles feedstock for domestic recycling.

---

[2] *WRAP (2012), Textiles flow and market development opportunities in the UK; Oakdene Hollins*
[3] *JMP Wilcox, personal communication*
[4] *http://www.letsrecycle.com/prices/textiles [accessed November 2012]*

2.2 Textiles 4 Textiles sorting

2.2.1 Technology description

An additional sorting technology is that developed by Textiles 4 Textiles in the Netherlands. [5] This has been developed to sort recycling grades after manual sorting of the re-use grades. It is based on a prototype developed under an EU CRAFT project (IDENTITEX) in 2000 that has been further refined. Currently a prototype system exists at a textile sorting enterprise in the Netherlands, but the system is not operating commercially.

The technology consists of the following:

1. A conveyor which elevates the mixed clothing onto the sorting line;
2. A person picks clothing from the first conveyor and places each piece of clothing onto the sorting conveyor. In a fully commercial system this person would probably be replaced by an automated system;
3. The clothing pieces pass under a near infra-red (NIR) detection system. This takes multiple measurements along each piece of clothing as it passes under the detector. If sufficient composition measurements (currently four measurements) agree, the composition is assigned. Compositions are determined by the detection system using a library of compositions and a self-learning system. Influences that affect the success of the system include temperature changes, mechanical shocks, vibrations and software. Recognition rates are currently in excess of 90% for pure fibres and around 70% for blends. Achieving higher rates depends upon greater training of the system with more materials and determining the subtle differences in spectra particularly with blends. As well as composition the detection system can determine colour and could sort e.g. light versus dark colours;
4. The conveyor then carries the clothing past a number of air blast nozzles which blow the clothing into the appropriate bin depending upon composition. Currently there are six nozzles/bins, but according to the machinery manufacturer this is expandable to as many as sixty. Maximum throughput is claimed by the machinery manufacturer as three items per second;
5. There is a control panel for the detection system and a control system with computer display that integrates the detection system into the overall sorting system. Percentages of each composition are shown in real time on a display monitor; and
6. The main services required are electricity for running the machinery, detection and control system, including an air compressor capable of 7 bar air for the air blast system.

The system is therefore well suited to markets that require fibre composition alone (e.g. chemical recycling), and do not require other forms of recognition such as denim versus other cottons, or by type or condition of clothing.

2.2.2 Economic assessment

The benefits of this technology are that it is automated and is able to sort post-consumer textiles by their colour and fibre composition. This sorting could in principle be conducted by hand, but the labour costs for Western European textiles sorting preclude this compared to the additional revenue that would be generated. The motivation behind the technology therefore is the premise that the value of recycling grades increases when the fibre composition is known and it has been sorted by colour. However, this is yet to be fully tested in the marketplace.

A detailed economic analysis was presented at a recent demonstration of the technology in the Netherlands.[6] An adapted summary is shown in Table 3 below.

---

[5] *http://www.textiles4textiles.eu/ [accessed November 2012]*
[6] *Wieland textiles presentation, business case sorting machine, November 2012*

- Investment costs for the T4T sorting machine were estimated at €430,000, and a 10 year period used for its depreciation. The machine is capable of sorting nearly 12,500 tonnes per year of used textiles, under a three shift operation, running at maximum capacity. However, in reality the machine is unlikely to operate continuously at maximum capacity owing to down time associated with maintenance or the speed at which feedstock is actually inputted. In this economic assessment an annual capacity of 10,000 tonnes is assumed, i.e. 80% capacity utilisation.
- Staff costs were estimated at 1.5 operators per shift.. However, as this does not include staff requirements for the warehouse, management, sales and administration, this appears to be an underestimate. Therefore to make it comparable to the other economic assessments in this report, 3 operators per shift has been assumed.
- Other costs are included such as for overheads and additional equipment, e.g. forklift trucks, baling machines, etc. This is in part because the machine is expected to be supplementing an existing textile sorting and recycling operation.

In terms of revenue, the business case assumes the additional sorting will offer an extra yield of €50-67 per tonne sorted. This is based upon sales prices of between €300 and €500 per tonne for the grades of sorted recycling materials, [7] and is presumed to exclude the costs of procuring feedstock. In Table 3, €60 per tonne has been modelled for the additional revenue generated. These compare to UK recycling grade prices of around £100 per tonne.

Textiles 4 Textiles noted, however, that these markets do not necessarily exist at present. For example, flocking and other nonwoven markets re interested primarily in the physical properties of their feedstock, e.g. toughness, which is markedly different between denim and T-shirts, although both could be made from blue cotton. The focus of this technology appears to be on emerging closed-loop fibre recycling technologies and higher value textile recycling such as those developed Teijin and Lenzing fibres for which this type of sorting could be an enabling technology. Some further market development appears to be necessary therefore to enable the commercial implementation of the Textiles 4 Textiles sorting technology.

Nonetheless the modelling suggests that a reasonable rate of return may be possible, with an 11.5% net profit margin estimated.

Table 3 Economic assessment for Textiles 4 Textiles sorting

Item	Quantity/Description	Cost (€)	Cost (£)[8]
Staff costs	Assumed 3 staff per shift rather than 1.5	€ 225,000	£180,000
Management/sales staff	Missing from T4T business case	€ 100,000	£80,000
Space costs	1,000 square metres at €50 per square metre	€ 50,000	£40,000
Energy costs	Based on T4T business case (3 shifts)	€ 65,000	£52,000
Overheads	Own Estimate	€ 25,000	£20,000
Maintenance	T4T business case	€ 13,000	£10,400
Sorting equipment	€430,000 CAPEX; 10 year lifetime assumed	€ 43,000	£34,400
Other equipment	Missing from T4T business case	€ 10,000	£8,000
Total costs		**€ 531,000**	**£424,800**
Revenue	Additional €60 per tonne sorted	**€ 600,000**	**£480,000**
Operating profit		**€ 69,000**	**£55,200**
Net profit margin		**11.5%**	

[7] *Wieland textiles presentation, business case sorting machine, November 2012*
[8] *Based upon a currency conversion of €1.25 = £1.00*

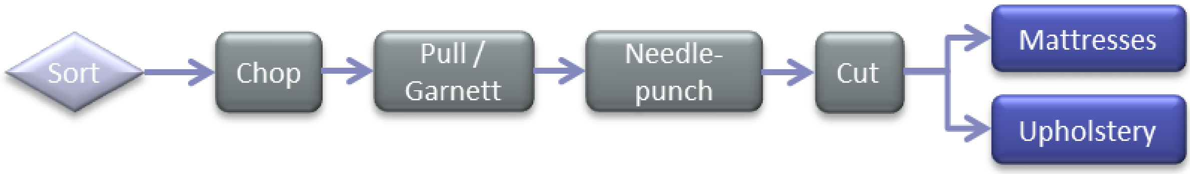
3.0 Flocking

3.1 Technology description

Nonwoven flocking, for use as stuffing materials for upholstery and mattresses, can be made from textile waste that has been chopped and pulled into fibres. Once the fibres are pulled, they are conveyed through a needle-punching machine. Fibres are blended according to their end purpose or the properties required.

After blending and pulling, samples of fibres are tested to verify wool content and low flammability before final products are made (see Appendix 1 for further technical details of mechanical recycling processes). A simplified process flow is shown in Figure 3.

Figure 3 Simplified process flow diagram for recycling to flocking



3.2 Feedstock specification

There are a number of different grades of input materials for flocking, which is fairly generic term used in the industry (Table 4). However a wide range of input grades are suitable:

- Wool based grades (flock-based and wool-rich), which are defined by their wool content and low flammability;
- Jazz materials are acrylic or synthetic mixed colour knitted material;
- Low grade: a catch-all grade for various types of post-consumer textiles; and
- Post-industrial textile wastes such as from spinning and threading.

Table 4 Example feedstock specification: Flocking material

Material description

- Sources: 100% textile material – fibres, garments, spinning and thread wastes may be used as raw materials.
- Grades: Flock-based (30-35% wool), wool rich (80% wool), jazz, low grade.

Characteristics

- Colour: Multi-coloured
- Odour: The material must not smell.
- Foreign parts: raw materials may contain foreign materials, e.g. metallic parts, plastic parts (such as metal buttons, rivets, and plastic tubes) or foam remnants.
- Delivery form: In bales up to 350 kg, with a good quality wrapping and strapping to allow ease of handling and input into machines.
- The bales must be clean, dry and without adhesions and agglutinations.

Prohibited materials

- Rubber, plastic, canvas, leather, denim, feathers, textiles from former mattresses; nylon content must be below 10%.
- The bales must not contain prohibited substances e.g. lubricants, harmful chemicals and heavy metals.

Testing procedure / incoming inspections

- New suppliers send representative samples that will be inspected on above points for quality.
- Incoming bales are given visual inspections upon arrival of content & moisture to verify quality.

Source: Produced based upon interviews with flocking manufacturers and other textile recyclers

As shown in Table 4, textiles must arrive clean and dry, as there is no washing process involved in flocking manufacture. However, due to the scale of production usually associated with flocking lines, the pulling machines are generally large enough to include suction and cyclones, and hence remove any foreign parts such as the buttons and zips contained in post-consumer textiles.

3.3 Outputs and markets

The major markets for flocking are as stuffing materials in mattresses and upholstery, such as in cushions and sofas. Currently the market conditions for both of these sectors is challenging due to the weak situation of the UK housing market.

The size of the recycled flocking market was estimated at 18,000 tonnes per year in the UK in previous research conducted for Defra,[9] although recent interviewers with manufacturers suggest that it is now significantly smaller. However, the overall flocking market, including virgin polyester and other products, is considerable larger, estimated at approximately 50,000 tonnes per year.[10] There is significant potential to expand the market for recycled flocking, as at most only around one in three mattresses currently contain recycled flocking.

The key factors in this substitution versus virgin fibres are:

- quality: recycled flocking is generally used for lower quality mattresses, and it is unlikely to substitute virgin fibres in higher end mattresses; and
- price: of underlying feedstock and cost comparison compared to virgin fibres. If recycled flocking were to become relative cheaper, it could possibly gain a greater market share.

A range of sales prices are achievable for recycled flocking starting at around £400 per tonne for the lowest quality, with £650-£750 realised for higher quality flocking.[11]

3.4 Economic assessment

The economic assessment for mechanical recycling for a typical 5,000 tonne-per-year flocking line is shown in Table 5. Smaller scale lines of 1,000-2,000 tonnes per year are also known to exist in the UK and also around the world. The economic assessment has been determined using a number of expert interviews, analysis of public accounts, as well as estimates to fill particular data gaps (more details are provided in an Appendix 2).

The largest cost is for staffing, with a total of 34 staff estimated to be employed for an operation of this scale. This includes a general manager, engineer, five admin or sales staff and a total production staff of nine workers per shift including those responsible for distribution and warehousing. The estimated factory size is 25,000 square feet including the space required for the warehouses and office. Total energy costs are approximately £150,000 tonnes per year.

Stakeholders put the capital expenditure for the recycling line equipment at approximately £2 million, the largest expense being that for a pulling machine at £1.5 million.[12] An eight year lifetime has been assumed in the straight line depreciation calculation. For other equipment such as forklift trucks, conveyor belts and bailers, £0.5 has been budgeted. The cost of the sorted feedstock is put at £100 per tonne, and an 80% production yield has been assumed. Other key costs are shown in Table 5 along with the source of their estimation. An alternative business model might be to purchase second hand equipment, at a discount

---

[9] *Defra (2009), Maximising reuse and recycling of UK clothing and textiles; Oakdene Hollins*
[10] *WE Rawson, personal communication*
[11] *Edward Clay, personal communication*
[12] *Allertex, personal communication*

of up to 50%, although this is dependent on its availability and specification, i.e. its ability to fit with other machines on the recycling line.

The sales revenue is assumed at £600 per tonne for average grade flocking and based upon a 4,000 tonne-per-year production; this gives total revenue per year of £2.4 million. Expected operating profits are estimated at approximately £160,000 per year with a net profit margin of 6.6%. Breakeven, in terms of feedstock prices, is approximately £130 per tonne. This assumes that all other costs and revenues are held constant. These results compare sensibly to the margins and profitability suggested by public accounts and the market commentary given by stakeholders.

Table 5 Economic assessment for flocking

Item	Quantity/Description	Cost
Staff costs	34 staff, includes national insurance contributions	£681,806
Rent	25,000 square feet at £4 per square foot	£100,000
Business rates	Tax rate of 40.7% applied to rental costs	£40,700
Energy costs	Based upon estimate by equipment manufacturer	£150,000
Other utilities	Own Estimate	£50,000
Transport	Based upon estimate by textile sorter	£150,000
Overheads	Estimate	£80,000
Maintenance	Estimate – 5% of CAPEX	£50,000
Recycling line equipment	£2,000,000 CAPEX; equipment manufacturer estimate, 8 year lifetime assumed	£250,000
Other equipment	£500,000 CAPEX; estimate, 4 year lifetime	£125,000
Feedstock	5,000 tonnes at £100 per tonne	£500,000
Disposal	1,000 tonnes at £64 per tonne	£64,000
Total costs		**£2,241,506**
Revenue	4,000 tonnes at £600 per tonne	**£2,400,000**
Operating profit		**£158,494**
Net profit margin		**6.6%**

3.5 Barriers and enablers

The barriers and enablers for the mechanical recycling of textiles into flocking materials for mattresses and upholstery are summarised in Table 6. It is already a relatively large market, and may be able to increase further should it become more cost competitive versus virgin fibres. On the negative side, the movement away from wool-rich clothing means that extra wool content is sometimes added to ensure low flammability properties are achieved. Different legislation on flammability properties is associated for each end-market.

Table 6 Summary of the barriers and enablers for flocking in mattresses and upholstery

Enablers	Barriers
Large market for recycled textiles, and potentially grow further.	Competition from virgin polyester products means market in decline.
Can take quite a wide range of materials, from both post-consumer and post-industrial sources	Weak performance outlook in home-building limiting demand for furniture and mattresses.
	Move towards man-made fibres and away from wool-rich clothing making the addition of flame retardants necessary to low-wool content mixes.

4.0 Other nonwoven fabrics

4.1 Technology description

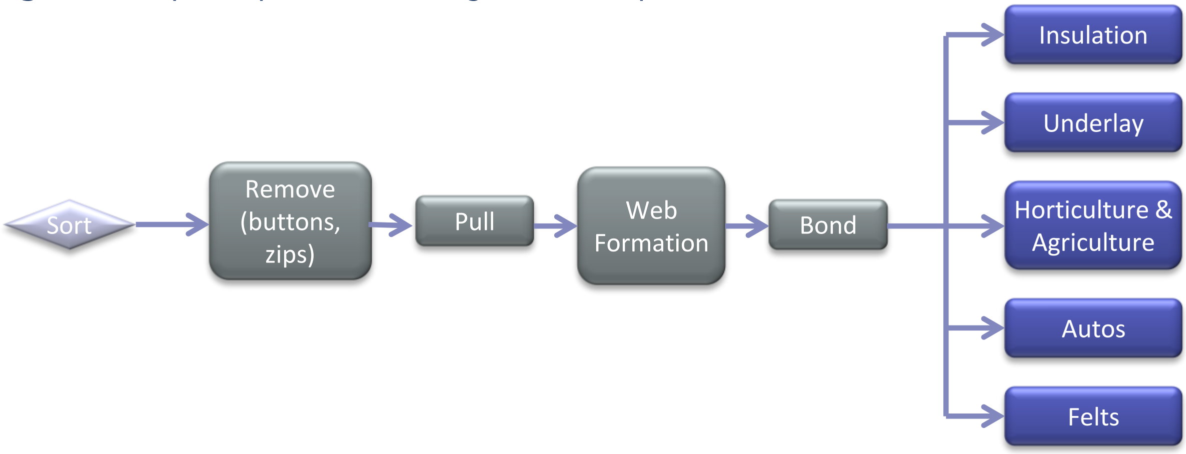
In addition to flocking products, there are a wide variety of other nonwoven products that can be produced from the mechanical recycling of used textiles. Figure 4 summarises the processes that are involved.

Once the textile waste has been sorted, the textiles are pulled to separate their fibres. Due to the smaller scale of the production associated with many other nonwoven products, foreign parts such as buttons and zips often must be removed by hand before the pulling process.

Then the fibres are then formed into webs and the webs are bonded. In spite of their various end applications, the web-formation processes are much the same for each product. These web-formation processes include carding and air-layering. Air-laying is the most efficient process but it requires a certain scale of operation of at least 5,000 tonnes per year; so for small scale production carding is often the preferred process.[13] (See Appendix 1 for further technical details of mechanical recycling processes).

For bonding there are typically multiple processes involved, the most common being thermal bonding as well as needle-punching, although horticulture and agriculture will card and needle-punch (see Appendix 1 for further technical information on recycling processes).

Figure 4 Simplified process flow diagram for the production of nonwovens



4.2 Feedstock specifications

The quality of the textile fibres is important in determining uses, and many recyclers prefer or even limit their feedstock to post-industrial off-cuts and fibres. Manufacturers also commonly source textile fibres that have already been pulled.

This is the case for automotive applications, as noted by a French government report,[14] and confirmed for the UK situation from other interviews (see example specification in Table 7). Recyclers such as Anglo Recycling in the UK also share this preference for post-industrial wastes for the manufacture of products such as underlay and matting.

Some other nonwoven applications such as oil absorbent products can take a wider range of input feedstock.

---

[13] *Matthew Tipper, NIRI, personal communication*

[14] *État de l'art du tri et de la valorisation des textiles d'habillement, du linge de maison et des chaussures consommés par les ménages, ADEME 2009*

Table 7 Example feedstock specification: post-industrial off-cuts for automotive felts[15]

Material description ■ Sources: 100% textile wool scraps, new material with >60% wool, only unused textiles (not any worn clothes) may be used as raw materials. **Characteristics** ■ Scrap size: Scraps are from the clothing industry; the clothing scraps must not be longer than 5m to make them suitable for handling. ■ Colour: Multi-coloured. ■ Foreign parts: The raw material must not contain any foreign materials like metallic parts, plastic parts (such as metal buttons, rivets, plastic tubes) or foam remnants. ■ Odour: VDA 270, sample quantity: 5g compressed, rating <=3. ■ Delivery form: In bales, fibre density in the bales: 500-700 kg/m^3. ■ The bales must be clean, dry and without adhesions and agglutinations. **Prohibited substances** ■ The bales must not contain prohibited substances, e.g. harmful chemicals and heavy metals. **Test certificates / incoming inspection** ■ Inspection certificate: Incoming deliveries must be certified according to the points 1, 2.1, and 2.2. Alternatively there may be an incoming inspection on arrival (fee required). ■ Requalification test: Once a year, to guarantee continuous delivery quality, the supplier has to carry out a requalification test. The test results must be made available on demand.

Source: based upon a sample specification received from an automotive felts company and other textile recycler interviews

4.3 Outputs and markets

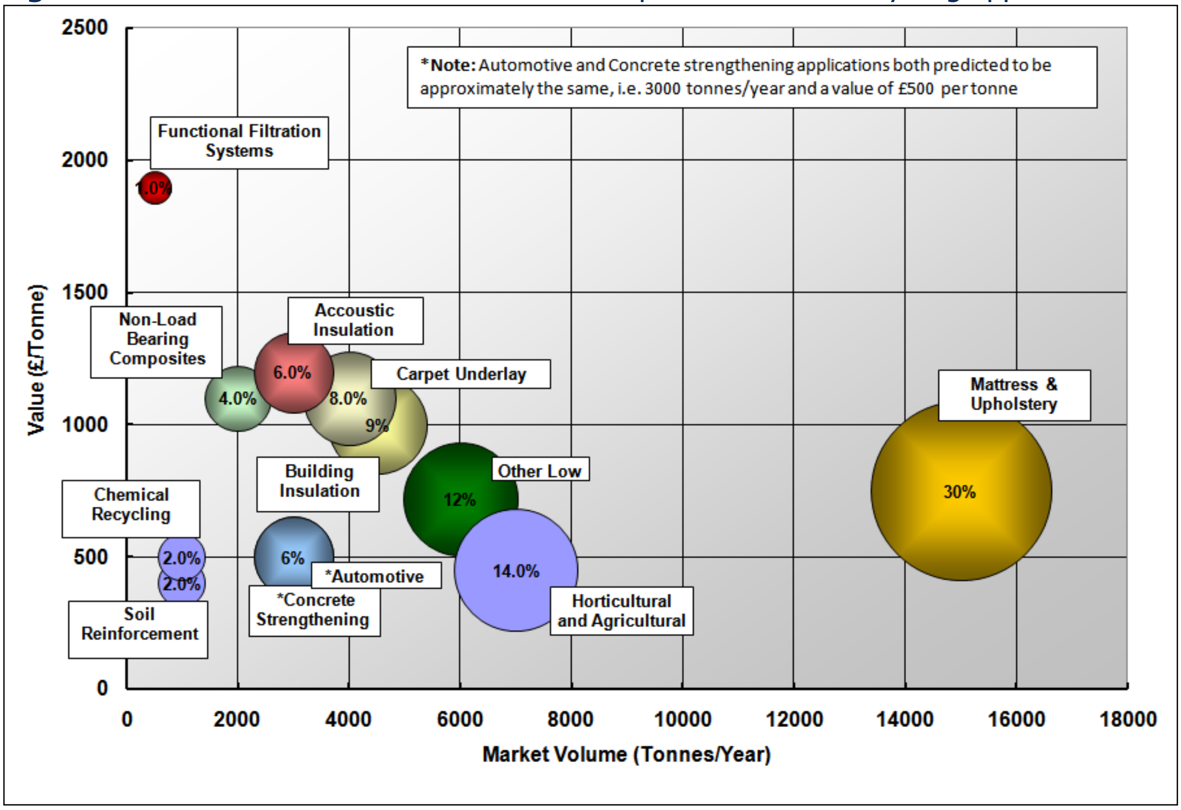
End markets for products made from this process include carpet underlay, automotive felt, insulation, oil sorbent materials and horticultural and agricultural products. In terms of the current size of these markets, recent data published by WRAP is not totally conclusive due to the number of textiles sorters who did not know the end-markets for their recycling grade (more than 50% of the weight of destination of recycling grades was unknown).[16]

However, the estimates seem to be in line with those published by Defra in 2009. In that survey of UK textile recyclers, the market size for these other nonwovens was approximately 8,500 tonnes per year, with around 3,000 tonnes recycled into carpet underlay, 3,500 tonnes into automotive felts and a further 2,000 tonnes into other nonwoven applications.[17]

In terms of the potential market size, this was estimated in a Defra (2009) report, under the assumption that collection of recycled textiles increased to 30,000 tonnes per year and carpets collection to 20,000 tonnes per year. Modest increases in energy and raw materials prices were factored in, as was the progression of a range of developmental market applications of nonwoven materials. This forecast is shown in Figure 5 for each of the major nonwoven applications, although it does not appear to be realised in the latest WRAP statistics.

[15] *The VDA 270 odour test involves storing a sample in an odourless jar under defined conditions (temperature, humidity, time). This is followed by the evaluation of the odour by a panel according to a six-part rating scale.*
[16] *WRAP (2012), Textiles flow and market development opportunities in the UK; Oakdene Hollins*
[17] *Defra (2009), Maximising reuse and recycling of UK clothing and textiles; Oakdene Hollins*

Figure 5 Estimated UK market size and value of potential textile recycling applications



Source: Defra (2009), Maximising reuse and recycling of UK clothing and textiles; Oakdene Hollins

4.3.1 Carpet underlay

One of the main end markets for nonwovens is carpet underlay, which can be made from recycled carpet. Wilcox specify 60% wool, 40% other (mostly polyester) for underlay. Anglo Recycling produces four types of underlay made from different input materials. Reco Wool underlay is made from recycled carpet fibres from carpet off-cuts, while FR Endurance underlay is made from recycled coffee and rice sacks and recycled wool. The Polymer-Felt range of underlays and the Felt Rubber Combination range both use recycled textiles including wool and have a recycled rubber backing. When these underlays are fitted, the natural 'give' in the wool, helps to even out any imperfections in the sub-floor.

4.3.2 Automotive felt

Another market for nonwovens is automotive underlay. For such uses only post industrial waste is suitable. Some applications (floor of vehicle, boot and under-bonnet) allow only 20-30% recycled synthetic fibre (typically polypropylene), whereas other applications (between the body and wheels, parcel shelves and ceiling) allow 70-80% recycled cotton[18]. These limitations are related to issues of mechanical strength and flame retardancy. The use of cotton in floor mats requires the use of flame retardants, while in other applications the use of cotton is prohibited owing to its flammability. In the UK, Anglo Recycling produces automotive felt made from 100% recycled natural fibres.

[18] *(ADEME 2009) État de l'art du tri et de la valorisation des textiles d'habillement, du linge de maison et des chaussures consommés par les ménages*

4.3.3 Insulation

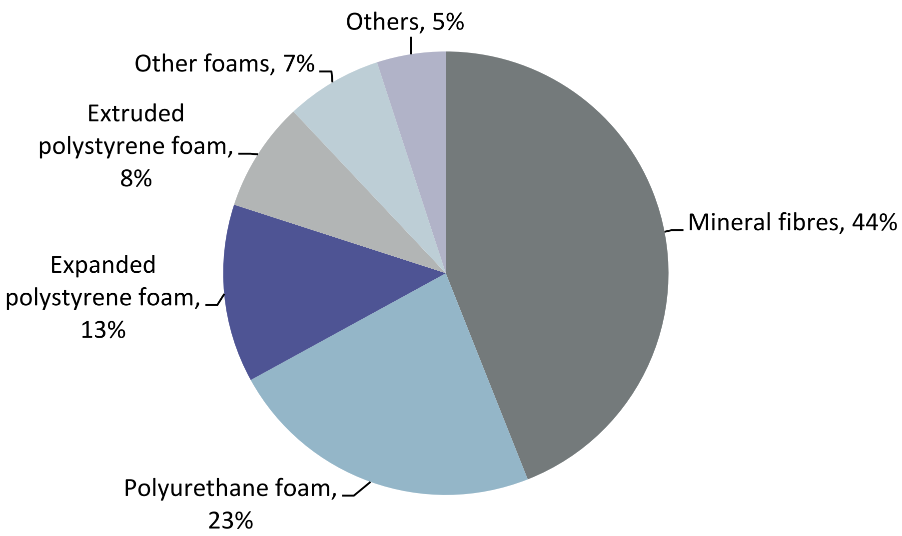
For insulation products manufactured from recycled textiles, two examples were identified:

- In the UK, Recovery Insulation manufactures a floor or acoustic insulation product called Inno-Therm® which is made from denim (industrial waste and jeans). In the U.S. a similar product called UltraTouch™ is made from denim by Bonded Logic Inc. and contains 80% post-consumer natural fibres; and
- In France, Le Relais makes insulation material from recycled textile fibres for acoustic and thermal insulation for walls, roofs, attics, partitions and floors.[18] It is made of 85% recycled textile fibres that come from second-hand clothes (70 % cotton, 15% wool-acrylic, or 45% cotton and 40% wool-acrylic) and 15% polyester. It has very low embodied energy (as it is collected, sorted and produced in France) and the product can itself be recycled when removed. Le Relais also make a loose insulation material made of recycled fibres.[19]

Overall predictions of the volume of insulation to be used relating to new buildings and renovations in the UK between 2006 and 2020 is calculated at nearly 400 million m^3 (approximately 11 million tonnes).[20] However, currently textile based insulation represents a very minor share of the market (perhaps just a few percent), with the majority being mineral fibres and foam based insulation (Figure 6).

Whilst textile-based insulation does offer high technical performance, it does not appear to be cost-competitive versus the alternatives. This is in part due to the cost of meeting fungal and flame retardant treatments necessary to comply with building codes.[21] For example Inno-Therm requires fire retardant to meet BS 5852 for fire safety.

Figure 6 Insulation types broken down by market value (%)



Source: Market Transformation Programme (2008), Insulation industry, product and market overview

[19] *Métisse Catalogue Produit, 2012*
[20] *Market Transformation Programme (2008), Insulation industry, product and market overview*
[21] *The elements to the BBA insulation are: internal fire spread, resistance to weather and ground moisture, conservation of fuel and power and materials and workmanship. See http://www.bbacerts.co.uk/ for examples of certifications.*

4.3.4 Oil sorbent materials

Another market identified in this research is oil sorbent materials for heavy industry. In Finland, oil sorbent materials are made by by Dafecor Oy. These require 50% wool with the remaining components being other materials such as polypropylene, or cotton and mineral oil lubricants.

There are again a significant number of competing materials in this market such as absorbent foams and paper. In the UK, for example, New Pig Ltd use recycled newsprint in products such as absorbent socks, which are used to absorb oil spills. Therefore, although this market can take a wide variety of feedstock it should be considered relatively low value. No overall estimate of the potential market size was identified.

4.3.5 Horticultural and agricultural matting

Nonwovens are used in the horticultural and agricultural sector for capillary matting and geo-textiles. This matting absorbs water, allowing plants placed on the matting to have a ready source of water from which they can draw, preventing them from drying out. Markets for these recycled productsare smaller and the quality of the products is less proven.

In the UK, Anglo Recycling makes horticultural capillary matting for a number of different applications. Matting made from 100% recycled wool is used by garden centres, nurseries and retail outlets and can be engineered to suit different applications, such as areas receiving a high degree of foot traffic or areas that need to be easily cleaned. Matting for biodegradable hanging basket liners can be made from recycled wool or from jute, which is recycled from cocoa and rice sacks. Matting from recycled jute is also used to make pot tops, which when placed around the top of plants helps protect them against weed growth. These pot tops can also be made from recycled polypropylene, which extends their lifetime and allows for their reuse. Edward Clay & Son Ltd is also active in this market with recycled jute products.

4.4 Economic assessment

For the other nonwoven applications there is a relative lack of information available on the costs and revenues that are applicable, so a detailed economic assessment is not possible to complete. This is in part due to commercial sensitivities as many of these recycling lines adapt equipment with the effect of creating a bespoke line, which they do not wish competitors to be able to replicate.

However, due to the similarity of the processes and costs involved in other nonwoven production compared to that of flocking production and shoddy, a degree of commentary is possible. The main differences that may emerge are the additional cost associated with using a proportion of virgin fibre, which may help realise a higher sales price for final product. This is linked to the choice of bonding process, i.e. needle-punching or carding versus thermal bonding. The cost of needle-punching versus carding or thermal bonding equipment was deemed to be relatively equivalent by stakeholders.

Ultimately the capital expenditure is estimated to be of the same order of magnitude as the £2 million required for the flocking recycling line. All of the other nonwoven lines incorporate a pulling machine, which is the major capital expenditure item. Second hand equipment is also a possibility (if available), and can offer a 50% discount. Other key costs such as for staff, rent, energy and transport are likely to be similar for a plant of a comparable scale. Yields are likely to be at most 80% because of the losses associated with pulling.

4.5 Barriers and enablers

To conclude by discussing the barriers and enablers that are observed for these products. These are summarised in a single table (Table 8), with further details provided for specific products in the relevant sections of 5.3.

All products are made to certain specifications relating to levels of performance (generally set by the customer), which means that products made using recycled textiles must be comparable to those of virgin product. This can lead to a preference for production off-cuts rather than post-consumer textiles. As with flocking, there is a relative decline away from wool-rich textiles; this is having an impact on the sector with respect to ensuring low flammability.

Other markets, such as insulation and oil absorbency, are potentially large markets for recycled textiles. However, there is strong cost competition against virgin or other types of materials, e.g. with mineral wool for insulation applications, absorbent foams for oil sorbent materials. Further discussion is included above in the relevant sections.

Table 8 Summary of the barriers and enablers for other nonwoven applications

Enablers	Barriers
Diverse range of current applications, so limited dependency on specific sectors.	Many applications limit production to off-cuts from production to maintain quality.
Promising new applications are in development. (Figure 5)	Can be a reluctance to shift from virgin fibres in some sectors.
	Shift away from wool may require imports to ensure low flammability.
	Often strong competition with virgin or other types of materials.

5.0 Shoddy, mungo and blending

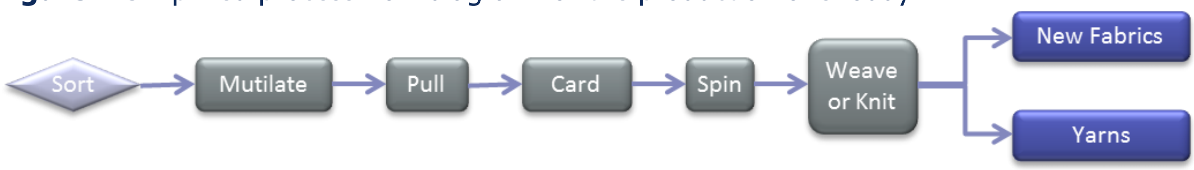
Shoddy and mungo are terms that are used relatively interchangeably to define low quality textile yarns and fabrics spun from recycled fibres. Generally a proportion of virgin fibre such as polyester or wool is blended to improve the properties of the shoddy yarn. The production of shoddy and mungo is currently limited to developing countries such as India and Morocco.[22]

5.1 Technology description

The processes involved in the production shoddy are numerous, as it involves pulling post-consumer textiles into fibre, before carding, spinning the fibres back into yarn, which can then be woven or knitted into new fabrics (Figure 7).

In India, the largest world's producer of shoddy, the industry is structured in three main parts: sort through to spin, weaving from yarn, and finishing mills. Some are fully integrated but most are small and separate. The processes involved in this are sorting, pulling and carding (See Appendix 1 for full details). The recycled fibres are then spun, woven/knitted in processes as is conducted for production of virgin yarns and fabrics.

Figure 7 Simplified process flow diagram for the production of shoddy



As a preliminary to the recycling process a detailed manual sorting process is undertaken first by broad material type and then by colour. This is a very labour intensive process with sorting conducted to around 16 shades for each colour. Other processing steps are the manual removal of buttons, zips and labels (metals are recycled and plastics are burnt), and the addition of batching oil to lubricate the process.

5.2 Feedstock specifications

Three main categories of post-consumer textiles are received to make shoddy (Table 9):[23]

- acrylic: loose knitted jumpers, synthetics, acrylic shoddy;
- original wool rag: coats, suits and jackets; and
- commercial all wool: 70-80% wool hosiery, i.e. jumpers etc.

Post-industrial waste such as cotton trimmings are accepted, and highly valued, as it is possible to re-use and make new garments by blending the recycled fibres with virgin fibres. Extra wool or polyester from post-industrial sources may be added if necessary, depending upon the eventual end-market.

In order to export textiles to reprocess into fabrics to countries such as India, where there are restrictions on the importation of second hand clothing, garments must be 'mutilated' prior to shipping: items are damaged sufficiently so that they cannot be re-used.[24] Detailed sorting is therefore commonly carried out in Gujarat (a Special Economic Zone) before mutilation and onward transit to places like Panipat in Haryana state in Northern India. Some sorting might be conducted within Europe, such as into the three main categories, although further sorting is conducted by colour outside of Europe.

---

[22] *Maximising Re-use and Recycling of UK Clothing and Textiles, Oakdene Hollins 2009*
[23] *Lucy Norris, UCL, Personal Communication, 2010*
[24] *This legal requirement may appear to be contrary to the waste hierarchy, but differences in climate second hand jumpers and coats have much less demand for re-use in African or Asian countries and are therefore widely available for recycling.*

Table 9 Example feedstock specification: Shoddy, mungo and blending

Material description

- Sources: 100% textile material; mutilated post-consumer textiles as raw materials.
- Grades: Commercial all wool: 70-80% wool hosiery, i.e. jumpers etc.; Acrylic loose knits: 100% synthetic hosiery, i.e. jumpers; Original woollen rag: 70-80% wool cloth, i.e. old coats.

Characteristics

- Colour: Multi-coloured (sorted into 16 shades of each colour on arrival).
- Odour: The material must not smell.
- Foreign parts: The raw material may contain foreign materials like metallic parts, plastic parts (such as metal buttons, rivets, plastic tubes) or foam remnants.
- Delivery form: In bales; vacuum-packed bales should be approximately 350 kg; loose bales can be 500-1,000kg; the bales must be clean, dry and without adhesions and agglutinations.

Prohibited substances

- The bales must not contain prohibited substances e.g. harmful chemicals and heavy metals.
- No specific fibre types contained in post-consumer textiles are expressly prohibited.

Testing Procedure / incoming inspections

- Bales are given visual inspections upon arrival of mutilation, content, and moisture to verify quality.

Source: based upon an interview and additional information provided from Lucy Norris at UCL

5.3 Outputs and markets

The end markets for the products of shoddy are woven fabrics that can then be made into new clothing, knitted blankets or jumpers, or yarns that tend to be exported to Africa. The quality of the output varies considerably. In Amritsar where quality inputs that are well sorted and more modern pulling machines are used, high quality output is achieved that can be sold to the middle classes or exported.[25]

The majority of shoddy the produced in India are low quality blankets, which are sold in India or as emergency blankets. Estimates of the scale of shoddy production in India are as follows:[26]

- Official imports of rag as a raw material was 110,260 tonnes in 2007/08;
- Outputs in Panipat for that year were 40,700 tonnes of yarn, 38,000 tonnes of shoddy fabric and 17 million blankets. 90% of blankets were sold to the domestic India market; and
- At least 70,000 people are employed by the industry at salaries ranging from $1.40 per day for unskilled roles to $3.50 for skilled spinners and weavers working a 12 hour shift.

5.4 Economic assessment

Conducting an economic assessment of shoddy manufacture that would be applicable for the UK is relatively challenging, as the industry structure is likely to be very different; therefore only approximate estimates are possible. For this economic assessment to be applicable for the UK, it has been assumed that a considerable portion of labour is substituted by additional capital. Nonetheless it has been assumed that 90 staff would work at this 5,000 tonne per

[25] *Lucy Norris (2005), Cloth that lies: the secrets of recycling, in Küchler, S. & Miller, D. (Eds.). Clothing and Materiality, Oxford, New York: Berg*
[26] *Lucy Norris (2012), Recycling imported second hand textiles in the shoddy mills in Panipat, India: an overview of the industry*

year facility (rather than approximately 3,000, as would be the case in India). These additional staff represent the numerous additional stages associated with dying, spinning and weaving to produce the final product; there will be additional sales staff, travel and transport costs due to the more fragmented and international customer base that is likely.

Many of the other costs have been scaled upwards to account for the increased size and complexity of the operation. CAPEX for dying, spinning and weaving equipment has been put at £4 million. For the recycling line, CAPEX of £2.5m has been assumed, although in India, second hand equipment is known to be commonly used instead of new equipment due to the cost savings that it offers. As very limited amounts of dying, spinning and weaving currently takes place in the UK, machinery may need sourcing from overseas.

The cost of additional sorting and virgin polyester are put at £150 per tonne and £2,000 per tonne respectively. Yield losses are assumed to be 20% at the pulling stage, and a further 20% for spinning and weaving. Because of the quantity of recycled fibres associated it is assumed that they cannot be return to the recycling process.

Sales prices are put at £1 per blanket weighing 0.5kg or £2,000 per tonne, which are realised for 4,000 tonnes of product. Operating profits are estimated at £275,000 implying a net margin of 3.4%. Breakeven, in terms of feedstock prices, are above £150 per tonne, suggesting that the industry may be able to outbid flocking for appropriate feedstock.

Table 10 Economic assessment for shoddy

Item	Quantity/Description	Cost
Staff costs	90 staff, includes national insurance contributions	£1,847,289
Rent	60,000 square feet at £4 per square foot	£240,000
Business rates	Tax rate of 40.7% applied to rental costs	£97,680
Energy costs	Based upon estimate by equipment manufacturer	£300,000
Other utilities	Estimate	£150,000
Transport	Based upon estimate by textile sorter	£300,000
Overheads	Estimate	£250,000
Maintenance	Estimate	£100,000
Recycling line equipment	£2,500,000 CAPEX; equipment manufacturer estimate, 8 year lifetime assumed	£312,500
Dying, spinning, weaving equipment	£4,000,000 CAPEX; own equipment, 8 year lifetime assumed	£500,000
Other equipment	£1,000,000 CAPEX; estimate, 4 year lifetime	£250,000
Feedstock	5,000 tonnes at £100 per tonne	£500,000
Additional colour sorting	5,000 tonnes at £150 per tonne based upon estimate provided by textile sorter	£750,000
Virgin polyester	1,000 tonnes at £2,000 per tonne	£2,000,000
Disposal	2,000 tonnes at £64 per tonne	£128,000
Total costs		**£7,725,469**
Revenue	4,000 tonnes at £2,000 per tonne	**£8,000,000**
Operating profit		**£274,531**
Net profit margin		**3.4%**

5.5 Barriers and enablers

The main barriers are summarised in Table 11. It is already a very large market for UK recycled textiles, taking a diverse range of input materials, although all of it is currently located outside of the EU. It is, however, a well-established industry in countries such as India, which appears to receive feedstock sourced from all over the world.

Recent statistics published by WRAP showed that approximately 60% of recycled grades arising within the UK (approximately 21,000 tonnes) were exported overseas.[27] Much of this is presumed to be manufactured into shoddy yarn, fabrics and blankets in India.

The economic assessment has identified that even with a large degree of substitution of labour by capital; the technology appears to be fairly marginal within the UK. Although the costs for Indian companies are not known, the economics of the process may be unfavourable in the UK and could lead to UK recyclers being outbid for feedstock.

The other major market barrier here is the lack of an end-market for shoddy blankets in the UK. Customers would therefore have to be located around the world, which represents a major risk to the successful operation of the business.

One example of a European company that did previously manufacture shoddy blankets for the emergency relief market is Fretex in Norway. However, Fretex withdrew from this market in 2010 citing the complexity and cost of the operation.[28] Fretex sold their machinery to a Chinese organisation.

More "niche shoddy" production may be possible in UK, for example, pulling and re-spinning high value fibres to produce new products. This is likely to be on a small scale in order to retain fibre length (large machines are too aggressive). A possible model is that for cashmere fibres, which is being pulled and re-spun in Italy for M&S. Additional examples in corporate wear also exist.

Table 11 Summary of the barriers and enablers for shoddy, mungo and blending

Enablers	Barriers
No materials are explicitly prohibited	All production is located outside EU.
	Industry has been associated with illegal activities e.g. smuggling.
	Little demand for shoddy blankets in the UK.

[27] *WRAP (2012), Textiles flow and market development opportunities in the UK; Oakdene Hollins*
[28] *Fretex, personal communication*

6.0 Chemical recycling

Chemical recycling processes take synthetic fibres, which are chopped and pelletised. This is then depolymerised using chemicals and re-polymerise to make new fabric. An overview of this process is shown in Figure 8. Specific details of the equipment are not available due to commercial confidentiality.

Figure 8 Simplified process flow diagram, chemical recycling

The research has identified three main commercial examples of the chemical recycling of textiles, each addressing different fibre types.

6.1 Teijin polyester recycling

The most widely quoted example of the chemical process utilised in the Teijin ECOCIRCLE™ system in Japan. This process makes polyester pellets from the garments, decomposes them using chemicals such as hydrochloric acid and sodium hydroxide, and returns them to the raw material (dimethyl terephthalate, DMT). This can then be polymerized again and finally spun into new ECOCIRCLE™ polyester fibres.

The outputs of the Teijin chemical recycling process are polyester fibres, equivalent in quality to virgin fibres, which can be woven again into polyester fabrics for apparel or other applications. However, the economics of the chemical processes are not favourable compared with virgin fibres (10-20% more expensive) so these processes are likely to remain low volume. The capacity of the Teijin plant is 10,000 tonnes of polyester per year, with an estimated 8,000 tonnes per year currently being utilised.

The feedstock specifications for the Teijin process are 100% polyester fabrics and also polyester rich fabrics where at least 80% of a garment's weight must be polyester. This however, excludes many common polyester/cotton mixes.[29] As zips and buttons are separated during the chemical recycling process, there is no need to remove them beforehand.

6.2 Texyloop PVC recycling

In France Texyloop recycle polyester textiles are coated in PVC. The process involves crushing and separating the PVC fibres before re-granulating using regeneration solvents and additives to enable PVC precipitation.[30] This process enables 100% recycling of the feedstock, and produces PVC granules and polyester fibres as outputs. These can be used to make products such as fabric, nonwoven insulation and waterproof membranes for ponds. The recycled polyester fibres fully substitute virgin material.

Texyloop recycles tarpaulins and sheets made of PVC coated polyester and off cuts from the manufacture of these materials. The plant has a capacity of 4 million m^2 per year (2,000 tonnes).[31] The main barrier apparent for its wider uptake is the insufficient supply of feedstock to allow for more than one processor.

[29] *Join Our "ECOCIRCLE"! s.a.; Recyclable items s.a.; Teijin Limited Annual Report 2008, 16*
[30] *ADEME (2009), État de l'art du tri et de la valorisation des textiles d'habillement, du linge de maison et des chaussures consommés par les ménages*
[31] *ADEME (2009), État de l'art du tri et de la valorisation des textiles d'habillement, du linge de maison et des chaussures consommés par les ménages*

6.3 Aquafil nylon recycling

6.3.1 Technology description

In Slovenia, Aquafil recycle nylon from a variety of post-consumer and post-industrial waste using both mechanical and chemical processes to recycle Nylon 6 into Caprolactam, the precursor for Nylon 6. The process begins by shaving and grinding the feedstock to obtain a Nylon6 fluff; and oligomers, which are waste generated by polymer industries in the production of Nylon 6. The oligomers are collected and partly ground to a suitable dimension for further processing. The method used for recycling the waste Nylon 6, termed the Econyl® process, purifies the waste materials without degrading the polymer, delivering a sustainable closed-loop polymer fibre system. The processes involved are collection and sorting of Nylon 6 feedstock, monomer recovery, and polymerisation. The fibres can then be spun and woven into new fabrics.

Chemical recycling of Nylon carpet also is increasingly common in the US. The benefits of chemical recycling are that there are no losses in product quality and the process is repeatable so that a closed-loop recycling system is possible. For post-industrial carpet waste BASF, the world's leading chemical company, has been recycling Nylon 6 for more than 30 years using a six stage process. [32]

6.3.2 Feedstock specifications

The Aquafil plant takes a wide variety of Nylon 6 feedstocks, including fishing nets, clothing and carpets. For example the facility is used by Desso for recycling Nylon 6 carpet tiles.[33] Aquafil is procuring post-consumer and post-industrial Nylon 6 wastes. An example feedstock specification is shown in Table 12. Nylon 6 and Nylon 6.6 cannot be mixed for chemical recycling due to the differing chemical composition of the polymers.

The resulting product uses a mixture of 70% recycled Nylon and 30% virgin fibre, though Aquafil hope to increase the quantity of recycled material to 100%.

Table 12 Example feedstock specification: Chemical recycling (Aquafil)

Material description

- Sources: 100% nylon materials; from both post-consumer and post-industrial
- Articles: acceptable articles include fishing nets, clothing and carpets

Characteristics

- Colour: Multi-coloured.
- Foreign parts: The raw material may contain foreign materials like metallic parts, plastic parts (such as metal buttons, rivets, and plastic tubes) or foam remnants.
- Delivery form: In bales; Bales must be clean, dry and without adhesions and agglutinations.

Prohibited materials

- The bales must not contain prohibited substances e.g. harmful chemicals and heavy metals.
- The bales must not contain polyester, nylon 6.6, polyurethane, acrylic, animal materials (wool, leather, linen, hemp).

Test certificates / incoming inspection

- Bales are given visual inspections upon arrival of content, colour, size, moisture to verify quality.

Source: based upon an interview with a chemical recycler and additional information from the literature

[32] *Maximising Re-use and Recycling of UK Clothing and Textiles, Oakdene Hollins 2009*
[33] *Keith Hall, Personal Communication, DESSO*

6.3.3 Outputs and markets

The output of the Aquafil process is Caprolactam, which is the chemical precursor for manufacturing Nylon 6. This is used to make Nylon 6 fibre, which can be used in a wide variety of applications, including the manufacture of new carpet. The quality of the fibres produced is equivalent to virgin nylon fibres.

Given that an estimated 58,800 tonnes of nylon and bitumen based carpet tiles arise in the post-consumer carpet waste stream per year, [34] there is therefore ample feedstock for a similar plant to be located within the UK.

6.3.4 Economic assessment

In 2011 the Aquafil Group in the US commissioned the Econyl Process, a Nylon 6 recycling operation in Slovenia.

An economic assessment of the Aquafil nylon recycling process has been conducted using publicly available information in the literature, as well as a number of educated estimates from a chemical engineer with experience in chemical process plant estimation and construction, such as on the number of staff likely to be employed and the identity and proportions of chemicals and water treatment required. In comparison to the mechanical recycling processes, chemical recycling involves a relatively small number of highly trained and therefore more expensive workers.

For a plant of around 10,000 tonne capacity (receiving feedstock of 11,000 tonnes and producing output of 10,000 tonnes per year[35]), 35 workers are expected and a total of £1.15 million has been budgeted, representing an average salary in excess of £30,000 per year. However, the cost of energy is significantly higher than that of labour, estimated at nearly £13 million per year. These estimates are based upon data contained in an EPD conducted by Aquafil.[36]

Capital expenditure for the plant is much higher at £20 million for the plant and a further £8 million for other equipment. Annual maintenance has been assumed to be 5% per year. Feedstock comprises a mixture of post-consumer and post-industrial sources with a cost per tonne thought to be relatively high to account for additional sorting costs and transportation from all over the world. Revenue is put at £3,200 per tonne[37], enabling the facility to make a relatively healthy profit margin at 15% (Table 13).

In comparison, the economics of polyester recycling by Teijin in Japan appear much less favourable with CAPEX of perhaps up to $100 million[38], lower market prices of nearer £2,000 per tonne for polyester,[39] and with only slightly reduced energy costs.[40] Hence Teijin must charge significantly higher prices for their recycled polyester, which has been a barrier to the uptake of this technology.

---

[34] *WRAP (2012), Textiles flow and market development opportunities in the UK; Oakdene Hollins*
[35] *Aquafil (2011), Econyl: A journey, a new idea of the future*
[36] *Aquafil (2011), Environmental product declaration for Econyl® Nylon Textile Filament Yarn*
[37] *Emerging Textiles (2011), Nylon/Polyamide and Caprolactam Market Prices*
[38] *Teijin, personal communication*
[39] *Emerging Textiles (2011), Polyester Prices Further Rising, But...*
[40] *BSR (2009), Apparel Industry Life Cycle* Carbon Mapping

Table 13 Economic assessment for nylon chemical recycling

Item	Quantity/Description	Cost
Staff costs	35 staff, includes national insurance contributions	£1,153,043
Rent	60,000 square feet at £4 per square foot	£240,000
Business rates	Tax rate of 40.7% applied to rental costs	£97,680
Electricity Gas	Using the information contained within the Aquafil EPD on energy requirements	£4,550,000 £8,400,000
Water & treatment	Estimate	£1,600,000
Transport	Based upon estimate by textile sorter	£750,000
Overheads	Estimate	£250,000
Maintenance	Estimate	£1,700,000
Recycling plant	£20,000,000 CAPEX;10 year lifetime assumed	£2,000,000
Other equipment	£8,000,000 CAPEX; estimate, 4 year lifetime	£2,000,000
Post-consumer feedstock	7,700 tonnes at £250 per tonne	£1,925,000
Post-industrial feedstock	3,300 tonnes at £750 per tonne	£2,475,000
Chemicals	750 tonnes at average price £270 per tonne	£202,500
Disposal	1,000 tonnes at £64 per tonne	£64,000
Total costs		**£27,107,223**
Revenue	10,000 tonnes at £3,200 per tonne	**£32,000,000**
Operating profit		**£4,892,777**
Net profit margin		**15.3%**

6.4 Barriers and enablers

As the economic assessments has indicated, the most commercially viable of the chemical recycling processes is that for nylon, currently operated by Aquafil in Slovenia. The main barriers are the high investment cost (around £20 million for plant) and energy use (around £13 million per year).

The benefits of chemical recycling are already appreciated by end-users who are attracted by the closed-loop recycling and high value end product. However, for all of the technologies there is a clear need to locate enough of a single stream feedstock and avoid contamination with other types of fibres. Table 14 summarises these barriers and enablers.

Table 14 Summary of the barriers and enablers for chemical recycling

Enablers	Barriers
Recycling is closed-loop	Textiles need to be highly sorted according to their fibre type to be chemically recycled
Attractive to end-users who manufacture products of a single synthetic fibre type	A number of materials cannot be processed and cause problems with use, e.g. wool, acrylic and leather
High value end product	Economics are not always favourable compared to virgin fibres or feedstock may be limited
Opportunity for corporate clothing take back schemes	Limited facilities

7.0 Carpets

The methods used for carpet recycling depend on the type and quality of the carpet. Therefore it is necessary to understand the material compositions. Carpets are grouped into three main types: rug construction (woven), tufted and needlefelt.

Tufted carpets represent more than 80% of the carpet and rug market in the EU. The typical tufted carpet consists of the face yarn and two layers of either jute or synthetic (mainly polypropylene, PP) backing between which there is a calcium carbonate ($CaCO_3$) filling, styrene-butadiene latex rubber (SBR) adhesive layer.

The yarn makes up approximately 46% of a new carpet by weight and the most common fibre types are wool blends, polypropylene and nylon.[41]

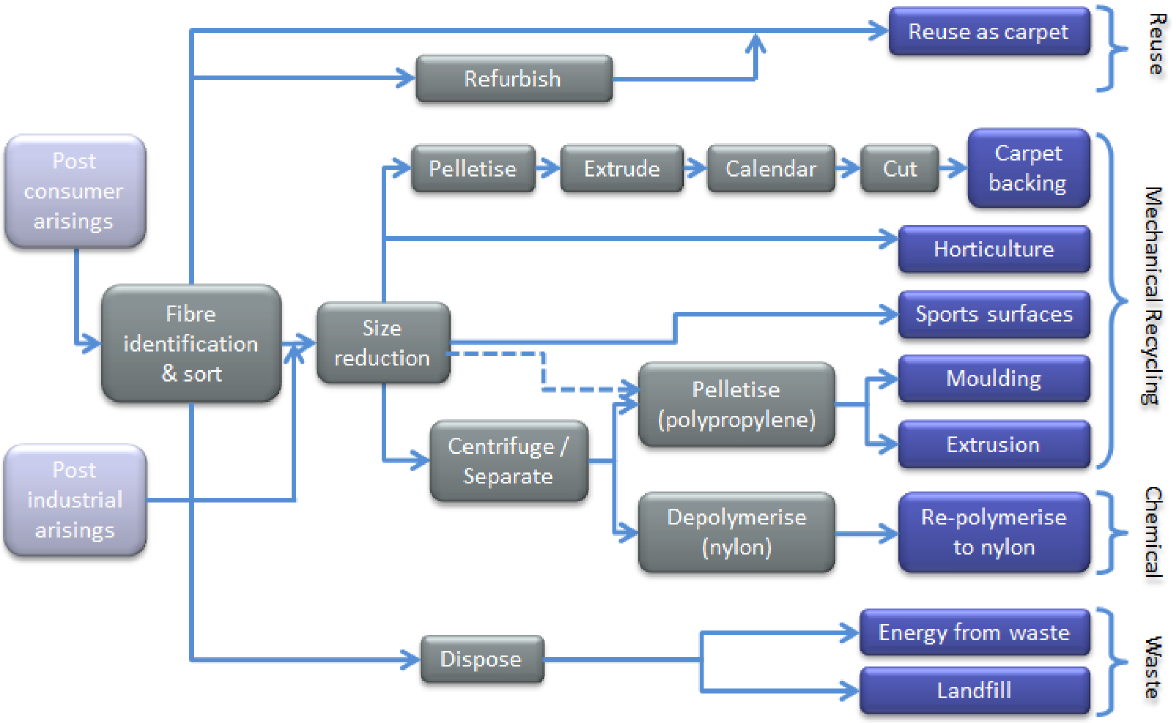
7.1 Technology description

There a quite a number of technologies that are available for the commercial recycling of carpets. These include:

- mechanical shredding for down-cycled applications;
- higher value recycling separating the yarn and backing; and
- chemical recycling of nylon carpets (see Chapter 6).

Figure 9 provides an overview of the carpet recycling technologies available and their end-markets. The following sections provide an overview of the technologies, outputs and end-markets for each of the main types of processes.

Figure 9 An overview of recycling for carpets



Source: Oakdene Hollins (2010), Studies on Recyclable Waste Textile; EC JRC-IPTS

[41] *Y Wang, Recycling in Textiles, Woodhead Publishing, 2006 & Carpet Recycling UK*

For many carpet recycling processes it is first necessary to accurately identify the fibre type to avoid contamination of the end product due to the mixture of fibres used to manufacture carpets. There are a number of identification processes currently in use, including:

- product labelling;
- NIR sorting: utilising NIR spectroscopy, carpet face fibres can quickly be analysed for their content and effectively using a hand-held device or on an automated process line;
- melting point identification: simple and low cost, this method involved applying heat to identify fibres according to their melting point;
- chemical testing: specifically used for Nylon 6 fibres, a dilute solution of hydrochloric acid is used to determine if the face fibre is Nylon 6; and
- visual inspection: requires specialised training and is open to a greater margin of error than the other methods.

7.1.1 Shredding and down-cycling

The recycling of used commercial and domestic carpets and rugs for medium to high value applications is a complex and relatively high cost process and therefore much of post-consumer carpet in Europe is either incinerated for energy recovery, or is sent to disposal. Exceptions to this in the UK include the Carpet Recycling Group who take any post-consumer carpet from HWRCs and recycle 23% with the remaining 77% used as fuel in cement kilns. Their intention is to be recycling around 50% by September 2013.[42] For all of the technologies listed below the processes involved include collection, sorting and shredding.

Relatively low value recycling applications, such as horticultural use (including composting) and use as sports surfaces, particularly in the equestrian sector, may involve relatively low cost processes that do not involve separating the face yarn from the backing composites.

- Wool-rich carpets, which will biodegrade, are possibly suitable for use as a soil improver in horticulture, although this market may require regulatory approval to be implemented.
- Synthetic carpets such as polypropylene and nylon are suitable for shredding for equestrian surfaces, because they do not biodegrade.

For these markets, carpets are size reduced by conventional shredding machinery and no further processing is required. Because of their low cost, these processes are more commonly in use currently (or are being trialled in some EU countries) in order to divert more carpet material away from disposal.

Examples of companies involved in carpet recycling in the UK include the following:

- Asmac Renovations Ltd reprocesses used carpet tiles either for the energy recovery industry or for road construction, roofing, recycling in carpet backing, mulch for play or sport areas, and re-use in social projects;
- The Carpet Recycling Group in the UK takes carpet tiles, underlay and mixed carpets and processes them for plastic recyclers and granulators, the equestrian surfaces market (as manege), and the horticultural market.[43] Their main site uses a patented 'MCT' recycling process and is capable of handling over 60,000 tonnes of mixed carpets per year;
- ECO2 Enterprise LLP collect and recycle sorted synthetic broadloom carpet and unsorted synthetic post-consumer mix for use as horse manege; and
- Desso use carpets tiles, unsuitable for chemical recycling, as a high-calorific fuel within the cement industry or recycling such as roadstone and roofing.

[42] *Chris Mountain, Carpet Recycling Group, Personal Communication, 2012*
[43] *Chris Mountain, Carpet Recycling Group, Personal Communication, 2012*

Other mechanical shredding processes have had more mixed commercial success.[44] A number of operations have used size-reduced carpet pieces extruded into material that may be used in new carpet tile backing. Again, there is no need to separate the face yarn and backing materials in these applications. An example of such processes is as follows:

- Size reduction: reclaimed material is reduced in size to small pieces ready for processing;
- Pelletising: the size-reduced carpet is processed into fine, uniform sized pellets;
- Extrusion: the pellets are extruded into a continuous, pliable rope which is transported by conveyor belt to the calendar;
- Calendering: the pliable material is rolled into a recycled composite sheet backing; and
- Cutting: The final backing material is rolled, cut ready for bonding to Nylon face materials.

7.1.2 Higher value fibre recycling

The separation of yarn and backing offers potential for higher value applications. This is not straightforward. Current practices entail 'shaving' the face yarn, ripping the carpet into pieces and shaking it aggressively to cause the yarn to detach from the backing. According to Interface, the former option is more suitable in the USA, as carpet depth is typically greater, and because broadloom carpets are more common than in the EU. However, neither process is entirely efficient, so Interface is in the process of developing a dissolvable adhesive which can be simply removed in specific conditions to allow far more yield from separation. Some US manufacturers use British technology developed by Sellars in Huddersfield to separate fibre from backing.[45]

According to Carpet Recycling UK, polypropylene (PP) recycling could be one of the most significant opportunities for post-consumer carpet recovery, in terms of higher-value end output. Polypropylene carpets, which tend to be used in the exhibition sector, can be recycled back into pellets following shredding. Centrifuge and separation is usually not necessary as exhibition carpets do not typically have a backing. Applications for the pelletised polypropylene include injection moulding and extruded products. In the UK, Reeds Carpets operates a take back scheme for its polypropylene carpets used in the events industry. These are then shredded and made into plastic pellets, which are used by the plastics industry to make new products such as dust bins, drain pipes and plastic roof tiles or can be used to manufacture their own closed-loop Reeds Evo-rib carpet.

Manufacturers that supply carpet made from recycled materials include:

- Invista, in the US, a manufacturer of Nylon carpet that includes within its content 30% pre-consumer and post-consumer recycled content;
- Shaw, in the US, operates a collection network for its recycling of post-consumer Nylon 6 carpet. Interface in the US recycles all carpet types. The technology used is supplied by Dell'Orco & Villani, with whom Interface have established their own patented system.
- Interface with their technology *ReEntry 2.0*. The face fibre and backing are cleanly separated and the fluff is re-melted into chips, which are then pelletized in a process called Reinyarnation™. Nylon 6 and 6,6 pellets are blended with virgin or post-industrial chips and extruded into fibre.[46] Reclaimed backing is shredded and formed into pellets, which are loaded into Interface's Cool Blue™ pellet processing machine and heated to create GlasBac®RE backing. Fibre and backing are then combined to create Convert™ recycled carpet. Interface has also established this technology in the Netherlands.[47]
- Anglo Recycling, in the UK, also recycles carpets and a variety of other materials for use as carpet underlay (see Section 4.3.1).

---

[44] *Maximising Re-use and Recycling of UK Clothing and Textiles, Oakdene Hollins 2009*
[45] *Laurance Bird, Carpet Recycling UK, Personal Communication, 2012.*
[46] *Note this is a mechanical recycling process, rather than a chemical process such as Aquafil (see Section 6.3). Therefore the process is able to accommodate both Nylon 6 and 6,6; as well as other types of polymers.*
[47] *Laurance Bird, Carpet Recycling UK, Personal Communication, 2012.*

7.2 Feedstock specifications

Many companies will only accept certain types of carpets for their feedstock, e.g. wool or nylon, or indeed the take-back of only their own brand of carpets. Some processes, however, will accept a wider range of carpets, although all operators will place restrictions on aspects such as moisture and contamination (Table 15).

Table 15 Example feedstock specification: carpets

Material description
- Sources: local authority bulky waste collection, HWRCs, retail take-back etc.
- Types: all types of carpets are accepted: wool, nylon, polypropylene etc.

Characteristics
- Delivery form: the carpets must be delivered clean and dry
- Damp or heavily soiled carpets will not be accepted

Prohibited substances
- The carpets must not contain prohibited substances, e.g. harmful chemicals and heavy metals.

Test certificates / incoming inspection
- Incoming carpets are given visual inspections upon arrival of moisture to verify

Source: based upon interviews conducted with carpet recyclers

7.3 Outputs and markets

Recent statistics published by WRAP indicate that 420,000 tonnes of carpet waste arise each year (75% domestic and 25% commercial). Current recovery rates for carpet are low at around 10% of the (3.5% is re-used or recycled and 6.5% is incinerated).[48] There is therefore considerable opportunity to increase carpet recovery.

The outputs and markets for post-consumer carpet recyclates have been described above within each of the descriptions of the technologies and processes. These include:
- shredding and down-cycling: energy-from-waste, equestrian manege, sports surfaces, soil improvers, construction (roofing and flooring), carpet backing and underlay;
- polypropylene products: dust bins, drain pipes, plastic roof tiles etc.;
- fibre recycling for use in the manufacture of recycled carpet or underlay; and
- chemical recycling: nylon 6 carpets back into fibre and pellets that can be recycled into carpets, backing and other products (see Section 6.3).

Most of these markets are relatively large such as energy-from-waste or plastics products, or they act as substitutes for fuels or other materials. Others markets are directly correlated with carpets, whether that be carpets themselves, backing or underlay.

7.4 Economic assessment

For carpets an economic assessment has been conducted for a relatively low value shredding operation, which is considered to be reasonable for a number of different applications. Here the feedstock is mixed post-consumer carpet from HWRCs. These are shredded and pelletised for recovery for use as a fuel in cement kilns (rather than recycled). This has been selected as it represents the most common route to divert carpets away from landfill. Alternative operations are possible including some fibre recycling (Chapter 3 and 4) and chemical recycling (Chapter 6). Indicative data for an economic assessment for these operations can be found in the relevant chapters of the report.

[48] *WRAP (2012), Textiles flow and market development opportunities in the UK; Oakdene Hollins*

In this operation, 10,000 tonnes of throughput are received at a gate fee of £100 per tonne (including inward transportation), hence saving the local authority the cost of disposal. The capital expenditure of the carpet shredding and pelletising equipment is estimated by current operators at £300,000, although some other equipment such as conveyor belts, forklifts and balers is likely to be needed in addition to the line itself.

The economic case is based upon being charged a lower gate fee by the cement kilns than charged for the feedstock, at approximately £25 per tonne, and being able to cover all the costs associated in the process within this price differential. Staff costs are a major expense, with 15 full time employees plus the use of a part time engineer. Four workers are expected for each of three shifts (three on production, and one on the warehouse), plus staff for general management, sales and administration.

The economic assessment suggests that profit margins for this type of operation are low at 3.1% and that therefore this operation is likely to be economically marginal (Table 16).

Table 16 Economic assessment for carpet shredding line

Item	Quantity/Description	Cost
Staff costs	15.5 staff, includes national insurance contributions	£322,538
Rent	16,000 square feet at £4 per square foot	£64,000
Business Rates	Tax rate of 40.7% applied to rental costs	£26,048
Utilities	Estimate	£50,000
Transport	Based upon estimate by textile sorter	£150,000
Overheads	Estimate	£25,000
Maintenance	Estimate	£20,000
Shredding/pelletising equipment	£300,000 CAPEX;8 year lifetime assumed	£37,500
Other equipment	£100,000 CAPEX; estimate, 4 year lifetime	£25,000
Cement kiln gate fee	10,000 tonnes at £25 per tonne	£250,000
Total costs		**£970,086**
Revenue	Feedstock gate fee at £100 per tonne	**£1,000,000**
Operating profit		**£29,914**
Net profit margin		**3.1%**

7.5 Barriers and enablers

The main barriers and enablers are summarised in Table 17. There are many technically successful projects that have existed, although there have also been numerous commercial failures in practice.

Table 17 Summary of the barriers and enablers for carpets

Enablers	Barriers
Technically successful projects	Previous failures in European carpet recycling due to collection logistics and high costs limit carpet recycling to low-value applications
Improvements in technology mean an increasing number of recyclers are entering this market	Difficulty to achieve separation of pile and backing
	Some of the technology is patented and some is used under exclusive licenses so may not be readily applied to the UK

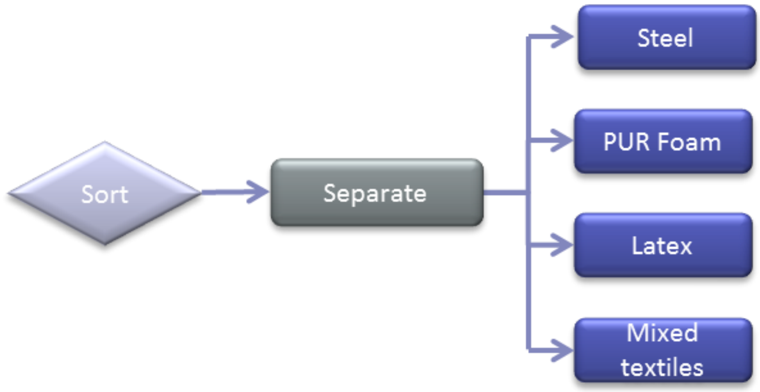
8.0 Mattresses

8.1 Technology description

Mattress recycling generally involves processing used mattresses into constituent materials and supplying these materials on to relevant end markets. The process flow is illustrated in Figure 10.

For recycling purposes mattresses are categorised based on their main core material, which fall into three common types: steel springs, polyurethane (PUR) foam, and latex foam. The core is also padded with flocking, and these materials are contained within a textile cover called tick which protects the internal components of the mattress. The separation of these components is usually carried out by hand because the variability in construction, design and materials makes the process difficult to automate effectively.

Figure 10 Simplified process flow diagram, mattress recycling



There are mechanical options which are designed to increase the efficiency of mattress deconstruction, ranging from a fully automated system capable of sorting and fully processing mattresses to general waste processing machinery. The functions required include separating the tick (outer fabric covering) from the internal mattress, and compressing springs using compactors.

Some pieces of equipment are available commercially such as shredders; others are bespoke pieces of equipment and have been developed in-house by businesses. One example is that of Retour Matras in the Netherlands who process 100,000-120,000 mattresses per year and benefits from considerable economies of scale. Their bespoke system involves electric cranes, metal detectors, cutting machines and magnets to separate the different materials.[49]

This study, however, focuses primarily on the manual processes, which were covered in the business case conducted by Zero Waste Scotland. Other UK examples include separating the steel and then shredding for energy-from-waste.

8.2 Feedstock specification

Mattress recyclers will accept all types of mattress. However a key issue for recyclers includes moisture content, which can be high when mattresses have been stored outside prior to collection. Also, heavily soiled mattresses are generally not accepted.

[49] *A Business Case for Mattress Recycling in Scotland, Zero Waste Scotland, 2012*

Table 18 Example feedstock specification: mattresses

Material description

- Sources: local authority bulky waste collection, HWRCs, retail take-back etc.
- Types: all types of mattresses are accepted: sprung, polyurethane and latex foam, and mixed materials etc.

Characteristics

- Delivery form: the mattresses must be delivered clean and dry
- Damp or heavily soiled mattresses will not be accepted

Prohibited substances

- The mattresses must not contain prohibited substances, e.g. harmful chemicals and heavy metals.

Test certificates / incoming inspection

- Incoming mattresses are given visual inspections upon arrival of moisture to verify quality.

Source: based upon interviews conducted with mattress recyclers

8.3 Outputs and markets

8.3.1 Steel

The metal components are used in the manufacture of steel. The market for scrap steel is well established and will accept the steel springs isolated from the mattress. The value of this material is potentially around £200 per tonne when collected.[50] However, the springs cannot be packed easily, making transport more difficult. This substantially reduces the value of the metal to around £80 per tonne, minus transport costs. Options for compacting the springs are available to increase the value. However, at present, these are reliant on machinery which is expensive to purchase, for example, a second hand compactor may cost in excess of £150,000.

8.3.2 PUR Foam

Three markets exist for separated PUR foam: recycling, Energy from Waste (EfW) and landfill cover (as part of mixed shredded materials).

- Recycling offers the highest value of these options, with markets varying depending on the source, quality and intended use. PUR foam from mattresses is typically used for re-bonding, with small pieces bound under pressure to form products such as carpet underlay or gym mats. A value of around £100 per tonne (when collected) was identified for post-consumer scrap. However, factors such as location and customer perception (particularly about hygiene) potentially limit the scale of this market.
- The two other markets offer lower value alternatives. Foam can be sent to EfW processing or resource derived fuel (RDF), with an estimated value of £34 per tonne. Alternatively it can be shredded, mixed with other materials and used as landfill cover, which is cost neutral as it avoids the cost of landfill.

8.3.3 Textiles

Mattresses contain a variety of different textiles in the covering (tick) and shell, outlined in Figure 10 highlighting the variety in textile types. The textiles are grouped together as they are difficult to separate and are sold onto the mixed textiles markets. Common materials found in the shell include nonwoven cotton, nonwoven wool, felt/flocking and other natural fibres. Tick is usually made from woven fibres such as cotton, polyester and Nylon.

---

[50] *A Business Case for Mattress Recycling in Scotland, Zero Waste Scotland, 2012*

The highest value for reclaimed textiles is associated with clean, high quality and separated types. However, evidence indicates that the textiles obtained from mattresses are often of low quality (short fibre length) and it is neither economic nor possible to separate them due to the stitching or bonding between the different materials and sections. Therefore most recyclers sell on mixed bundles of textiles. When sold as mixed textiles their market value is around £88 per tonne, and some materials in the mattress may have already been sourced from recycled mixed textiles. However, concerns were expressed from the industry about recycling through this route, mainly due to concerns over hygiene and cleanliness because of previous use in mattresses. Recyclers do not view washing as cost-effective due to the low value of the textiles. These concerns have affected the ability of similar operations to sell on textiles to higher value markets.

However, these textiles are acceptable to some lower value markets, and are commonly sold via a broker for around £50 per tonne, which can help disguise their original source. This value has been used for the income from the textiles stream as sales to other markets appear not to be reliable according to a range of industry stakeholders. For example, according to mattress recyclers, the composition is not sufficiently consistent to be used in shoddy. Textiles which are sent to recycling markets need to be dry and baled to achieve the maximum value. It is also assumed that local markets need to be found for these materials; if transportation over long distance is required the value obtained for these materials is likely to be lower.

8.3.4 Other materials

Latex can be sent to EfW or used as landfill cover (as mentioned previously for PUR foam). Natural fibres in mattresses can also be (but are not always) separated from textiles. Evidence from mattress recyclers indicates that end markets for these materials are not established, reducing options for disposal. Where this is the case they will be sent to EfW to recover calorific value as the alternative is landfill.

8.4 Economic assessment

A detailed business case has already been conducted on mattress recycling, so this information is summarised in the economic assessment shown in Table 19, which is based upon the detailed information collected for Zero Waste Scotland.[51]

Mattress recyclers charge to take mattresses, which are generally negotiated with the local authority source. Average gate fees that recyclers currently charge are of the order £4-£5 per mattress, although they can be as low as £2.50.[52] In this business case a relatively high gate fees of £6.50 per mattress has been charged. It is noted that this is above the current market rate, although as landfill tax rates continue to rise it may become more reasonable. A total 18,500 mattress are processed per year (approximately 400 tonnes).

The modelling assumes material sales at approximately £1.15 per mattress (£54 per tonne), of which approximately 70% of the mattress components are recycled, with the remaining 30% used for solid recovery fuel. This is in line with common practice at organisations such as the Mattress Recycling Group in the UK.

In addition, very low labour costs and second hand equipment are assumed. Despite these cost-saving measures, the operation barely makes any profit, at only £3,000 per year or a net profit margin of 2.2%.

[51] *A Business Case for Mattress Recycling in Scotland, Zero Waste Scotland, 2012*
[52] *A Business Case for Mattress Recycling in Scotland, Zero Waste Scotland, 2012*

Table 19 Economic assessment for mattress recycling operation

Item	Quantity/Description	Cost
Staff costs	5.5 staff, includes national insurance contributions	£88,745
Rent	8,000 square feet at £3 per square foot	£24,000
Business Rates	Tax rate of 40.7% applied to rental costs	£9,768
Utilities	Estimate	£5,000
Maintenance	Estimate	£500
Overheads	Estimate	£6,116
Capital expenditure	Approximately £12,000 CAPEX for second hand equipment, 4 year lifetime assumed	£2,975
Total costs		**£137,104**
Gate fees	Based on £6.25 per mattress, 18,507 mattresses	£118,815
Raw material revenue	Sale of steel, textile and other materials	£21,302
Total Revenue		**£140,116**
Operating profit		**£3,013**
Net profit margin		**2.2%**

8.5 Barriers and enablers

From the analysis conducted above it appears that the manual recycling of mattresses is not currently commercially viable in the UK. Table 20 summarises the barriers and enablers for recycling mattresses.

However, the review undertaken by Zero Waste Scotland nonetheless identified a number of operating mattress recycling facilities in the UK. Statistics published by WRAP indicate that 25,000 tonnes of mattresses are recovered per year (out of 170,000 tonnes of mattresses consumed).[53] This represents a recovery rate close to 15%; however, it does include Energy-from-Waste as well as recycling.

Table 20 Summary of the barriers and enablers for mattresses

Enablers	Barriers
Technically successful projects	Difficulty obtaining high enough gate fee to sustain the business
Increasing gate fees may make recycling process economic	Low value of material to end markets
	Inability to reduce costs due to tight margins
	Landfill cheaper than recycling at present

There are two main ways of improving the commercial viability of mattress recycling:

- Reduce labour costs such as through a social enterprise model or by improved automation such as that exhibited at the larger scale operation in the Netherlands; and
- Find a means of raising the gate fees. This might be through the introduction of an advanced disposal fee, charged upon the sale of mattresses by retailers. An alternative option is to use the funds charged by many local authorities or retailers for the collection of used mattresses to cover a higher gate fee.

[53] *WRAP (2012), Textiles flow and market development opportunities in the UK; Oakdene Hollins*

9.0 Footwear

9.1 Technology description

With the exception of a few take-back recycling schemes, footwear recycling is not well established. There is a considerable number of small scale or developmental examples, which are summarised in this chapter. Because of the current state of footwear recycling, this chapter takes a more descriptive approach.

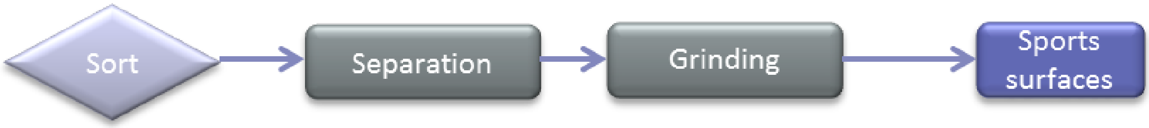
The alternative to recycling post-consumer shoe waste is Energy from Waste to generate heat and electricity, including incineration and gasification.

9.1.1 Nike's Reuse-a-Shoe

Take-back schemes include the *Reuse-a-Shoe* program offered by Nike in which sports shoes can be taken to a Nike store and from there recycled predominantly into sports surfaces (Figure 11), although applications in insulation and underlay have potential.

At Nike's US plant, the sports shoes are first manually separated into three constituent parts: rubber sole, fabric upper and foam midsole. These are then passed through grinders that chop them into raw materials referred to as *Nike Grind*. At their plant in Belgium the shoes are not manually separated but are passed through a grinder and the various resulting materials are sorted using air-based methods, based upon the differing weights of each of these components.

Figure 11 Simplified process flow diagram for footwear recycling



Nike's *Reuse-a-Shoe* scheme permits the recycling of any brand of training shoe. Currently the recycling of mixed footwear waste is not carried out. A key issue is sorting: the level of sorting required to enable effective footwear recycling may not be feasible with current collection infrastructures. However, this is at least in part due to the current lack of markets for the end products. Should demand for sorted footwear become apparent, it is believed that current clothing sorting techniques could be expanded to separate out footwear. Many facilities already separate shoes for export.

One of the main problems for recycling mixed footwear products is the diversity of the constituent materials and that some of the main materials (leather, rubber, foam and textile) have similar or overlapping density ranges, which affects the ability to separate and reclaim the different materials. Research to solve these issues includes that carried out at Loughborough University's Innovative Manufacturing and Construction Research Centre. One method exploits air-based techniques to separate granulated shoe particles based on the difference in size and weight.

Nike recycles sports shoes for use in three different athletic surfaces. The fabric upper becomes padding for basketball courts; the rubber sole becomes materials for running tracks and the foam midsole is used to make tennis courts surfaces. Other potential outputs include insulation materials, and underlay products. In the UK a manufacturer of play surfaces called Playtop uses Nike Grind in some of their products. In Germany, SOEX is known to be also working on developing a similar process for sports shoe recycling for sports surfaces.

9.1.2 Other footwear recycling processes

There are a wide number of other noteworthy examples that were identified in the course of the project research. These developmental and small scale initiatives include the following:

- In the US, Okabashi make flip-flops from a mixed plastic material called Microplast™, which can be recycled in a closed-loop system. Okabashi operates a take back system and manufacture new flip flops using 25% of the recycled Microplast™, 25% of the constituents of their flip-flops are from recycled material. Around 2% of the recycled material is used to make blankets and industrial carpets.[54]

- In France, For Your Earth (FYE), in partnership with collector Le Relais, produce shoes that have a sole made of up to 50% from recycled shoes. The shoes are first crushed in order to obtain fragments of rubber and textile fibres, and metals are extracted using a magnet. The fragments are then mixed with natural and synthetic rubber at a ratio of 20-50%. This amount determines the final shade of the sole (the higher the level of concentration, the darker the shade). For aesthetic reasons, the level of proportion of recycled rubber is usually set to 20%. The resulting mix of materials is compressed into a thick, supple tablet, which is then put into outer sole moulds. All the excess materials are collected and recycled by being reinserted into the production cycle.[54]

- In 2013 LYF shoes in the US will trial closed-loop recyclable shoes in Seattle and Rayleigh. In this system the shoes are designed for disassembly using interlocking components and locking pins. All parts of the shoe can be re-used or, if worn out, can be recycled. If it is successful in the US, Worn Again intends to introduce this concept into the UK.[55]

- Loughborough University has developed technology to recycle shoes, separating material into individual components which can then be used as raw materials for other products.[56] The process is carried out in three stages: sorting, metal removal, fragmentation and material separation. Material output is split into five fractions: metal, textile, rubber, foam and leather; various end applications have been identified for these materials. These include using material in sports surfaces and nonwoven textile products. The University believes that the rubber fraction, which can be up to 90% pure, can be used within a closed-loop process to be recycled into the soles of new footwear.

---

[54] *Eco-TLC (2012) É tat de l'art du tri, du recyclage et de la valorisation des chaussures à destination des ménages*

[55] *Nick Ryan, Worn Again, Personal communication, 2012*

[56] *Recycling process for footwear, Lee, M & Rahimifard, S, (2012), unpublished*

9.2 Economic assessment

Due to the more developmental nature of footwear recycling technology, as well as a lack of available data on the Nike *Reuse-a-Shoe* scheme, a full economic assessment has not been conducted. For the Nike *Reuse-a-Shoe* scheme a number of the mechanical processes and equipment, such as the separation of components and grinding have similarities to those for carpet recycling (Chapter 7).

The barriers and enablers are summarised in Table 21 for recycling footwear. Although there is a large potential supply of recyclable material, the diversity of materials from mixed footwear provides considerable challenge to its development.

Table 21 Summary of the barriers and enablers for footwear

Enablers	Barriers
Large potential supply of recyclable material.	Diversity of constituent parts inhibits ease of separation and recycling.
Potential for research initiatives such as those at Loughborough University.	Limited market need for current products of recycling, e.g. sports surfaces. Also must compete against lower cost of new raw materials

For Loughborough University's experimental system, some preliminary economic analysis has been conducted:[57]

- A small scale system could process 0.5 tonnes an hour, with operating costs (including labour) estimated at approximately £37 per tonne;
- A system such as this would require an initial outlay of approximately £160,000;
- However, if considering cost of disposal to landfill, or processing at mechanical and biological treatment facilities, then a gate fee of £57 is considered justified, and more attractive than disposal.

Numerous other economic factors need to be considered for a full analysis, including market conditions, transport, labour and other costs. Without better understanding of end revenues, economic viability is difficult to determine. However, once markets are established, improved economics are likely.[58]

[57] *Recycling process for footwear, Lee, M & Rahimifard, S, (2012), unpublished*
[58] *Recycling process for footwear, Lee, M & Rahimifard, S, (2012), unpublished*

10.0 Findings and conclusions

The findings of this report identify relatively few technical barriers for the uptake of the textile fibre recycling technologies apart from closed loop fibre recycling, particularly of mixed fibres. Discussion with various industry stakeholders all indicated that if greater quantities of used textiles were to be collected, there would be markets for these materials. However, these would not necessarily high value markets or located within the UK.

The main market enablers and barriers of each of the technologies reviewed is summarised in Table 22. Some technologies, such as flocking, are well-proven and have operated in the UK for many years.

With the exception of footwear recycling, all of these technologies are commercially available, that is they are in operation somewhere else in the world whether that be in the UK, OECD countries (US, EU, Japan) or developing countries, e.g. India. The indications are that the trend is for greater overseas textiles sorting e.g. in Poland and Eastern Europe; and for greater textiles recycling in countries such as India.

The economic assessments identified nylon recycling as being commercially viable for the UK. The other technologies are economically more marginal or have significant barriers preventing their (wider) uptake in the UK.

Table 22 Summary of main enablers and barriers for each technology

Technology	Main Enablers	Main Barriers
Automated sorting	■ Able to sort by colour and fibre composition ■ Reduces cost of textiles sorting	■ End-markets do not exist for sorted grades ■ Development of closed-loop recycling technologies required
Flocking	■ Large and well-proven market available if the prices are right	■ Competition for feedstock and against virgin raw materials ■ Shift away from wool-rich fibres problematic
Shoddy, mungo and blending	■ No materials are explicitly prohibited	■ Production is located outside EU ■ Little demand for shoddy blankets in the UK
Other nonwovens	■ Diverse range of current applications ■ Promising new applications in development	■ Preference for production off cuts rather than post-consumer textiles ■ Often significant competition with virgin or other types of materials
Chemical recycling	■ Closed-loop recycling, which is attractive to end-users ■ High value end product	■ Textiles need to be highly sorted by fibre type ■ Economics not always favourable ■ Limited facilities
Carpet recycling	■ Technically successful projects ■ Improving technologies	■ Often easier or more cost effective to divert to Energy-from-Waste rather than recycling
Mattress recycling	■ Increasing gate fees may make recycling process economic	■ Low value of constituent materials ■ Landfill cheaper than recycling
Footwear recycling	■ Numerous development initiatives under way	■ Diversity of constituent parts ■ Relatively limited end-markets

11.0 Key recommendations

We are upfront in our recommendations regarding the choice that exists between simply allowing the market to determine end-markets for used textiles, or making policy interventions to encourage specifically UK sorting and end-market. The following recommendations focus on further developing UK textiles sorting and recycling.

The key recommendations of the report include:

- Greater collection of used textiles should be promoted, as end-markets already exist for these materials. Measures to encourage this include consumer education, expansion of the household collection of textiles such as through segregated and survival bags. Policy measures such as landfill bans and extended producer responsibility are possible.
- Promote the greater sorting of used textiles in the UK. The evidence suggests that once used textiles leave the UK for sorting overseas, the recycling grades are seldom re-imported, but make their way for recycling in the Indian Subcontinent. One policy measure to support this might be a stricter interpretation of waste shipment regulations prohibiting the export of unsorted used textile waste. Such an interpretation already exists in a number of European countries such as the Netherlands and Germany.
- Support to enable the continued commercial viability of the flocking and nonwoven industries in the UK. A possible model is that Eco-levy applied in France to the sale of new clothing, at approximately 0.5 Euro cent per garment. The funds are used to support the French textile sorting and re-processing industry, as well as related innovation funding. The levy is justified on both environmental and employment grounds. An additional approach would be to promote the end-markets for used textiles such as Green Public Procurement or Ecolabel criteria, which favour the use of recycled fibres.
- We do not recommend establishing a UK-based shoddy blanket industry akin to that in India. This is due to the high labour costs associated, as well as the lack of end-markets in the UK. An alternative approach is to investigate developing supply chains for niche re-spinning operations such as those witnessed in India, and whether these might be replicable in the UK. European networking is suggested to achieve this.
- Commence discussions with Aquafil about bringing nylon recycling technology to the UK, which appears to be commercially viable in a UK setting. In contrast the current polyester fibre recycling process operated by Teijin in Japan does not seem to be commercially viable in the UK at present.
- Technological and market development work for fibre-to-fibre recycling technologies, such as the closed-loop recycling of cellulosic fibres, polyester and mixed fibres, for which automated textiles sorting is a complementary and enabling technology. Monitoring work and further investigation the possible UK end-markets for automated textiles sorting technology may be warranted.
- Developmental work should continue for high value carpet recycling technologies. There are already a number of lower value technology options for carpet recovery. Technology development is under way for high value fibre recycling and should be monitored.
- Further development of mattress recycling processes. Although the manual dismantling of used mattresses is technically feasible, it lacks the scale economies to make it commercially viable. Investigation of more automated processes such as those operating the Netherlands should be considered and possibly trialled.
- Technical development work is required for footwear recycling. There are various promising footwear recycling technologies, although none are currently operating commercially. UK trials or innovation funding could be considered.

Appendix 1: Mechanical recycling process

The recycling processes that produce nonwoven flocking, other nonwovens, and shoddy, mungo and blends all require preliminary chopping and pulling stages. The whole of the nonwoven process (from pulling to bonding) generally takes place at a single plant in order to benefit from the economies of scale, although some small scale operations are known only to pull the fibres before selling them on.

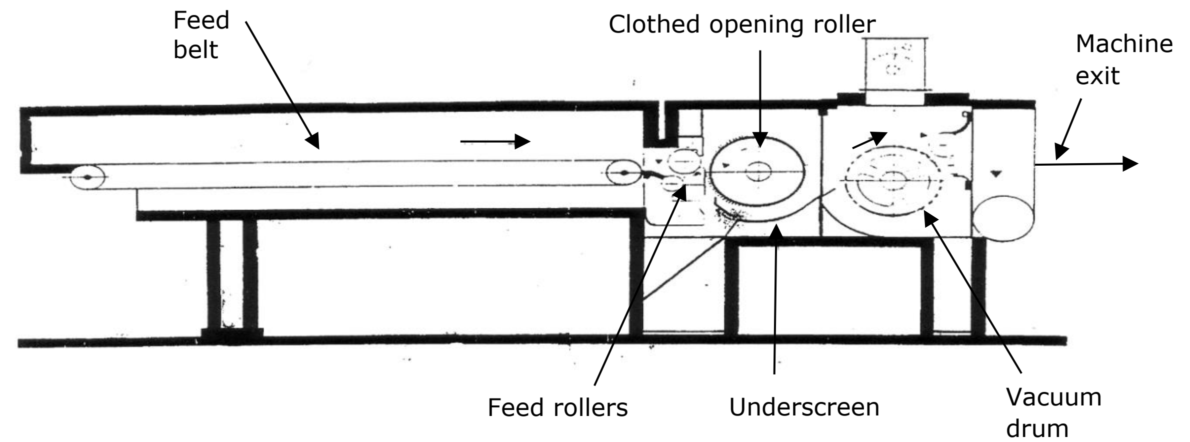
Chopping, cutting

It may be necessary to chop or cut fabrics and fibres to a manageable size for a number of stages in the process, such as pre-pulling or after needle-punching in flocking. Various cutting and shredding machines are available for this purpose.

Pulling machines

Textiles that are not suitable for re-use as clothing or as wipers are reduced to individual fibres by chopping and then pulling open the textiles using machines with spiked rollers. Zips and buttons are removed using suction and cyclones. A schematic illustration of pulling technology is shown in Figure 12.

Figure 12 Schematic representation of the pulling equipment



Source: Tipper, M, "The Hydro-entanglement of Jute Fibre Webs", Leeds University Dissertation, 1999.

Willowing and garnetting

Other processes that may be undertaken are willowing or garnetting. In willowing, fibres are dragged through the teeth of surfaces, which will open and partly clean compacted and entangled fibres.[59] Garnetting uses 'swifts' running against smaller rollers with saw toothed wire, and is capable of reducing cord, thread, carpet backing, filament and fabric trim into fibres. Following these processes the fibres are baled and used in the different mechanical recycling processes.

Bonding and web formation

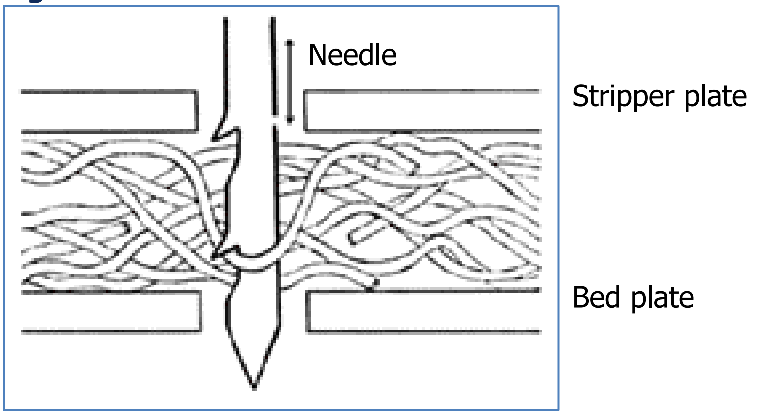
Bonding usually requires several processes, which can be mechanical or thermal. The most common methods are thermal bonding and needle-punching, although horticulture and agriculture will card and needle-punch. Extra steps that might be used are calendaring (squashing), heat treating (flattening), impregnation and coating. The exact processes depend upon performance requirements.

[59] *Y Wang, Recycling in Textiles, Woodhead Publishing, 2006, p142*

Needle punching

Once the fibres are pulled, they are conveyed through a needle-punching machine (Figure 13) which passes barbed reciprocating needles through the loose web of fibres causing them to become interlocked. This results in a coherent low strength structure, which is then cut to size. Needling machines can take fibre length of 5mm or more.

Figure 13 Schematic of needle fibre interaction in needle-punching

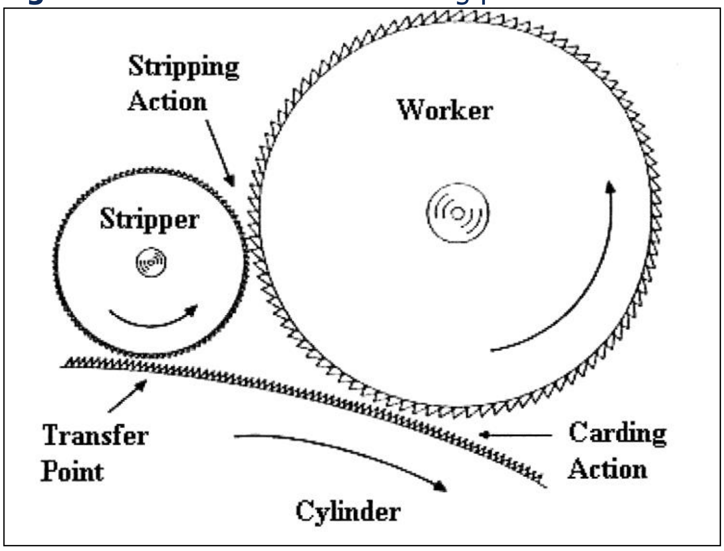


Source: "Recycling of Low Grade Clothing Waste", Oakdene Hollins 2006

Carding

Carding machines use a series of rotating pinned rollers to separate the fibres. By varying the relative direction of the pins on each roller, the gap setting and the speed of rotation, the degree of opening and mixing can be controlled. The basic principles of carding are illustrated in Figure 14.

Figure 14 Schematic of the carding process



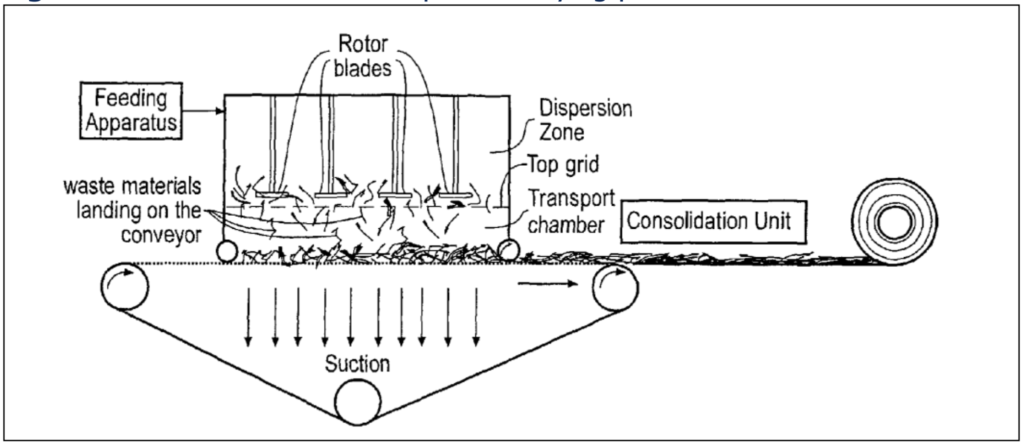
Source: "Recycling of Low Grade Clothing Waste", Oakdene Hollins 2006

Air layering

Air-laying uses revolving pinned rollers to separate fibres, and this technique has been adapted for use with mixed waste particles and fibres without the need for pre-sorting or separation. In the adapted technique a dilute mixture of fibre in air is created and these fibres are circulated in the airflow using rapidly rotating paddles.

The turbulence produced separates the fibres and particles distributing them randomly in air; through the action of beating and the turbulent air currents, the fibres remain suspended in air. As the fibres fall through the pull of gravity they are sieved through a metallic grid which influences the uniformity of fibre length and particle size in the web. Passing through the grid the fibres fall onto a perforated belt that has a vacuum applied beneath. In this way the fibres are held to the belt and a web is assembled. The landing distribution of the fibres creates an isotropic web and the isotropy translates into the final product properties after bonding. Figure 15 is a schematic of the basic principles of this process.

Figure 15 Schematic of the adapted air-laying process

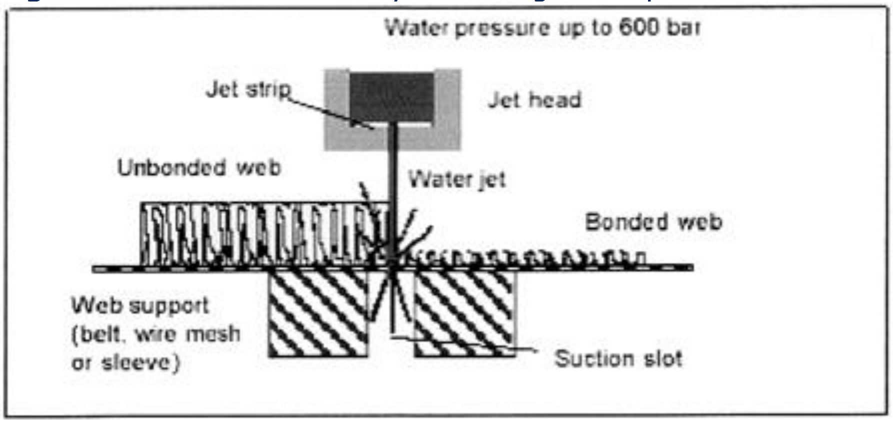


Source: "Customisation and safety provide new potential for automotive textiles", Technical Textile Markets, 4th quarter 2005

Hydro-entanglement

A further technique is hydro-entanglement (Figure 16), which involves the use of high pressure water jets to entangle the fibres forming them into a web. This well established technique pumps water through small holes in a metal plate, creating fine columns of water that are directed onto preformed fibre webs on a travelling belt. The force of the jets on the fibres causes them to interlock.

Figure 16 Schematic of the hydro-entanglement process



Source: Recycling of Low Grade Clothing Waste, Defra, 2006.

Thermal bonding

If a proportion of the fibres constituting the blend are thermoplastic (such as polyester and polypropylene) they can then normally be thermally bonded. If the fibres are not thermoplastic there is a requirement for fibres which melt at low temperatures to be introduced before web formation.

During web formation (carding, needle-punching, air-layering etc.), these are evenly distributed throughout the web structure. The fibres commonly have a sheath-core construction in which the sheath has a lower softening and melting temperature than the core. When heated, the sheath polymer melts and flows to the fibre contact intersection points. When cooled the polymer solidifies, bonding the fibre network. Pressure may be applied to aid polymer flow and bonding and to increase fabric density.

Appendix 2: Methodology and data sources used for economic assessment

Overview

The economic assessment has been based upon the data collected from stakeholders in the course of the technology review, in combination with other data identified and appropriate estimates. This has been used to determine the commercial viability of each technology and its suitability to the UK context. This includes a brief UK market overview of market size, capacity, availability of feedstock etc. Much of this data has already been collated in the WRAP textiles flow report[60] and existing Defra research[61].

Due to the commercial sensitivity of the data, the economic assessment required piecing together from a variety of sources, using some appropriate estimates where necessary (Table 23). Expert opinion from a range of specialities within Oakdene Hollins was used to validate the economic assessments.

As anticipated, the textile recyclers were not willing to disclose all of the required data. Some pricing data was fairly readily available, and equipment manufacturers provided data on capital expenditure and estimated maintenance and energy bills. Labour costs were indirectly estimated based upon the size of the workforce or by analysing company accounts data for existing operations.

Table 23 Parameters for economic assessment

Enablers	Barriers
■ Capital equipment expenditure (purchase costs, interest, depreciation etc.) ■ Energy use & maintenance costs	Equipment manufacturer interviews
■ Cost of purchasing feedstock ■ Transport costs	Textile sorter interviews
■ Revenues from product sales	Textile recycler interviews
■ Labour costs	Estimates based upon size of workforce
■ Rent & business rates ■ Overheads	Estimates from accounts or other sources

The following public accounts were obtained from Company House:

- Anglo Recycling Technology Limited
- Coppermill Limited
- Edward Clay & Son Limited
- The European Recycling Company Limited
- JMP Wilcox & Co Limited
- John Cotton Fibres Limited
- Playtop Limited
- W.E. Rawson Limited.

However, due to the company size of most of these operators, relatively limited data was obtained of specific value for conducting the economic assessments. One of these companies was large enough to present full accounts, which was useful in scaling a number of costs according to the size of different types of operations.

[60] *WRAP (2012), Textiles flow and market development opportunities in the UK; Oakdene Hollins*
[61] *Defra (2009), Maximising reuse and recycling of UK clothing and textiles; Oakdene Hollins*

Here are further details of what each category within the economic assessments includes:

- Rent: assumed to be approximately £4 per square foot for industrial premises – indicative for rental costs in a location such as Yorkshire or the North West of England;[62]
- Recycling equipment: generally includes CAPEX, advice and installation costs
- Other equipment: includes personal protective equipment (high visibility vests, safety boot, gloves, goggles, dusts masks etc.), forklift trucks, conveyor belts, balers, compactors, warehouse cages, pallet trucks and racks etc.;
- Maintenance: commonly assumed to be 5% of capital expenditures, includes the maintenance of recycling equipment as well as other equipment;
- Utilities: includes energy, water, wastewater treatment etc.; and
- Overheads: includes: office supplies & ICT, business development & marketing, travel, training, bank charges, insurance, legal costs, general expenses and contingencies.

These costs have been scaled according to the size and complexity of the operation.

Labour cost assumptions

The economic assessments contain a summarised form of the labour costs assumed on the recycling lines. These salaries have been informed by web data such as Total Job Salary Checker,[63] as well as in-house expert judgement. Employers' National Insurance contributions have been included at 13.8% for annual earnings exceeding £7,488.

Table 24 Assumptions on labour costs for flocking

Staff member	Number	Annual Salary	NI	Salary Costs
General manager	1	£50,000	£5,867	£55,867
Engineer	1	£35,000	£3,797	£38,797
Senior sales	1	£30,000	£3,107	£33,107
Sales	2	£25,000	£2,417	£54,833
Admin	2	£15,000	£1,037	£32,073
Shift leader	3	£25,000	£2,417	£82,250
Operating staff	18	£15,000	£1,037	£288,660
Distribution/warehouse	6	£15,000	£1,037	£96,220
	34			**£681,806**

Table 25 Assumptions on labour costs for shoddy

Staff member	Number	Annual Salary	NI	Salary Costs
General manager	3	£50,000	£5,867	£167,600
Engineer	2	£35,000	£3,797	£77,593
Senior sales	2	£30,000	£3,107	£66,213
Sales	6	£25,000	£2,417	£164,500
Admin	5	£15,000	£1,037	£80,183
Shift leader	12	£25,000	£2,417	£329,000
Operating staff	50	£15,000	£1,037	£801,833
Distribution/warehouse	10	£15,000	£1,037	£160,367
	90			**£1,847,289**

[62] http://www.compropregister.com/ *[accessed November 2012]*
[63] http://www.totaljobs.com/salary-checker/salary-calculator *[accessed November 2012]*

Table 26 Assumptions on labour costs for nylon recycling

Staff member	Number	Annual Salary	NI	Salary Costs
General Manager	1	£60,000	£7,247	£67,247
Senior Engineer	1	£45,000	£5,177	£50,177
Engineer	1	£30,000	£3,107	£33,107
Senior Sales	1	£40,000	£4,487	£44,487
Sales	2	£30,000	£3,107	£66,213
Admin	5	£15,000	£1,037	£80,183
Shift Leader	3	£40,000	£4,487	£133,460
Operating Staff	12	£35,000	£3,797	£465,560
Distribution/Warehouse	6	£15,000	£1,037	£96,220
Utilities	3	£35,000	£3,797	£116,390
	35			**£1,153,043**

Table 27 Assumptions on labour costs for carpet shredding

Staff member	Number	Annual Salary	NI	Salary Costs
General Manager	1	£50,000	£5,867	£55,867
Engineer	0.5	£35,000	£3,797	£19,398
Sales	1	£25,000	£2,417	£27,417
Admin	1	£15,000	£1,037	£16,037
Shift Leader	1	£25,000	£2,417	£27,417
Operating Staff	8	£15,000	£1,037	£128,293
Distribution/Warehouse	3	£15,000	£1,037	£48,110
	15.5			**£322,538**

Chemicals cost assumptions for Nylon Recycling.

For chemicals recycling the quantities and costs assumed are shown in Table 28. The cost estimates used in the economic assessment in Section 6.3.4 have been rounded to account for some losses.

Table 28 Chemicals used for chemicals recycling process

Substance	Quantity (tonnes)	Price (£/tonne)	Total Cost (£)
Hydrochloric acid	130	£100	£13,000
Sulphuric acid	100	£180	£18,000
Phosphoric acid	180	£520	£93,600
Hydrated lime	45	£200	£9,000
Limestone crushed	40	£100	£4,000
Titanium dioxide	16	£2,500	£40,000
Gravel	200	£50	£10,000
Total	**711**	**£264**	**£187,600**
Rounded total	**750**	**£270**	**£202,500**

Source: estimated from Aquafil (2011), Environmental product declaration for Econyl® Nylon Textile Filament Yarn and a web search for current chemicals prices

Textiles 4 Textiles Business Case

In this section the original business case presented by Textiles 4 Textiles in the Netherlands is presented. As noted in Section 2.2.2 of the report, it has been adapted somewhat to make it more reasonable for a stand-alone company, although the currency has been left in Euros.

Table 29 Costs Textiles 4 Textiles Machine

Costs T4T Machine	Cost (€)
Investment (machine only) approx.	€ 431,000
Fixed costs per year	
Depreciation (10 years)	€ 43,100
Interest 50%	€ 12,930
Maintenance	€ 12,930
Annual updates library[64]	€ 3,500
Annual costs space (€50,- ^{m2})	€ 35,000
Total fixed costs per year	**€ 107,460**
Manpower	
Operators per shift	1.5
Operator costs per year	€ 25,000
Total costs per shift per year	€ 37,500

Source: Wieland textiles presentation, business case sorting machine, November 2012

Table 30 Annual costs for Textiles 4 Textiles

Sorting capacity/year		Energy	Man-power	Fixed costs	Total costs	Cost per kg
Number of shifts	kg	(€/year)	(€/year)	(€/year)	(€/year)	(€/kg)
1	4,147,200	20,736	37,500	107,460	165,696	0.040
2	8,294,400	41,472	75,000	107,460	223,932	0.027
3	12,441,600	62,208	112,500	107,460	282,168	0.023

Source: Wieland textiles presentation, business case sorting machine, November 2012

Table 31 Return on investment for Textiles 4 Textiles

Number of shifts	kg sorted per year	Investment (euro)	extra yield per kg (euro)	Extra yield per year (euro)	Return on Investment (years)
1	4,147,200	€ 431,000	€ 0.050	€ 207,552	2.077
2	8,294,400	€ 431,000	€ 0.063	€ 522,564	0.825
3	12,441,600	€ 431,000	€ 0.067	€ 837,576	0.515

Source: Wieland textiles presentation, business case sorting machine, November 2012

[64] *Annual subscription to fibre recognition data library*

Mattress Recycling Business Case

As Zero Waste Scotland has already conducted a detailed business case on mattress recycling,[65] this is not repeated in this study. This information is summarised from Table 32, with the costs and revenues from Year 2 used as the basis for the economic assessment in Section 8.4 of the report.

Table 32 Mattress recycling business case, assuming £6.25 gate fee

Cash Flow	Year 1	Year 2	Year 3
Total receipts	**£74,195**	**£ 140,116**	**£ 264,843**
Gate fees:	**£62,656**	**£ 118,815**	**£ 225,464**
Materials:			
Steel	£4,972	£9,179	£ 16,970
PUR Foam	£1,913	£3,531	£6,528
Textiles	£3,860	£7,125	£ 13,172
Latex	£217	£ 400	£ 739
Natural fibres	£577	£1,066	£1,971
Total materials	**£11,539**	**£ 21,302**	**£ 39,379**
Capital expenditure	**£11,200**	**£ -**	**£700**
Operating expenditure	**£129,582**	**£ 134,129**	**£ 228,923**
Total salaries & NI	£83,054	£ 88,745	£ 144,855
Rent	£24,000	£ 24,000	£ 48,000
Business rates	£9,768	£9,768	£ 19,536
Utilities	£5,000	£5,000	£8,000
Maintenance	£500	£ 500	£ 500
Personal & other equipment	£760	£1,216	£2,432
Office supplies & ICT	£1,000	£ 500	£ 500
Business development & marketing	£1,000	£1,000	£1,000
Travel	£500	£ 500	£ 500
Training	£1,000	£ 200	£ 700
Bank charges & insurance	£1,000	£1,200	£1,400
Legal costs	£1,000	£ 500	£ 500
General expenses & contingency	£1,000	£1,000	£1,000
Tax	£-	£ -	£ -
Net cash flow	(£66,587)	£5,988	£ 35,220
Cumulative net cash flow	(£66,587)	(£ 60,599)	(£ 25,379)
Mattresses processed	10,025	18,507	34,213
Tonnage	215	396	732

Source: A Business Case for Mattress Recycling in Scotland, Zero Waste Scotland, 2012

[65] *A Business Case for Mattress Recycling in Scotland, Zero Waste Scotland, 2012*

Project team

The methodology utilised in the economic assessments conducted in this study relies on the expert knowledge and judgement of the project team, as well as a number of internal expert reviewers. It is therefore useful to summarise their background and role on the project.

Nick Morley is Director of Sustainable Innovation at Oakdene Hollins. Nick has over fifteen years' experience in techno-economic studies and the co-ordination of sustainable innovation projects, including technologies for the recycling/reuse for textiles. Nick is a member of the RITE Group on sustainable textiles, is on the Steering Group of the MISTRA Future Fashion R&D project and is on the Steering Panel of the Huddersfield University End of Life Management of Textiles Project. He has presented nationally and internationally on textile reuse and recycling at the European Round Table of Sustainable Consumption and Production, the Swedish Sustainable Fashion Academy, Waste 06. Nick has considerable technical experience of textiles recycling technologies having been involved in two Defra projects and one for the European Commission that reviewed the opportunities to increase the recycling of low grade textile grades. These reviews of technologies and markets identified a wide number of potential and current opportunities which are considered within this project.

Peter Willis is a Senior Economist at Oakdene Hollins and has worked on a wide variety of projects providing expert economics input such as the resource efficiency opportunities in business. He has considerable expertise in market analysis, economic valuation and in building an evidence base for policy. Peter's research on textiles includes a textile flow map for WRAP. This project involved the analysis of production, sales, trade and waste data in order to produce separate material flow analyses for clothing, carpets, household textiles and mattress for the UK as a whole and for the individual UK nations. His previous research for the EC JRC-IPTS involved reviewing the technical and commercial potential of various textile recycling technologies.

Dr Paul Thompson is a Technical Consultant following completion of a doctoral programme at UCL. Paul is a gifted communicator, combining excellent writing skills obtained during his former career in educational publishing with confident and clear presentation skills developed during his doctoral studies. He is also an analytical thinker with extensive experience from both publishing and academia in the rapid understanding, interpretation and explanation of complex data. He has presented his research at international conferences both in the United States and Europe and his results have been published in academic journals.

Due to the range and type of skills required to complete the economic assessment required for this study, a wide range of internal expert reviewers were engaged with the aim of refining and validating their assumptions and results:

- **Jo Morley**: a qualified management accountant who is familiar in interpreting and reviewing public accounts and economic assessments of the sort presented in this study. Jo made a number of contributions in refining the economic assessments and scaling the costs and revenues according to the company size.
- **David Parker**: a qualified chemical engineer, who previously worked for DuPont Polyester Technologies. David made contributions to chemical recycling economic assessment based upon his previous experience of examining the economic feasibility of new technologies in his years at the company.
- **Steve Slater** has previously managed and overseen production at a range of factories in a number of light industries. Steve reviewed the economic assessments associated with mechanical recycling technologies, paying particular attention to the costs such as overheads, rent and rates and utilities associated with operations of this scale.
- **Dr Adrian Chapman** contributed his insights on the technologies and costs associated with mattress recycling, based upon the knowledge gained in a project for Zero Waste Scotland on this topic.

Oakdene Hollins is registered to BS EN ISO9001:2008, certificate number 21298

This report has been prepared for WRAP by:	Dr Paul Thompson Peter Willis
Checked as a final copy by:	Lesley Maddox
Reviewed by:	Nick Morley
Date	29 January 2013
Contact:	paul.thompson@oakdenehollins.co.uk
File reference:	WRAP01 327 MPD007-009.docx v4 FINAL

Contents amendment record

This report has been amended and issued as follows:

Version	Date	Description	Author	Editor
0	5/11	WRAP01 327 Technical Review	PT	NM
1	23/11	WRAP01 327 MPD007-009.docx v1	PT/PW	NM
2	11/12	WRAP01 327 MPD007-009.docx v2	PT/PW	NM
3	21/12	WRAP01 327 MPD007-009.docx v3	PT/PW	NM
4	29/1	WRAP01 327 MPD007-009.docx v4	PW	NM

Waste & Resources Action Programme

The Old Academy
21 Horse Fair
Banbury, Oxon
OX16 0AH

Tel: 01295 819 900
Fax: 01295 819 911
E-mail: info@wrap.org.uk

Helpline freephone
0808 100 2040

www.wrap.org.uk/relevant link

Printed on xx% recycled content paper