



OAKDENE HOLLINS



Recycling of Low Grade Clothing Waste

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Glossary

AAP	Acetylacetone Peroxide
AC	Activated Carbon
ACS	Association of Charity Shops
ADF	Advanced Disposal Fee
BATC	British Apparel and Textile Confederation
BFA	British Footwear Association
BMW	Biological Municipal Waste
BTTG	British Textile Technology Group
CAT	Charities Advisory Trust
CNC	Computer Numeric Control
CSM	Chopped Strand Mat
DEFRA	Department for the Environment, Food and Rural Affairs
DEPA	Danish Environmental Protection Agency
DTI	Department for Trade and Industry
EDIPTX	Environmental Design of Industrial Products - Textiles
ELV	End of Life Vehicles
EPR	Extended Producer Responsibility
EU	European Union
GRP	Glass Reinforced Plastic
IPP	Integrated Product Policy
LATS	Landfill Allowance Trading Scheme
LA	Local Authorities
LARAC	Local Authority Recycling Advisory Committee
LCA	Life Cycle Analysis
MBT	Mechanical Biological Treatment
MC	Marginal Costs
MD	Machine Direction
MDF	Medium Density Fibreboard
MFA	Multi-Fibre Arrangement
MR	Marginal Revenues
MRW	Materials Recycling Week
MSW	Municipal Solid Waste
MTP	Market Transformation Programme
NIRI	Nonwovens Innovation and Research Institute
OE	Original Equipment
OECD	Organisation for Economic Co-operation and Development
OHL	Oakdene Hollins Ltd
PCM	Phase Change Material
PMC	Polymer Matrix Composite
PRN	Packaging Recovery Note
PVC	Polyvinyl Chloride
RORO	Roll On Roll Off
RPI	Retail Price Index

RRE-USE	Re-use and Recycling European Union Social Enterprises
RTM	Resin Transfer Moulding
SATCoL	Salvation Army Trading Company Limited
SEPA	Scottish Environment Protection Agency
TRA	Textile Recycling Association
TRAID	Textile Recycling for Aid and International Development
UPS	Unit Pricing Systems
WCA	Waste Collection Authority
WDA	Waste Disposal Authority
WTO	World Trade Organisation
WEEE	Waste Electronic and Electrical Equipment
WRAP	Waste and Resources Action Programme

Definitions

It is important to clarify the precise meaning of key words that are the subject of this report.

A textile is defined as any type of material made from fibres or other extended linear materials such as thread or yarn. Classes of textiles include woven, knitted, knotted or tufted cloth, and nonwoven fabrics such as felt. A textile can also be a single fibre, thread or yarn.

Clothing is any item of apparel made primarily from textile materials, but excluding footwear as defined below.

Footwear relates to items such as shoes and boots. Textiles represent only a small percentage by weight of footwear materials.

Non-apparel material relates to all textiles that are not made into clothing, such as household linens, carpets and curtains.

The secondary textile industry collects, sorts and sells or recycles all types of used textiles and related items. Clothing makes up the majority of material by weight, but footwear, household linens, carpets and curtains are also collected. The term “textiles” is widely used in the industry to include all such items. Unless more specifically defined, “textiles” in this report is therefore used generically to refer to all materials handled by the industry.

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1 Executive Summary

1.1 Background

The primary purpose of the study into the Recycling of Low Grade Clothing Waste is to integrate an economic and market study of the used clothing recycling industry in the UK with technological developments which are aimed at improving the markets for recycling grades of clothing. The study also considers possible economic instruments and policy interventions, based on optimum financial and environmental impacts that could further develop secondary textile markets.

Whilst the study is primarily directed at used textile clothing, the economic and market analysis of collection, sorting and re-sale operations necessarily included footwear and non-apparel textiles, such as household linens, curtains and carpets. Reference to textiles in the report should be taken to include all such items unless more specifically defined. Indeed, the majority of the arguments presented in this report apply equally to all categories of the industry although the re-use and recycling of footwear and carpets are not considered in the technical and market development part of the study.

The project was carried out between August 2005 and August 2006.

In detail, the objectives of this project were:

Economic Analysis and Policy Study

To carry out an economic study of the used clothing recycling industry, examining the existing policy framework alongside the applicability of measures such as producer responsibility in the clothing sector. Specifically to:

- Identify, using compositional data analysis and other desk based research, the dynamics of the current market for used textiles, in particular used clothing
- Identify market failures, if any
- Establish how existing policy framework is applied to textile wastes diverted from Municipal Solid Waste (MSW) to recycling and re-use
- Forecast, through a review of the existing market structure and data obtained from the second-hand clothing collectors, the likely changes in textile waste arisings due to World Trade Organisation (WTO) changes, in particular the ending of the Multi Fibre Arrangement, and to consider the sociological effects of these changes
- Identify how much additional textile waste is likely to be redirected to MSW and whether this will continue after market adjustments.

- Identify, through liaison with waste contractors, the implications for non-thermal MSW treatment technologies from an increase in textile wastes in residual MSW.
- Identify the marginal increase in collection costs if textiles were to be included in various kerbside and bring collection systems.
- Identify the impact on substitute collection systems (charity shops and bring systems) should Local Authorities start a new service of collecting textiles as part of a kerbside system.
- Investigate appropriate policy interventions that could address identified market failures, to consider economic instruments - such as producer responsibility - as alternative policy measures and to compare costs and outcomes of such measures based on the existing policy framework.

Technical and Market Development Study

To research and develop new nonwoven textile materials which will seek higher value end product applications thereby improving the markets for recycled grades of clothing. Specifically to:

- Produce nonwoven materials from recycled clothing fibres utilising a novel process
- Identify six markets for the new nonwoven materials
- Identify promising potential partners or customers within those markets and provide them with product samples
- Obtain feedback from potential customers on performance
- Prioritise markets and customers for detailed development work and identify methods of taking forward promising projects.

1.2 Report Layout

The report is divided into three volumes as follows:

Volume I	Economic and Market Analysis	Sections 3 to 7
Volume II	Policy Intervention	Section 8
Volume III	Technical and Market Development	Sections 9 to 12

Each volume includes a conclusions section, references and appendices, where appropriate, for each element of the project. Overall project findings and proposals are set out below.

1.3 Findings

1.3.1 Economic and Market Analysis

General

The findings of this market study independently confirm that a combination of increasing affluence and lower prices of clothing and other textiles is causing a significant increase in the volume of textile products consumed in the UK. Specifically, new clothing sales volumes in the UK have increased by 60% in ten years. This has the potential to greatly increase the volume of textiles in the waste stream if all the new textiles consumed were discarded to waste. The secondary textile industry, which operates in a free market, collects just 17% of all textiles consumed, with the balance being either stockpiled or discarded to the household waste stream.

The study also confirms adverse perceptions within the secondary textiles industry of the economic and market situation and the impact of the ending of the Multi-Fibre Arrangement. Although the industry is currently enjoying firm prices for used clothing, particularly in Eastern European markets, arising from the shortage of suitable quality material, these are seen as being short-lived. In the longer term there is likely to be a decline due to falling prices in new clothing coupled with reducing product quality of used clothing being collected, and rising costs at all levels. Indeed, prices of new clothing are likely to continue to fall over the next five years. This has a double effect of placing higher volumes and lower qualities of used clothing on the markets which in turn is driving used clothing prices down thus affecting the long term viability of the textile recycling industry.

Charity shops are responding by moving into the sale of alternative used products, such as books, toys and electronic media and into new products such as greeting cards and fair trade commodities. As a result, they are reducing the percentage of sales from used clothing. Some textile merchants are responding by closing down sorting activities and by shipping unsorted material directly to overseas traders or to sorting operations in low labour cost countries.

Waste textiles Arisings and Disposal

Approximately 1,812k tonnes of textile products, originally purchased as new, and a further 53k tonnes of used products entered the secondary UK textiles market in 2003. Of this quantity, a net 303k tonnes (16%) were collected by the secondary textile industry and 1,165k tonnes (63%) were disposed of by consumers and the industry. The balance of 397k tonnes, equivalent to just over 6kg per head of population per year, is unaccounted for, and is therefore presumed not to have been discarded and to be

increasing the total stocks of clothing and other textiles held by householders. It is assumed that this stockpiling, or increase in the “national wardrobe”, has been occurring for a number of years, generating a potentially large quantity of latent waste.

Over time, the quantity of textiles that can be stockpiled is limited, apart from satisfying population growth. Given this fact, and the likely increase in new clothing sales, it follows that the quantity of used textiles entering the waste stream will increase in the medium term. Textiles would currently represent 5.2% of total household waste if all textiles consumed were discarded to waste.

Of the net 303k tonnes of textiles collected in the UK in 2003, 41k tonnes of clothing were re-sold for re-use as clothing in the UK and 174k tonnes were exported for re-sale as clothing abroad.

A further, unknown portion of clothing and other textiles will have been re-used in the household as wipers, etc. Re-used items will, in time, be disposed to the waste stream after re-use. Only 262k tonnes (14%) of consumption were diverted from the UK waste stream in 2003, through recycling into new product or by being exported for re-use and/or recycling. The conclusion is that there is a large re-use/recycling opportunity for both the industry and for waste disposal authorities which has not yet been exploited.

Collection Activity

The present infrastructure of the UK secondary textiles industry is designed to collect wearable, re-usable clothes, and not to collect as high a portion of textiles as possible. Collection economics have been driven by the value in textiles reused as clothing. The sales value of recycling grades of material has fallen by some 71% in real terms over 15 years, largely due to the introduction of “value” clothing, and is now less than the cost of collection and sorting donated textiles.

The expected decline in the collection market will not be impacted by existing mechanisms that drive wastes from landfill, i.e. the landfill tax and the use of the Landfill Allowance Trading Scheme (LATS) by Local Authorities. Although there is a clear case, on environmental grounds, for additional collection and diversion of textiles from the waste stream, textile wastes have barely featured in waste disposal authority waste management strategies to date. Local Authorities are concerned with achieving tonnage based recycling targets and in reducing the tonnage of biodegradable wastes directed to landfill. Textile wastes are largely irrelevant to these metrics.

Increasing the collection rates can be achieved by Local Authorities, but the cost of this is significant relative to the value of textiles collected, even for those authorities that operate existing kerbside schemes.

Increased collection could be carried out either acting in co-operation with the existing industry stakeholders or independently. Even assuming that only half of the current stocking and disposal tonnage is, sensibly recoverable, this would mean that an additional 800k tonnes of textiles could be collected per year, equivalent to 2.2% of the household waste stream and this would contribute significantly to Local Authority waste recycling targets. In this scenario, however, the quality mix of the materials collected would deteriorate as the quantity increased, and the industry as a whole, would be faced with significant technical and marketing challenges to re-use or recycle the additional materials generated.

It is assumed that the ability to export the additional tonnage generated will be limited. Indeed, it is likely that export opportunities will decline, keeping higher tonnages of material in the UK for further processing.

Other Findings

Amongst leading UK retailers we uncovered, with a few notable exceptions, a low level of awareness of textile wastes management issues. More concern was noticed in the packaging and food wastes area. However, it is perceived that sustainability issues in general are becoming increasingly important in the sector.

A further influence on the value of recycling grades is the fashion trend to apply novel treatments for the base textiles and to adorn clothing with embellishments which add complexity to the recycling process. Such treatments often cause equipment malfunction and contamination of the secondary material and end product. Indeed, the increasing use of synthetic base materials in the clothing market has already caused the waste management industry to ask for textiles to be separated from the household waste stream, MSW, prior to treatment by the new technological processes such as autoclaving and pyrolysis.

1.3.2 Policy Intervention

It was found that, in the context of the carbon dioxide (CO₂e) impacts of waste disposal choices, the re-use of clothing shows a large and positive benefit over recycling or disposal. However, much of this benefit occurs outside of the UK. Recycling textiles shows a significant benefit over landfill and energy recovery and this is second only to aluminium in terms of its CO₂e benefits compared to the recycling of other components in the household waste stream. Substitution of virgin fibres via recycling (or new clothing via re-use) has a high potential for greenhouse gas reduction, albeit

not in the UK. Charity shops and the textile recycling industry therefore have a strong environmental benefit. They currently displace about 8m tonnes CO₂e per year, albeit not in the UK.

Justifications for extended producer responsibility (EPR) measures, such as that proposed for WEEE, are not justified because of the low pollution potential of clothing at end of life. Policy should focus on how to conserve the resources embodied in clothing through encouraging re-use and recycling.

Although EPR is not applicable, we think the retail industry should do more through voluntary agreements (cf. the Courtauld Commitment to retailer waste minimisation) to promote and stimulate appropriate conservation of resources, including greater liaison with organisations dealing with discarded clothing. Voluntary agreements by leading retailers could encourage consumers to donate high quality garments to the existing networks.

Information should be provided to consumers via product labelling and promotional activity to enable more sustainable consumption. In the long term a novel labelling solution may be developed to also assist the sorting and reclamation of clothing. The compilation of a standard or publicly available specification for recycled textiles would also address information failures within the secondary textile industry.

Policies to address major externalities, such as the impact of pesticides and water use in cotton production, should be carried out as close to the point of pollution as possible. For example, it is probably not appropriate to try to levy eco-taxes in the UK on cotton manufactured elsewhere, but better for the UK to encourage the grower countries to address these externalities through national economic instruments.

We propose using the existing recycling credits system to support the collection of used clothing in order to smooth out the significant fluctuations in economic viability for this collection infrastructure. Textile collectors (charities or for profit organisations) should be given recycling or re-use credits where they are prepared to enter into long term contracts for taking clothing from Local Authorities.

Target setting for Local Authorities for textile recycling, in preference to other materials where carbon benefits are lower, would be preferred to the existing tonnage based recycling targets. The promotion of textile recycling should initially focus on the diversion of higher quality clothing from the waste stream.

The projected decline in recycling activity from 2005 is being caused by a fall in the value of used clothing both for re-use and for fibre and a

historical lack of innovation in the sector. In order to reverse this decline and to support higher levels of textile recycling, markets for lower grade recycled textiles will be required. Any policy intervention aimed at increased collection rates, however, must take into account the finite infrastructure of the collection and processing sectors. The secondary textile industry could not cope with a rapid increase in collection rates, especially as it is likely to be accompanied by a further reduction in quality.

There is a need for considerably more research and development driving innovation in the use of textile fibres for new applications. Currently there is a mismatch between the strong growth of clothing arisings suitable for recycling and the mature/declining nature of many traditional markets for recycled fibre such as wipers for engineering, mattress spring padding, shoddy and mungo manufacture. One role for government could be to co-fund innovation and market development in this area to provide market “pull” for used textiles.

We anticipate the development of tradable carbon instruments that will be applicable to clothing and other wastes management activities. Clothing businesses with an interest in the carbon agenda may be encouraged to engage in the design of such instruments.

Finally, we are proposing that consideration is given to the implications of relaxing the regulations restricting the export of unsorted used textiles. These restrictions are closely allied to the definition of waste as it relates to textile collections. With appropriate controls, any relaxation may permit increased collection rates in the UK.

1.3.3 Technical and Market Development

From the above market study it is estimated that the UK market for recycled textiles is approximately 62k tonnes per annum, of which just three main application areas consume 53k tonnes per annum.

The largest volume application in the UK is for mattress/upholstery products with 66% of all recycled material going into this market. Carpet underlay and automotive applications (mainly sound insulation materials) are much lower volume markets representing 11% and 9% respectively. There are also many other much smaller diverse application areas that comprise almost one sixth of the total market including horticultural basket liners, capillary matting, and thermal insulation.

The values of recycled textiles for these traditional markets, at processor selling prices, range from £600 to £1,100 per tonne. It is expected that the added-value applications that are being developed as part of this project

will be able to generate returns in excess of £1,000/tonne, the market value for volume underlay products. If the specifications can be achieved to meet the more demanding applications, prices around £2,000/tonne may be realised.

The technical work to date has verified the feasibility of different processing methods for recycling low grade clothing waste. The six market areas identified were low-modulus fibre reinforced composites and bio-composites, capillary matting, automotive headliner and bootliner components, automotive flooring component systems, pre-seeded horticultural matting and air filtration. The footwear/odour absorption market, identified as a priority during the project, was quickly discounted as the sector did not accept recycled content into their products for reasons of protection of their brand image.

Six potential customers, who currently operate commercially in these market sectors, were approached. Once interest was established, NIRI proceeded to design evaluation samples specifically for these applications in accordance with their technical and commercial requirements.

The firm interest established is being utilised to identify how the concept samples can be further developed to a commercial stage. Sources of internal and external funding are being identified to assist in further collaborative work with the sponsoring companies.

It is evident from the work conducted in the study that through using a technological approach to utilising recycled fibres and their inherent properties that a premium product market can be targeted. The added cost advantage of recycled fibre, usually less than 40% of the cost of the virgin fibre equivalent, makes the use of recycled fibre very attractive.

1.3.4 Recommendations for Further Study

A number of areas to be considered for further study were identified during the project. They are:

- The payment of re-use and recycling credits by Local Authorities for diversion of various waste materials is patchy across the 469 authorities in the UK. A consistent approach is recommended. Prior to this, the actual level should be established by further study.
- The quality of textiles discarded into the waste stream and their suitability for re-use and recycling should be determined as a precursor to policies that target increased collection. This work would be linked to the waste composition studies using standardised protocols. Also it would be important to establish the actual composition of textile materials achieved from the various collection methods.

- Life cycle analysis (LCA) studies make many assumptions on the environmental impact of clothing during its useful life. It would be valuable to determine the average lifespan of clothing (length of ownership) and the number of cleaning cycles incurred in the lifespan. We should consider trends in lifestyle that impact on clothing cleaning habits (e.g. increased use of tumble dryers rather than line drying, decreased use of dry cleaners).
- More work is required on consumer purchasing and discard decisions. Improved knowledge of the relative impacts of the consumption of higher quality garments, kept and used over an extended period, and lower quality items, which are discarded within a shorter time frame, would inform product labelling decisions. Also, collection activity would benefit from more evidence relating to discard patterns, i.e. what is discarded, when is it discarded, and how often do consumers clear their used textiles.
- The study finds that a “national wardrobe” exists which represents a considerable tonnage of latent waste material. It is necessary to establish the actual level of this stock.
- Many LCA studies focus on carbon impacts of waste streams. We should consider the case for economic instruments for clothing from a resource conservation, rather than a pollution, impact perspective (which is the traditional driver for producer responsibility measures).
- There is little evidence of “closed loop” recycling, whereby recycled fibres are used in the manufacture of new clothing in the place of virgin fibres. Based on the experience of the paper making industry, it is important to understand the reasons for this and to undertake comparative LCA studies.
- To improve understanding of the secondary market dynamics it is important to determine the degree to which second hand clothing acts a substitute for new clothing in secondary markets.
- The technical and market development work in this project, which has reached the stage of identifying a number of new high value applications for recycled textiles, requires to be continued. More investment is needed to turn these into commercial reality. We need to view these items as a raw material and show “industry” how to make use of them.
- A key point is the collection system. This not only applies to textiles but increasingly to all secondary use materials. We need to understand the true economies of resource management and not just look at the collection cost, but the overall cost to UK plc.
- Textile manufacturers, designers, retailers and the secondary textile industry need to be encouraged to work together to address, and to develop solutions to, the issues raised by this report. To this end some projects are identified for further collaborative work aimed at improving the sustainability of the wider textile industry.

2 Project Organisation

The project was carried out by a consortium of companies, listed below.

Lead Organisation: Oakdene Hollins Limited (OHL), consultants in waste management, environmental policy and sustainable technologies.

Partner: Salvation Army Trading Company Limited (SATCoL), the trading arm of The Salvation Army working in partnership with Kettering Textiles Limited, is the UK's largest collector of used clothing.

Partner: Nonwovens Innovation and Research Institute, Leeds University (NIRI) which is one of the UK's leading research groups in the technologies of nonwoven production.

Assistance with the market was obtained from the Textile Recycling Association (TRA) and from a number of stakeholders in the textile industry. The input from all stakeholders is gratefully acknowledged.

Volume I

Economic and Market Analysis

3 Background to Economic and Market Analysis

3.1 *Scope of Textile Materials*

Whilst the study is directed primarily at the markets for used clothing, the textile recycling industry also handles shoes, leather goods and non-apparel textiles such as household linens, soft furnishings and some carpets. Clothes and shoes dominate the market, with non-apparel materials making up a relatively small portion of the total.

3.2 *Material Flows*

In the UK, the collection of used textiles is largely carried out by charity organisations through a combination of door-to-door collections, textile banks, and receipts at the high street charity shops themselves. Items that are saleable in the shops are retained and the surplus is sold to textile merchants for sorting and onward sale, either as re-useable clothing to export markets, or as recycling grades for pulling and conversion into felts, etc. by textile processors. In continental Europe, collection of textiles involves a considerable number of non profit-making social enterprises whilst most of the sorting is carried out by commercial companies. A degree of waste is generated at the collection and sorting stages. This will comprise items such as wet or soiled clothes, carrier bags and other waste items, and these will have to be disposed of to the waste stream at a cost to the organisation handling the materials.

Whilst the industry sorts and distributes used textiles into some 140 different grades, this report simplifies consideration of the market by using five categories as follows:

- UK Re-use. Wearable items resold in the UK through retail shops. This is considered the 'cream' of used textiles.
- Export Re-use. Wearable items exported for resale in second-hand 'retail' outlets and markets.
- Wiper Grade. Material suitable for use as rags and wipers with little or no further processing.
- Recycling Grade. Material suitable for pulling or shredding into fibres for use in new end products.
- Waste. Material that cannot be resold or recycled which is disposed to the UK waste stream.

Material flows in the UK secondary textiles market are shown in Appendix I.

Prior to this study, no accurate figures were available for either the quantity of textiles being discarded by UK consumers or the tonnage of waste textiles entering the waste stream in any year. It was estimated that all textiles entering the waste stream make up around 2-4% of the municipal solid waste (MSW). This is the major portion of the total discarded. The degree to which consumers stockpiled used clothes was not known but was perceived to be significant and represented a third factor in the mass balance equation for textiles as a whole.

3.3 Market Trends

It is perceived that the economics of textile re-use and recycling are deteriorating because:

- The rapidly declining price of new clothing entering the market, through imports from low labour-cost countries in the Far East, is lowering the price being realised for the re-sale of wearable clothing in the UK and in export markets
- The re-use proportion of textiles collected is declining because of the increased mix of low quality items
- The recycling proportion is increasing, but selling for flocking or shoddy generates only about 10% of collection costs i.e. there is a lack of value-added markets for recycling grades of textiles
- Regulatory and employment costs in the UK are increasing
- Disposal costs of residues not suitable for recycling are increasing.

Collection economics are driven by the value in textiles re-used as clothing, which subsidises the increasing losses on recycling and disposal. The adverse trends in the market are highly likely to result in an increase in the amount of textile waste being discarded to the waste stream and a reduction in the extent of textile recycling. This will occur at a time when certain alternative technologies for biological municipal waste (BMW) treatment, such as autoclaving and anaerobic digestion, are under demonstration. These technologies will have little impact on textiles, which are retained in the process residues and adversely affect the economics of the technologies. Under current policy conditions, which are generally based on weights diverted from landfill, Local Authorities are incentivised to remove denser items from the waste stream (e.g. cardboard and glass) and the lighter textile stream is likely to remain untouched. The textiles area also falls outside the priority areas of the Waste and Resources Action Programme (WRAP) and they have no interest in supporting it.

3.4 Textile Recycling

Technical recycling processes have changed little in the last century. The most common process involves the material being shredded or pulled apart into small fractions and fibres, called shoddy or mungo. Traditional applications for these fibres include industrial filling materials, for mattresses and upholstery, sound insulation panels and carpet underlay. Shoddy from sorted fabrics can be combined with virgin fibre, which is then carded to homogeneously mix the fibres and to produce a web, which is the pre-cursor for various textile and nonwoven materials. Subsequently, fibres are spun ready for weaving or knitting into new products, or the web is bonded directly to form a nonwoven structure. There is a significant UK nonwoven presence in traditional recycled textiles market supplying mattress/upholstery, carpet underlay and automotive markets.

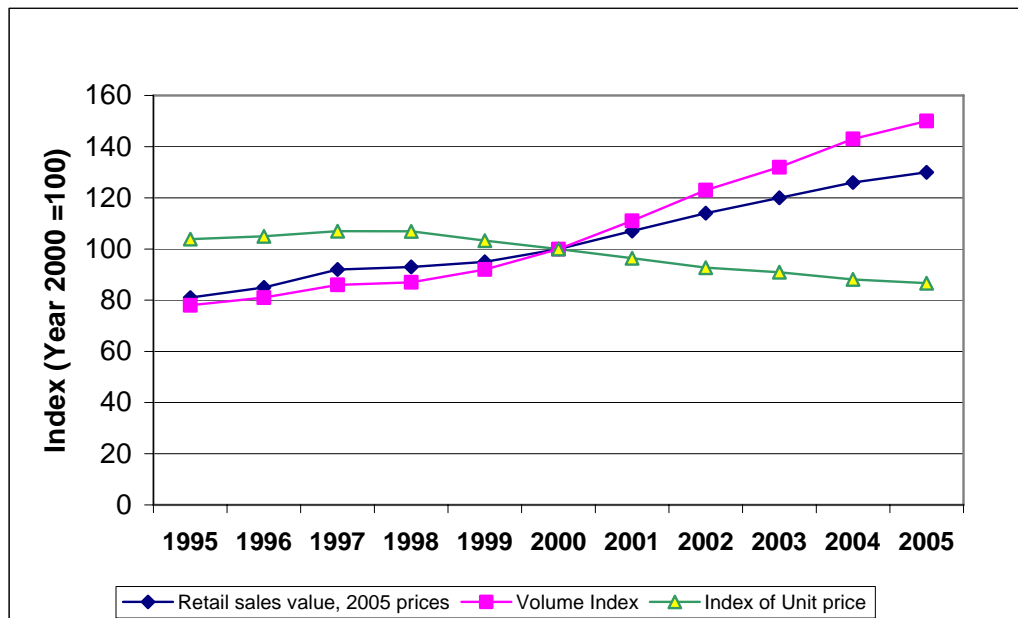
These traditional markets for recycled textiles are mature and offer very little opportunity for added-value. The study includes the examination of the feasibility of making nonwovens from a range of low-grade clothing waste, which would normally be sent to landfill, to create high added-value products consisting of up to 100% recycled waste materials as well as blends with functional materials. The aim is to identify and approach potential customers in these markets to form the basis of longer term collaborations.

4 Overview of Market

4.1 The New Clothing Market

Figure 1 shows the growth in volume in the UK new clothing market over ten years and this is compared with the reduction in unit prices.

Figure 1: New Clothing Value, Volume and Unit Price Trends



Source: ONS

The chart shows that unit prices of new clothing have declined substantially since 1998 as cheap imports and the value retailers have come into the market. However, volumes - as measured by value of sales adjusted by RPI - have increased by some 60% in the same period, due to a combination of lower prices and increasing affluence. This finding is supported by a paper produced by Mark Hudson of PwC (Transaction Services) for the March 2005 Retail Week Conference. The paper refers to a study of the fashion retailer Next Direct's catalogue between 1995 and 2005 which confirms that prices have dropped 40% in that time in real terms (equivalent to 60% after inflation). In summary, the consumer is buying more clothes but at lower prices. The data for all textiles, including shoes and leather items, show a similar if less marked trend.

The implications of this for the secondary textiles sector is that lower quality, items are being collected, and there is a reduction in the sales value of the wearable items. The consumer has to choose, say, between a new shirt, now available at £5, and a second-hand shirt at £3. When the new item was above £10, it was easier to make the decision in favour of the used item. In addition, the re-saleable proportion of the collected items is declining, meaning that increasing quantities have to be recycled, or disposed of to the waste stream, at a cost to the collector or merchant.

These trends in volumes and prices are likely to accelerate as a result of the cessation of the World Trade Organisation (WTO) Multi-Fibre Arrangement (MFA) in January 2005, especially when the current transitional arrangements are exhausted. China and India will dominate the production of new textile materials and products through major vertical integration programmes. Both economies produce high technology, high quality fabrics and have low garment production labour costs. Pacific Rim Multi-Fibre Alliance countries such as Indonesia, Cambodia and Vietnam will increasingly rely on Chinese fabrics, and manufacturing will suffer here when the market is fully freed up. China and its 'satellite' countries will be used more for the long run, stable designs such as jeans, tops, T-shirts and underwear, with the less predictable, low cost fashion items more likely to come from North Africa, Italy and Turkey.

Whilst China sees its participation in the textile industry as 'transitory', i.e. that they will want to be out of it in, say, 20 to 30 years time, the changes that they will cause in the world textile market are seen as irreversible. The belief in the industry is that prices will drop a further 30% from today's levels when China is supplying the market free of import restrictions. Whilst all figures must be treated with caution, because of the changes in fashion during the last ten years, it is the trends in the market place that are irrefutable.

This activity in the new clothing market will further weaken collection economics and depress the sales and margins of second-hand clothes. All of these problems, which affect the charity shop and commercial textile recyclers, have been widely reported in the national and trade press.

4.2 *Arisings of Used Textiles*

Used clothing and other textiles are discarded by the domestic consumer in one of six ways, depending on the level of local involvement by Local Authorities, charities and commercial operators. Some return is obtained for a small proportion through resale, but the overwhelming majority, in terms of tonnage, is donated free by the original owner or is disposed of to the waste stream. These discard routes are summarised below:

- Private Sales. Textile items are sold through jumble sales or boot fairs. Also, some high value clothing is sold through commercial second-hand clothes retailers with a proportion of the sales value of each item being returned to the original owner. Surplus, unsold material from these ventures will be sold to the merchants. A recent but increasing private sales route is through the internet using the online auction website, eBay.
- Textile Banks. The items are taken to a local textile 'bring' bank which is operated by either a charity-linked organisation or by a strictly commercial collector.
- Charity Shops. The items are taken to a local charity shop.
- Door-to-door Collections. Collection bags are delivered to the householder's doorstep by a charity or a commercial collector.
- Kerbside Recycle Schemes. These schemes are operated on behalf of Local Authorities, either by waste management companies or by resource management consortia which include textile recycling companies. The schemes usually involve collection bags being supplied to every doorstep in the district. When the bag is filled by the householder it is left out for collection, and a replacement bag is issued.
- Disposal. The items are placed in the household rubbish bin, sometimes after re-use as rags, wipers, etc. Bulky items such as curtains or carpets may be taken to the local civic amenity disposal site.

Each of the above routes will generate material that is neither suitable for resale nor recycling. This will include such items as single shoes, carrier bags, coat hangers and wet or soiled textiles. Indeed, the secondary textile industry as a whole has expressed concern over the amount of unusable material which they receive. This material has to be disposed of to the waste stream at significant cost to the industry.

Used clothing and other textiles will also arise in industrial and commercial waste streams. One particular source which is of interest is that of the

corporate clothing sector, which is discussed separately in this report. Off-cuts and waste generated by textile product manufacturers will also form a significant part of the waste stream, but these are chiefly disposed of through the industrial and commercial route and are not considered in this study.

4.3 Consumer Discard Patterns

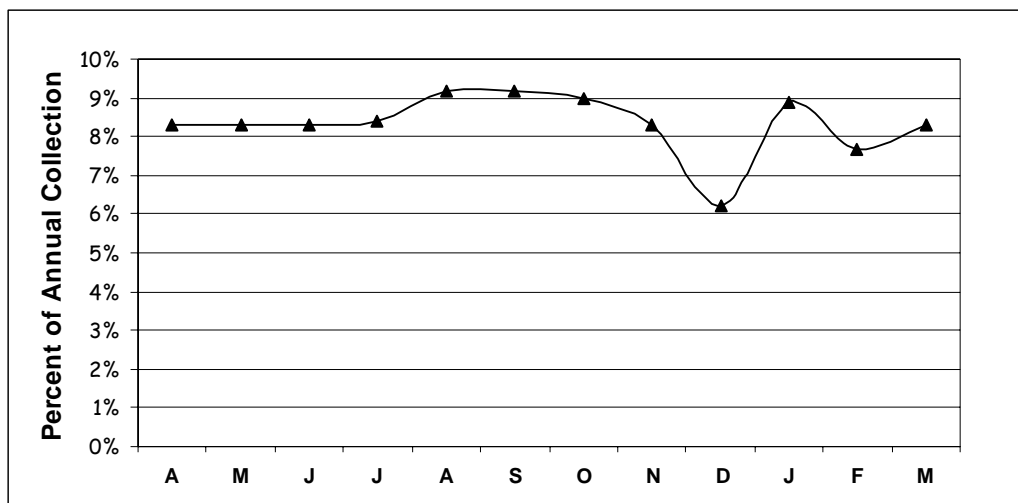
Unlike the majority of household waste materials, which are generated regularly and frequently, it is believed that consumers tend to 'clear their wardrobes' periodically and thereby generate relatively large quantities at infrequent intervals. External factors, such as disaster appeals and 'promotions' by local collectors can also influence the clearouts.

Figure 2 charts the Salvation Army Trading Company's textile bank collection patterns by month averaged over the last five years. The chart shows that collections peak in the autumn months, to 110% of average, and fall significantly, to 74% of average, in December. The fall in December cannot be explained by a reduction in activity by the industry during the Christmas holiday season because:

- Collections from textile banks in December continue on all but the two bank holidays
- The 'lost' tonnage is not recovered in January and February.

The figures, therefore, clearly indicate that considerably less material is donated during December.

Figure 2: Seasonal Variation in Used Textiles Collections



Source: SATCoL

A key unknown factor in consumer discard patterns is the extent to which consumers are increasing or reducing their stocks of clothes.

In May 2006 a survey questionnaire was sent to 250 consumers in order to help substantiate the perceived trends in consumer purchasing and discard patterns for clothing. The questionnaire results were interpreted by a consultant working in fabric and fashion design for 'high street' and 'designer' clothes retailers. The survey cannot be considered to be statistically significant since the respondents were taken from a limited cross section of consumers. However, the results provided some confirmation of the perceived trends. Specific results were as follows:

- 63% of respondents agreed that clothing has become lighter in weight over the last three years, and that this trend is accepted as continuing for the foreseeable future.
- On average 4.1 items of clothing are purchased per household per month with the highest proportion being children's clothing (which generally doesn't wear out but is 'grown out of').
- 62% of respondents thought that the lifetime of clothing is shorter than it was three years ago. The actual expectation from clothing is less and we are not expecting things to 'last a lifetime' any more. Retailers are responding to this in the garment specifications by lowering the standards on fabric, trimmings and manufacturing.
- 47% of total respondents thought clothing was less expensive today than three years ago.
- Of the total respondents nearly 40% were buying more at lower prices than in previous years.
- When 'having a clear out', 59% of all respondents take clothing to a charity shop, with 20% giving to friends/family.
- 2% of all respondents regularly sell used clothing, for instance on e-Bay: within respondents under 30 years old, this figure rises to 5% being sold.
- The remaining 19% take used textiles to a clothing bank or throw them away.
- 45% of all respondents have a 'clear out' of clothing once a year and 42% once every six months.
- 44% of respondents clear out "the same as you used to" and 17% "less often than you used to".

This survey therefore suggests that clothing is seen as becoming lighter and cheaper. The UK public are certainly buying more new clothing than they used, to but the survey does not indicate that they are necessarily clearing their wardrobes less often or that they are hoarding clothing.

It is suggested that consumer clothing discard patterns should be the subject of further research.

4.4 Existing Regulatory Framework

4.4.1 National

A summary of relevant EU directives and English and Welsh legislation affecting the secondary textiles industry is set out in Tables 1 and 2.

The major problem restricting the flow of materials in the textiles waste stream is the definition of waste. Under current UK legislation, a product is classified as waste from the point that it is discarded by the primary consumer. However, because donated clothing is deemed to be wearable, and therefore re-useable as clothing, it is not classified as waste in some circumstances.

Table 1: Summary of Legislation affecting the Secondary Textiles Industry

Legislation	Information
Environmental Protection Act (1990), Part II	Waste textiles considered as 'controlled waste'. Specifies collection, disposal and treatment of controlled wastes.
Waste Minimisation Act (1998)	Powers to WDAs and WCAs to minimise the generation of controlled wastes.
EC Council Regulation (EEC/259/93) Supervision and Control of Transfrontier Shipments of Waste	Regulates the shipping abroad of used textiles.
Controlled Waste Regulations 1992	
Landfill (England and Wales) Regulations 2002	Imposed controls on inputs to landfill sites, specifically targets for diversion of biodegradable wastes from landfill.
Pollution Prevention and Control (England and Wales) Regulations 2000	

Table 2: Other Regulatory Measures affecting the Secondary Textiles Industry

Measure	Information
Landfill Tax Escalator	Currently (2005/06) £18 per tonne, and increasing by £3 per tonne per year.
Definition of Waste	
Landfill Allowance Trading Scheme	Financial incentive to WDAs to reduce landfilling. Recycling credits to collectors and re-processors?
Waste Incineration Directive	

The Environment Agency, in a letter to a major textile merchant in August 2005, confirmed that:

.....for second-hand clothes to cease to be waste they must:

- i. be suitable for continued use as clothes; and*
- ii. be being exported for sale and/or use as clothes.*

It needs to be emphasised that if the clothes are fit for use as clothes but are exported for shredding/making into dish cloths or for some other application than direct re-use as clothes, then we'd consider that to be an export of waste.

As such, if clothes go through a sorting and quality control process to remove unsuitable clothes from the higher grade material the clothes cease to be waste and are therefore not subject to the requirements of the Waste Shipment Regulations 259/93/EC.

The legislation is therefore interpreted by the Environment Agency, for used textiles, as follows:

- Material from textile banks, either at civic amenity or public sites, is classed as waste since it is discarded by the original user and is assumed to contain considerable amounts of unusable material. Transporting and shipping textile bank material, therefore, is only allowed through a waste carrier's permit, etc.
- Bags of textiles arising from door-to-door collections are deemed not to be waste, because it is expected that they will contain all usable (wearable) material. In this case it is assumed that the householder discards clothing with the belief and intention that it will continue to be used as clothing.
- The same applies to the surplus textiles, unsuitable for re-sale in the UK by the charity shops, which are forwarded to the merchants for re-sale abroad. This is not waste because it is deemed to have been sorted and any unusable material to have been removed. Of course, the definition of what is or is not usable lies with the sorter.
- Where a merchant ships used textiles destined for wiper rags or shredding, then this is waste.

Telephone discussions with the Agency in November 2005 confirmed that donated clothing, collected from a textile bank, is a discarded material and as such is classified as waste at the point of collection. However, it is noted that clothing donated directly to a charity shop, or through a door-to-door collector, is not regarded as waste since it is not deemed to be discarded and is assumed to be suitable for continued use.

The classification of textile bank material as waste is disputed by the merchants who argue that 'waste' should be defined by the intention in the

mind of the person discarding the material. If it is clearly being 'donated' for secondary use, then it is not waste. Furthermore, the Agency argument will depend on the amount waste material in each textile bank load, many of which may contain less waste material than in loads from other sources. Both the Agency and the merchants agree, however, that once sorted the re-usable portion of textile bank collection is no longer waste.

4.4.2 Local Authority

It is the Landfill Regulations that motivate Local Authorities to promote recycling in the household waste stream through the setting up of the Landfill Allowance Trading Scheme (LATS). Targets for the diversion of biodegradable waste from landfilling are driving the move to increasing kerbside collection of a variety of wastes which are suitable for recycling. Because 50% of used textiles are biodegradable, some authorities have either set up schemes for textiles or are co-operating positively with the existing collection infrastructure.

4.5 Public Perception

The key factors directing consumers to donate their used clothing and other textiles for free, rather than to dispose of them to waste, are:

- The public perception that the giving of used clothing to a textile bank, a charity shop or to a door-to-door collection scheme is a charitable donation to Third World countries.
- The growing awareness, through public promotion, of the environmental benefits of the re-use and recycling of as much household waste as is practical. This in turn is driven by the financial incentives placed on Local Authorities to achieve increasing recycling targets.

As noted above, a small amount of clothing may be sold privately rather than donated free to the charities. Some retailers sell second-hand clothing as agents for the original owner, who then receives a percentage of the sales price once the item is sold. This disposal route is only suitable for relatively high value items and is not considered further in this study.

Clearly many charities benefit from the profit made through the re-sale of donated used clothes. However, it is not widely realised that the ultimate Third World beneficiaries are, in fact, paying for the clothes donated, and that once the materials are passed on from the collecting charity to textile merchants and exporters, trading is carried out purely on a commercial basis. This fact is, of course, a fundamental requirement of merchant's

involvement in textile collection. Where the trade in any importing country is significant there are benefits both to the national economies and to the recipients of the clothing. Considerable levels of employment are sustained and individuals, who could not otherwise afford to replace clothing regularly, benefit from low cost, good quality, 'western' fashions. However, it is reported that there is a risk in some regions that such trade can undermine local clothing manufacturing industries where they exist. It is difficult to assess the degree of this risk since there are other contributing factors which adversely impact indigenous industries such as cheap new clothing imports from low cost Asian economies, supply-side constraints and limited local infrastructure¹.

The Charities Advisory Trust, in 2000, showed that 94% of the public believed that charity shops were a good way of raising money for charity. A survey by the Association of Charity Shops (ACS) in 2003 showed that supporting charities/helping someone else was the single most important reason for 51% of those that had recently donated used items. The need to clear out unwanted goods was the second most important factor with the general need to recycle registering as the third most important.

The perceived charitable nature of the donation of used clothing is, in fact, exploited by purely commercial door-to-door collectors who often imply through distributed leaflets that donated clothing will benefit charitable causes. These dealers sell to export markets directly, often without sorting, and some are operating illegally. The number of such enterprises is not known, and will vary from year to year depending on the availability of material and on-spot market prices. It is, however, known that they represent a significant volume of the export trade, estimated at c.20% of throughput.

5 Economic and Market Data

5.1 *Arisings, Recovery and Disposal*

5.1.1 Methodology

Prior to this project no accurate figures existed for the quantity of used textiles discarded by the primary user in the UK. Reasonably accurate figures do, however, exist for the consumption of new clothing and other textiles. As noted in Section 4.3, therefore, consideration needs to be given to whether consumers are increasing or decreasing their stocks of textiles - particularly clothing - over time. If they are not, then the consumption of new clothing and other textiles in any one year may be taken as proxy for the quantities of textiles discarded in that year. If clothing and other household textiles are being hoarded, then the arisings of used textiles have to be quantified using an alternative model.

The following model is used by this study:

- Quantification of UK consumption of new clothing and footwear
- Quantification of UK consumption of non-apparel textiles
- Assessment of weight of textiles entering the waste stream
- Research and assessment of the weight of textiles collected by the secondary textiles industry and the fates of those materials
- Computation of arisings, recovery and disposal.

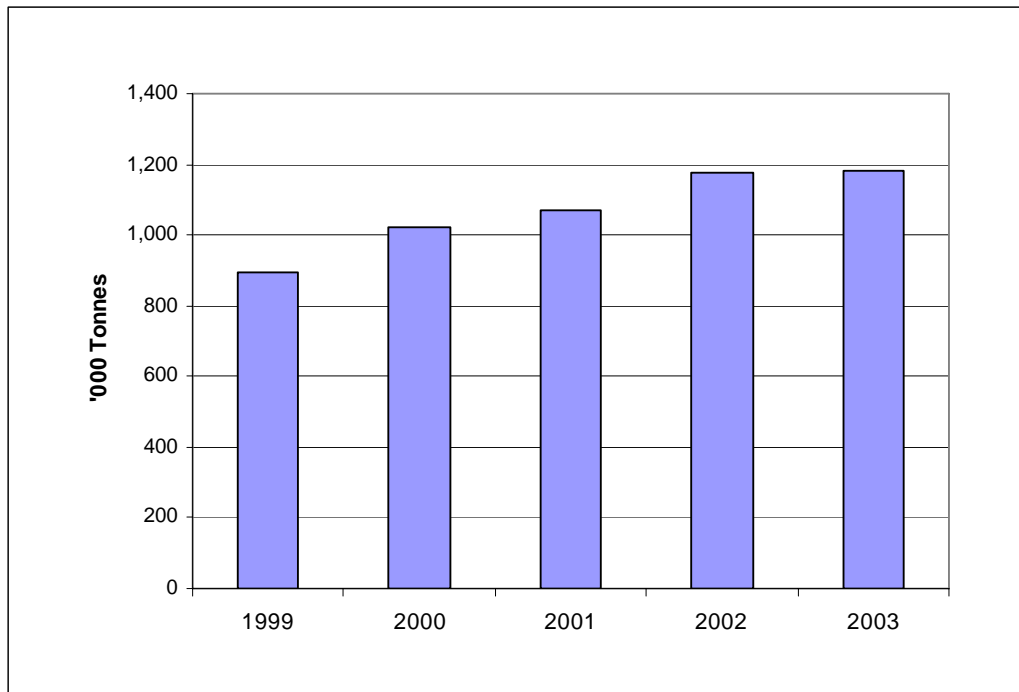
5.1.2 Apparent Consumption

Tables supplied by the British Apparel and Textile Confederation (BATC) show the import, export and production volumes, by unit and value, for all categories of clothing in the UK in a year. From these are computed the annual 'apparent consumption' volumes within the UK. Clearly the apparent consumption figures assume that there are no significant stock changes within the fashion industry supply chain within each year.

Average unit weights of each category of used clothing, based on weight at the point of discard, were established by the Textile Recycling Association (TRA). Apparent consumption volumes converted by these weights yield the tonnage of clothing that is consumed within the UK market. On this basis, consumption of men's and women's new clothing totalled 505k tonnes and 676k tonnes respectively in year 2003. The detailed figures are shown in Appendix II.

Similar calculations were applied to volume data for years 1999 to 2002 in order to confirm the recent growth trends, see Figure 3.

Figure 3: Apparent UK Consumption of Clothing, 1999 to 2003

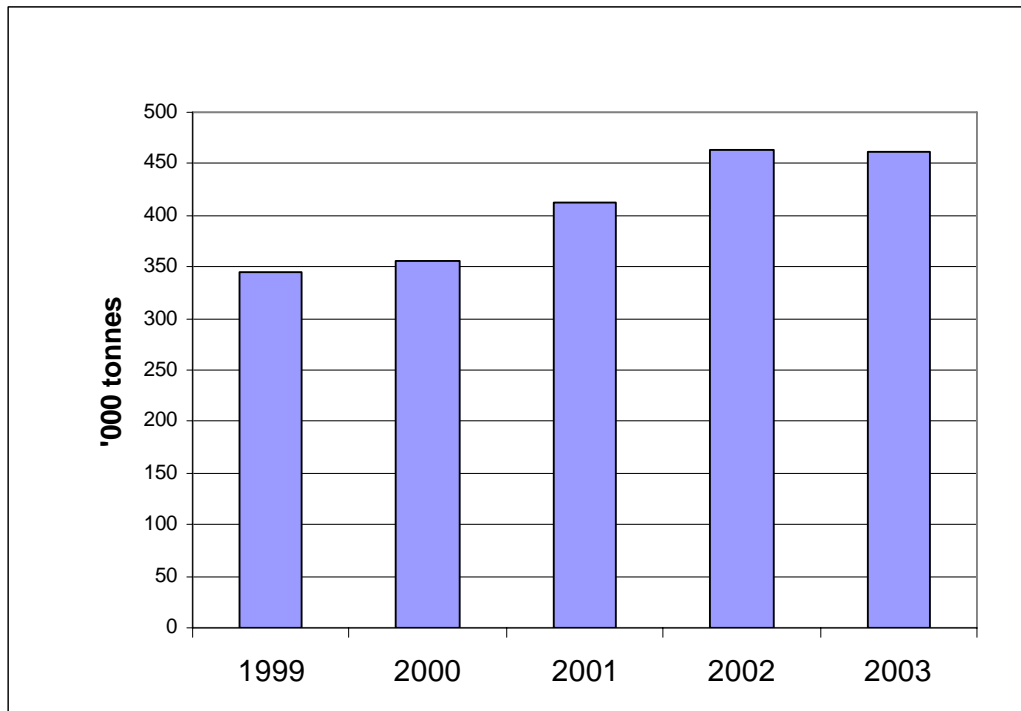


Source: BATC/TRA

Further tables supplied by the BATC give apparent consumption for non-apparel textile items, such as towelling products, bed linen, curtains, carpets, etc, although there are a number of gaps in the data base. For instance, UK production units are not recorded for some products, although value figures are provided. Also, data are provided by weight for some items, such as household linens and curtains, and by surface area, for carpets and blankets. By making some assumptions to calculate weights where data are missing, and by assuming a percentage loss of weight of the products due to wear and tear, a reasonably accurate estimate is made of the total tonnage, based on weight at the point of discard, of non-apparel products consumed within the UK market in a year. This totalled 462k tonnes in 2003. The TRA estimated this figure independently and confirmed that the weight of non-apparel textiles consumed in the UK is, indeed, of the order of 500k tonnes per year.

Similar calculations were applied to volume data for the years 1999 to 2002 in order to confirm the recent growth trends. The detailed figures are shown in Appendix III and summarised in Figure 4.

Figure 4: Apparent UK Consumption of Non-Apparel Textiles



Source: BATC/OHL

In addition to textile clothing, 338 million pairs of footwear were sold in the UK in 2003 (source: British Footwear Association) at an average 0.5kg per pair, i.e. 169k tonnes.

Two further elements of consumption are included for completeness. Firstly, it is noted that, at times of shortage of used clothing in the UK, some secondary textile traders are importing small amounts of material from (chiefly) France and Germany in order to maintain supplies to their export customers. UK Trade Statistics showed that imports of used textiles totalled 12.3k tonnes in 2003. Secondly, the sales of used clothing, chiefly through the charity shops, calculated in Section 5.1.4 below at 41k tonnes, represents additional consumption.

The addition of the above figures suggests that the consumption of all textiles and footwear in the UK in 2003 was 1,865k tonnes. The figures are summarised in Table 3.

Table 3: Apparent UK Consumption of Textiles and Footwear, 2003

Apparent Consumption	'000 tonnes, 2003
Men's Clothing	505
Women's Clothing	676
Household Fabrics, etc.	462
Footwear	169
Imports of Used Textile	12
Sales of Used Clothing etc.	41
Total	1,865

This is an estimate of the total tonnage of textiles that could be potentially discarded in a year at steady state. The figure is compared with a total municipal solid waste (MSW) arising in the UK of 36.4 million tonnes in 2003 and suggests that textiles would represent 5.1% of total household waste if all textiles consumed in the year were discarded to waste.

In view of the assumptions made in the above calculations, comparison was made with similar recent studies of the textiles market. A report issued by the Market Transformation Programme, dated October 2005, estimates the tonnage of new clothing sold in the UK in 2003 at 217k tonnes only. However, the report goes on to suggest that some 700k tonnes of textiles enter the municipal waste stream and other industry sources put the total of discarded textiles at between 850k and 1 million tonnes annually. Whilst it is accepted that the latter figures represent all textiles, i.e. including non-apparel items, this does not explain the apparent difference between new clothing sales and total textiles discarded.

Further confirmation of the reliability of the market data presented in this report was provided through the mass balance study, currently being compiled by the Cambridge University Institute for Manufacturing. This study uses as its base the UK Trade Statistics, showing imports and exports of all textiles and textile products. From discussions with those compiling the study, it is clear that this alternative model is providing similar figures for consumption and disposal as have been calculated in this report.

The data presented in this report have been estimated in conjunction with both SATCoL and the TRA who both concur with the reliability of the base data and the applicability of the model used.

5.1.3 Textiles entering the waste stream

Waste compositional analysis studies are used to arrive at the approximate tonnage of textiles actually entering the waste stream. These studies have been carried out in England by the Defra Strategy Unit in 2002 and in Northern Ireland by a Waste Characterisation Study in 2000. The Scottish Environment Protection Agency (SEPA) provides up-to-date compositional analyses in Scotland through the annual Waste Data Digest. By multiplying the percentage of textiles in MSW from these sources by the total MSW tonnage for each country in 2003, an approximation of the tonnage of textiles in the waste stream is calculated as follows:

England	3.0% of 30,200	= 906 k tonnes
Wales	3.0% of 1,800	= 54 k tonnes
Scotland	4.8% of 3,300	= 158 k tonnes
Northern Ireland	1.4% of 1,100	= <u>15 k tonnes</u>
Total		= <u>1,165k tonnes</u>

By relating this to the data in Table 3 it is estimated that some 647k tonnes of textiles do not enter the waste stream.

A recent study by A. Maunder et al², commissioned by the Defra Waste and Resources R&D Programme, suggests that textiles represented almost 8% by weight of UK household waste in 2005, rising to c. 11% by year 2020. The 2005 level of 8% would imply a far greater consumption and discard rate of all textiles than can be substantiated by either our model or that of the other studies mentioned above. However, the forecast by the Defra study that “Textiles are the fastest growing sector in terms of household waste” does support our own findings.

5.1.4 Textiles diverted from the waste stream

Methodology

This section considers the quality mix and quantity of used textiles that are collected by the UK charity shops, commercial collecting businesses and the textile merchants for resale, export or recycling. Given that these figures are not recorded directly within the various sectors of the industry, estimates made from differing information sources are compared in order to arrive at a single, more reliable, estimate.

Charity Shop Figures

In 2001 the Association of Charity Shops (ACS) carried out a survey of 54 charities running 3,771 shops and 2,044 textile banks, to ascertain data on collections and disposal of used textiles. The data were extrapolated to the then total of 7,000 charity shops in the UK and 4,000 charity textile banks. The fates of the 113,000 tonnes of textiles collected or donated in the year are summarised in Table 4.

Table 4: ACS Survey Results, 2001

Fate	Collections and Donations	Percent of Total
Re-sale in UK	31,200kg	27.5%
Sold to the 'trade'	75,100kg	66.2%
Exported directly	2,800kg	2.5%
Waste	4,300kg	3.8%
Totals	113,400kg	100%

The 2001 figure of 75k tonnes of used textiles that were not suitable for resale in the UK shops, and were sold on to the trade as 'rag', was equivalent to approximately 11 tonnes per shop per year. A more recent survey of London-based shops showed that the proportion of collected clothing that is suitable for resale in the UK shops has deteriorated considerably and that the quantity of material being passed on to the trade for export and recycling is now in excess of 15 tonnes per shop per year. This order of throughput is confirmed by the Charity Finance Shops Survey which analyses returns from over 80 charities in the UK. Through interpolation of the returns for 2005, the total tonnage of rag sales is calculated at 106k tonnes in the UK.

Since 2001 the quantity of used clothing collected by the charities has also increased, particularly with the placing of more textile banks. It is estimated by industry sources that there are now 9,500 charity and non-charity textile banks in the UK.

Merchant Figures

The Salvation Army Trading Co Ltd/Kettering Textiles Ltd 2003 report "The Second-hand Clothing Market" notes the findings of a sampling survey of textile banks in England and Wales. The fates of the 44,000 kg of textiles donated in the survey are summarised in Table 5.

Table 5: SATCoL/Kettering Textiles Bank Survey 2003

Quality	Donations	Percent of Total
Wearable	31,400kg	71.3%
Recyclable	9,800kg	22.3%
Rubbish	2,800kg	6.4%
Totals	44,000kg	100.0%

SATCoL revisited these figures in 2005 based on current experience, and further data were obtained from a survey by the Textile Recycling Association (TRA) of 22 members in November 2005. The figures are summarised in Table 6.

Table 6: Summary of Qualities/Fates Surveys

Disposal Route	SATCoL (2003)	TRA (2005)	SATCoL (2005)	Average 2005 SATCoL/TRA
UK Re-use	71%	3%	3%	3%
Export Re-use		63%	55%	60%
Wiper Grade	8%	10%	14%	12%
Recycling Grade	15%	18%	21%	19%
Waste	6%	6%	7%	6%

The 'average' column represents the best indication of the current mix of the basic qualities being processed by the trade, i.e. the collection and sorting sector. The figures clearly show the recent decline in the proportion of textiles, particularly clothing, that is suitable for re-use, and the increase in the proportion of wiper and recycling grades.

Of the wiper and recycling grades it is estimated that 15% and 40% respectively, representing approximately 10% of the total, will be exported for further processing.

Quantity of Textiles Diverted from the Waste Stream

The tonnages of discarded textiles that are diverted from the household waste stream, and are handled by the secondary textile industry, were calculated from two distinct models.

UK Trade Statistics for material category 6309 give the recorded exports of all used textiles which include both the re-useable items and the materials

exported for further processing. The statistics show that 199.5k tonnes of used textiles were exported in 2004. From the above figures it is noted that export for re-use is 60% of the grader/collector's business. After adding in the quantities exported for re-processing, this increases to 70% exported. Applying this percentage to the export figure from the Trade Statistics provides an estimate of the total collected textiles that are handled by the UK collector/sorters at 285k tonnes annually.

Returns from the 2005 survey of TRA members were used in order to provide a check on the validity of this figure. Whilst many members did not provide actual throughput tonnages, for reasons of commercial sensitivity, good returns were obtained on the source of their materials. These figures put charity collections at 49% of their throughput. This would put the TRA affiliated trade's business at 216k tonnes. The trade figure was also estimated from the actual returns from the 15 TRA members who were prepared to supply quantitative throughput information. Generally, these returns, totalling 71.5k tonnes, were received from the larger operators. Given that there are some 60 operators in the UK, it is estimated that this figure represents one third of this sector's throughput, giving a total of 215k tonnes, which is comparable with the above.

SATCoL/Kettering Textiles is a major operator in the secondary textiles market but is not a member of the TRA. It was therefore excluded from the survey. The company processes 90% of the material that it collects, equivalent to approximately 22k tonnes. To this must be added the quantity of material collected through commercial textile banks and by commercial door-to-door collectors who may ship unsorted materials to export markets directly. It is estimated that this represents a further 20% of the trade's throughput.

By adding the above figures, the amount of textiles collected from all sources that go to the collector/sorters is 297k tonnes per year (see Table 7).

Table 7: Throughput based on TRA Member Source Returns, 2005

	Source	Total '000 tonnes per year
Total charity shop 'rag' sales	From above	Ref. only: 106
TRA member returns	Source 49% from charity shops	216
Plus Kettering/SATCoL	SATCoL	22
Plus commercial collections	Industry estimate 20% of total	59
Total		297

The figure of 285k tonnes, as derived from the mix of business reported by the 'trade', coupled with the UK Export figures, is taken as a reasonably reliable estimate of the current annual tonnage of used textiles entering the secondary processing route. An additional 39k tonnes are resold or disposed to waste in the UK shops. Hence our best estimate of used textiles collected annually in the UK is 324k tonnes.

5.1.5 Summary of Fates of Discarded Textiles

The material flow chart in Appendix I shows the arisings and discard routes of clothing and other textiles in the UK.

As stated in Section 3, the industry sorts and distributes used textiles into some 140 different grades. This report simplifies consideration of the market by using five categories as follows:

- UK Re-use
- Export Re-use
- Wiper Grade
- Recycling Grade, and
- Waste.

The tonnage of material entering each disposal route in 2004/5 is calculated from the above returns, as follows (Table 8):

Table 8: Summary of Disposal Routes, 2004/5

'000 tonnes per year	Charity Shops	Collector/Sorter	Total
UK Re-Use	32	9	41
Export Re-Used	3	171	174
Wiper Grade UK	N/A	28	28
Wiper Grade Export	N/A	6	6
Recycling Grade UK	N/A	34	34
Recycling Grade Export	N/A	20	20
Waste	4	17	21
Total	39	285	324

5.1.6 Summary of Arisings and Fates

Table 9 summarises the figures calculated in this section. For clarity in interpreting the figures, reference is again made to the Material Flow Chart in Appendix I.

Table 9: Summary of Arisings and Disposals

	'000 tonnes	'000 tonnes	% of New Consumption
Apparent consumption of new textiles	1,812		
Imports of used textiles	12		
Consumption of used textiles	41		
Total Consumption		1,865	100%
Textiles entering the MSW waste stream		1,165	63%
Textiles collected for resale and recycling	324		17%
Of which:			
Resale for re-use in the UK	41		
Exported for resale for re-use	174		
Recycled in the UK	62		
Exported for recycling	26		
Rubbish, returned to waste stream	21		
Net textiles diverted from waste stream		303	16%
Textiles unaccounted for		397	21%

For the purpose of analysis, it is assumed that the recycled portion is not part of the MSW figures, since many of the recycled products will ultimately enter the industrial waste stream, and will not therefore be classed as municipal waste. Also, the UK resale quantity is assumed to be sensibly constant from year to year. From the figures, certain deductions can be made, as follows:

- The quantity of textiles collected in the UK in 2004/5 was 324k tonnes, which represents a recovery rate of 17% of the apparent consumption. 21k tonnes of this, equivalent to 1% of consumption, are unusable by the secondary textile industry and are returned to the waste stream as rubbish.
- There is a considerable quantity of textiles unaccounted for, amounting to 397k tonnes, or just over 6 kg per head of population per year. Here it must be remembered that this figure includes non-apparel textiles. Assuming that this is an annual occurrence and has been happening for some years, there must be large quantities of textiles accumulating in the 'national wardrobe'. Considering the reduction in storage space in modern housing, pressures may be building to clear this accumulation of 'latent rubbish'.

- The industry is currently diverting 262k tonnes, or 0.7% of the household waste stream, to export markets and to recycling processing in the UK.
- In spite of the activity in the secondary textile industry, 1,165k tonnes annually remain available for recovery from the waste stream. Indeed, at the point that the 'national wardrobe' is only increasing at the rate of population growth, then the potential for additional recovery from the waste stream becomes approximately 1,560k tonnes.

There is, therefore, the potential to deliver an improvement in used textiles waste recycling rates equivalent to an additional 4.4% of the household waste stream, providing there is the processing capacity within the UK or Europe. However, any initiative designed to increase recycling must take potential rapid de-stocking into account in order to avoid overwhelming the secondary textile industry.

5.2 Quality and Price Trends

The best quality used clothing is received from donors who drop old clothes at the charity shops. At an average selling price of £2 to £3 per item, and a maximum average weight per item of 0.3kg, these can be worth between £6,000 and £9,000 per tonne at resale value after sorting. The next best quality is that arising from door-to-door collections. Collections from textile banks yield a mix of very slightly poorer quality material and can occasionally contain contaminated, spoiled and totally worn out products, together with small amounts of rubbish. Textile bank material is worth approximately £200 per tonne after sorting and clearance of the rubbish. There are no overall regional differences in the quality of clothing donated although, clearly, within each region there will be less affluent areas which tend to donate less quantity and lower value material.

Shoes tend to have a higher value than clothes and attract some £100 per tonne more than textiles at point of sale to the rag collector. Non-apparel items such as bedding, curtains, and carpets also get donated, but this is a small percentage.

The prices paid by the collector/sorters to the collection organisations, normally the charity shops, have fluctuated considerably over the last 15 years. Prices have been as low as zero, when there has been a glut of material or a restriction in a key export market, to £270 per tonne. From evidence received, prices paid have realistically ranged from £60 to £220 per tonne. In March 2005 textile processing companies were paying on average £150 per tonne for surplus textiles from the charity shops. Further anecdotal evidence suggests that purchase prices are holding at above £200

per tonne due to a shortage of supply of wearable quality materials, and some traders report, on occasion, having to import small amounts of used clothing from the near Continent in order to maintain supplies to their export customers.

Prices over the past four years have continued to fluctuate but, after smoothing, it is noted that there has been an overall small upward trend approximately in line with inflation.

Prices are generally set as a result of spot deals. Whilst there are many merchants in the industry, there are few, if any, long term contracts. The merchants range in size from a 'man and van' to national dealers and recyclers. Rags tend to be traded in bag loads or by the kilo. The merchant will carry out spot checks on regular supplies, or an assessment of a batch of clothes at source, and will offer a spot price. Attempts have been made to set up national pricing data (witness Materials Recycling Week's (MRW) fibres section) but this is not seen by the industry as a reliable source of information, and the data tend to lag behind actual events in the market.

The selling price of wearable items in the various export markets has also fluctuated considerably, with no discernable trend. However, the selling price of recycling grades has clearly declined over the past fifteen years as the traditional markets for wipers and recycled products has declined. Indicative selling prices enjoyed by the merchants for specific qualities of used textiles in 1990 are compared with the prices currently being obtained in Table 9.

Table 9: Rag Sales Prices 1990 and 2005

Sales price per tonne		1990	2005
Recycling Grades	White wipers	£600	£200
	Other wipers	£150	£50
	Wool knits	£500	£300
	Uni-colour acrylic knits	£220	£110
	Filling materials	£100	£30
Clothing Grades	Clothing for re-use Africa	£1,000	£900
	Clothing for re-use Pakistan	£220	£200

A crude (un-weighted) average of the above prices paid for recycling grades suggests a decline of 55% over 15 years. This is equivalent to a decline in real terms of 71% after inflation, clearly a major reduction in

income for the merchants where it represents some 30% (including wiper quality) of the tonnage throughput of the merchants.

The average sale price for one tonne of sorted clothing grade product over last few years is estimated at approximately £400 per tonne.

Finally, it is noted that a recent report by the Brussels-based RRE-USE¹, a network of 18 national and regional social economy federations and enterprises with activities in re-use and recycling, summarised the problems facing the industry through interviews with market stakeholders across Europe. The report found that, over the past five years, the quality of collected material has declined as shown in Table 10.

Table 10: RRE-USE Survey of Quality

	% Re-used 2000	% Re-used 2005
UK	65%	50%
France, Belgium, Netherlands	60%	40%
Germany	50%	30%

It is noted that the RRE-USE 2005 UK figure of 50% re-usable does not match that which was computed from the SATCoL and TRA surveys and calculated in Section 5.1, namely that 63% of collections from all sources is re-usable. It has not been possible to interrogate the RRE-USE figures and, therefore, the survey returns from the SATCoL and TRA surveys are taken as the best estimates. Importantly, the data from both sources clearly show the decline in the quality of materials collected.

5.3 Collection and Sorting Costs

5.3.1 General

In order to provide an indication of the declining margins within the secondary textile industry, the operating costs of the charities and the merchants were considered against the above declining sale prices of material collected.

5.3.2 Charity Shops

Increasingly the shops are moving into other donated items, such as books, toys and CDs and new products such as greeting cards and fair trade commodities. Oxfam is opening up some 'books only' shops. The annual Charity Finance Shops Survey for 2005 reported that sales income of shops surveyed was £469 million, of which new product sales averaged just over 5%. The survey does not, however, report the mix of other items within this sales figure. Industry estimates put the sales of used clothing at approximately 50% of the total shop sales, i.e. £235 million.

The Association of Charity Shops confirms this rate of change in the past three years in the mix of sales in the shops. Member returns show that, by value, the percentage of shop sales that was used textiles has fallen from 70% to 51% in that time.

The ACS reports that the net profit of shops is a healthy 22%, and this is borne out by the Charity Finance Shops Survey for 2005. However, the profit on sales of used clothing is reported by ACS at only 2% to 4%. Clearly the costs of operating the shops are spread across all ranges. It is, therefore, not meaningful to estimate operating costs that relate solely to used clothing sales.

The charities benefit from low rate premises, typically at 20% of the local business rate, and considerable volunteer labour. Indeed, published profit statements from leading charities such as Oxfam confirm that the sector would suffer heavy losses if all volunteers were replaced with salaried labour. However, many costs are increasing at or above inflation. In particular, employment costs are increasing, with many shops reporting difficulty in getting sufficient volunteers. The Charity Finance Shops Survey for 2005 reported that the number one concern across the sector is the shortage of volunteers. It is also accepted, however, that the shops must recruit and train professional, salaried staff for both support operations and shop management in order to maintain competitiveness with the wider retail sector. The Children's Society, for instance, has approximately 50% salaried shop staff and this figure is increasing. Legislative changes, such as the recent increases in National Insurance contributions and the minimum wage, further add to the burden of employment costs. The Charity Finance Shops Survey shows that salary costs as a percentage of sales income have risen from 21.8% in 1995 to 30.5% in 2005.

Waste disposal costs are also increasing above the level of inflation due to the Landfill Tax escalator, escalating the per tonne price of landfilling by £3 per year above inflation, and due to an increasing volume of unsuitable donated materials. The Association of Charity Shops estimates that their members expend £4.5 million annually storing, sorting and disposing of unusable items. Oxfam recently announced that it spent £500k in disposal

costs last year and that this figure had increased by £60k (14%) since the previous year. An appeal was made to both over-generous, but misguided, donors and to the 'fly tippers' who leave unsuitable bags of textiles on charity shop doorsteps out of trading hours. This is not a message which charities would want to broadcast regularly, since any suggestion that the industry does not welcome donations would discourage donors of quality items as well.

5.3.3 Merchants

Estimates of the trend in the main costs experienced by the merchants are set out in the Table 11.

Table 11: Operating Cost Trends

Operating costs, per tonne	1990	2005	% Increase
Collection from nationwide bank	£110	£155	41%
Collection from local bank	£80	£115	44%
Door-to-door collection nationwide ¹	£250	£300	20%
Door-to-door collection local ¹	£210	£260	24%
Sorting into 140 grades	£80 to £105 ²	£150 to £200	90%

Notes: 1. Door-to-door costs include the cost of bags and literature.
 2. 1990 sorting costs estimated from 2005 costs using ONS earnings indices and estimates of landfill cost escalation.
 None of the above costs include contributions to a charity or council

No historical data are available for sorting costs, but as for the charities, key elements of these will be employment and disposal costs, both of which have also risen in real terms in recent years. From earnings indices and from landfill cost changes it has been possible to calculate likely sorting costs for 1990.

When compared to inflation of c.52%, as measured by the RPI, collection costs appear to be reducing in real terms. Given above inflation increases in fuel and employment costs, this is thought to have occurred largely as a result of the efficiencies of scale that have occurred over the period.

The 2005 RRE-USE report suggested that, across Europe, sorting costs have increased by 25% in five years and, except in Poland, the number of recycling enterprises has been declining by 10% to 20% per year.

5.3.4 Summary

It is generally accepted by the charities that there has been an over-reliance on used clothing, and that the shops must diversify. This trend has already started with a significant move into the sale of alternative used products, such as books, toys and electronic media and into new products such as greeting cards and fair trade commodities. As a result, the charity shops are reducing their percentage of sales from used clothing. With prices of new clothing expected to fall by a further 30% in the next five years, the price of all but high fashion, high quality used items will have to fall in comparison. The annual Charity Finance Shops Survey for 2005 reports collection and employment costs for the shops rising both above the level of inflation and as a percentage of sales income. This trend is expected to continue. With the resultant decline in margins for used clothing, the charity shops will continue to diversify out of clothing into other commodities.

The merchants, faced with rising sorting costs in the UK and declining qualities and selling prices, are increasingly shipping unsorted clothes, either for sale directly to export markets or for sorting in lower labour cost countries. As discussed in Section 4.3.1 above, the apparent legal position relating to the export of unsorted textiles is of concern. In summary, collections of used textiles from textile banks are classified by the Environment Agency as waste until they have been further sorted into useable material, recyclable material and rubbish. Handling, transportation and direct shipments of unsorted textiles would, therefore, incur a regulatory and financial burden which further adds to the pressure on the economic viability of the merchants. It is suggested that further discussion is required between the regulatory authorities and the trade in order to clarify the situation. With appropriate controls, relaxation of the Agency position would support the practice of exporting unsorted used textiles to low labour cost countries for sorting. This would help maintain the viability of the collection sector, possibly permitting increased collection rates and avoiding increasing landfilling of textiles in the UK.

6 Implications for Waste Stream

6.1 *Market Forecast*

As calculated in Section 5 above, uncollected textiles currently total 1,165k tonnes per year and this is expected to rise to 1,560k tonnes per year, representing 4.4% of the UK MSW arisings, in the foreseeable future as the storage of used textiles by householders' levels out. The WRAP Analysis of Household Waste Report, December 2002, indicated that 50% of textile waste is bio-degradable. It follows that half of any additional waste textiles recovered for recycling would count towards the LATS allowance for Local Authorities if collected.

The tonnage of material entering the waste stream would clearly increase further if there were a significant decline in the collection industry. The trend towards lower quality clothing entering the secondary textile stream is already being seen in the UK charity sector, as increasing tonnages of materials collected are being diverted from resale in the UK to the merchant sector. The merchants in turn have seen a volume increase, but a major decline in the price of recycling grades. Export trade has held up as a result of the opening up of the Eastern European markets and the general preference of this and the African markets for British fashion items. However, with prices of new clothing predicted to fall a further 30% in the next five years, it is likely that prices and volumes to these traditional markets will also start to decline.

Even without further decline in the markets, both national and local governments could take up this opportunity by increasing the rate of collection, either through economic assistance in the secondary textiles sector or through direct involvement through increased kerbside collection of textiles. It is assumed that the ability to export the additional tonnage generated will be limited. Indeed, it is likely that export opportunities will decline, keeping additional tonnages of material in the UK for further processing.

It follows that such a policy shift in favour of kerbside or other collection systems, whilst improving recycling rates for Local Authorities, will place considerable pressure on the infrastructure of the secondary textile industry. The processing sector will in turn be required to find new products and markets for the recycled materials. These must be high value outlets relative to the traditional products in order to retain and attract investors in the secondary textile industry. Furthermore, the quality of collected material, already seeing a decline as a result of greater quantities

of low priced clothing entering the market, is likely to deteriorate further as collection rates increase.

Here it is noted that in Germany, for example, where there is an ecological tradition and an established textile recycling industry, some 70% of available textiles are collected. Only 35% of this is suitable for re-use as clothing³. The equivalent figures for the UK, as calculated in Section 5, are 17% collected, of which 63% is suitable for wearing again.

6.2 *Implications for Local Authority Activity*

6.2.1 Local Authority Textile Collection Schemes

The majority of the 469 Local Authorities (LAs) in the UK are involved in some form of textile collection scheme. It is estimated that between 10% and 15% of these operate, or support, kerbside collection schemes which include textiles. Discussions were held with a number of LAs who either operate their own scheme or who work in co-operation with a scheme run by a charitable organisation. This established an estimate of the level of success of kerbside schemes and the potential cost of implementation.

Waltham Forest Council has operated a textile collection scheme since 1998. The scheme serves 79,000 households and collects 60 tonnes of textiles per year out of a total of 6,000 tonnes of recyclates. This scheme succeeds because people who are interested enough to recycle will apply some care: Householders place textiles in carrier bags to keep them clean and dry. Bags are placed into separate stillages on the collection vehicle. At the depot, the bags are transferred to a RORO container which is collected by the merchants, who currently pay £52 per tonne, regardless of quality. Kerbside quality is better from outside the M25 than it is from within, a reflection of the relative affluence of the two districts.

By comparison, the textile banks at the bring sites in the district collected 210 tonnes of textiles in 2004. The Local Authority stated that the merchant only pays a nominal amount for this tonnage because the overall quality is poor relative to the kerbside collected material which is believed to be of good quality.

Sefton Council operates split compartments on 'Greenbee' vehicles run by a commercial contractor. All 123,000 households are covered. Most are given a Salvation Army bag which is replaced when the collectors pick up a full bag from the household. Bags are placed in a carrier vehicle at the depot which is taken away when full. This scheme met with high volumes when it was introduced but has since fallen back. 116 tonnes of textiles were

collected in 2005/06. Textile banks yield, approximately, an additional 100 tonnes in a year. Sefton Council is currently trying to boost the returns through leaflets, education, training of collectors, etc.

Stoke on Trent City Council also runs a Salvation Army scheme which is similar to that at Sefton. Kerbside collection rates are significantly greater, achieving 215 tonnes, from 106,000 households, in 2005/06.

Islington Council provides an example of good co-operation with the charities, to whom they leave all textiles collections. When asked, they provide residents with a number for the local textile collecting charity and distributed leaflets ask the residents to put in the wheelie bin only textiles which are unsuitable for re-use or recycling.

Lewes District Council's own crews operate electric vehicles which are compartmentalised for various recyclates. Textile collections are through a bag system from c.28,000 properties. They have collected 13.9 tonnes in the last two quarters, i.e. a rate of 27.8 tonnes textiles per year. In this case the merchant does not pay for the goods collected. However, the Council receives recycling credits from East Sussex County Council at the rate of £36 for every tonne of textiles collected. The Council believed that the costs of adding textiles to the system are minimal, just the bag and leaflet printing costs, once the vehicle is in place.

Table 12 summarises the above kerbside collection data:

Table 12: Local Authority Kerbside Collection Activity

Local Authority	No. of Households	Approximate Kerbside Collection Tonnes p.a.	Return Rate Kg per Household p.a.
Waltham	79k	60	0.8
Sefton	123k	116	0.9
Stoke-on-Trent	106k	215	2.0
Lewes	28k	28	1.0
Totals	336k	419	1.25

It can be assumed that the above figures represent a reasonable cross-section of the kerbside collection schemes in the UK. The overall return rate is clearly very low when compared to the quantity of new textiles entering each household which is estimated at approximately 70kg per household per year, (computed from the data in Section 5 and the number of households in the UK, approximately 25million). However the disparity

between return rates of the collection schemes is worthy of note, varying from less than 1kg per household to over 2kg per household per year in the above, albeit limited, sample. This variation is likely to be attributable to both the method and the scale of the collection scheme as well as the affluence of the area served. Another factor is the age of the scheme, with many achieving high collection rates in the early months and then falling back with time.

From the above, it is noted that if all Local Authorities in the UK operated such schemes at the average return rate, the potential collection would be approximately 30k tonnes per year. (The average collection rate of 1.25 kg per household per year multiplied by 25million households). Clearly a vastly improved returns rate would have to be achieved from kerbside collection schemes in order to achieve a significant improvement in Local Authority recycling rates, even if this policy were to be adopted nationally.

6.2.2 Economic Considerations

The Local Authority Recycling Advisory Committee, (LARAC), noted that there are no publicly available data on either the extent or the costs of kerbside collections. They estimate that it costs up to £450 per tonne to collect plastic containers, from a base of zero, because of the high volume/weight ratio. Textiles are relatively dense by comparison, but there are a number of add-on costs that would apply if they were to be added to an existing collection round. These would comprise mainly operational costs, such as bags and leaflets and additional labour.

The following additional operational costs are estimates based on industry experience:

Purchase of bags and leaflets costs between £30 and £70 per 1,000. Experience shows that only 150 bags per 1,000 bags distributed are returned and these, on average, will generate 500kg of clothes. It follows that:

Bags etc. cost per tonne collected £60 - £140 per tonne

The additional labour time to collect and load a bag of clothing at the kerbside (assuming that no further sorting is required) is assessed at a minimum of 30 seconds per bag. This is equivalent to 150 minutes per tonne collected. At a marginal labour and overhead rate of £20 per hour, this costs a further £50 per tonne. The total marginal cost is, therefore, estimated at:

Bags and Leaflets	£100 per tonne (average)
Marginal Labour	<u>£50 per tonne</u>
Total marginal cost	<u>£150 per tonne</u>

These costs assume negligible additional overhead or capital costs such as separate stillages on collection vehicles and storage. For an authority that is not already operating a scheme, the costs will be higher. The figures also assume that no sorting, checking of quality, or disposal of rubbish found in the bags is required. Indeed contamination levels in some collection schemes mean that none of the textiles are suitable for re-use or recycling.

The marginal cost of implementing additional collection activity to include used textiles, therefore, is likely to be considerable, relative to the value of the materials collected, even for authorities with existing kerbside recycling schemes. However, any incremental costs may be offset by the returns achieved from the sales value of the collected material, currently of the order of £50 per tonne, and by savings of recycling credits.

6.2.3 Recycling and Re-use Credits

Currently Local Authorities can opt to pay recycling credits to third party organisations involved in the diversion of materials from the household waste stream for recycling. This option was extended in April 2006 to include payment to organisations that re-use as well as recycle materials. Because this arrangement is voluntary, its application across the UK is patchy. To assess the size and extent of the payment of recycling and re-use credits a survey questionnaire was sent to each of the 469 Local Authorities in the UK in June 2006. The results of the survey are summarised below:

No. of responses	118
Percentage of respondents to total LA's	25%
No. of LA's paying credits for textiles	58
No. of above providing a value for credits paid	46
Average rate of credit per tonne of diverted	£36.47

The percentage of LA's paying credits for textiles therefore is 49% of the respondents to the questionnaire. This figure is considerably higher than that believed to be the case from anecdotal evidence within the industry, which is closer to 10%. This finding may be explained by the possibility that LA's that do not pay credits are more likely to be those that did not respond to the survey. In this case, the survey figure would represent a maximum percentage of those LA's that pay recycling credits for textiles. The average per tonne paid is comparable with landfill disposal costs and is therefore seen as a representative figure.

The percentage (of respondents) of LA's paying credits for any waste material varies from 34% to 53% depending on the material collected. Of the 49% of respondents that pay credits for textiles, 71% pay to the benefit

of a charitable organisation and/or a community group, and only 16% pay to a commercial, i.e. profit making, organisation.

The implications of these findings for policy options are discussed in Section 8.6.2.

7 Market Imperfections

7.1 Summary of Market Failures

The OECD paper “Improving Recycling Markets” reviews recycling market inefficiencies and failures under five headings. They are set out in Table 13.

Table 13: Potential Sources of Market Inefficiency

Causes of Market Inefficiency	Explanation
Transaction Costs in Secondary material markets	Costs arising from the diffuse and irregular nature of waste generation and from the heterogeneous nature of the secondary materials.
Information Failures Related to Waste Quality	The difficulty of buyers to detect waste quality, and the relative ease with which sellers can conceal inferior quality waste.
Consumption Externalities and Risk Aversion	Low market penetration due to the quality of final goods derived from secondary materials being perceived as inferior to those derived from virgin materials.
Technological Externalities Related to Products	Low recycling levels due to the sub-optimal technical characteristics of the material and products from which the secondary materials are derived.
Market Power in Primary and Secondary Markets	Substitution between primary and secondary materials may be restricted due to imperfect competition and strategic behaviour on behalf of dominant firms.

A number of these inefficiencies occur in the used textile market and these are discussed in the following sections.

7.2 Transaction Costs

Transaction costs are those costs in the buying and selling of goods that are not directly related to the physical handling or processing of the goods themselves. Examples are costs associated with discovering prices, searching for buyers and sellers, and overcoming export and permit issues.

It is the latter that appears to be the major influence in the used textile market. A high percentage of used clothing is exported overseas and in particular to third world countries in Africa. The Salvation Army Trading Company / Kettering Textiles 2003 report “The Second-hand Clothing Market” confirmed the situation involving the many politically unstable markets to which they export. Wars, coups or changes of policy by governments can close markets literally overnight, by either banning imported clothing or by imposing restrictive import duties. Where this

disrupts the material flow in the industry, significant costs can arise through additional storage and shipping delays.

Inadequate information concerning prices is also a feature of many recycling markets. Prices of textiles are published regularly by MRW but these show a broad range of prices and categories of clothing and are not seen by the industry as being responsive to short term fluctuations in price. Considerable negotiation and bargaining costs are incurred as a result.

Little evidence could be found of the existence of contractual relationships between the charities and the merchants or between the merchants and their overseas customers. The Recyclatex scheme operated by the Textile Recycling Association is designed to give the operators of textile banks, and the Local Authorities a guarantee that bank materials will be collected, but prices continue to be based on negotiation and are influenced by market forces at the time of collection.

7.3 *Information Failures*

Full information flow is an important factor in the successful functioning of all markets. The uncertain quality of exported used textiles leads to a number of potential problems and encourages rogue operators into the market to the detriment of bona fide merchants. The buyer is taking on trust the quality of the mix of clothing within each bag delivered, and this will vary from bag to bag and from shipment to shipment. Clearly the heterogeneous nature of the product is an issue in many waste streams, but the remoteness of the markets from the shippers makes this a considerable complication in the export of used textiles. This will increase as more and more merchants attempt to reduce costs by shipping bulk textiles abroad without prior sorting of the material.

Merchants shipping unsorted waste to export markets will, by definition, be shipping a mix of good and marginal quality re-useable clothing and materials that are waste and which will require disposal. The greater the mix of low grade items and waste in the shipment, the lower the profit margin and the higher the disposal costs for the buyer. Some buyers will collect at source and this gives them the ability to check quality before shipment.

7.4 Consumption Externalities

Consumption externalities are the market effects caused by the consumer's perceived quality of secondary materials and products when compared with new manufacture. An example is that of retreaded tyres which are perceived as inferior to new tyres for passenger car use by many motorists. This perception significantly reduces the market for tyres recycled in this way even though the quality of retreads now matches that of virgin tyres.

This was seen as a possible issue with recycled fibres, especially if the fibres are used in the manufacture of new clothing for domestic consumption. The research at NIRI, which has been a key element of this study, has shown that it is possible to improve the functionality of recycled fibres in new end products for industrial markets. Negative perceptions are not likely to be significant in these markets, where functionality and price are the driving forces.

Some efforts have been made to 'recycle' used clothing into new clothes. The charity Textile Recycling for Aid and International Development, (TRAID), operate a remanufacturing team of 10 designers in Brighton who take a small number of items, approximately 1% of their collected materials, for re-design and formation into new garments under their "Remade" brand. In a recent development, designer clothes from recycled textiles have gone on sale in Topshop's flagship store on Oxford Street, London under SATCoL's "Emmeline 4 RE" brand.

7.5 Technological Externalities

Technological externalities exist where the technical characteristics of the virgin material interfere with the downstream recycling process. This is increasing in relevance in the textile markets where fashion designers are increasingly looking to apply novel treatments for the base textiles and to adorn clothing with embellishments which add complexity to the recycling process. This is driven both by the fashion trends themselves and by the need to add value to a product that is coming under increasing price pressure from low labour cost manufacturing countries. Examples of the latter would be thermoplastic 'non-iron' and 'breathable' coatings, applied to virgin wools and cottons. The coatings melt under pulling by conventional methods and cause equipment malfunction and contamination of the secondary material and end product. Indeed, the increasing use of synthetic base materials in the clothing market has already caused the waste management industry to ask for textiles to be separated

from the household waste stream, MSW, prior to treatment by the new technological processes such as autoclaving and pyrolysis.

7.6 Market Power

Inefficiency caused by market power occurs when a market is dominated by a small number of large producers of the primary material who undermine the market for the secondary material, even if it is competitive in terms of quality and price. This is not found to be a significant factor in the textile industry. It is the falling price of new clothing alone that provides the threat to the re-used clothing market by reducing the margins of the collectors, shops and processors.

Within the secondary clothing industry there are few economies of scale that will provide collectors or processors the opportunity to expand to dominate the market. Indeed, there is evidence that short term high prices currently being enjoyed in the market have attracted a number of new entrants in collection and these are able to operate competitively with the larger and national collectors. It follows that there is insufficient market power in the hands of the larger players to influence either the prices paid for their source materials or the prices they can achieve in their markets.

There is an issue with the charitable status of the second-hand clothing retail shops. As a body, the concessions that they enjoy, such as reduced rates on their premises and volunteer labour, means that there is imperfect competition with commercial, profit based organisations. On the other hand, there is evidence that some collectors exploit the public perception that donating clothes benefits only charities by concealing the commercial nature of their business.

7.7 Potential Solutions to Market Failures

Some of the potential policy interventions by national and local governments, and by the wider textile industry, directed at providing solutions to the above market failures, are covered in detail in Section 8 of this report.

Volume I References

¹ Baden, S., Barber, C. "The Impact of Second-Hand Clothing Trade on Developing Countries", Oxfam, 2005

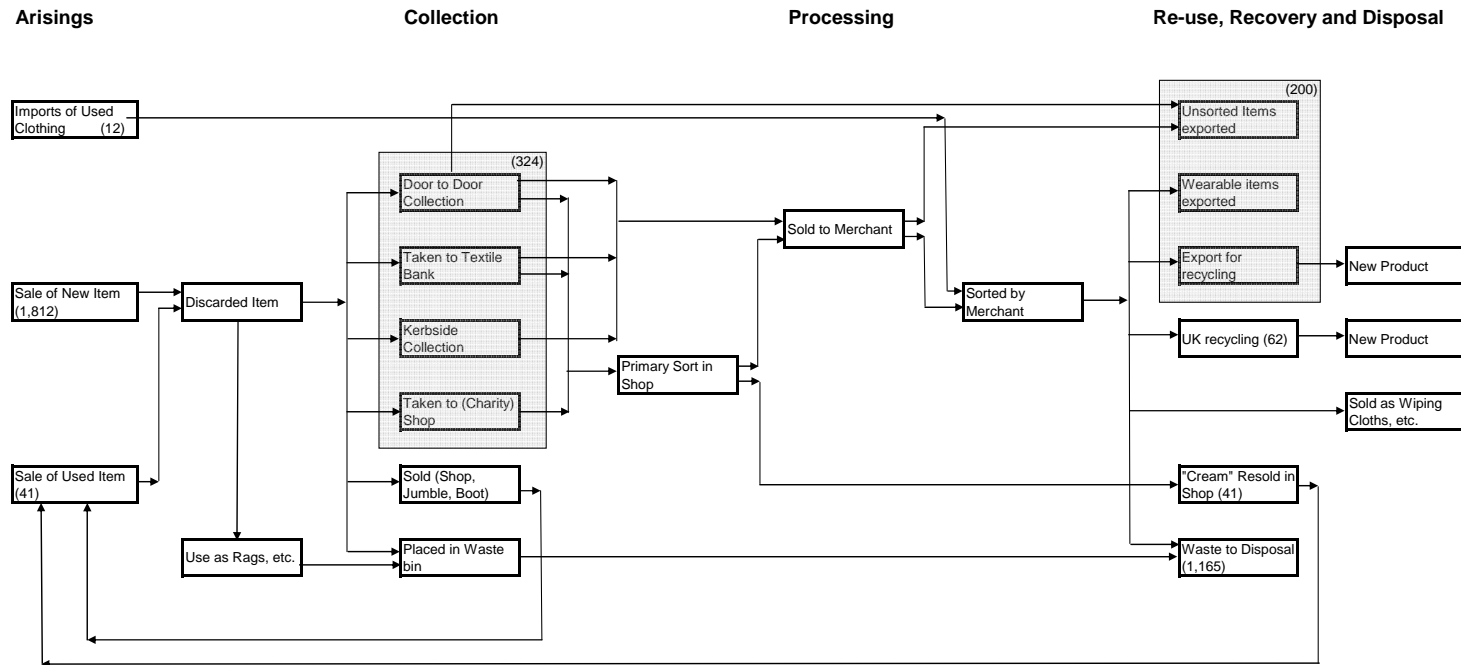
² A. Maunder et al. "Modelling the Impact of Lifestyle Changes on Household Waste Arisings" 2005.

³ "Report by Textile Reuse and Recycling Players on the Status of the Industry in Europe", RREUSE, June 2005

Volume I Appendices

- I UK Secondary Textile Industry, Material Flow**
- II Apparent Consumption of Clothing, 2003**
- III Apparent Consumption of Non-apparel Textiles, 1999-2003**

UK Secondary Textile Industry Material Flow



Figures in '000 tonnes, Year 2003

Apparent Consumption of Clothing, 2003

	Approximate item weight (kg)	'000 Items			Tonnes		
		Men's Clothes	Women's Clothes	Total	Men's Clothes	Women's Clothes	Total
Pullovers, etc.	0.91	63,753	63,753	127,505	58,015	58,015	116,030
Trousers (woven)	0.68	192,767	192,767	385,533	131,081	131,081	262,162
Blouses	0.23		163,287	163,287		37,556	37,556
Women's Jackets & Coats	1.59		29,041	29,041		46,175	46,175
Men's Jackets & Blazers	1.59	9,596		9,596	15,258		15,258
Men's Suits (Woven)	2.27	10,833		10,833	24,591		24,591
Women's Suits (Woven)	2.27		17,352	17,352		39,389	39,389
Men's Suits (Knitted)	2.27	1,668		1,668	3,786		3,786
Men's Coats	1.59	17,470		17,470	27,777		27,777
Anoraks	0.23	-49,762	-49,762	-99,524	-11,445	-11,445	-22,891
Dresses	0.91		38,254	38,254		34,811	34,811
Skirts	0.68		82,216	82,216		55,907	55,907
Workwear (Industrial)	1.36	21,787	21,787	43,573	29,630	29,630	59,259
Trousers (Knitted)	0.68	67,594	67,594	135,187	45,964	45,964	91,927
Tracksuits	0.5	480	480	959	240	240	480
Swimwear	0.23	16,661	16,661	33,321	3,832	3,832	7,664
Women's Suits (Knitted)	2.27		2,383	2,383		5,409	5,409
Ties	0.036	22,431		22,431	808		808
Other Outerwear (Woven)	1	43,158	21,579	64,737	43,158	21,579	64,737
Other Outerwear (Knitted)	1	15,799	15,799	31,598	15,799	15,799	31,598
T-Shirts	0.15	382,210	382,210	764,420	57,332	57,332	114,663
Shirts (woven)	0.23	48,240	48,240	96,480	11,095	11,095	22,190
Pants/Briefs	0.1	201,944	201,944	403,887	20,194	20,194	40,389
Nightwear (Woven)	0.45	33,421	33,421	66,842	15,039	15,039	30,079
Nightwear (Knitted)	0.45	28,588	28,588	57,176	12,865	12,865	25,729
Slips, etc. (Knitted)	0.13		6,920	6,920		900	900
Sheer Tights & Stockings	0.1		192,151	192,151		-19,215	-19,215
Socks & Other Tights	0.1		577,030	577,030		57,703	57,703
Bras	0.0625		72,411	72,411		4,526	4,526
Corsetry	0.23		8,906	8,906		2,048	2,048
Apparent Consumption		1,128,635	2,235,009	3,363,643	505,017	676,428	1,181,445

Apparent Consumption of Non-Apparel Textiles 1999 to 2003

	Consumption Unit	Convert to weight at:	1999		2000		2002		2003	
			Units	'000 kg	Units	'000 kg	Units	'000 kg	Units	'000 kg
Cotton Terry	'000 kg	1.00	23,506	23,506	27,823	27,823	30,384	30,384	34,767	34,767
Bed Linen	'000 kg	1.00	48,329	48,329	57,073	57,073	90,887	90,887	97,434	97,434
Table Linen	'000 kg	1.00	14,199	14,199	15,326	15,326	12,560	12,560	15,351	15,351
Curtains	'000 kg	1.00	104,976	104,976	92,107	92,107	85,329	85,329	91,193	91,193
Blankets	'000 sqm	0.50	6,147	3,074	5,015	2,508	3,903	1,952	3,309	1,655
Flax Table Linen	'000 kg	1.00	1,078	1,078	2,616	2,616	652	652	551	551
Carpets	'000 sqm	1.25	188,661	235,826	198,431	248,039	285,528	356,910	269,524	336,905
Apparent Consumption			430,988		445,492		578,674		577,855.5	
Totals after 20% loss of weight			344,790		356,394		462,939		462,284	

Assumptions: "Units" are apparent consumption units from BATC data.
 Where some consumption base figures are not available, data have been pro-rated based on value of equivalent trade.
 Given weights are "as new".
 Items have lost 20% by weight at the point of discard.

Volume II

Policy Interventions

8 Economic Instruments & Policy Interventions

8.1 Economic Instruments

8.1.1 Background

Economic instruments have been introduced or proposed in the UK to address waste from a number of product groups, such as packaging, waste electronic and electrical goods and end of life vehicles. Most recently these initiatives have been based on making the producer responsible for the product at the end of its life ('extended producer responsibility'). Similar measures have been lobbied for by the textile recycling industry, as the proportion of collected textiles that can be re-used at a profit has fallen. The industry argues that recycling is environmentally, socially and economically beneficial, and that these benefits are not currently reflected in the price of clothing collected for recycling: therefore, it is argued, some kind of subsidy for recycling is justified⁴. Interventions by European governments in the sector in Europe have included:

- A direct subsidy of collectors: in Flanders, for example, Local Authorities reportedly allocate collectors €180 / tonne
- Subsidy of research and development (R&D) costs in France for new applications such as insulation materials.

The purpose of this part of the research was to examine the evidence base for a producer responsibility initiative in this sector.

8.1.2 Extended Producer Responsibility (EPR)

Extended producer responsibility legislation is aimed at delivering sustainable development by concentrating the costs of end of life management on producers, implementing the 'polluter pays' principle⁵. In the UK the most recent and prominent forms of producer responsibility legislation have concerned packaging waste, end of life vehicles (ELV's), and waste electrical and electronic equipment (WEEE).

EPR Policy instruments include:

- Product take-back (voluntary and mandatory)
- Economic instruments
 - Deposit/refund schemes
 - Advance disposal fees
 - Material taxes
 - Subsidies
- Standards
 - Minimum recycled content requirements
- Other measures such as product leasing and servicing.

8.1.3 Integrated Product Policy (IPP)

IPP is generally defined as an approach that considers the whole of the product lifecycle with the aim of reducing its environmental impact. For a discussion on the relationship between IPP and EPR, see OECD (2001)⁶.

According to OECD, the appropriate producer responsibility measures should be:

- For post-consumer products with a positive value; market-based instruments
- For post-consumer products with a negative value but low environmental impact; voluntary programmes.

8.2 Social and Economic Issues

8.2.1 Background

The scope of this report is primarily environmental. However to give a complete picture of the impact of the re-use and recycling industry, it is necessary to describe the social and economic issues that arise from its activities. The main issues highlighted by the industry⁷ are:

- Economic benefits of textiles sold through the charity shop sector
- Employment, particularly among ethnic minorities and difficult-to-employ categories
- Economic benefits to the developing countries to which the clothing is exported:
 - Making clothing more affordable
 - Creating employment in importation and trading
- Negative effects on employment within the textile industry in countries importing used clothing from the UK.

8.2.2 UK Economic and Employment Impact

As stated in Section 5 of this report, charity shops in the UK had total sales of £469m in 2005, of which about £235m was estimated to come from textiles. Resale of clothing rags (the residue that is un-saleable for re-use) gave a sales income of approximately £18 million⁸. The shops employed almost 10,000 paid staff (compared to 96,000 volunteers). In addition to charity shop employment must there is direct employment by the textile recycling industry.

Total profit by charity shops for all products was £95m in 2005⁹.

8.2.3 Impact on Developing Countries

The impact of second hand clothing exported to developing countries has been studied recently^{10,11}, concluding that the trade has clear benefits to consumers in developing countries and supporting livelihoods. Although there has been negative impact on indigenous textile industries, the main adverse impact on these industries has been from globalisation of garment production and low priced imports, rather than from second hand clothing.

8.3 Market Failures and Textile Recycling

8.3.1 Types of Market Failure

Economic instruments and in particular extended producer responsibility (EPR)^a measures represent one category of response to defined market failures. Common types of market failure¹² in the wastes management sector are:

- Negative or positive externalities
- Information failures
- Absence of perfect competition
- Use of public goods
- Constraints on Free Trade.

Defining the type of market failure and evaluating the extent to which it explains the environmental problem of suboptimal resource use requires careful evaluation before policy instruments are proposed. Proposing a higher level of recycling than that delivered by the existing market

^a EPR is a policy in which a producer's responsibility for a product is extended to the post-consumption stage of the product life-cycle.

structure may not of itself deliver the policy goal of improved use of resources¹³.

8.3.2 Negative or Positive Externalities

Where the production, sale, use or disposal of textiles create measurable consequences for the welfare of individuals, groups or society in general, the consequences are referred to as externalities. Typically the monetary value of these consequences are not internalised in the prices paid for clothing, hence the term externalities. They need not always be negative. The disposal of textiles may create positive externalities in the form of lower intensity use of detergents and energy for drying. On the other hand, negative externalities may result in the form of greenhouse gas impact from biodegradation in uncontrolled landfill or reduced efficiency in autoclave systems handling MSW.

Once the externalities have been identified and valued, if the issue is considered to be sufficiently significant, a mechanism to alter the pricing structure through taxes, subsidies or tradable systems can provide a means of compensation.

Negative externalities in manufacture arise from environmental impacts from fibre growth and the apparel manufacturing process. These include dyeing and finishing, distribution and retail impacts. These may be due to energy use, chemicals (pesticides, dyes) or water over-abstraction. For textiles sold in the UK, almost all of these activities occur in countries outside the European Union. The externalities are largely imposed on the local or regional population and consequently it is for authorities in those countries to intervene.

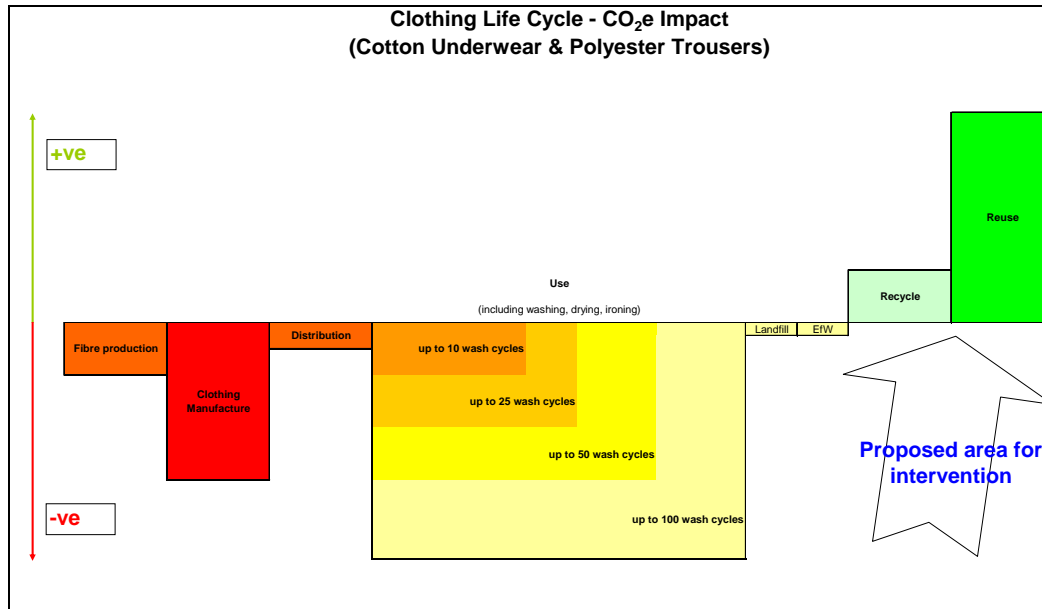
The equivalent emissions of CO₂e during the life cycle of textiles are shown graphically in Figure 4. This includes CO₂e impact through fibre production, product manufacture and distribution through usage to disposal of, in this example, cotton underwear and polyester trousers. This implies that significant impacts in use arise from the consumption of energy and detergents for washing, drying and ironing. The in-use impacts clearly depend on the number of wash cycles during the life of the item. Four different scenarios, between 10 washes and 100 washes, are shown. The lifecycle analysis used assumed around 100 wash cycles, therefore this phase of the life cycle dominated overall impact. Any externalities associated with the consumption of detergents and energy should be tackled directly and not indirectly through textile consumption.

Externalities may arise once clothing has been discarded. Certain new technologies for biodegradable municipal waste (e.g. autoclaving) have

specific problems with textiles in the waste stream and this has a minor impact by slightly increasing the cost of waste treatment and disposal¹⁴.

However, it is probably the case that these minor impacts have been taken into account for pricing purposes and consequently should not be regarded as externalities.

Figure 4: CO₂e Impact of Life Cycle of Typical Items of Clothing



Based on Defra¹⁵, Marks and Spencer¹⁶, Woolridge et al¹⁷

The waste management sector has been subject to various fiscal and regulatory interventions in order to address externalities arising from specific waste treatment technologies. Textiles form some 3% of household waste and probably less than this for all commercial and industrial wastes. The textile-specific externalities arising in the waste management sector are insignificant and are already being addressed by other instruments such as the Landfill Tax. Consequently, using the OECD guidance (Section 8.1.3), there is no case for a specific instrument to address disposed externalities arising from textile wastes.

8.3.3 Information Failures

Information failures that arise between product designers and the waste treatment and disposal industry are common. The use of mixed, complex and laminated fabrics in sports clothing offers many positive benefits to the user but when the garment is discarded, the existing recycling technologies cannot de-construct it so that it can be recycled. A sophisticated and high

added-value item is, therefore, directed either to landfill or energy recovery. As clothing designers increasingly work with a broader range of more sophisticated materials, the recycling sector only discovers the problems of recycling them once the materials start to appear in the clothes collected or donated for recycling. The compilation of a standard or publicly available specification for recycled textiles, as being developed for other waste streams, might address information failures in this respect.

The increasing use of added-value textiles implies that this is an area in which intervention might be justified. Research and development grants to develop new ways of accommodating the novel textiles are a common way of addressing this issue; especially where the research and development is carried out by consortia that includes clothes designers.

Labelling for sorting

Overcoming information failures between designers and the waste treatment industry may be assisted in the long term by innovative labelling approaches, such as embedded electronic devices which carry product information for the recycler. However such techniques would require substantial development due to the sophisticated and fast hand sorting that can be achieved currently using experienced personnel.

Labelling for consumers

Clothing labelling giving environmental information to consumers such as ease of recycling, organic or 'green' cotton content, would probably also assist in making more sustainable consumption of textiles possible by overcoming information failures between producers and consumers.

Innovation

Innovation is almost absent from the textile recycling sector. The fragmented structure, low barriers to market entry and poor profitability are structural reasons that may explain such a low level of innovation. Whilst the protection of intellectual property rights provides some incentive, further innovation may be encouraged by intervening specifically to assist research and development in the sector. Such innovation would need to be targeted at activities that would contribute to a significant improvement in the scope, scale and economics of recycling. A striking difference between textiles and other waste products such as paper, metals and rubber is that so little is recycled as new textiles, including clothing. In practice, almost all recycling activity in the textile sector is 'down-cycling'. This feature of the market deserves closer analysis as research and development support is likely to improve the level of closed-loop recycling.

8.3.4 Absence of Perfect Competition

The relaxation of constraints on international competition through the cessation of the Multi-Fibre Arrangement has increased the level of competition and reduced prices to consumers. Although not a formal part of our research, there appears no evidence of a lack of competitiveness in any aspect of the clothing sector to date.

8.3.5 Use of Public Goods

'Public goods' are commodities and services that are managed at the point of consumption by society as a whole and not by the individual. In the UK, the household waste disposal service is an example. Individuals have access to a public waste disposal service that does not distinguish between the costs of managing individual components of the waste. Consequently, textiles can be discarded at no cost to the individual. If unit pricing systems (UPS), more commonly referred to as 'pay as you throw', were applied to household waste disposal systems there would be a mild incentive to divert used textiles to recycling systems. However, an intervention that specifically bans textile wastes from the waste disposal service may not have the positive outcome anticipated as discarded clothing includes a wide range of components; from the valuable (wool overcoats) to the valueless (old underwear, rags etc). Increasing the amount of valueless materials in the composition of the textiles diverted from the public waste collection system may have the perverse impact of increasing the cost of sorting and thereby reduce the economic returns available to the recycling sector.

In the UK, the weight-based recycling targets applied to the public good of waste collection causes used textiles to be overlooked in favour of heavier materials such as paper. If resource-based targets were used, more textiles would be collected (see Figure 5).

8.3.6 Constraints on Free Trade

Defining the constraint of free trade as a market failure relies on a broader definition of the market that includes the agencies of Government. In the case of textiles it is the enforcement of regulations restricting the export of unsorted textiles that have been identified as an issue.

Although the views expressed to us have been in favour of achieving a higher standard of inspection and enforcement, there may be a case for relaxing these regulations on condition that sorted textiles in the receiving country are put to beneficial use and not merely dumped. Such a relaxation may increase the demand for textiles suitable for sorting and re-sale or recycling in low cost economies.

8.4 Evidence on Environmental Externalities of Textiles

Evidence on the environmental impact of textiles across the lifecycle was obtained from the following sources:

- A streamlined Life Cycle Analysis (LCA) study on cotton briefs and polyester trousers for Marks and Spencer¹⁸
- A complementary streamlined LCA study on the recycling of clothing for the Salvation Army Trading Company¹⁹
- A BTTG report on textile mass balance and product lifecycles for polyester/cotton sheets, polyester/worsted suiting, a knitted nylon shirt and wool/nylon carpeting²⁰
- An LCA study on a woman's knit polyester blouse for the American Fiber Manufacturers Association²¹
- A review of LCA literature on textiles by Chalmers University, Sweden²² which cites and summarises eight further textile LCA studies and four relevant inventory reports
- An LCA study on three different fibre types for a sofa covering in Sweden²³
- An LCA study on cotton towels in the UK²⁴
- The EDIPTEX project²⁵ funded by the Danish Environmental Protection Agency. This comprises LCA studies of the following products:
 - A T shirt of 100% cotton
 - A jogging suit of nylon micro fibres with cotton lining
 - A work jacket of 65% polyester and 35% cotton
 - A blouse of viscose, nylon and elastane
 - A floor covering of nylon and polypropylene.

The generally agreed conclusions from these studies were:

- The greatest environmental impact (typically around 50-80%) is concentrated in the consumer use phase. The greatest opportunities for decreasing impact lies in changing drying habits (line vs. tumble drying) and improving washing cycles (e.g. lower temperatures).
- The only exceptions to this were:
 - low washing temperatures and line drying used in the EDIPTEX viscose blouse example meant that materials and manufacturing greenhouse gas impacts were 3-4 times greater than in-use impacts.
 - the floor covering (carpet) example in EDIPTEX when infrequency of cleaning led to the materials and production phase dominating.
- Manufacture, distribution and retail had a smaller but significant impact of up to 20%. The main manufacturing impacts were

concentrated at the early stage of production, with the later stages (garment make-up, distribution, retail) having only a small impact. The actual impacts depended on fibre type, but major impacts were attributed to:

- Energy and oil requirement in the production of synthetic fibres
 - Water and pesticide/herbicide use in the production of cotton. Water impact was up to 29 tonnes/ kg cotton
 - Land use, ammonia impact, methane emissions from sheep and the effluent from wool scouring
 - Yarn blending and production.
- The environmental impact (and hence externalities) associated with disposal were low. In clothing, a benefit was associated with the displacement effects of virgin materials, but the studies generally either assumed collection and distribution costs only (e.g. to developing countries) or assumed disposal via incineration with energy recovery. This is partly because some of the LCA's considered textiles other than clothing (e.g. sofa coverings) which were unlikely to be re-used or recycled.

However, the extent of domination of the use phase in environmental impact may be overstated due to:

- Changes in energy efficiency in domestic appliances and in the specific assumptions of the case studies: for example in the Marks and Spencer study some of the data on energy efficiency of washing machines dates back to before 1995 and does not take account of increased energy efficiency. Current average energy consumption for new washing machines is 0.2kWh/kg²⁶ compared to 0.87kWh/kg assumed in the Marks and Spencer case study. Similarly wash temperatures (50°C) and detergent use (135g/load) appear higher than normal. Tumble drier energy efficiencies reported in the study were however comparable with current averages.
- The assumption that products will be well worn (e.g. 92-104 wash cycles) before disposal. This is likely to be a worst case, rather than an average: many clothes are discarded after relatively few wash cycles due to changes in fashion, size of the wearer (especially children). The evidence is the 10% 'cream' of the clothing discard that is re-sold in UK charity shops, which must necessarily show little or no sign of wear in order to be re-saleable.

Figure 4 shows diagrammatically the effect of different levels of reduced use on the life cycle impact.

The linked LCA studies for Marks and Spencer and The Salvation Army found that processing and distribution of post consumer clothing consumes 1.7kWh of extracted energy per kg of second hand clothing. This compares to approximately 100kWh of extracted energy for the manufacture of a kilogramme of polyester trousers. There is, therefore, significant energy benefit to be obtained from the displacement of new product. This is approximately 90kWh/kg for polyester and approximately 65kWh/kg for cotton products. Assuming that UK textiles are roughly composed of 50% of each type, this gives a net displacement of extracted energy of 77.5kWh/kg clothing. Since the majority of re-used clothing is exported to developing countries, a key assumption is that the clothing displaces other more expensive first hand clothing.

Using a very approximate conversion from UK marginal electricity supply of 1kWh = 0.43kg CO_{2e}, the CO_{2e} impact of re-use of clothing would be around 33kg CO_{2e}/kg clothing if there were perfect substitution of new clothing by re-used clothing on a one-for-one basis. Since this is unlikely (given the cheaper price of re-used clothing), this figure should be seen as a theoretical maximum rather than an actual estimate.

8.5 Carbon Impacts of Different Disposal Options

8.5.1 Background Data

The impact of different disposal/recycling/re-use options with respect to greenhouse gas emissions is particularly relevant given the UK's targets under the Kyoto Protocol and the waste management sector's significant contribution to greenhouse gas emissions. Recently presented data²⁷ gives the following emission factors for textiles:

Table 14: Emission Factors for Textiles under Different Waste Treatment Processes (kg CO_{2e}/kg textiles processed)

Process	UK	Non-UK
Recycling	0.02	- 7.90
Energy from Waste	0.22	0
Gasification	0.24	0
MBT	0.09	0
Landfill	0.17	0

Source: Defra (2005)

The strong non-UK benefit of recycling is due to the displacement of the manufacture of virgin cotton fibre and polyester granulate (the model assumes that textiles comprise a 50:50 mix of these two fibres). This model is also predicated on:

1. Recycled textiles are recycled as fibre rather than re-used as clothing
2. Recycled textile fibre is a perfect substitute for virgin fibre

Assumption 1 will tend to understate the impact of clothing within the textile waste stream that is abstracted and re-used as clothing.

Assumption 2 will tend to overstate the impact of recycling. Quantitative adjustments to these assumptions are calculated below based on the more detailed information available on the textile recycling industry.

8.5.2 Assumption 1: Recycling and Re-use of Textiles

From Section 5 of this report, the fate of textiles collected for recycling or re-use in the UK is as follows:

Table 15: Fate of Textiles Collected in the UK

	'000 tonnes per year	Percentage
Re-used in the UK	41	13%
Re-used overseas	174	54%
Recycled in the UK	62	19%
Recycled overseas	26	8%
Disposal	21	6%
TOTAL	324	100%

It has been previously calculated that maximum re-use benefits are of the order of 33kg CO_{2e}/kg clothing for a sample of cotton and polyester clothes, compared to a maximum of about 8kg CO_{2e}/kg for fibre recycling i.e. about four times greater. The Marks and Spencer study previously cited gives the extracted energy of cotton product and fibre manufacture as 5.3 times greater than cotton fibre manufacture alone, and 2.9 times greater when the comparison is carried out for polyester. Therefore, an average of four times greater maximum impact from re-use than recycling to fibre appears reasonable. Using data from Table 15 it can be seen that the overall

beneficial impact of re-use on the carbon impact of used textile treatment in the UK is therefore substantial.

8.5.3 Assumption 2: Imperfect Substitution of Virgin Material by Recycled Material

At present recycled fibre is an imperfect substitute for virgin. The main markets for recycled textiles, in order of importance, are²⁸:

- Wipers (main substitute: paper. Used in printing, engineering)
- Filling materials (main substitute: virgin fibre. Used in e.g. mattress fillings, spring covers)
- Reclaimed fibres (main substitute: rubber, plastics including a high proportion of recycled. Used in e.g. carpet underlay).

Hence, there is a spectrum of substitutes: virgin textile fibre, other recycled materials and paper. Where the recycled textile displaces a recycled material such as rubber, there is no benefit. If recycled fibre were a perfect substitute for virgin, then the energy impact would be comparable to displacing virgin fibre (rather than virgin apparel), which would still be substantial. If the textile displaces paper, paper has an extracted energy of around 20kWh per kg, compared to around 65-90kWh per kg for textiles²⁹. Thus it is estimated that an equivalent displacement of around 50% of virgin fibre is realistic, and the benefit of the recycled component of the textile waste stream should be reduced accordingly.

Using the data from Table 15, but adjusting the figures according to the modified assumptions, this gives the following estimates for the carbon impact of textile recycling/re-use:

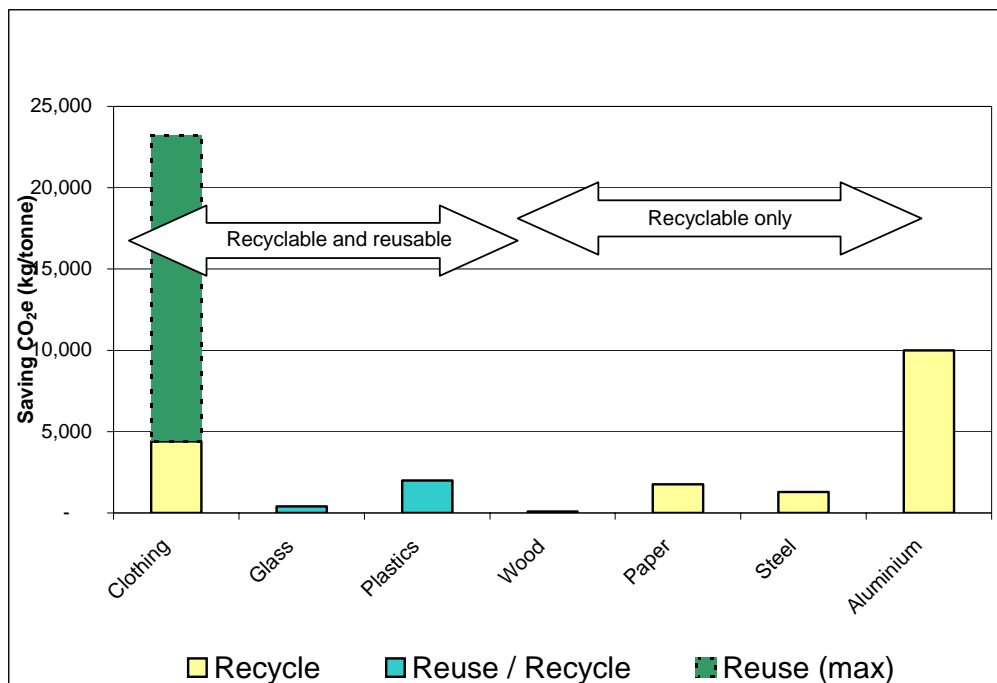
Table 16: CO₂e Impact of Textiles Collected in the UK

Fate of collected textiles	Proportion	Emission Factor kg CO ₂ e/kg	Corrected Emission Factor
Recycled	0.27	-7.9 x 0.5	-1.1
Re-used	0.67	<-33	<-22.1
Disposal	0.06	0.2	0
AVERAGE			<-23.2

It is estimated that re-use of textiles in the current proportion improves the emission factor by up to -23.2 kg CO₂e/kg textiles from the -7.9 kg CO₂e/kg

textiles currently estimated. These emission factors are shown in comparison to other common recycled materials in Figure 5.

Figure 5: CO₂e Benefits of Closed Loop Recycling / Reuse compared to Landfill Disposal



Source: Based on Defra³⁰, Marks and Spencer³¹

Using UK data the approximate carbon impacts over the lifecycle of sample clothing is as follows:

Table 17: CO₂e Impacts (kg CO₂e/kg Textile)

Stage of Lifecycle	Cotton	Polyester
Apparel manufacture	42	51
Consumer use	167	163
Recycling	-22	
Disposal	0.1-0.2	

Source: Marks and Spencer³², Defra³³

Notes:

- Consumer use figures are used as published without adjustment for possible overstatement of energy use in domestic appliances.
- The apparel manufacture and consumer use extracted energy figures have been converted to CO₂e using a conversion factor of 1kWh = 0.43 kg CO₂e. This is justified since:
 - Life cycle impacts are dominated by in-use washing and drying
 - Only approximate impacts are required for the purposes of comparison.

The disposal figures are consistent with the LCA studies reviewed, which show disposal impact to be 0-3% of the total.

8.5.4 Conclusions

Therefore, our conclusions on the overall environmental impacts of clothing are:

- Life cycle impacts are dominated by consumer use, even though these may be somewhat overstated.
- Re-use of clothing compared to recycling saves up to 29kg CO₂e per kg of clothing compared to recycling and up to 33kg CO₂e/kg compared to disposal.
- Recycling of clothing in the UK currently saves approximately 4kg CO₂e per kg of clothing compared to disposal.
- The CO₂e impacts of re-use and recycling occur largely through displacement of virgin clothing and fibre manufacture respectively.
- Thus UK charity shops and textile recyclers and their overseas sales chains have an impact of about 7.3m tonnes per year CO₂e from their recycling and re-use operations.
- The differences in the CO₂e impact of different disposal methods such as MBT, incineration or landfill are not significant in the context of the whole product lifecycle.

8.6 Policy Proposals and Extended Producer Responsibility

8.6.1 Waste Management versus Resource Management

The current waste management framework provides little incentive for Local Authorities to encourage clothing re-use or recycling:

- In contrast to packaging materials such as glass, wood, plastic and metals, there are no specific targets for textile re-use or recycling.

- On the other hand, textiles are assumed to be 50% biodegradable when Local Authorities calculate diversion of biodegradable waste from landfill in order to meet LATS targets.

The outcome from this framework is that current textile recycling delivers diversion from landfill of only 0.3m tonnes per year out of a total of 1.2m tonnes clothing consumption per year.

However, Section 8.4 demonstrates that there are comparatively high CO₂e benefits from increasing the level of re-use and recycling of textiles and diverting clothing waste from landfill and energy recovery. These conclusions are reinforced by the draft conclusions of other research currently being undertaken in the Defra Waste Research Programme³⁴. Policy frameworks that optimise resource management with respect to greenhouse gas emissions have already been published³⁵. Therefore, if a framework were to be implemented in future in which Local Authorities are set resource management targets that minimise greenhouse gas impact, then textile re-use and recycling would be given a higher priority.

8.6.2 Economic Considerations

The existing market structure depends to a large extent on the donation of clothing through collection from the door-step and delivery to charity shops or textile banks. The value of these donations is approximately £250 million annually (i.e. the value to the charity sector of selling the clothes donated to them plus the sale of 'rag' to the merchants). At low recycling rates these 'bring' systems will dominate clothing collection, assuming that the value of the clothing stream remains modest, as shown in Figure 6.

Marginal costs of collection and sorting and onward sale (MC) increase as the proportion of clothing collected increases and greater effort is required to abstract smaller and smaller proportions of textiles from the waste stream. Typically for high rates of clothing recycling, doorstep collection would be required, which has higher costs than the 'bring' systems. MC would be improved by reductions in costs of the collection and sorting process, such as sorting overseas in lower labour-cost countries or nearer to the main end-markets for re-use.

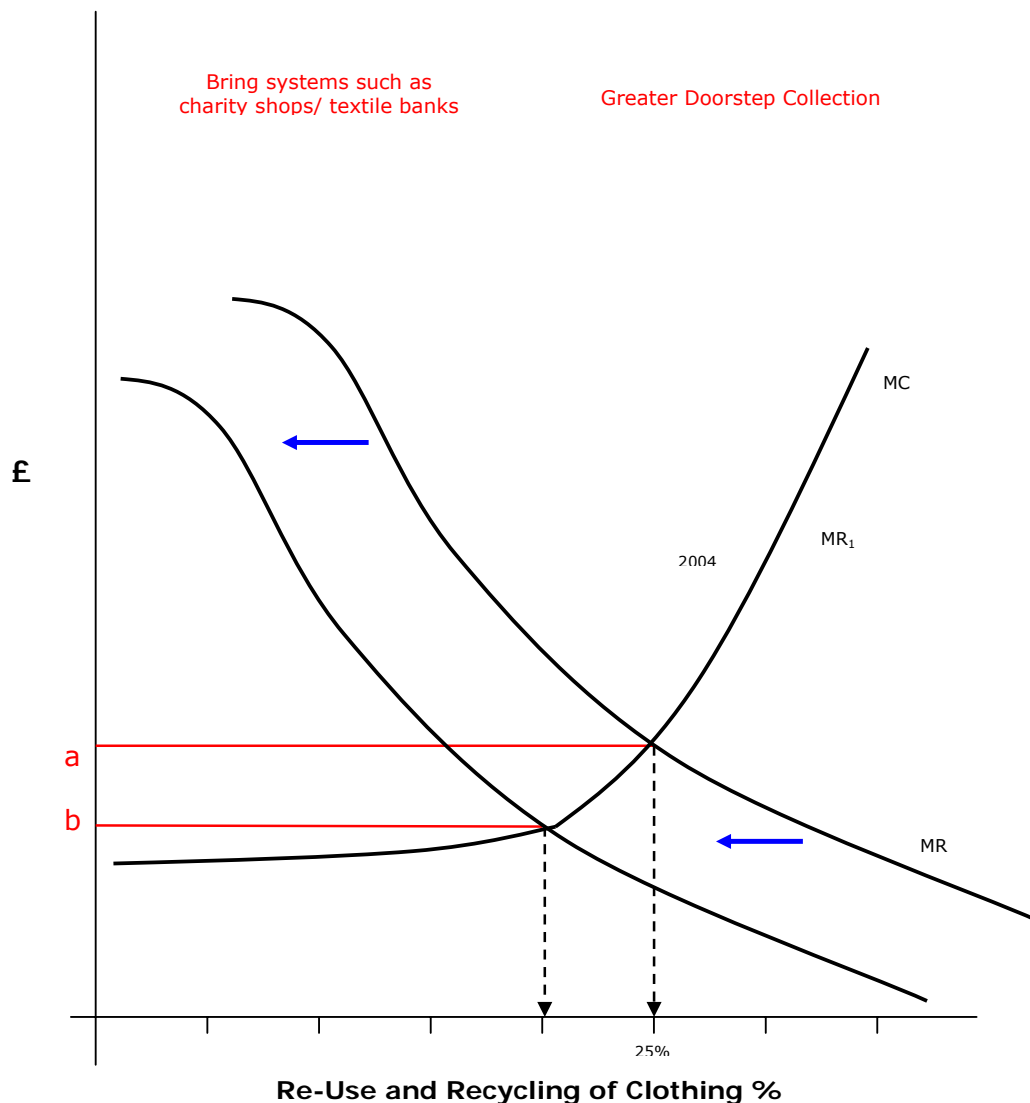
The principal reason for any decline in the level of recycling and re-use is that new clothing and fibre can be purchased at lower prices as restrictions on international trade are removed, which will lower the prices achievable for clothing or fibre by the recycling industry. In Figure 6 this change is represented by a leftward shift in the marginal revenue curve (MR) to a new position MR₁. This shift makes door-step collections uneconomic and causes the closure of some charitable retail activity. Evidence for this includes the focus of certain charity shops (eg Oxfam) on non-clothing sales

and the closure of a number of retail shops announced in January 2006 by the charity Scope partly because of competition with new clothes from the value retailers³⁶.

The financial value of an intervention to restore the recycling level to its previous position is represented by the value (b-a).

Figure 6 highlights where any intervention is best directed for increased recycling rates; improving the viability of door-step collections and coordinating voluntary activity by industry and the charitable sector to support donor giving. A key evidence base need is the determination of any changes in textile composition and value when textiles are collected with other recyclates in door-to-door collections as compared to bring schemes.

Figure 6: Changes in Marginal Revenues and Costs for Clothing Re-use and Recycling



8.6.3 Support for Door-Step Collections

Payment of Recycling Credits

As noted in Section 6.2.3, currently Local Authorities can opt to pay recycling credits to third party organisations recycling materials that would otherwise be included in the household waste stream. Distribution to clothing collection companies is patchy. From a survey carried out in June 2006 (see Section 6.2.3) it is estimated 49% of Local Authorities pay credits for textiles, with others opting not to. However, discussion with textile recycling industry sources indicate that this figure could be much lower, perhaps only 10%. If true, this suggests that it is mainly those Local Authorities paying recycling credits which had responded to the survey, whereas those not paying credits had not responded.

The survey indicated that 71% of Local Authorities who pay credits pay them to charitable organisations whilst only 16% pay credits to commercial organisations. This may reflect reluctance to pay credits to organisations that collect sporadically when the market conditions are attractive. However, the payment of recycling credits to those organisations prepared to enter into long term collection contracts with Local Authorities appears a reasonable and measured response to the long term declining attractiveness of the textile recycling industry.

Extension of Recycling Credits to Re-use

From April 2006 it was permissible for Local Authorities to pay recycling credits to organisations that re-use as well as recycle wastes. Clothing discarded to (or by) charity shops or collected door-to-door is not defined as waste, but clothing collected by textile banks is defined as waste. This appears somewhat perverse, since collection organisations encourage the same mix of materials and attitude from the householder towards textile banks and door-step collection.

The life cycle evidence indicates that greater environmental benefit comes from the displacement of new clothing than from avoidance of disposal. Notwithstanding policies that are structured around the recycling of 'waste', there appears, therefore, to be a case for incentivising re-use to a greater extent than recycling: existing policies create a perverse incentive to low grade, non-viable collection systems that collect only materials suitable for recycling.

8.6.4 Support for the Sale of Used Clothing

Voluntary Actions by Industry

Using OECD policy advice (Section 8.1.3) voluntary agreements by leading retailers could encourage consumers to donate high quality garments to the existing networks. Additionally the creation of something similar to the Courtauld Commitment³⁷, in which major grocery retailers have pledged to reduce the amount of packaging and food waste, could be applied to the end of improved environmental impact of clothing. However, it is likely that this type of intervention would 'skew' collections to charity shops from the banks and the infrastructural needs would have to be reviewed. Encouraging the use of a labelling system on garments that could in the long run reduce the costs of sorting and treating textiles might also be taken up on a voluntary basis. Such a labelling system is likely to be developed when innovation in the textile recycling industry, designed to address the increasingly complicated sorting and treatment issues, has been concluded. At present, with a recycling infrastructure that has barely changed its methods of working for a century, a labelling initiative would merely slow the manual sorting system with a concomitant increase in costs.

8.6.5 Support to Address Information Failures

Innovation as a Public Good

Increasing complexity of textile products, in terms of the range and mix of fabrics, has created new problems of identification, separation and re-use, which are likely to increase in the future. They present an area of research and development that is unlikely to be funded by the existing industry structure. An international review of innovation in the textile recycling sector is highly likely to uncover improvements that could be applied in the UK-based sector. That such information has not been taken up by the recycling sector represents an information failure in this market.

8.6.6 Producer Responsibility Measures

Advanced Disposal Fees

We have considered the introduction of an ADF (Advanced Disposal Fee) for textile products, similar to that proposed in France³⁸. However, the intervention is only likely to be helpful if the funds so raised could be directed to addressing the key market failures; lack of innovation in the recycling sector, information failures between textile producers and recyclers and on-going externalities in cotton production. The cost of addressing the lack of innovation is probably relatively modest compared to government funded innovation programmes in other sectors. Addressing the cost of information failures is likely to be equally modest. It would be more efficient to address the externalities in cotton production

directly by applying taxes to the pesticides and water used in production in the country of origin. Since the administration costs of collecting an ADF on every textile transaction is likely to be large, this option is unlikely to be favoured. In the event that further evidence is provided of the environmental benefits arising from higher levels of textile recycling, the use of an ADF could finance an improved collection infrastructure.

Recycling Targets & PRN's

Approximately 75% of clothing items are not collected. Unlike packaging glass and metal cans the heterogeneous composition of the waste stream implies that there is currently little value in the 75% of clothing that is not collected. Setting targets at a higher level will tend to draw in a lower quality of used clothing and other textiles and increase the costs of collection and sorting. In the light of the evidence of carbon savings from recycling these materials compared to some other packaging materials, it may be a more efficient use of recycling funds to increase the level of clothing recycling rather than to achieve even higher levels of recycling for glass, paper or wood.

An innovation with minor impact would be the permitting the issuance of paper PRN's (Packaging Recovery Notes) for the use of rags in high quality paper-making. This may encourage the support of a higher recycling level whilst achieving higher paper recycling targets at a lower cost.

8.7 Conclusions

- In the context of the CO_{2e} impacts of waste management choices, the re-use of clothing shows a large and positive (albeit non-UK) benefit over recycling or disposal. Recycling shows a significant benefit over landfill and energy recovery and recycling textiles is second only to aluminium in terms of its CO_{2e} benefits compared to other recyclable components in the household waste stream.
- Charity shops and the textile recycling industry have a positive environmental benefit, displacing about 8 million tonnes of CO_{2e} per year, albeit not in the UK.
- Textiles present insignificant environmental pollution potential at end of life: there is therefore not, as yet, an evidence base to support extended producer responsibility (EPR) measures in this sector. Where there are significant environmental impacts, such as through the use of pesticides in cotton growing, these are best addressed directly in the local jurisdiction.

- Although EPR measures are not supported, there are a number of market failures in the textile waste management sector that could be addressed.
- The absence of innovation in the recycling sector contrasts with the rapid development of new types of textiles. In contrast with other recycled materials such as paper, very little used textile is recycled in a closed loop: most is 'down-cycled' to lower value uses. To address this market failure, research and development (R&D) funding is required.
- To supplement the longer-term progress from R&D, there is a need to develop markets for lower grade textiles. A review of international work and dissemination in the industry is needed
- Improved labelling may assist consumers to make informed choices. In the longer term more sophisticated labelling schemes may improve sorting infrastructure in the UK.
- Waste management of resource-intensive textiles is overlooked by Local Authorities more concerned with weight and biodegradability. Hence, in the shorter term, there is a case for encouraging Local Authorities to pay recycling credits for textile re-use and recycling.
- As used clothing currently has a neutral or positive economic value and presents insignificant environmental pollution potential at end of life, there is a case for voluntary industry agreements, perhaps modelled on the Courtauld Commitment. These should seek outcomes such as support for R&D, new labelling systems and setting standards for recycled fibre content in new textiles.
- There is a case for less intervention in the area of used textile exports. Restrictions on this trade could be relaxed, with the potential consequence of an improved collection rate for recycling.
- The priorities for further work in the used textile sector are:
 - Progress the R&D objectives for the sector
 - Explore payment of re-use and recycling credits by Local Authorities
 - Undertake comparative LCA study of using recycled fibres in closed-loop uses compared to virgin fibre
 - Investigate the reasons for such low levels of closed loop recycling
 - Promote textile recycling starting with abstraction of the highest quality clothing from the waste stream.

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Volume III

Technical and Market Development

9 UK Market for Recycled Textiles

9.1 Market Background

The economic and market review, carried out as part of this project, calculates the levels of textiles entering the UK waste stream and the potential levels of discarded material based on new textiles entering the UK market in 2003. These are put at 1.16 million tonnes and 1.8 million tonnes respectively (Section 5.1.4 and 5.1.5).

The study further estimates that 324,000 tonnes of post consumer textiles are recovered annually. The estimate of the breakdown for recovered post-consumer textiles is in Table 18.

Table 18: Breakdown of Recovered Post-Consumer Textiles

Application	'000 tonnes per year	Percentage
UK Re-Use	41	13%
Export Re-Use	174	54%
Wiper Grade	34	10%
Recycling Grade	54	17%
Waste	21	6%
Total	324	

The last option for waste textiles, other than disposal, is reclamation or recycling. In practice, the most common process involves the material being shredded or pulled apart into small fractions and fibres, called shoddy or mungo. Traditional applications for these fibres include industrial filling materials, for mattresses and upholstery, sound insulation panels and carpet underlay. Shoddy from sorted fabrics can be combined with virgin fibre, which is then carded to homogeneously mix the fibres and to produce a web, which is the pre-cursor for various woven and nonwoven textile materials. Subsequently, fibres are spun ready for weaving or knitting into new products or the web is bonded directly to form a nonwoven structure.

There is a significant UK nonwoven presence in traditional recycled textiles market supplying mattress/upholstery, carpet underlay and automotive markets. As Table 18 suggests, the quantity of UK-sourced textiles

reclaimed or recycled is currently around 54,000 tonnes annually. A proportion of this material is exported for recycling overseas. These traditional markets for recycled textiles are mature and offer very little opportunity for added-value.

The scope of this study is to examine the feasibility of making nonwovens from a range of low-grade clothing waste, which would normally be sent to landfill, to create high added-value products consisting of up to 100% recycled waste materials as well as blends with functional materials (e.g. activated carbon).

Feasibility has now been established and a number of applications identified for the nonwovens produced. The aim is to identify and approach potential customers in these markets forming the basis of longer term collaborations.

9.2 UK Market for Recycled Textiles

The UK market for recycled textiles is estimated to be around 62,000 tonnes per annum. Other sources suggest that the market is dominated by three main application areas consuming 53,200 tonnes per annum of recycled textile products.

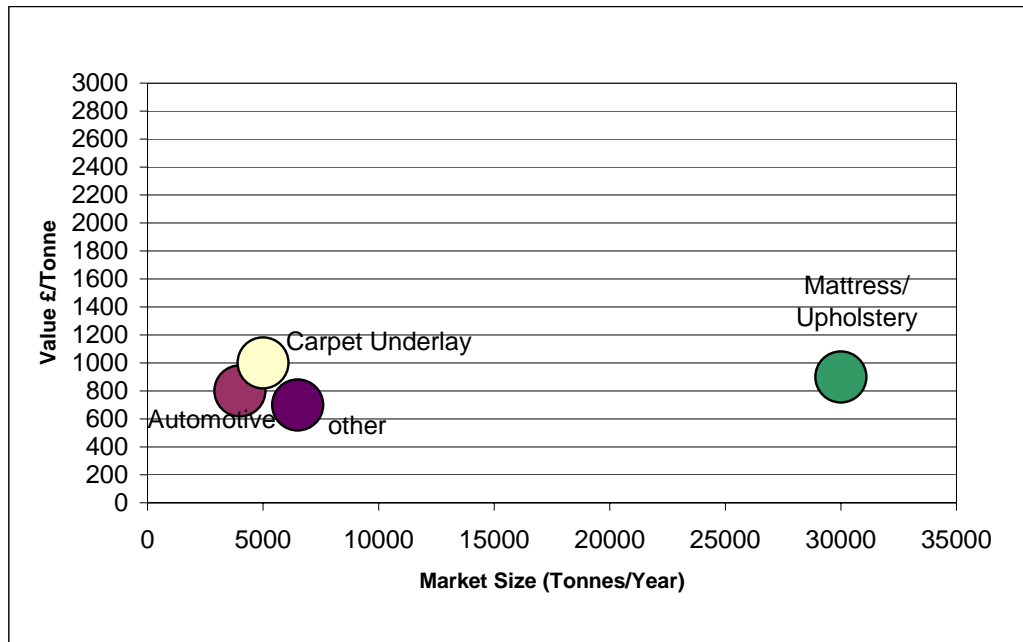
The largest volume application in the UK is for mattress/upholstery with 66% of all recycled product being in this market. Carpet underlay and automotive applications (mainly sound insulation materials) are much lower volume markets (11% and 8.7% respectively). There are also many other much smaller diverse application areas that comprise almost one sixth of the total market, including horticultural basket liners, capillary matting, and thermal insulation. The market is summarised in Table 19.

Table 19: Breakdown of the UK recycled textile market

Application	Volume (Tonnes/yr)	Market Proportion (%)
Mattress/Upholstery	41,000	66
Carpet Underlay	6,800	11
Automotive	5,400	8.7
Other	8,800	14.3
Total	62,000	100

Figure 7 compares these main market applications with approximate unit values of the various grades of recycled textiles. Values are based on processor selling prices.

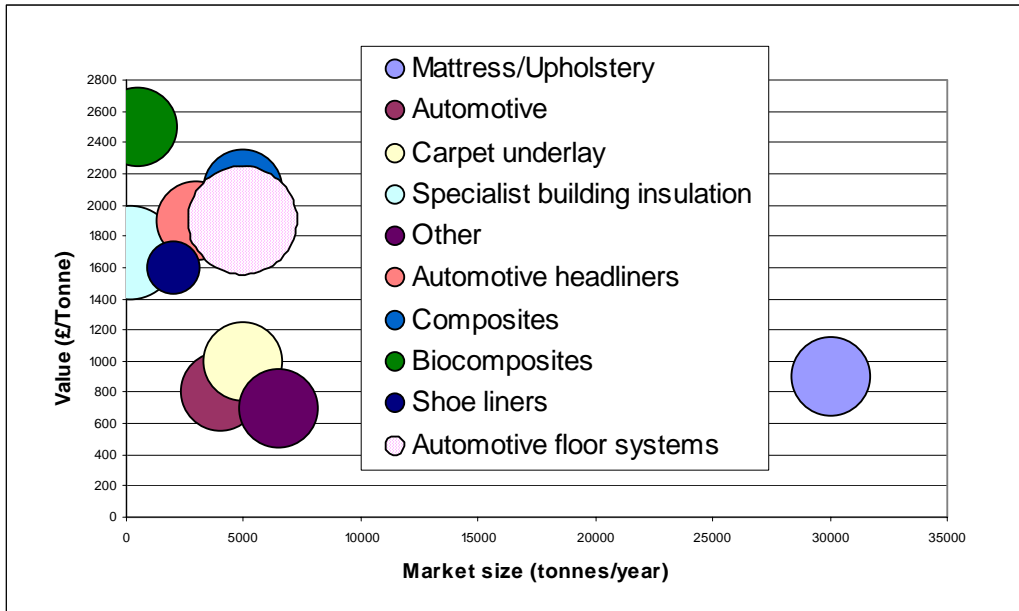
Figure 7: Market Evaluation for Traditional Recycled Textiles



It is expected that the new added-value applications for recycled materials will be able to generate returns in excess of £1000/tonne, the market value for volume underlay products. If the specifications can be achieved to meet the more demanding applications, prices around £2000/tonne may be realised. These higher performance applications place greater demands on the physical properties and functionality of the fabrics produced from waste materials.

Section 12 of this report details the potential higher value products and market applications and Figure 8 compares these new applications with the traditional markets. Clearly, at this stage, unit values and volumes are estimates.

Figure 8: Market Evaluation for Added Value Recycled Textiles



10 Feasibility of Making Nonwovens

10.1 Fabric Samples

A variety of woven and knitted clothing samples were supplied by the Salvation Army Trading Company. These samples were representative of the poorer quality textiles that are collected and which currently have low market value. These garments and fabrics were of the type that are not suitable for resale in UK charity outlets, are unwanted by merchants and are generally sent to landfill at cost to the collector. Included in the samples were woven denim fabrics containing cotton (in the form of jeans and jackets) acrylic weft knitted jumpers, woven polyester/wool blend trousers, weft knitted cotton T-shirts and printed polyester woven fabric.

10.2 Material Preparation

Before nonwovens could be manufactured, the raw clothing materials had to be converted into a form that was compatible with nonwoven production. The most widely accepted preparatory method is 'mechanical refiberisation'. This involves passing cut fabric pieces through two nipped feed rollers that grip the textile while a rapidly rotating cylinder covered in sharp metallic pins mechanically opens the fabric into smaller fractions.

The product of mechanical pulling typically consists of a mixture of individual fibres, yarn segments and smaller fabric pieces. Further separation stages are employed to increase the reduction of the segments and pieces into fibre form. The fibre is then collected on a vacuum-assisted drum and fed out of the machine (see Appendix IV).

The structure of the textile being refiberised influences the dimensions, degree of separation and homogeneity of the fibrous product. Dense woven textiles tend to produce very short fibre lengths, which are unsuitable for use in traditional yarn processing but may process readily on certain nonwoven machinery. More loosely formed structures, such as weft knitted textiles, tend to have lower density structures which yield longer fibre lengths when reprocessed.

10.3 Web Formation

Once the textiles have been reconverted into fibrous form, the fibres must be assembled into a uniform web structure in order that a bonding process can be applied to stabilise the tenuous network. The most common form of

dry-laid web formation is carding, but heavier-weight webs containing waste fibres are also commonly formed into webs using Garnett machines.

The mechanically recovered fibres were processed on the NIRI nonwoven carding system (Appendix IV) and good compatibility was observed in terms of web weight uniformity and the degree of fibre separation.

Immediately after carding, the webs were parallel-lapped, which involves laying the webs over one another in the machine direction (MD) to improve final web uniformity further without changing the predominant fibre orientation. The resulting web is anisotropic in nature, in that fibres are preferentially aligned in the longitudinal direction. After subsequent bonding, the final fabric tensile strength will tend to be higher in the longitudinal direction.

Whilst most air-laying techniques designed for waste fibre recycling have traditionally utilised revolving pinned roller to transport fibres^{39,40}, a second method of web formation involves converting very short fibres (less than 10mm) using an adapted air-laying technique of the sifting-type⁴¹. This system has been modified to handle mixed waste particles and fibres without the need for pre-sorting or separation. Such materials are not compatible with carding and therefore their commercial value in textile recycling is limited.

Much work has been completed to verify the uniformity of the webs produced using this technique^{42,43,44}. The short fibres and particles that are recovered from the clothing waste, which are incompatible with both carding and garnetting were found to be particularly suited to conversion using the adapted air-lay method. The fibres were separated efficiently during processing and formed a uniform web with isotropic properties. The addition of a proportion of homofil thermoplastic fibres, powders or bicomponent thermoplastic fibres provided a convenient means of bonding the webs by through-air bonding.

10.4 Bonding

10.4.1 Introduction

After the web formation stage, there is a requirement to bond the fibres together. This can be completed by mechanical, chemical or thermal means. The processes employed at NIRI were mechanical (hydro-entanglement and needle-punching) and thermal (through-air bonding).

10.4.2 Hydro-entanglement

Hydro-entanglement, as the name suggests, involves bonding through the use of high pressure water jets to entangle the fibres together by hydraulic forces. The recovered fibres in web form processed reasonably well using this system (see Appendix IV). The resultant fabric weight was 130g/m².

The fibre composition utilised to produce this fabric was recovered from a very tightly woven fabric. As a consequence the fibre length was very short producing a fabric with low strength compared to products currently on the market.

10.4.3 Needle-punching

Needle-punching involves bonding of the fabric by means of reciprocating barbed needles passing through the web to mechanically interlock the fibres together and create a coherent structure.

The fibre recovered from the knitted clothing waste lent itself well to this process since the residual fibre length was longer than in fibres recovered from woven waste garments e.g. denim. The webs formed by carding were of good uniformity and bonded satisfactorily using the needle-punching process.

The resultant fabric was 140g/m² which is relatively light for the needle-punching process. Fabrics sold in the marketplace are commonly between 200 and 1000g/m². The ability to form lightweight fabrics using 100% recovered fibre extends the potential applications for fabrics produced using this approach.

10.4.4 Thermal bonding

If a proportion of the fibres constituting the blend are thermoplastic then they can normally be thermally bonded. Thermal bonding may be introduced by means of several commercial methods⁴⁵:

- Area bond calendering
- Point bond calendering
- Through-air bonding
- Ultrasonic bonding
- Radiant bonding.

The fabrics produced at NIRI were bonded in a through-air oven, which circulates hot air by permeation through the web to facilitate thermal bonding. On exiting the oven the web was calendered with an unpatterned

metallic squeeze roller. This process creates materials that are relatively stiff, inextensible and strong⁴⁶.

To assess the bonding characteristics of a range of bicomponent fibres (see Appendix IV), it was necessary to blend the fibres with the refiberised clothing waste and then to thermally bond the web.

Table 20 summarises the bicomponent fibre types introduced in blends with the recycled fibres.

Table 20: Bicomponent Fibres Used to Bond Clothing Waste

Bicomponent	Composition	Bonding level
Grilon Fibre Type K	Co-polyamide 4.2 dtex, length 6.0mm	Poor
Griltex Powder D1500 P82/P25	Co-polyamide Powder	Good but poor distribution
AL special C	Polyethylene/Polypropylene 1.7 dtex, length 6.0mm	Very good

The co-polyamides, in both powder and fibre form, were found to produce weaker constructs after bonding compared to the polyethylene/polypropylene bicomponent fibres. The co-polyamide fibre did not separate well during processing and consequently was not homogeneously distributed in the final web. This created discrete areas of high and low bonding. Retention of the co-polyamide powder within the porous fibre network was compromised by the small particle size leading to poor bonding.

The polyethylene/polypropylene bicomponent fibre had good process compatibility, due in part to the low fibre linear density. The fibre distributed evenly throughout the web and created good bond strength after thermal treatment.

11 New Market Applications

11.1 Non-Load Bearing Composites

The composites industry employs over 400,000 people worldwide and is estimated to generate €41.5 billion per year. About 70% of the composites market is represented by the automotive (23%), building and public works (21%), aeronautics (17%) and sports (11%) markets⁴⁷. Industry growth has been estimated at 4% to 5% per year in volume for the period 2003-2008, with 2% to 3% per year in terms of value. The main growth sectors are wind energy (+20% per year), aerospace (+9% per year), automotive (+7% per year), and shipbuilding (+7% per year). Several market segments in the value chain such as thermoplastic resin production, wood fibres, carbon fibres and automatic injection processes are expected to experience stronger worldwide growth estimated between 6-15% per year in value⁴⁸.

Polymer Matrix Composites (PMCs) are the industry standard for many composite applications areas. Also known as FRP, Fibre Reinforced Polymers (or Plastics), these materials use a polymer-based resin as the matrix, and a variety of fibres such as glass, carbon and aramid as the reinforcement. Glass reinforced PMCs represent the highest proportion of this sector^a.

Glass reinforced plastics (GRP) are found in non-structural applications such as electrical housings, light switches, telecommunication housings amongst others. There is a possibility that recycled fibre materials could replace a proportion of the glass in such applications. Market price for glass roving, the form utilised in the manufacture of CSM, is currently around £1000/tonne, with glass nonwoven structures selling for as much as £3500/tonne. The purpose of this preliminary investigation was to determine if nonwoven media containing fibres recovered from clothing waste could be suitable for composite manufacture.

To manufacture experimental composites (for process details, see Appendix V), a preformed web was placed in a silicone rubber mould. The epoxy resin was mixed with the hardener and applied to the web. The resin was left for two hours to set, full hardness being achieved in two days.

^a Glass fibres are formed into a fabric such as Chopped Strand Mat (CSM). This fibrous network is then impregnated with a thermosetting resin system, commonly polyester, epoxy or phenolic based, which will harden to create a coherent composite part. Glass is selected on the basis of its relatively low cost, high strength to weight ratio and resin compatibility.

Experimental composite Sample 1 (right in Figure 9) was made directly from a reinforcing web of recycled polyester/cotton fibres: no bonding was employed before forming the composite. Experimental composite Sample 2 (left in Figure 9) incorporated a needle-punched fabric composed of recovered polyacrylonitrile fibres as the precursor.

Figure 9: Formed Composite Materials Reinforced with Clothing Fibre Waste



The waste fibre reinforced composite materials produced were strong, light and relatively stiff and appeared promising for use in non-load bearing composite applications. Quantitative analysis is on-going to determine the mechanical properties and thermal properties of these composite materials compared to commercial materials produced from synthetic compounds.

11.2 Emergency Thermal Insulation

Emergency blankets are designed to protect individuals in the event of an accident or natural disaster; they must be cost-effective and rapidly available. Hydro-entanglement was selected to produce fabrics for this application to give good mechanical conformability. Fabrics were produced from recovered acrylic/wool blended garments because of their inherently low thermal conductivity. The fibre was combined with two pre-made, lightweight spunlace fabrics to produce a multi-layer construct (for process details, see Appendix V). The final fabric was then produced by thermal lamination with aluminium foil films to further improve thermal properties in relation to radiation, see Figure 10.

Figure 10: Experimental Emergency Blanket Nonwoven Composites



The fabrics produced were flexible with low bending stiffness up to 5mm in thickness. The outer layers improved the attritional properties, whilst the recycled fibres in the centre gave the necessary volume required to maximise thermal insulation.

11.3 Automotive/Added Functionality

11.3.1 Introduction

The automotive industry is an extremely price-sensitive market and already uses recycled textiles in moulded interior applications such as parcel shelves and head-liners. The purpose of this preliminary investigation was to determine the possibility of introducing added functionality such as temperature regulation or thermal insulation using a waste fibre matrix as a delivery system. Web formation was facilitated by the adapted sifting air-lay system, which permitted waste particles and/or short variable length fibres to be combined in air with functional solid particles.

11.3.2 Phase Change Materials

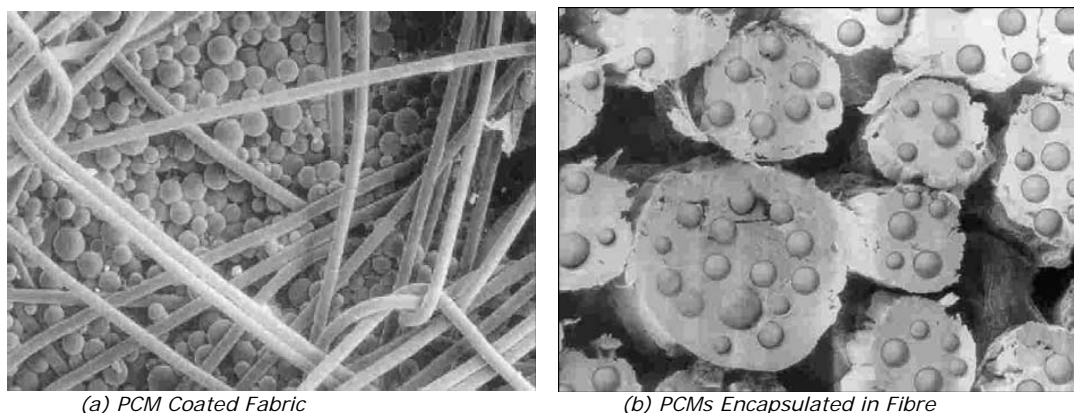
Phase Change Materials (PCMs) smooth fluctuations in temperature of an enclosed space by lowering the peak and increasing the trough temperatures^a. PCMs have been successfully incorporated into textile structures through incorporation in the polymer dope prior to melt spinning⁴⁹. There are also commercial examples of aqueously coated PCM textiles⁵⁰.

^a Most commercial PCMs are solid at room temperature. When the temperature increases, PCMs liquefy and absorb and store heat, thus cooling the surrounding air. Conversely, when the temperature decreases, the material solidifies and gives out heat, warming the surrounding air. This conditioning system has been successfully applied in clothing systems.

The NIRI air-laying technique was used to combine fibres recovered from clothing waste with PCMs. Wax-based PCMs are usually available as fine powders and these were found to have good compatibility with the air-lay system, producing an even distribution throughout the web.

The recycled fibre fabrics were thermally bonded by the addition of at least 33% owf bicomponent fibre in the blend (for process details, see Appendix V). In virgin fibre compositions, approximately 20% is required as a minimum. Figure 11 shows fabric containing PCMs.

Figure 11: Electron micrographs of PCM Coated Fabric and PCMs Encapsulated in Fibre⁵¹



The fabric produced had a high flexural rigidity in comparison to conventional textiles, although the structure may be thermoformable owing to the high proportion of thermoplastic components. Thermoformability is a desirable characteristic for moulded interior automotive parts such as carpets, parcel shelves and head-liners.

11.3.3 Silica Aerogels

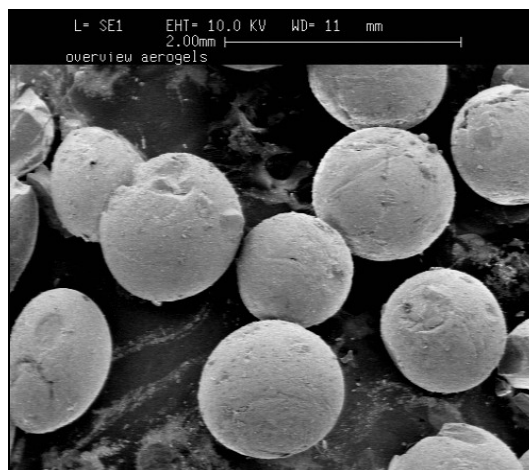
Silica aerogels have extremely low thermal conductivity and a very low density ($\sim 0.1\text{g/cm}^3$) and as a consequence have many applications where heat must be retained within an atmosphere. They have found applications in textiles where thermal insulation is important, for example, in extreme-cold, high performance clothing. Additionally, there may be many areas, including automotive applications, where an aerogel textile may be exploited.

The excellent thermal insulation properties of aerogels are influenced by their nanoporous structure which provides a barrier to the collision of gas molecules. As a result of the retarded motion of the gas molecules in the

aerogel, the thermal conductivity of the gas in an aerogel is about half that of the gas in free space (see Appendix V).

Fabrics were manufactured from recovered waste fibres using the adapted air-laying approach. An important consideration when handling aerogels is to avoid compression as they are brittle materials. Although little mechanical damage to the aerogel was observed during air-laying, subsequent calendering tended to crush the aerogel particles. This was overcome by creating a multi-layer structure in which half of the recycled fibre was laid down first, followed by the aerogel layer and finally the remainder of the recycled fibre. This approach contained the aerogel in the centre of the structure, partly protecting the aerogels during subsequent processing (Figure 12).

Figure 12: Electron Micrograph of Silica Aerogel Particles



11.4 Odour Control Fabrics

11.4.1 Activated Carbon

The term activated carbon (AC) incorporates a vast range of carbon based materials the exhibit a high degree of porosity. Industrially, activated carbons have been used since the early 20th Century, replacing bone-char in the sugar refining process⁵². Through its excellent adsorption properties, activated carbon has been used to purify, decolourise, deodorise, dechlorinate, detoxicate, filter, remove or modify salts, separate and concentrate to permit recovery⁵³.

Applications for ACs include air purification, respirators, recovery of butane and propane from natural gas, refining of sugar, oils and fats and bacterial detoxification medicine. Air purification in inhabited spaces operates at pollutant concentrations approximately 2-3ppm enabling the use of panel-type carbon filters. As the pollutant concentration is low these filters can work for an extended period and the spent carbon can be discarded⁵⁴.

The NIRI air-laying technique was used to combine fibres recovered from clothing waste with a fine AC powder which processed well, giving an even distribution throughout the web.

Normally fabrics will bond together when using 20% bicomponent fibre in the blend: for these fabrics however, it was necessary to increase the level of low-melt fibre in the blend to approximately 33% (for process details, see Appendix V). Figure 13 shows the structure of the porous activated carbon.

Figure 13: Electron Micrograph of Activated Carbon Structure



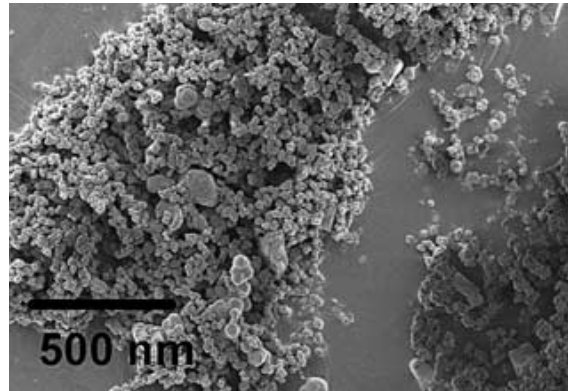
11.4.2 Zeolites

Zeolites are inorganic hydrated, microporous crystalline solids based on aluminosilicates containing exchangeable cations. They contain many small pores (1-20Å diameter)⁵⁵ running throughout the solid. They are naturally occurring and were discovered by Cronstedt in 1756⁵⁶. Synthetic zeolites were commercialized by Barrer in the early 1940s⁵⁷.

Zeolites are characterised as having a narrow range of pores sizes in the solid because the materials are crystalline, imparting better selectivity than non-crystalline materials. This means that the action of zeolites can be much more focused. For example in odour control it may be possible to target one particular compound e.g. ammonia.

The NIRI air-laying technique was used to combine fibres recovered from clothing waste with zeolites particles. The zeolite used was a fine powder and processed well, giving an even distribution throughout the web. Again the proportion of bicomponent fibre in the sample had to be around 33% in order for sufficient bonding to occur (for process details, see Appendix V). Figure 14 shows the zeolite structure.

Figure 14: SEM Micrograph of Zeolite Structure⁵⁸



11.4.3 Biocomposites

The traditional composites market is based on synthetically derived products that have an adverse effect on the environment. Composite materials include fibres with little or no biodegradability utilising inorganic substances such as glass in conjunction with synthetic resins based on chemicals such as polyester, styrene and formaldehyde. Prior to the synthetic revolution, natural materials had been used to make composite structures. As early as the 1940s the automotive industry discovered soybean oil could be moulded into fibre based plastic⁵⁹.

Since the early 1990s much research has been undertaken investigating the use of biodegradable, sustainable fibres in composites structures, many of these have found their way back into automotive applications combining wood fibre and thermoplastic materials such as polypropylene⁶⁰.

Utilising natural fibres in conjunction with synthetic polymers has had considerable commercial success but research has now begun to focus on the production of bioresins to create sustainable biocomposites.⁶¹

Formaldehyde-based resins are used in many applications including composite materials for furniture construction; wood based panels such as chipboard and MDF and also in vehicle bumpers and other mouldings but the key substance is toxic, irritant and carcinogenic.⁶²

Figure 15: Biocomposite Orientated Strand Board for MDF Replacement⁶³



A lot of the current research has focused on replacement of building products such as MDF. Nonwovens represent a new area for the application of these resin types. Samples of a suitable resin have been arranged for investigation of bio-composite nonwovens created from low grade clothing waste and bioresins derived from rapeseed (Canola) oil.

12 Market Development

12.1 Introduction

Having identified and verified the feasibility of different processing methods for recycling low grade clothing waste, the principal objective of this part of the study was to complete six feasibility studies within promising markets. A brainstorm session was conducted by all of the partners in the project to identify potential product applications. These were then ranked in order of priority in order to establish the main focus for market development. The results of the brainstorm session are set out in Table 20.

It was then necessary to identify and approach six potential customers who currently operated commercially in the priority market sectors. Once interest was established, NIRI proceeded to design evaluation samples specifically for these applications in accordance with their technical and commercial requirements.

It was not intended to reach a final design that was ready for market but rather to provide samples for evaluation. This was intended to generate feedback and to gauge potential for further commercial and technical development. The six market areas studied included low-modulus fibre reinforced composites and bio-composites, capillary matting, automotive head-liner and boot-liner components, automotive flooring component systems, pre-seeded horticultural matting and air filtration. The footwear/odour absorption market, identified as a priority in the brainstorm, was quickly discounted as the sector did not accept recycled content into their products to protect brand image.

A firm commercial interest has been established and is being utilised to identify how the concept samples can be further developed to a commercial stage. Sources of internal and external funding are being identified to assist in further collaborative work with the companies.

Table 20: Results of the Product Applications Brainstorm

Application	Sub Sector	Score	Priority
Automotive Head-liners		4	=1
Thermal Insulation		2	=4
Acoustic Insulation	Buildings		
	Transport		
	Office Dividers		
	Automotive	1	
	Wall Lining (e.g. plasterboard)	1	
	Manufacturing Noise Control		
Hydroponics/Horticulture	Capillary Matting – Water	4	=1
	Capillary Matting – Additional Functionality		
Peat/ Artificial Growing Media			
Geotextiles	Pre-seeded Mattings	2	=4
	Mulch Mattings		
Oil Spill Mattings			
Anti-spill Mattings			
Extreme Conditions Clothing		1	
Emergency Blankets			
Filtration	Water	2	=4
	Industrial Liquids and Gases		
	Scrubbing/Emissions Control	1	
	Automotive Oil and Air Filters		
	Automotive Air Conditioning		
Traditional	Mattresses		
	Carpet Underlay		
	Felts		
	Spring Covers		
Odour Control	Footwear and Pet Bedding	3	3
	Hygiene (e.g. portable toilet)	2	=4
Composites/FRP – Replace Glass – Natural Resins	Internal Building	2	=4
	Electrical Component Housing	2	=4
	Electrical Trunking		
	Electrical Boxes		
	Phone Booths		
Electrical Insulation	Water Resistant Cable	1	

12.2 Composite Market

12.2.1 Overview

The market for natural fibre composite materials has intensified over the last 10 years. For example, in 1999 to 2000 there was a 90% increase in demand for natural fibres for the composite market; such materials are seen as having 'environmentally friendly' credentials as well as a good performance/cost quotient. Such fibres are replacing higher density materials such as glass, as well as wood fibres in certain sectors. In 2000, the European Automotive industry consumed 28,300 tonnes of natural fibre, mainly flax, jute and hemp⁶⁴.

There is some debate in the industry about the suitability of recycled low modulus fibres (compared to glass, carbon, for example) in composite reinforcement. A comparison of composite properties using various textile fibres is given in Table 21.

Table 21: Composites Properties for Textile Reinforcements⁶⁵

Fibre Type	Density g/cm ³	Strength GPa	Elongation %	Modulus GPa
E-Glass	2.54	1.4-2.6	2	75
Flax	1.4-1.5	0.3-0.96	1.5-4.0	27-80
Hemp	1.4-1.5	0.5-1.04	1.0-6.0	32-70
Jute	1.4-1.5	0.4-0.8	0.8-2.0	13-26.5
Viscose	1.5	0.31		11

Although popular in thermoplastic applications, these low-modulus materials have fallen short of widespread adoption in thermoset applications. There is some evidence to suggest that this is not because of strength but the product designers at the automotive companies are unwilling to specify modulus (see Appendix VI) levels low enough to allow textile fibres to be used.

For reasons outlined in Appendix VI, the technology developed at NIRI would find many obstacles to penetrating the automotive market and hence it would be prudent to approach another area of the composite market that would have a higher likelihood of penetration.

In discussion with specialist moulders of GRP, a number of products that do not require high modulus reinforcement were identified. The company

was started in 2000 and recently extended its premises to 10,000 square feet and continues to grow and develop. With facilities for Light Resin Transfer Moulding (Light RTM) and CNC machining the company are equipped to take projects from conceptual design, through pattern and mould making to component manufacture. Typical applications for low-modulus composites include:

- Telephone hoods, kiosks and shelf mouldings
- GRP covers & guards
- Composite housings, e.g. for telephone exchange, general storage and lock boxes.

We developed initial concept samples using nonwoven technology to produce pre-form textile reinforcements for a range of thermoset resins such as polyester and epoxy. These pre-form architectures were then impregnated with epoxy resin and bioresin (from rapeseed oil) to produce comparatively low-modulus composites structures. It was decided to use this approach when designing structures for low modulus applications.

12.2.2 Experimental Work

Developing the concept from the original sample, the general requirements for a substrate for reinforcing a LRTM composite panel were described as:

- Lightweight
- Must provide stiffness to the final part
- Must allow resin to flow through the sample whilst being compressed under a vacuum
- Must have a degree of conformability.

Based on these criteria a nonwoven architecture with a proportion of fibres periodically oriented in the Z-direction (through the fabric plane linking the top face to the bottom face) was produced. This fabric resisted total compression of the structure under vacuum. The most appropriate nonwovens technology was dry-laid needle-punching. It was decided that the fibre selection, based on the criteria above, must include a proportion of glass as well as recycled textile to provide adequate stiffness properties and therefore, the fibre blend was as follows:

56.6%	Glass fibre
26.7%	Recycled Acrylic fibre (Salvation Army Trading Company)
16.7%	Bicomponent Polyester/Co-polyester

The fibres were mechanically blended and carded to produce a coherent cross-laid web. The web was subsequently needle-punched using the conditions shown in Table 22.

Following needle-punching, the fabric was structured, using fork needles to create a rib structure and further orientate the fibres in the Z-direction. The fabric was then stabilised by treatment in a through-air bonding oven at 150°C which allowed flow and fusion of the low-melt sheath of the polyester fibre and the introduction of thermal bonding. The final sample weights varied between 330-460 g/m².

Table 22: Needle-Punching Process Parameters

Process Parameter	Setting
Needle gauge	32
Needle penetration depth Side 1	10mm
Needle penetration depth Side 2	7mm
Machine speed	2m/min

The fabrics produced using this approach can be seen in Figures 16 and 17. Figure 16 shows the structured nonwoven material. Channels can be seen on the surface of the fabric created by the fork needles.

Figure 16: Sample 1, Needle-Punched and Structured Glass/Recycled Fibre Reinforcement

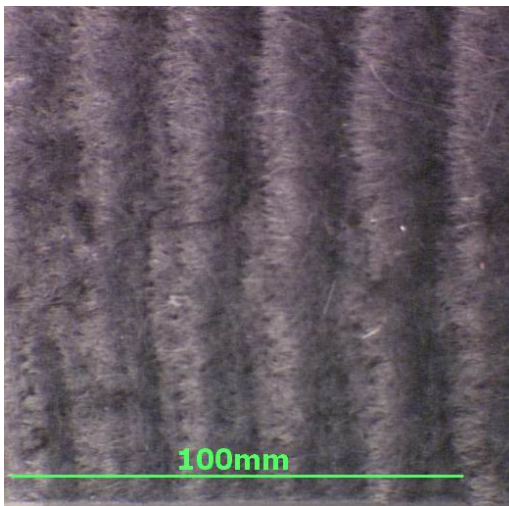
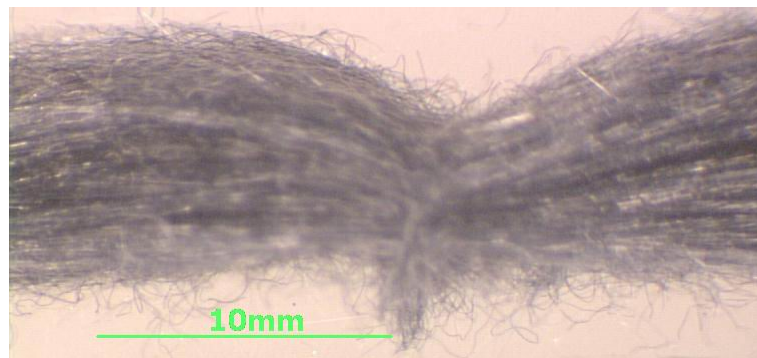


Figure 17 exhibits a cross-section of one of the structuring points, it can be clearly seen that fibre has been reoriented through the structure, in the 'Z' direction. It is this architecture that will provide some degree of resistance to compression during composite manufacture.

Figure 17: Cross-Section of Structuring Point



A second design was produced. This approach used differential bonding to create differences in compression resistance. Discrete bands of needles were removed prior to manufacture to create longitudinal areas of bonded fibre and non-bonded fibre. These can be clearly seen in Figure 18. Figure 19 shows a cross-section of the structure which demonstrates the 'node' architecture. It is envisaged that the differential bonding creates areas with differing compression resistance to aid composite manufacture.

Figure 18: Sample 2, Differentially Bonded Glass/Recycled Fibre Reinforcement (Plan view)

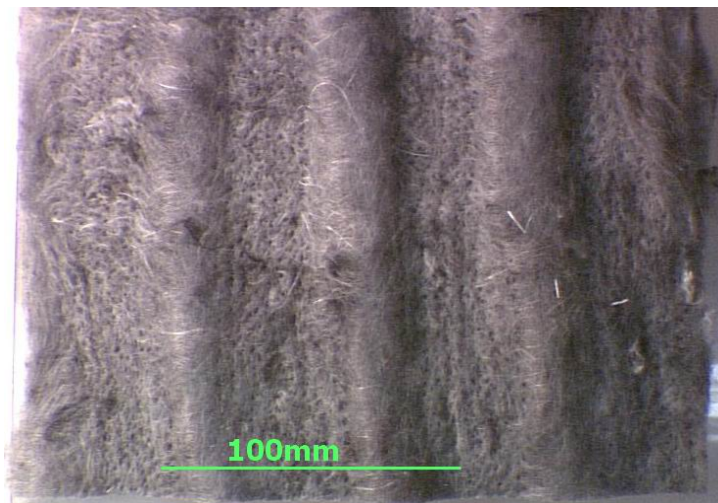
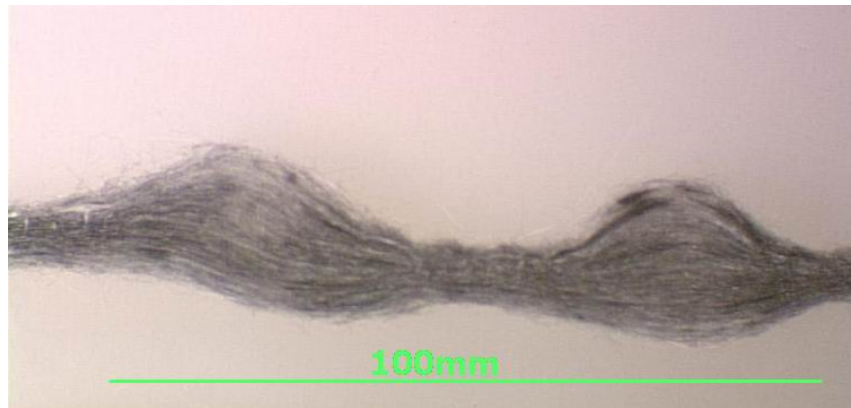


Figure 19: Cross-section of Differentially Bonded Nonwoven Reinforcement



A second approach was adopted to introduce flow channels to a pre-formed glass substrate. An air-laying technique developed at Leeds was utilised to distribute recycled fibre into discrete locations in the fabric to create periodic longitudinal channels of fibre interspersed with a continuous cavity. The composition of the final fabric is given in Table 23.

Table 23: Composition of Glass/Recycled Fibre Concept Samples

Component	Description	Weight (g/m ²)	% of overall weight
Glass	CSM	450	40.9
Recycled Acrylic	Short fibre distribution	140	12.7
Bicomponent Polyester	Fibre, 50mm MFL	60	5.5
Glass	CSM	450	40.9
Total		1100	100

The fabric was treated at 150°C in a through-air oven to bond the recycled fibre using the low-melt bicomponent polyester fibre. Resultant fabric weight was in the region of 1100 g/m². There were two fabrics produced; Sample 3 had more numerous narrow channels whilst Sample 4 had fewer wider channels. Figures 20 and 21 show the structure of Sample 3. Figures 22 and 23 display the wider channel fabric (Sample 4) in plan and cross-section view.

Figure 20: Sample 3, Narrow Channel Air-Laid Fabric

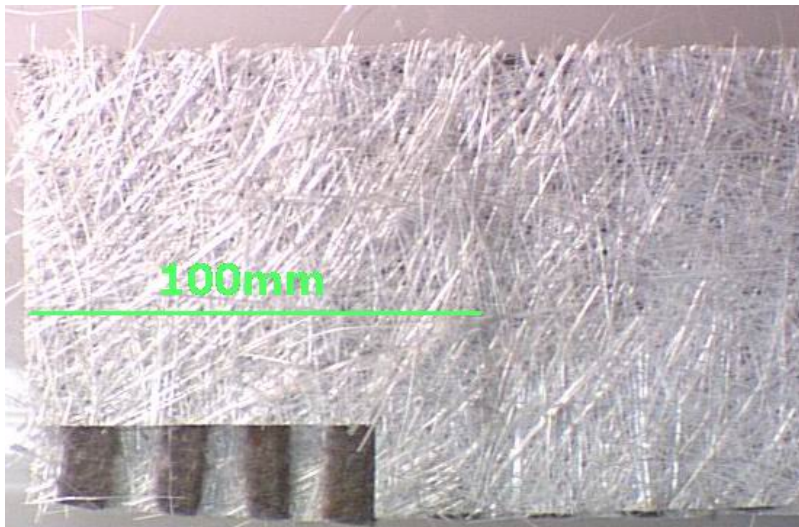


Figure 21: Cross-section of Narrow Channel Air-Laid Fabric

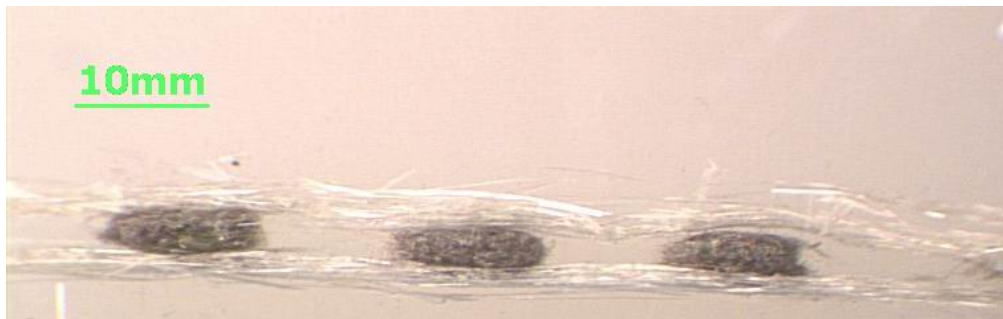


Figure 22: Sample 4, Wide Channel Air-Laid Fabric

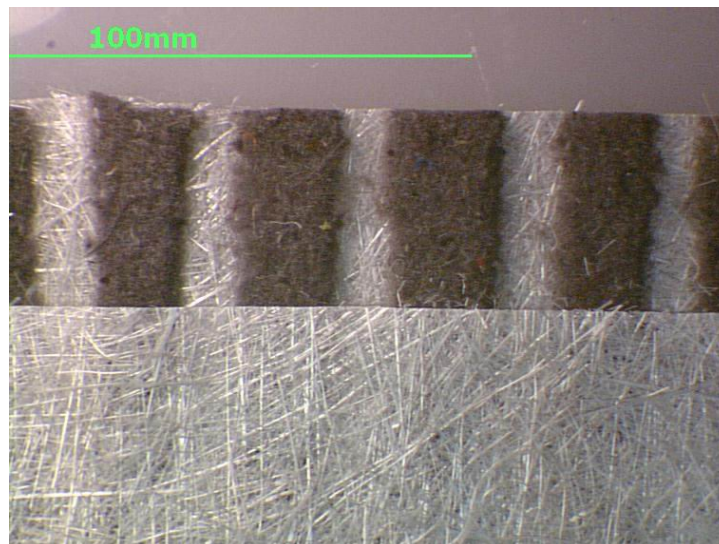
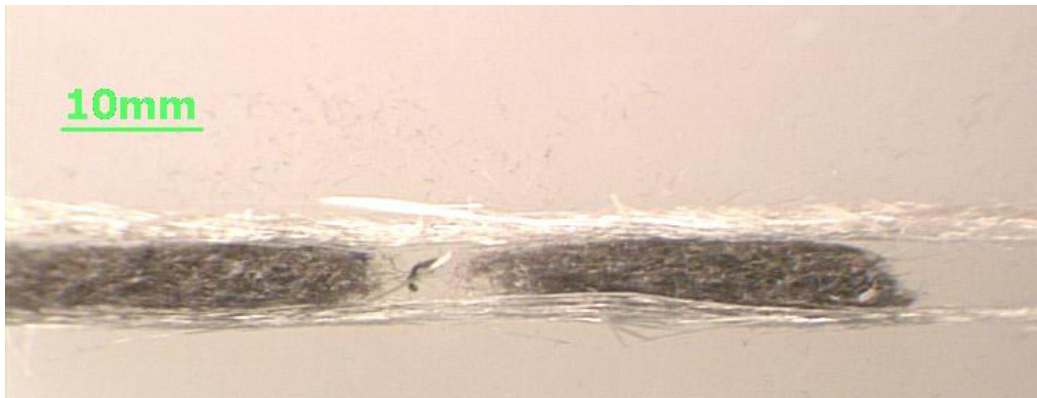


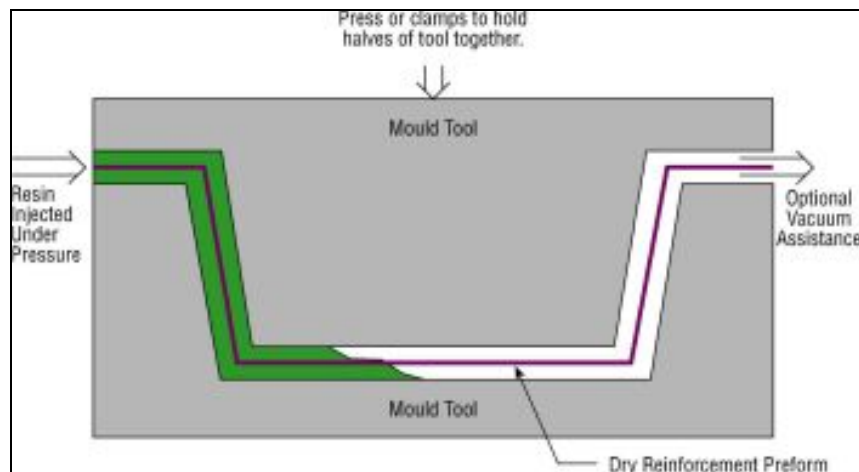
Figure 23: Cross-section of Wide Channel Air-Laid Fabric



12.2.3 Evaluation, Feedback and Next steps

The concept samples were evaluated by a commercial company. The panels were manufactured using Light Resin Transfer Moulding (LRTM), a technique currently experiencing rapid increases in popularity in the composite market. Figure 24 demonstrates the principle behind the manufacture.

Figure 24: The LRTM Method of Composite Technology⁶⁶



During processing the reinforcement layer is laid up on a release coated female mould that has been coated in a thin layer of gel coat. The male side of the mould is secured around the outside of the reinforcement layer. Inlet and outlet points are secured through the mould so that air can be removed through the use of a vacuum pump and replaced with resin. Pressure is applied to the laminate once laid-up in order to improve its consolidation, the air in the mould is then extracted by the vacuum pump and thus up to

one atmosphere of pressure can be applied to the laminate to consolidate it⁶⁷. The resin may be injected into the mould under pressure to improve flow characteristics.

The resin system used was Class 2 fire retardant polyester that was unfilled, using 2% of catalyst acetylacetone peroxide (AAP). The resin injection pressure was 1.0 bar and a vacuum pressure of 0.5bar was employed.

As a control, two layers of CSM were infused using the same resin system, which is a typical lay up in the GRP composites industry. All the samples were compared to these in terms of ease of infusion, appearance and flexural stress. The three-point flexural stress was measured using a modified version of EN ISO 14125:1998, using a span of 75mm, the results can be seen in Table 24.

Table 24: Flexural Stress at break for composite panels

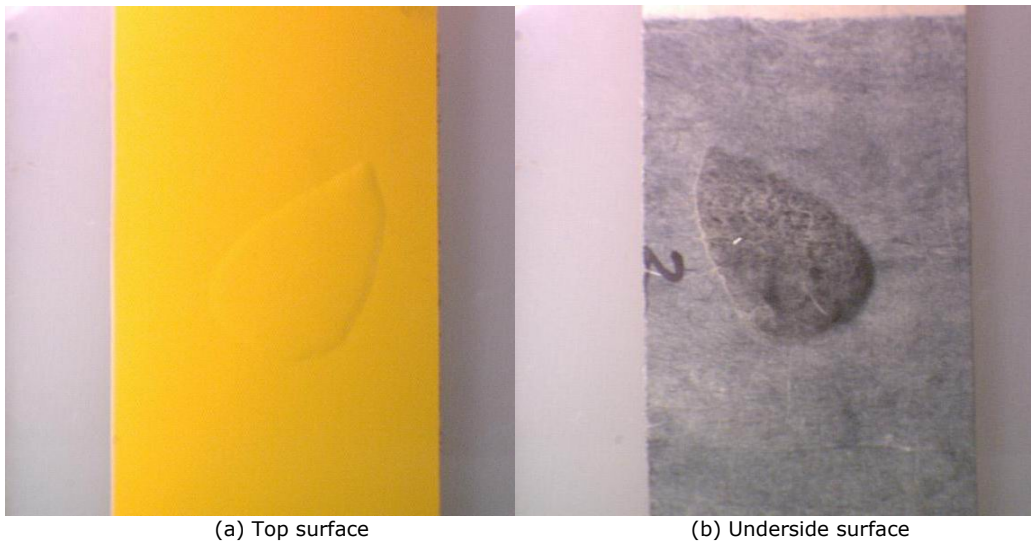
Sample	Load N	Deflection mm	Thickness mm	Width mm	Span mm	Flexural stress MPa
CSM	142	10.9	2.67	16.2	75	138.33
Sample 1	66.5	7.8	3.06	16.1	75	49.63
Sample 2	89.1	11.08	3.22	16.2	75	59.68
Sample 3	190	11.77	2.63	16.3	75	189.59
Sample 4	176	11.47	2.52	16.2	75	192.46

Sample 1 filled slower compared to the CSM sample, possibly owing to the compression resistance of the fabric. The saturation levels appear to be good and the surface finish was average compared to the CSM standard sample; linear imperfections could be seen coinciding with the structuring points of the fabric. The flexural stress was low compared with the CSM panel, less than 38% of the CSM panel.

Sample 2 had problems filling the reinforcement resulting in a large surface 'bubble' into which no resin flowed, which can be clearly seen in Figure 25. This created a large 'dry spot' which is unacceptable for composite applications. This may be a manufacturing fault or be caused by a variation in weight. The surface finish on the surrounding areas appeared to be poor compared to the CSM sample; linear bands of imperfection were noted corresponding to the bonded areas of the reinforcing fabric. A sample of the filled surrounding area was tested for flexural stress and found to be marginally better than Sample 1 but over 50% of the CSM panel.

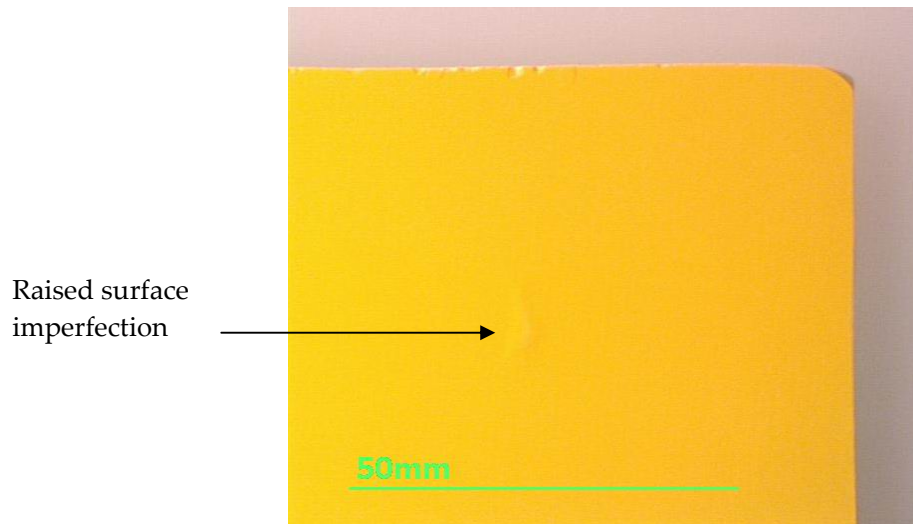
Sample 3 filled quickly in comparison to the CSM fabric, the flow channels appeared to have an influence. The surface finish was relatively poor, certainly worse than the CSM panel, as there were a number of drier areas where resin had not infused completely corresponding to the discreet areas where large pieces of recycled fibre were present. Where resin has infused fully the surface finish was comparable to the CSM plaque. It is possible that there is not enough recycled fibre in the reinforcement resulting in some areas being too resin rich and air not being removed efficiently. The flexural properties were very good, superior to the 100% glass reinforcement, possibly owing to the two layers glass fibres being kept slightly apart, locating the glass at the surfaces of the composite.

Figure 25: Sample 2, Composite Panel with Resin Starved Area



Sample 4 showed similar characteristics to Sample 3 although the surface finish was slightly improved. The flexural stress was the highest of all the samples. Figure 26 exhibits the surface imperfections observed in Samples 3 and 4.

Figure 26: Surface Imperfections Observed on Sample Panels 3 and 4



Overall the approach of using recycled material as a core component in composite reinforcement shows considerable promise and is worthy of further investigation. Improvements can be made by altering the blend components to optimise the mechanical requirements of the composite with conformability, weight, processability and cost. The structure can be optimised in terms of designing the orientation of fibres for maximum flow characteristics; looking at different structuring techniques for improving flow. Varying fibre types and dimensions to ensure compatibility with different resin types is required. Another potential approach involves using NIRI's air-laying technology to introduce short textile fibres to pre-formed glass products to prevent the need for surface veils or the introduction of flow channels.

The outcome of this study is that funding will be sought to facilitate further development in the composites market together with commercial partners. The most likely route will be through the DTI Technology Programme in conjunction with a consortium including a manufacturing company, one of their customers and relevant partners such as a resin supplier. There is an industry need to produce new structures that work particularly well in complex shapes.

12.3 Capillary Matting

12.3.1 Overview

Capillary matting is commonly used in the horticultural and domestic markets. Its function is to assist in the propagation of plants and cuttings by transporting water from the water source to the area the plant is situated. The water is transported by capillary action along the plane of the fabric; the fibres acting as capillary tubes. Commonly used by professional horticultural organisations, there is also a burgeoning retail market through garden centres in the UK for people wishing to water their plants whilst away on holiday.

With new water legislation driving horticultural growers to reconsider all aspects of water usage on nurseries, cost-effective methods of irrigation are becoming increasingly important. One study compared capillary matting beds with overhead sprinklers and Efford drained sand beds. The capital cost saving compared to drained sand beds of around £6/m² and at minimum saving of 65% of water compared to overhead irrigation systems makes this method of irrigation extremely attractive⁶⁸.

Several companies' market capillary matting products in the UK and evaluations were conducted with one of the UK leaders, who are horticultural and agro-textile specialists, with sales access to both the horticultural and retail markets. Additionally, they currently market a product constituted from recycled fibres although the product is relatively crude in construction and therefore does not enjoy a premium position in the market. The market requirement is to have an improved capillary matting product in terms of capillary performance at a price to suit the domestic retail market.

12.3.2 Experimental Work

Samples of commercially available capillary matting products were provided by our commercial "partner". Analysis of these materials identified two different generic structures. The first sample was constructed of layers of pre-bonded nonwovens that had been mechanically integrated together, the second sample consisted of a fibrous network that had been mechanically entangled and attached to a pre-bonded nonwoven layer. The fibre used was composed of coarse polypropylene of >5dtex. The second type of construction lent itself most favourably to the recycled fibre route.

Recycled acrylic fibre extracted from knitted garments (supplied by The Salvation Army Trading Company Ltd) were assembled in to needed

fabrics and, the low density construction allowed maximum fibre sizes to be attained. Recycled cotton extracted from denim garments (supplied by SATCoL) was also evaluated with but was discounted owing to the short recovered length (<15mm) and surprisingly hydrophobic nature of the recycled fibre. A virgin polypropylene fibre with a hydrophilic finish was selected to act as the scaffold fibre in the product to provide the flow characteristics and mechanical strength. This component was 6.7dtex with a mean fibre length of 75mm.

The fibres were prepared by blending and carding into web form. The blend proportions were varied to include different proportions of recycled fibre. Three samples were prepared with 25/75, 40/60 and 50/50% recycled acrylic/polypropylene proportions. The webs were then needle-punched using the settings given in Appendix VI. A spunbond nonwoven scrim fabric was attached to one side to improve the appearance characteristics and to assist wet dimensional stability. The total fabric weight was 300g/m².

12.3.3 Evaluation, Feedback and Next Steps

The initial results have not been encouraging. None of the original samples evaluated provided vertical wicking to the height required (20cm). It has been noted that the hydrophilicity of the fibre is of paramount importance⁶⁹ and that it may be preferable to use a combination of hydrophilic and hydrophobic polymers⁷⁰. To this end the polypropylene was replaced with a virgin hydrophilic cellulosic fibre and lower proportions of recycled material were employed. Also critical to the wicking performance is the density of the fabric: the density must be sufficiently high to provide wicking performance. Using a woven fabric to act as a scrim material has also provided wicking properties.

There is now an immediate requirement for further development in this area the company who carried out the evaluation is very keen to progress the project to a commercial scale. Ongoing work is focusing on the performance of the base fibre composition, which needs to maximise liquid transfer by capillary pressure. Potential manufacturers of this type of product are also being investigated.

12.4 Pre-seeded Matting/Green Roof Applications

12.4.1 Overview

There is a large international market for pre-seeded matting products for 'instant gardens' and 'green roof' applications as well as more traditional horticultural applications. The UK market however is currently quite small with only 4-6 green roofing projects completed per year. However, the roof sizes tend to be large and the trend is for increasing volumes of roofs to be of this type. Furthermore, there may be opportunities in London for increasing the levels of green roofing, The Mayor of London is currently looking at plans to promote retrofitting of green roofs in London, to reduce the 'urban heat-island' effect and prevent London being typically 1-2°C higher than the rest of the UK.

Green roofs not only enhance the insulation properties of a building but also store additional water meaning less heat is lost to atmosphere and the building is heated more efficiently. Financial incentives may be offered to balance the cost of installing green roofing structures.

The structure of the market is such that green roofs are sold by the existing PVC roofing contractors as an alternative to traditional synthetic designs. When a green roof is proposed these companies involve horticultural consultants to help design the product.

The growing medium is only a small part of green roof systems which typically include:

- waterproofing layer
- drainage layer
- filter layer
- growing medium
- inspection chambers.

Designs for the growing medium will depend on the needs of the vegetation.

The following requirements for pre-seeded matting for green roof applications have been identified:

- high recycled content
- biodegradable
- ground life (maintaining integrity) 12-18 months
- 100-200g/m²

In addition, roofing contractors are seeking new lightweight solutions for green roofing substrates. Weight is a very important criterion as the roof structure has to be designed around holding significantly higher weights than a standard PVC roof structure, affecting costs accordingly.

The air-laying techniques are especially suited to processing recycled fibre whilst at the same time adding particulate matter. A second approach uses needle-punching technology to encapsulate seed within the fabric architecture whilst minimising mechanical damage.

12.4.2 Experimental Work

Air-laying involves dispersing fibres and/or particles in air, transport of the solid/fluid mixture followed by separation to form a low density web. This approach was chosen owing to the ability to easily incorporate particulate matter, such as seeds, into the structure. A second approach utilised needle-punching technology to limit seed damage.

The fibre selection was limited owing to the biodegradability requirement. In terms of low-grade clothing waste, many of the garments in the waste stream are composed of synthetic fibres or blends of natural fibres with synthetic fibres, for example cotton and polyester. The selection therefore had to be either 100% cotton or viscose garments or 100% cotton denim. The denim was selected on the basis of its availability.

The garments were mechanically fiberised and blended with 20% low melt bicomponent polyester fibre to assist subsequent bonding. The fibre blend was processed through the air-laying machine; the settings are given in Appendix VI.

During processing, grass seed was added at an addition of 35g/m², the recommended coverage for the specified grade of seed. An initial 100g/m² of fibre was air-laid, followed by the addition of the seed and subsequently a final 50g/m² of fibre was applied to create a sandwich construction with a thin top layer to allow the seed to germinate effectively. The web was further processed by bonding the structure in a through-air oven at a temperature of 150°C and a speed of 2m/min.

The second approach used a needle-punching technique to bond the fibres together but also limit seed damage through the action of the needles. This approach was suited to the application because it required no additional non-biodegradable low melt component to bond the structure coherently.

Having treated the initial web with a fully set needle-board, the seed was added at 35 g/m². A second, lighter-weight web was then placed on top and subsequently processed. Small sections of needles were removed from

the needle-board creating 'unbonded' zones of fibre where the seeds could be stored without mechanical damage.

A final sample of seeded matting was manufactured using a fully set needle-board to compare the level of mechanical damage to the seeds.

12.4.3 Evaluation, Feedback and Next Steps

The fabrics essentially worked as a pre-seeded grass mat. Propagation occurred with good coverage of grass seed as the random nature of the scattering application gives good distribution. The needle-punched approach is preferred, as the short fibre used in the air-laid approach limits the propagation owing to the decreased porosity. There was no noticeable difference between the selectively needled sample and the fully needled approach. Little or no damage to the seed was imparted by the needle-punching process.

The basic pre-seeded fabrics are very inexpensive owing to their limited technological approach. The addition of fertiliser within the fabric structure, to aid propagation, was discussed in detail but thought to be of limited use owing to the addition levels required and the multiple applications usually added. After initial technological success there was no interest in developing the concept further.

12.5 Automotive Head- and Boot-Liner Components

12.5.1 Overview

The UK automotive manufacturing sector contributes around £8.4bn added value to the economy, accounting for 1.1% of GDP. Approximately 237,000 people are employed in the design and manufacture of vehicles and components in the UK⁷¹.

The global volume of the automobile supply industry amounted to €932 billion in 1998 out of which €695 billion for Original Equipment (O.E.) and €237 billion for replacement of parts in the after-sales market.

The aftermarket is that part of the automotive components industry that provides services and equipment, i.e., parts, accessories, consumables etc. for the motor vehicle after it has gone into use. In 1998 there were around 2,000 UK component manufacturers supplying the aftermarket industry through approximately 2,500 distribution outlets and 55,000 retail outlets⁷².

The demand for replacement parts is being fuelled by increasing numbers of cars on the UK roads. There are currently 30 million vehicles registered in the UK and a report by Trend Tracker suggests this will rise further to 33.8 million by 2010.

The demand for enhanced comfort and improved safety in the automotive sector will result in a significant increase in the use of textile materials in a typical mid-size car over the next five years from less than 21kg in 2005 (Table 25) to 26kg in 2010. Furthermore, by 2020 textile usage is predicted to reach 35kg⁷³.

Table 25: Textile usage in a mid-size car, 2005

Component	Weight (kg per car)
Carpets	4.5
Upholstery	3.5
Belts, tubes, tapes	1.6
Tyre cord	1.5
Safety belts	1.9
Airbags	1.2
Components	4.5
Others, including filters	2.2
Total	20.9^a

^a Total based on the addition of rounded data.
 Source: Saxony Textile Research Institute

The head-liner is an integral part of the interior of the automobile. It provides sound absorption and thermal insulation in the car ceiling, as well as having an aesthetic function. Figure 27 shows a typical head-liner and its position within the car. Usually a textile composite structure, the head-liners are heat moulded into the required shape for the requisite model of car. It is presently common practice to use recycled material within the construction but face this with a virgin material in order to provide the aesthetic properties. This lends itself well to the air-laid technology approach to impart additional functionality.

Figure 27: Automotive Head-liner



The scope for the development work focused on turning a relatively passive head-liner system imparting sound absorption properties to an active system i.e. sound-absorption and local temperature control. The costs associated with delivering additional functionality could be potentially offset by the greater use of recycled fibres in the construction.

12.5.2 Experimental Work

The experimental approach utilised an air-laying technique to incorporate particulate phase change materials (PCMs) into the structure. This can then form the underside (non-face), functional layer of the head-liner which is thermoformable owing to the thermoplastic content of the structure. Short-fibre waste was mixed with the PCMs in the turbulent air stream during the air-lay process. The process settings are given in Appendix VI.

12.5.3 Evaluation, Feedback and Next Steps

The fabrics were evaluated by a leading headliner producer and useful discussion was conducted about the potential for improving the functionality of soft components within the main cabin and boot compartments using the fabrics produced. At present a consortium is being assembled, including this manufacturer, a leading car manufacturer and NIRI to develop for a two-stage collaborative research and development project.

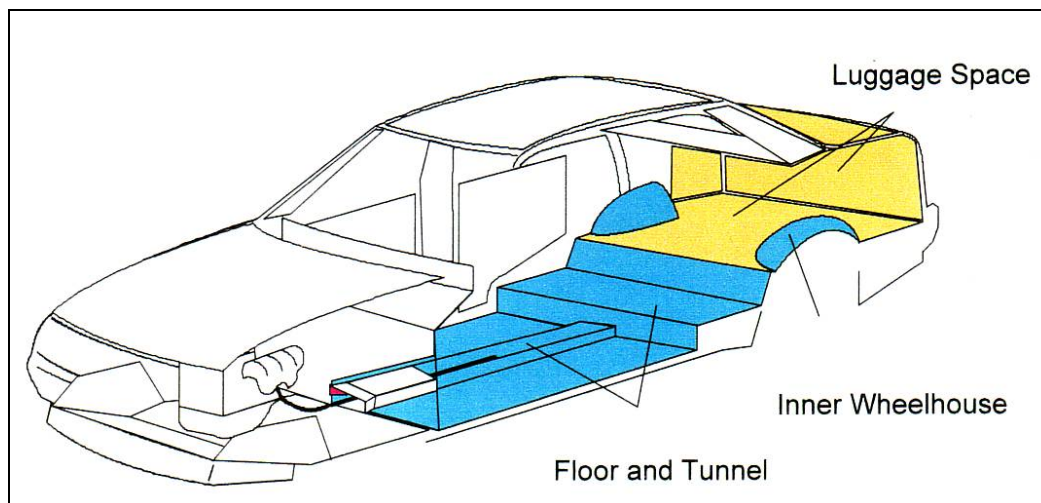
12.6 Automotive Flooring Systems

12.6.1 Overview

As described in Section 12.5, the automotive market is a large global industry. Table 25 displays that 4.5kg of textile on average is used per car in the manufacture of the flooring system. Within the last few years there has been an amount of consolidation in the automotive industry, with the trend towards fewer, larger suppliers.

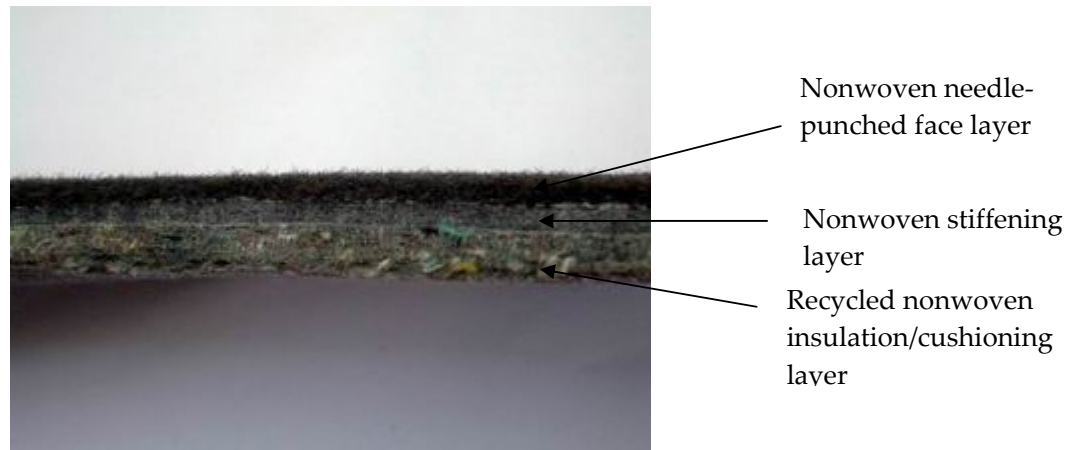
Automotive flooring systems are essentially passive and have the primary objective of providing sound absorption properties as well as comfort and aesthetics. Figure 28 shows the area of the car that incorporates the flooring system.

Figure 28: Automotive Flooring System



The systems are comprised of a composite construction including a needle-punched nonwoven or tufted face layer, a stiffening layer and an insulation layer. A typical construction can be seen in Figure 29.

Figure 29: Example of a Flooring System Construction



One of the areas of interest is to include additional functionality to the system. Temperature regulation is seen as an interesting concept. This lends itself well to the air-laid technology approach to impart the additional functionality.

12.6.2 Experimental Work

The same experimental work was used as in automotive head-liners (Section 12.5.2), incorporating PCMs into the air-laid structure.

12.6.3 Evaluation, Feedback and Next Steps

The fabrics were evaluated externally with positive results. The evaluating company was happy that there was merit in the concept and that further work is required to develop a commercial product. At present there is potential in combining the work with the composite project and develop a two-stage collaborative research and development project.

12.7 Air Filtration

12.7.1 Overview

Products for the filtration of air, in applications such as air conditioning systems and face masks, have become increasingly popular and more sophisticated over the last 50 years⁷⁴. One of the common methods of air filtration is through an electrostatic system i.e. small particles are removed from the air using electrostatic forces rather than a physical capture mechanism. This allows an open structure to be used so the pressure drop through the filter is not excessive.

One method of generating electrostatic charges for a filter is through tribo-charging^{75,76}. Tribo-charging is the generation of static charge through rubbing and separation of two materials, one that charges negative and the other positive. On separation of these two materials each material is left with its respective charge on the surface; if these charges are balanced then a mixed material will remain charged.

This approach lends itself well to nonwovens as tribo-electrically differing fibres may be blended and separation be completed during the web forming carding process. A common blend is of polypropylene fibre and modacrylic or acrylic⁷⁷.

12.7.2 Experimental Work

One of the fundamental costs of fibrous electrostatic air filters results from the need to remove fibre finish left over from the spinning process⁷⁸, in order to obtain a high level of charging. Fibre finishes traditionally contain lubricants and antistats⁷⁹, materials which aid the dissipation of static charge and therefore must be removed prior to processing if a static charge is to be generated. The most common way to remove finishes is through scouring in baths of hot water with a detergent. This is a process that is slow and utilises large quantities of energy and as a consequence is relatively expensive; to be able to remove this step would represent a considerable cost saving. Fibre from a garment source has been washed throughout the life of the garment by the owner. This repeated washing should have removed the original fibre finish added by the fibre/yarn manufacturer, potentially negating the need for scouring.

The fibre selected was acrylic from a low-grade knitted garment source. Only 100% acrylic garments were selected on the basis of reducing contamination from foreign fibres. The garments were refiberised using the opening equipment at NIRI. Without trying to remove any of the finish the fibre was blended in a proportion of 1:1 with a scoured polypropylene fibre.

The blended mixture was then carded and needle punched to produce a fabric approximately 50 and 300g/m². The needle-punching conditions are detailed in Appendix VI.

The samples of filter fabric were sent to a major UK supplier of such fabrics, part of a multi-national corporation.

12.7.3 Evaluation, Feedback and Next Steps

The evaluation took place in the form of a salt (NaCl) aerosol test (BS EN 1822-3:1998), whereby a fine dispersion of salt particles (mass median of 0.6µm) is sprayed directly into the filter material. A sensor on the other side of the filter detects the level of particles not captured by the filter and hence a percentage of efficiency can be calculated.

Table 26: Results of the Salt Aerosol Test

Sample Fabric	Salt Particles detected (%)
Standard scoured production fabric	0.5
Fabric produced from unscoured fibre	>90
Fabric produced from recycled acrylic	42

As can be seen from Table 26, the results are worse than expected. There is some degree of tribo-charging occurring but not at the levels required for air filtration. It is possible that during re-fiberisation some fibres that have not been exposed on the surface of the yarn are released with some residual fibre finish not removed by domestic washing. However, the results are sufficiently promising to merit further investigation. Ongoing development work is continuing in conjunction with the company to look at the possibility of removing the surface finish from the recycled fibre to improve the filtration efficiency.

12.8 Conclusions

It is evident from the work conducted in the study (Table 27) that, through a technological approach to utilising recycled fibres and their inherent properties, a premium product market can be targeted. The added cost advantage of recycled fibre, usually less than 40% of the cost of the virgin fibre equivalent, makes the use of recycled fibre very attractive.

Table 27: Summary of Conclusions of Market Study

Market	Technical Feasibility	Economic Feasibility	Further work/ Sources of funding
Composites & Biocomposites	Very High – new approach very attractive	Market price for Composite reinforcement is £2400-2500/tonne. Economically very attractive.	Commercial partners very keen to identify materials with improved conformability and appearance- enhancing properties. Consortium being assembled for DTI funding bid.
Capillary Matting	Very High	UK manufacture is attractive owing to high transport costs of such materials. Economically attractive.	Further work is continuing to source cost -effective UK manufacturing route.
Pre-seeded Matting	Opportunities for high levels of technical innovation are low.	Low technical application attracts low added value.	No further work planned.
Automotive Head-liners	Technically, the likelihood of success is high, recycled fibre already used in constructions so no barriers to adoption.	Cabin temperature control of interest to car manufacturers. Would be focused towards high-value area of automotive market.	Further work required to refine and assess the approach. Consortium-based project funding to be sought.
Automotive Flooring Systems	Technically, the likelihood of success is high, recycled fibre already used in constructions so no barriers to adoption.	Cabin temperature control of interest to car manufacturers. Would be focused towards high-value area of automotive market.	Further work required to refine and assess the approach. Consortium-based project funding to be sought.
Air Filtration	Average feasibility owing to the inconsistent nature of the recycled material.	Economically attractive as direct replacement for virgin fibre content.	Further work continuing to refine and assess the approach.

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- IV Process methods for making nonwovens**
- V Manufacture for new markets**
- VI Market Development**

Appendix IV ***Process methods for making nonwovens***

Material preparation

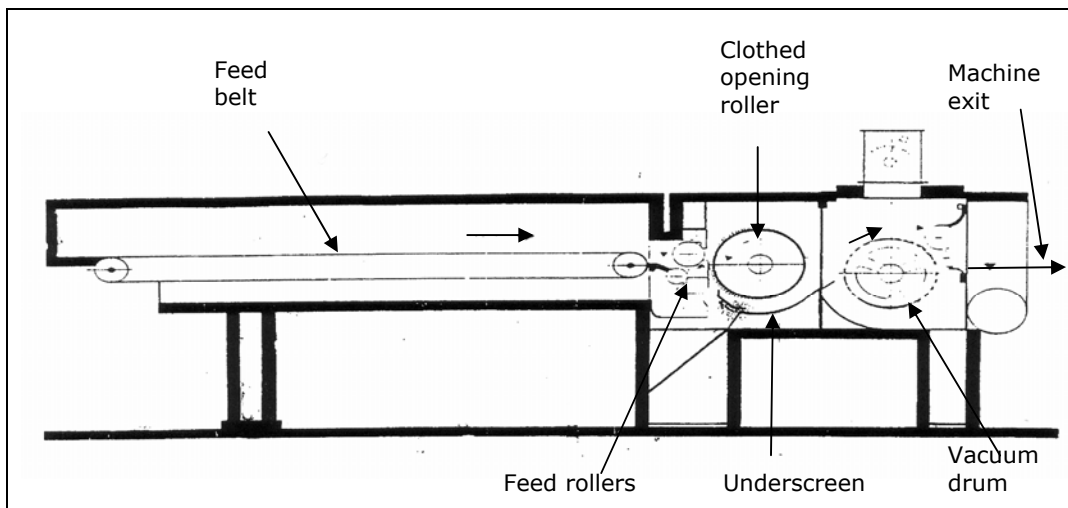
The most widely accepted preparatory method is 'mechanical refiberisation'. This involves passing cut fabric pieces through two nipped feed rollers that grip the textile while a rapidly rotating cylinder covered in sharp metallic pins mechanically opens the fabric into smaller fractions.

The product of mechanical pulling typically consists of a mixture of individual fibres, yarn segments and smaller fabric pieces. Further separation stages are employed to increase the reduction of the segments and pieces into fibre form. The fibre is then collected on a vacuum-assisted drum and fed out of the machine.

It is usually not feasible to feed in entire garments as this mitigates against effective separation of the fabric in the system. The opening power is a function of the number of pins per gram of fibre which is controlled by the feed rate to the system (g/min), the surface speed of the cylinder (m/min) and the pin density (pins/cm²). The design of pin or metallic wire covering is also important in determining the degree of opening.

Figure A1 shows a schematic of a pulling machine utilised in this work. Other mechanical systems are in use; their suitability depends principally on the state of the in-feed raw material and the required state of the pulled fibre in terms of the fibre dimensions, the degree of mixing and the extent of extraneous particle removal. In this particular system, the degree of separation and individualisation of the fibres is a function of the number of nip-fed opening rollers fitted to the machine and the number of successive nipped feed elements.

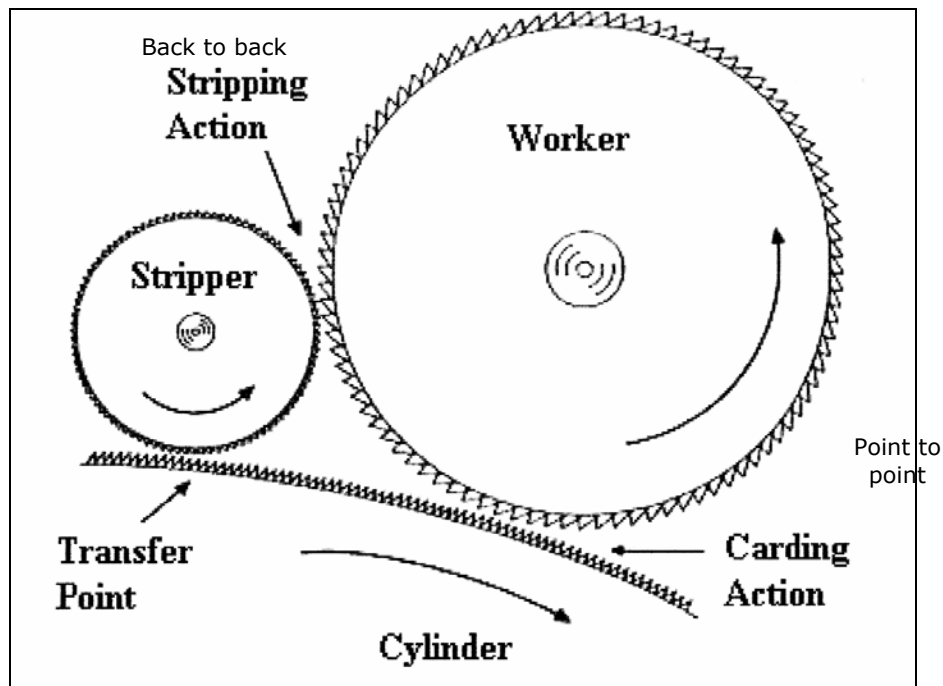
Figure A1: Schematic Representation of the Pulling Equipment⁸⁰



Carding

Carding progressively separates the fibres from each other using a series of rotating pinned rollers; 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 structure of the web in terms of its dimensions and geometry, which influence subsequent fabric properties, can also be varied. Figure A2 demonstrates the principle of the carding action. Carding also involves longitudinal mixing of fibre components and levelling before a final web structure is formed.

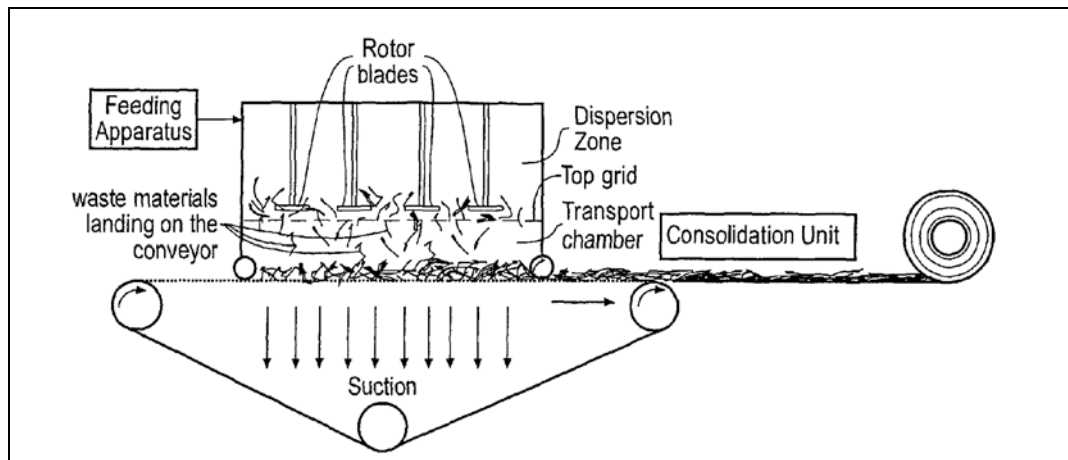
Figure A2: Principle of carding action



Adapted air-lay technique

The adapted air-lay process involves creating a dilute mixture of fibre in air and circulation of these fibres 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 in to the final product properties after bonding. Figure A3 is a schematic of the basic principles of this process.

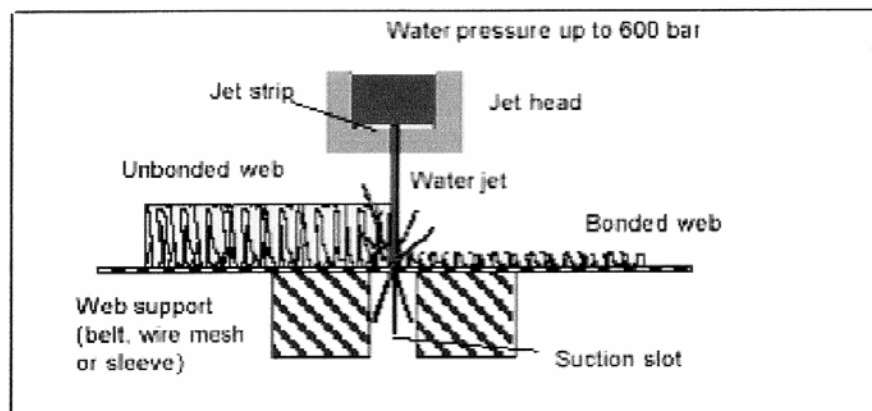
Figure A3: Schematic of Air-laying Process⁸¹



Hydro-entanglement

Hydro-entanglement, as the name suggests, involves bonding through the use of high pressure water jets to entangle the fibres together. The process is well established having been developed in the 1960s^{82,83,84}. The water is pumped through a series of small orifices in a metal plate. This creates fine columns of water that are directed onto a travelling belt which carries the preformed webs. The web of fibres is then fed into the machine and the energy of the jets is transferred onto the fibres causing them to interlock together and provide integrity to the structure. Figure A4 demonstrates the basic principles involved.

Figure A4: Schematic of the Hydro-Entanglement Process



Important parameters include the applied input energy, which is a function of water pressure and flow rate amongst other variables, fibre stiffness, fibre dimensions and wettability⁸⁵. Appropriate conditions need to be employed to maximise bonding and to avoid disruption of the webs. The recovered fibres in web form processed

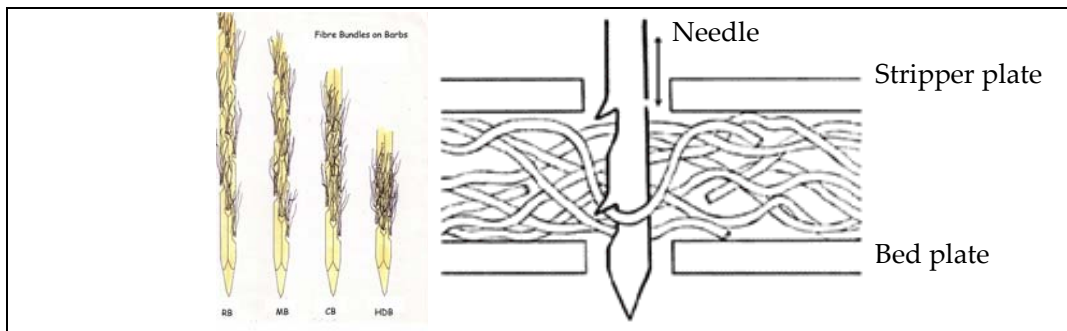
reasonably well using the hydro-entanglement system with the following processing conditions:

Web weight	150 g/m ²
Belt speed	2.5 m/min
Water pressure	50 Bar
No. of Jets	1250 Jets/m
Diameter of hole	130 µm
Pitch	0.7 mm

Needle-punching

Needle-punching involves bonding of the fabric by means of reciprocating barbed needles passing through the web structure in order to mechanically interlock the fibres together and create a coherent structure. Fabric properties are influenced by a variety of parameters including needling density, the depth of needle penetration, the needle design, web drafting, fibre type being processed and the speed of the web passing through the needles. For example, fibre fineness has been seen to affect fabric packing density, for a set punch density finer fibres produce significantly higher packing density than coarser fibres.⁸⁶

Figure A5: Schematic of Needle Fibre Interaction in Needle-punching



As indicated in Figure A5, the action of the barbed needle relocates some fibre segments through 90°, the bed plate restricting the movement of the fibrous mass and allowing mechanical interlocking to occur. This results in condensation of the re-orientated fibres into bundles, increasing the fibre-fibre friction so that fibre consolidation is achieved⁸⁷. The stripper plate then removes the fibre from the needle as the needle lifts. Altering processing conditions can have a marked effect on needle-punched fabric performance. For example, fabric air filtration efficiency can be affected by the gauge of the needle employed; Igwe⁸⁸ found evidence that increasing the needle gauge (making the needle finer) increased the filtration efficiency of the fabric.

The fibre recovered from the knitted clothing waste lent itself well to this process since the residual fibre length was longer than in fibres recovered from woven waste garments e.g. denim. The webs formed by carding were of good uniformity and bonded satisfactorily using the needle-punching process. The processing conditions were as follows:

Web weight	160 g/m ²
Needle density	75 punches/cm ²
Needle gauge	40 (fine gauge)
Machine speed	0.75 m/min
Depth penetration	10 mm

Thermal bonding

If a proportion of the fibres constituting the blend are thermoplastic then they can normally be thermally bonded. If the fibres are not thermoplastic there is a requirement for low temperature melting fibres, either homofil or bicomponent fibres, to be introduced before web formation. During web formation, these are evenly distributed throughout the web structure.

Bicomponent 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 V Manufacture for new markets

Non-load-bearing composites

The process parameters were:

Resin Type:	Epoxy
Composition:	Aliphatic glycidylether, Bisphenol A/F, Epichlorohydrin resin, Epoxy resin
Product code:	UKR01
Supplier:	UK Epoxy Resins

Emergency blankets

The processing conditions were as follows:

	Bottom layer	Top layer
1 st pass through the jets	30 gm ⁻² spunlace PET	Acrylic/wool web 160 gm ⁻²
2 nd pass through the jets	30 gm ⁻² spunlace PET + Acrylic/wool web 160 gm ⁻²	30 gm ⁻² spunlace PET

Web weight	150 gm ⁻²
Belt speed	2.5 m/min
Water pressure	80 Bar
No. of Jets	1250 Jets/m
Diameter of hole	130 µm
Pitch	0.7 mm

Automotive PCMs

The specific processing conditions are given below:

Recovered Fibre	60.7%
Bicomponent fibre	33.3%
PCMs	6.7%
PCM type	Thermasorb T83
Web weight	150gm ⁻²
Oven temperature	150°C
Oven belt speed	1 m/min
Calendering	YES

Motion of gas molecules in aerogel

Molecular collisions give rise to heat transfer in a still gas. Faster (hot) moving molecules collide with slower (cold) moving molecules and pass on some of their heat energy. This collision process can be prevented by a barrier so that the molecules will not collide with each other, but rather will collide with the barrier from which they rebound and therefore retain their heat energy.

The average distance which a gas molecule travels before it collides with another molecule is defined as the mean free path. A molecule moving through a gas collides with other molecules in a random fashion. To prevent these collisions, the barriers need to be separated by a distance smaller than the mean free path.

The mean free path of gas molecules l_{m_0} in free space obeys the equation:

$$l_{m_0} = \frac{1}{\sqrt{2}n_g \pi d_g^2} \quad [1]$$

Where:

$$\begin{aligned} n_g &= \text{Number density of gas molecules} \\ d_g &= \text{Diameter of gas molecules} \end{aligned}$$

The mean free path of gas molecules in aerogels l_m can be expressed as:

$$l_m = \frac{1}{\sqrt{2}n_g \pi d_g^2 + S_s \rho_{por} / \Pi} \quad [2]$$

Where:

$$\begin{aligned} S_s &= \text{Specific surface area of the aerogel defined as surface area per unit mass} \\ \rho_{por} &= \text{aerogel density} \\ \Pi &= \text{Porosity defined as the volume of the pores divided by the total volume of the matrix} \end{aligned}$$

As may be observed, the mean free path of gas molecules in an aerogel is smaller than in free space because of the addition of $S_s \rho_{por} / \Pi$ to the denominator of equation [1]. As a result of the retarded motion of the gas molecules in the aerogel, the thermal conductivity of the gas in an aerogel is about half that of the gas in free space.

The process parameters for the aerogel composite are given below:

Recovered Fibre	66.7%
Bicomponent fibre	30.0%
Aerogel	3.3%
Aerogel type	Cabot OT01N
Web weight	150gm ⁻²
Oven temperature	150°C
Oven belt speed	1 m/min
Calendering	YES

Activated Carbon

It is the extended surface area of activated carbons that imparts the versatile adsorbent properties of activated carbons. Commercially available activated carbons have specific surface areas in the order of 800-1500m²/g. However studies on biomass flax fibre, chemically activated using zinc chloride, have produced activated carbons with surface areas up to 2400m²/g⁸⁹.

This large surface area is the result of the activation process which involves oxidising carbonaceous char in an atmosphere of air, CO₂ or steam at elevated temperatures (800-900°C). The major raw materials are wood, coal, lignite, coconut shell and peat.

These materials come in granular and powdered form. The granular form is characterised by a large internal surface area and small pores. The powdered form generally exhibits larger pore diameters than the granular form at the expense of smaller internal surface area. Powdered ACs have diameters less than 100µm, typically 15-25µm on average. Owing to their large external surface the adsorption rate is very high. Conversely, granulated ACs are associated with lower adsorption rates.

The exact processing conditions are below:

Recovered Fibre	60.7%
Bicomponent fibre	33.3%
Activated Carbon	6.7%
Grade of AC	Chemviron Pulsorb FE06104A
Web weight	100gm ⁻²
Oven temperature	150°C
Oven belt speed	1 m/min
Calendering	YES

Zeolites

The processing parameters are listed below:

Recovered Fibre	60.7%
Bicomponent fibre	33.3%
Zeolite	6.7%
Grade of Zeolite	Ineos Silicas Zeocros 100E
Web weight	150gm ⁻²
Oven temperature	150°C
Oven belt speed	1 m/min
Calendering	YES

Biocomposites

Unsaturated vegetable oils such as oilseed rape, linseed and soy that are available in huge tonnages at low cost can now be utilised to create bioresins⁹⁰. Ozonolysis of these oils in the presence of a participating co-reactant can be used to form reaction products particularly suitable for use in the formation of resins⁹¹. The technology uses the natural reactivity of ozone to attack the double bonds present in the oil, forming oxygen linkages that can subsequently breakdown into cross-linkable units⁹². Other reactive chemicals can be incorporated into the formulation to facilitate curing, such as tannins and resorcinols, to enhance the resin properties to enable rapid curing of the composite structures. These resins replace urea/phenol/melamine formaldehydes in various applications giving a genuine formaldehyde-free alternative.

Appendix VI Market Development

Low modulus fibres, thermosets and bioresins

Products with moduli below 3500N/mm² start to compete with vacuum thermoformed plastics (a thermoplastic rather than a thermoset process), one of the oldest and most common methods of processing plastic materials. Thermoforming involves heating a plastic sheet until soft and then draping it over a mould. Vacuum forces are then applied, conforming the sheet into the shape of the mould. The low forming pressures utilised during the process results in comparably low tooling costs. Unlike thermoset forming processes, where resin is the starting point, vacuum forming uses extruded plastic sheet; the forming process is quicker and the tooling costs are up to 50% lower.

Although the process efficiencies make the market price competitive there is some cross-over of thermoset and thermoformed products. Higher modulus thermoformed products use material such as acrylonitrile butadiene styrene, which can cost £1800/tonne; traditional GRP (Glass Reinforced Plastic) raw materials are around £900/tonne for polyester resin and £2500/tonne for glass reinforcement structures. Replacing the glass with lower cost recycled textile reinforcement could make a product well placed to compete against high-end thermoformed products. There is also potential for filler addition (e.g. calcium carbonate) during the composite process to improve cost competitiveness. Modulus may be increased by using a proportion of glass fibre in conjunction with recycled fibre.

For biocomposites the challenges remain the same, although added-value should be higher for the sustainable nature of the end products. In automotive markets the End-of Life Vehicles (ELV) Directive is having a large impact on the material selection of the car manufacturers. Its aims are to ensure that a minimum of 85% of vehicles are re-used or recovered (including energy recovery) and at least 80% must be re-used or recycled from 2006, increasing to a 95% re-used or recovered (including energy recovery) and 85% re-used or recycled by 2015. This has put the emphasis on recycling materials rather than making them sustainable.

Thermoset plastics such as the bioresins are not recoverable as thermosetting is a 'one-way' only process, unlike thermoplastic products produced by vacuum forming and injection moulding which can be re-used. Recycling may take place in the form of grinding into particulate matter but application areas are somewhat limited at present.

The strong odour associated with bioresins was not seen to be a major disadvantage: resins currently employed in thermoset plastics have quite strong odours. Polyester resins can have a strong odour of residual styrene but yet this has not hampered the use of such resins in many applications. Additionally, the dark brown colour of bioresins such as those derived from rapeseed oil was not seen to hinder market penetration: phenolic resins currently enjoy a healthy position in the thermoset

composites market despite their dark brown appearance. Pigmentation of resins is relatively inexpensive and easy to administer but visually demanding applications use separate gel coat layers to create the final composite part colour.

Process parameters for end-products

Needle-punching process parameters for capillary matting:

Process Parameter	Setting
Needle gauge	32
Needle penetration depth Side 1	12mm
Needle penetration depth Side 2	10mm
Machine speed	2m/min

Machine settings for pre-seeded matting:

Process Parameter	Setting
Paddle speed	2500 rpm
Conveyor speed	2m/min
Mesh size	10mm ²
Heat-set settings:	
Temperature	150°C
Conveyor speed	2 m/min

Settings for air-laid head-liner construction:

Process Parameter	Setting
PCM type	Rubitherm PX27 Powder
Overall fabric weight	1100 g/m ²
Fabric Composition:	
Mixed waste fibre	65%
Bicomponent fibre	20%
PCMs	15%
Airly settings:	
Conveyor speed (m/min)	2
Paddle speed (rpm)	2500
Mesh size (mm ²)	10
Heat-set settings:	
Temperature	150°C
Conveyor speed	2 m/min

Needle-punching parameters for an air filtration fabric

Process Parameter	Setting
Recycled Acrylic	50%
Polypropylene, 2.8dtex, 50mm	50%
Final Fabric weight	50 & 300g/m ²
Needle Gauge	38
Needle penetration depth	13mm
Machine speed	1m/min

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