

# Technologies for sorting end of life textiles



A technical and economic evaluation of the options applicable to clothing and household textiles

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**Front cover photography:** Waste textiles awaiting recycling

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# Executive summary

This report builds on previous work on textile recycling commissioned by WRAP and Defra. It explores whether technology can be used to increase the fraction of discarded clothing and household textiles that are reprocessed in a financially viable way. A technical and economic assessment identified four candidates:

- manual sorting, the incumbent method;
- fourier transform infra-red spectroscopy (FTIR);
- radio frequency identification (RFID) tags; and
- 2D bar codes.

The current method is manual sorting. It operates at a small margin and it is only possible to sort by parameters that humans can readily determine. These do not necessarily match high value markets for recyclates.

FTIR is potentially able to determine the colour and fibre content of textiles and as a result the selected recyclate outputs should be able to command slightly higher prices. Further work is needed to develop the technology so that it functions in this industrial environment.

Every textile item could potentially have a unique RFID tag applied to it. In theory this could permit dynamic sorting at low cost on a wide range of criteria, in response to market demand, and thereby achieve a high margin for recyclates. However, RFID tags that can survive the use phase of the textile, particularly the laundry cycle, do not yet exist at a sufficiently low price and in a suitable form for this application. Furthermore, tag readers are not yet able to determine the physical location of an individual tag in a jumble, which is an essential requirement to instruct automated sorting machinery.

A 2D bar code label could be used to inform the reprocessor how to sort an item, achieving the same benefits as RFID tags. The 2D bar code label must be manually presented to a reader, meaning the condition and quality of the textile can be ascertained at the same time.

There is an important distinction between these options in that, for manual sorting and FTIR identification, the reprocessor incurs the capital and operational expense but receives all the remuneration. For RFID tags and 2D bar codes the manufacturer/retailer incurs the cost of tag or label management, while the benefits accrue mostly to the reprocessor.

The technology that is potentially closest to helping achieve a circular economy in textiles is 2D bar codes:

- The modest cost of making and attaching the bar code label would fall to retailers but, in return, they would benefit from a new marketing channel to customers and corporate social responsibility benefits.
- As consumers can read the 2D bar codes with a smart phone App, the environmental information provided could help with new approaches to take-back and recycling.
- Reprocessors can also read 2D bar codes to sort accurately and reliably by new criteria, using a technology that can be integrated into their existing manual sorting process. This characteristic will be an advantage during the long interim phase when only a limited proportion of textiles carry 2D bar codes.
- Further work is first required to define the bar code format and identify a label material that remains machine readable at end of life.

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# Glossary

2D	two dimensional
ASTM	American Society for Testing and Materials
CSR	corporate social responsibility
DNA	deoxyribonucleic acid
DSC	differential scanning calorimetry
FTIR	Fourier transform infra-red spectroscopy
GCMS	gas chromatography / mass spectroscopy
MICR	magnetic ink character recognition
OCR	optical character recognition
OMR	optical mark recognition
QR code	quick response code (trademark for a type of matrix (2D) barcode)
RDF	refuse-derived fuel
RFID	radio frequency identification
TGA	thermogravimetric analysis
UIN	unique identifier number
WEEE	waste electrical and electronic equipment

## 1.0 Background

The UK industry that reprocesses discarded clothing and household textiles is facing the combined challenges of rising costs and falling demand. At the same time, environmental pressures are placing expectation to recycle ever larger quantities of waste textiles.

Against this background, WRAP commissioned this study to evaluate whether technology exists that could be used to assist in sorting of end-of-life textiles and to evaluate how the technology might affect the economics of the recycling operation. This study aims to build on previous work on textile recycling commissioned by publicly funded bodies including:

- *Evaluating the financial viability and resource implications for new business models in the clothing sector*, WRAP RNF100-005, February 2013;
- *A review of commercial textile fibre recycling technologies*, WRAP MPD007-009, November 2012;
- *Textiles flow and market development opportunities in the UK*, WRAP MPD005-001, September 2012;
- *Environmental Improvement Potential of Textiles (IMPRO-Textiles)*, JRC Scientific and Technical Reports, 2011;
- *Studies on Recyclable Waste Textiles in the Context of the Development of the End-of-Waste Criteria for the EU Waste Framework Directive*, Institute for Prospective Technological Studies IPTS 2009 Jo6-OC Lot 2, August 2010;
- *Maximising Re-use and Recycling of UK Clothing and Textiles*, Defra EV0421, December 2009;
- *Mapping of evidence of sustainable development impacts that occur in life cycles of clothing*, Defra, 2007; and
- *Recycling of Low Grade Clothing Waste*, Defra WRT152, September 2006.

The underlying premise of this study is that the ability to accurately identify textiles by a variety of attributes might provide a route to a more circular economy. In undertaking this review, the viewpoints of the three main stakeholders in the textile life-cycle - the retailer (manufacturer), consumer and reprocessor - are considered.

## 2.0 Scope

The scope of the work was to investigate tagging and sorting techniques which are available on the global market and to evaluate their cost-effectiveness and minimum economic scale for the additional purpose of reducing the cost of sorting discarded textiles. This involved evaluating existing information on the commercial use of these techniques in the textiles sector, and extending the analysis to the specific application of textiles reprocessing. Where necessary, consultation with textiles reprocessors, technology providers, logistics experts, retailers, academics and other industry stakeholders was undertaken.

The economic analysis required many estimates and assumptions to be made; in particular, that technology can be used to sort all textiles in the waste stream. In practice, this level of utilisation will take many years to achieve. The approach taken was as consistent as possible so the technologies could be compared relative to each other.

## 3.0 Technologies to identify textiles

A number of technologies exist that could be used to identify textiles as they pass through a reprocessing facility. They are examined in detail in Annex 1. There are four candidates:

**Manual sorting.** This is the incumbent technology. Using this method it is only possible to separate textiles by parameters that humans can detect by sight and touch. Consequently the description of the output bins is limited to:

- colour – limited range, as presented and not necessarily the original dye colour;
- fabric – limited range, such as leather, wool, cotton, denim;
- quality – whether the textile is worn, damaged, repaired, soiled etc.;
- style – shirt, dress, socks, child etc.;
- brand – particularly for denim;
- complex textiles – the use of various fabrics/materials in different areas; and
- unusual – vintage, wedding dress.

**Fourier transform infra-red spectroscopy (FTIR).** FTIR is one of a family of hyper-spectral imaging techniques. It is potentially able to determine the colour and fibre content of a textile. However, it has not yet been developed to the point where, under real operating conditions, it discriminates significantly better than a skilled manual sorter. When this technical ability is realised, FTIR is possibly best viewed as a useful augmentation to manual sorting, since it can refine some of the steps of sorting by fibre type and colour, and hence add value to those output streams.

**RFID Tags.** An RFID tag can be thought of as a “wireless USB memory stick” that can carry data and which can be remotely read. The tag is attached by the manufacturer and travels with the textile throughout its life. The tag contains a precise description of a textile, which can include items of complex construction. On arrival at the reprocessor the tag can be read, permitting sorting of the textile to an appropriate bin. The very high specificity of sorting possible means that the waste stream can be processed dynamically to achieve best value. Low cost RFID tags that can survive multiple laundry cycles do not yet exist, and tag readers will require modification - which may or may not be possible - to guarantee association of one tag with one textile during interrogation of the tag.

**Bar codes.** A 2D bar code label can also carry information about the textile to instruct a sorting process. In this instance, the black and white pattern of the label is read by camera and decoded by computer. Work is required to identify the most appropriate data format for the bar code and to verify labels will remain machine-readable at the end of the use phase of the textile. Where the bar code directs the consumer or reprocessor to an external link, the associated databases, Apps and web landing pages all need to be written and managed.

#### **4.0 Sorting method and equipment**

Each of the candidate sorting technologies is based on a different sorting method as shown graphically in Figure 1. Manual sorting uses a multi-stage tree sort (1: M: N), where each stage has between five and eight parallel outputs. FTIR and RFID use a 1: N topology where each item is interrogated in turn and directed to the desired output bin in a single step. Bar codes also operate on a 1: N topology, except that, due to the slowness of interrogation, multiple stations feed single sorting equipment. Thus the topology is better described as M:N. This means a bar code sort can be combined with a manual sort, but FTIR and RFID require the process flow to be configured differently to accommodate these identification technologies.

**Figure 1** Textile sorting topologies



In manual sorting, the operators place or throw items into the appropriate bin or chute. The most widely used automated equivalent is by 'blowing' using a jet of compressed air. To be effective it is essential that the textiles are 'singulated' (separated into single items). Because textiles can easily become tangled, any singulation by machine is always supplemented by a human operator.

Another sorting criterion only humans can undertake is determination of quality; this step, together with removal of non-textile items from the waste stream, must be conducted manually.

## 5.0 Economic evaluation

A detailed analysis comparing manual sorting, manual sorting augmented by FTIR, sorting by RFID tags and sorting by reading bar codes is provided in Annex 2. Manual sorting is used as the base line for comparison. For a facility with a capacity for 16,500 tonnes per annum, operating on feedstock that has been 100% converted to the technology being utilised, the findings are summarised in Table 1.

For completeness, also included in Table 1 is the cost of the marker (applies to RFID tags and 2D bar codes) and the cost of attaching the tag or label to the textile.

Manual sorting is the most expensive, least accurate and lowest resolution option. However, only manual sorting is able to remove non-textiles, separate the textiles as single items and ascertain their quality. Therefore these steps must still be done manually as part of any automated sorting process and are included in the cost models.

The ability of FTIR to sort only by fibre type and colour limits the range of textiles to which it can usefully be applied. The main application is likely to be sorting wiper and recycling grade material, potentially securing higher value for this stream owing to the greater precision and accuracy of output. This restricts the economic benefit, since only around 20% of the textile stream passing through reprocessing facilities is of these grades.

**Table 1** Economics of sorting technologies

Parameter	Technology			
	Manual	Manual + FTIR	RFID	Bar code
Labour, £/tonne	200	160	70	70
Capital requirement, £k	Inc. in 'Labour'	424	645	1120
Running cost, £/tonne	Inc. in 'Labour'	5	7	6
Feedstock, £/tonne	550	550	550	550
Sales price, £/tonne	780	785	785	785
<b>Profit, £/tonne</b>	<b>30</b>	<b>70</b>	<b>155</b>	<b>150</b>
<b>Margin, % of sales price</b>	<b>4</b>	<b>9</b>	<b>20</b>	<b>19</b>
Marker cost, £	0	0	0.50 – 0.75	0.01
Marker attachment cost, £	0	0	0.02	0.02

Economic evaluation of the business case for RFID tags and bar codes is more uncertain since neither technology has been developed to operate in this environment, necessitating a number of assumptions to be made over important variables like capital cost and throughput. The high capital cost of 2D bar codes stems from the slowness of the associated manual handling to find and present the bar code label to the reader. Thus a large parallel operation is required to achieve the same throughput as the other options. Despite this, both RFID tags and 2D bar codes are economically favourable compared with manual sorting and manual sorting supported by FTIR.

## 6.0 Stakeholder perspectives

The perspectives of the five key stakeholders, the manufacturer, logistics chain, retailer, consumer and reprocessor towards each technology may be summarised in the flag chart given in Table 2.

**Table 2** Traffic-light viewpoint of stakeholders towards each technology

Stakeholder	Technology			
	Manual	FTIR	RFID	Bar code
Manufacturer	Amber	Amber	Amber	Amber
Logistics chain	Amber	Amber	Green	Amber
Retailer	Amber	Amber	Green	Amber
Consumer	Amber	Amber	Amber	Green
Reprocessor	Amber	Green	Green	Green

Green = positive, Amber = neutral, Red = negative

## 6.1 Manufacturer

Only the two technologies, RFID tags and bar codes, are of concern to the manufacturer. Both have negative consequences since they require marrying a tag or label to an item. This means a control system will be required to ensure textiles are correctly marked, plus a quality system and corrective action process to detect and rectify errors. Managing the supply of markers to the factory represents an addition cost and an additional cause of delay and reason for holding work in progress. RFID tags have potentially greater negative impact since they are more likely to be used for item-specific tagging, and therefore require more detailed management than 2D bar codes that will probably be used for batch-level marking.

## 6.2 Logistics chain

The only technology that can benefit the logistics chain is RFID tags. Because textiles are uniquely tagged, item-level tracking from the manufacturer to the point of sale is rendered possible. RFID tags can be remotely interrogated *en masse* and this makes it possible to determine the contents of a volume, such as a carton, without opening it. The supply chain will need to invest in hand-held RFID tag readers and suitably equipped gantries and doorways to make full use of the technology.

## 6.3 Retailer

The retailer is essentially ambivalent to manual sorting, and manual sorting supplemented by FTIR, since they provide no direct benefit. But, neither do they involve any cost. RFID has high cost but potentially high benefit since it permits item-level tracking through the supply chain to the point of sale, and potentially to the textile's end of life at the reprocessor. Bar codes incur a smaller cost that might be offset by intangible benefits including corporate social responsibility and the intriguing potential of a new marketing conduit to consumers.

## 6.4 Consumer

There is a potential issue with RFID tags over privacy of information. Consequently a small flag in Table 2 is set to red for this technology. Bar codes are the only technology where there is scope for interaction with the consumer. Many styles of 2D bar codes can be read by smart phones, so, when combined with an App, it should be possible to provide the consumer with local information on how to dispose of a textile when it is no longer wanted. This may include retailer take-back schemes and other incentivised options and marketing opportunities. The 2D bar code also could carry a link to a web page managed by the retailer, facilitating targeted marketing.

## 6.5 Reprocessor

All the identification technologies will involve the reprocessor in some capital and set-up cost. To a first approximation these are similar for all cases, but RFID tags and bar codes deliver faster return by being applicable to all (marked) textiles in the waste stream.

A key difference between RFID tags and bar code labels is that a sorting facility based on reading bar codes could also be operated manually, with the operator entering a short code on a keypad based on his/her assessment of the textile<sup>1</sup>. This would be beneficial in the transitional phase while technology is introduced over several years and the proportion of textiles marked by bar codes slowly rises.

Recycling organisations, such as charity shops, would also benefit from the availability of RFID tags or bar codes on textiles, since the presence of an in-built identification number and product description would assist both the sorting process and store management (inventory management, pricing, and gift aid reclamation). Charity shops already use the ISBN code on books for this purpose.

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<sup>1</sup> <http://www.youtube.com/watch?v=Pl7H7JAtnl4>

## 7.0 Conclusions

Manual sorting of textiles operates successfully, but at a small profit margin because sorting criteria are not aligned with the markets for recyclates. FTIR can only sort by fibre type and colour, limiting its applicability. RFID tags and 2D bar codes can sort by any level of description that can be encoded. Economic models suggest the capital and running costs of sorting by RFID and 2D bar codes could be easily recouped through reduced operating costs and by targeting higher value markets for recyclates once the proportion of marked textiles in the waste stream is very high.

None of the technologies is yet developed to the point of being usable for this application. FTIR works only for a very restricted range of colours and fibre types, while low cost RFID tags will not survive the laundry cycle and tag readers able to interrogate tags on single items in a batch have not yet been developed. Bar code labels that remain readable at the textile's end of life are currently unproven, but can probably be developed without major investment.

Machines capable of handling the sort stage of textile recycling are available commercially. Generally they comprise a linear conveyor with perpendicular diverters operated by compressed air. The sort command is currently derived from a code manually input onto a keypad, but this could be easily changed to an RFID tag or bar code reader. Because this approach to sorting could be enhanced simply by changing one part of the process, the existing operational textile sorting systems could easily be rendered capable of sorting simultaneously into hundreds of output bins.

# Annex 1: Technology options

This Annex provides a review of available and emerging technologies that could be used to identify clothing and household and textiles so they may be sorted and recycled at end of life.

## A1.1. Identification technologies

The technologies that can be used to identify textiles can be grouped into three categories, as follows:

- manual;
- chemical; and
- machine-readable marker.

The merits and limitations of each identification technology will now be considered in turn.

## A1.2. Manual identification

Manual identification is the incumbent technology. As the textile can immediately be sorted by the same operator who does the identification, this usually called "manual sorting". Manual sorting can sort by a wide variety of indicators including size, fibre and colour. It is the only technology that can make a subjective judgement about the 'quality' of an item; for example, whether it is vintage, designer label, new or worn, torn or soiled. The manual sorting process is well developed and continues to evolve and improve in tandem with our understanding of human physiology and psychology. Factors such as ambient lighting, shift length, background music, conveyor belt height etc. can all be adjusted to obtain small gains in human performance. A commercial manual sorting process is capable of addressing up to 500 output bins, although usually only a smaller number are targeted at any one time.

## A1.3. Chemical identification

Chemical identification entails some form of analysis from which the fibre type, dye colour and sometimes the dye composition can be deduced. The available techniques can be grouped into four categories, by the attribute on which the process operates. They are:

Attribute	Technology
Enthalpy	Differential scanning calorimetry (DSC)
Pyrolysis (evolved gas)	Thermogravimetric analysis (TGA) Gas chromatography / mass spectrometry (GCMS)
Reflection spectrometry	Infra-red (FTIR) spectrometry Visible-ultra violet (UV-Vis) spectrometry X-ray fluorescent (XRF) spectrometry Hyper-spectral imaging
Solubility	Acids and alkalis Organic solvents

The merits and limitations of each chemical technology are discussed in turn below.

### Differential scanning calorimetry (DSC)

DSC entails taking a small sample of material (typically 5-10 mg) and heating it at up by 400°C/min from room temperature to around 500°C. The output is the instantaneous energy exchanged between a sensor and the sample through this temperature range. Different

materials have different heat flux characteristics that can be used to identify natural and synthetic fibres and blends.

DSC equipment is relatively low-cost and interpretation of the results is straightforward. However, the relatively long time taken for each analysis, of minutes per sample, means that it is unsuitable for this application. Furthermore, DSC cannot be used to determine another critical parameter: namely, dye colour. Due to these major short-comings, DSC has not been considered further as a candidate technology for identifying textiles.

### **Thermogravimetric analysis (TGA)**

TGA detects changes in the physical and chemical properties of materials; either as a function of increasing temperature at constant heating rate, or as a function of time at constant temperature. Like DSC, the method requires a small sample of material to be taken and the output is a curve that requires either interpretation or comparison with a library.

TGA is generally unsuitable for use in a textile sorting facility: it is necessary to take a physical sample for analysis; the analysis is slow, taking minutes per sample; and the technique is unable to resolve dye colour.

### **Gas chromatography / mass spectrometry (GCMS)**

GCMS is a common laboratory technique for analysing mixtures of chemicals. GCMS uses a combination of two instruments – a gas chromatograph coupled to a mass spectrometer. Gas chromatography separates the components of a mixture enabling mass spectroscopy to characterize each of the components individually. By combining the two methods, it is possible to quantitatively evaluate a sample containing a number of chemicals. The sample can be in solid, liquid or gaseous form, providing a number of options for introducing an unknown textile to the instrument. For example, a laser could be used to vaporise a small area of the material and the resulting gas plume collected and analysed by GCMS.

While GCMS can determine the exact chemical make-up of a sample, the high capital cost (>£100,000), running cost (£50/hour due to helium consumption), and slow throughput (3-4 samples/hour), rule it out as a technique for identifying textiles in a recycling facility. However its accuracy means it is the technique of choice in forensic analysis of fibres.

### **Reflection spectrometry**

When materials are exposed to radiation, the reflected spectrum can convey information about the chemical make-up. Fourier transform infra-red (FTIR) spectroscopy entails illuminating a sample with broad-band infra-red light. The resulting absorption bands in the reflected spectrum provide information on the type of chemical bonds within a sample. By comparison with a library of profiles for known materials, it is possible to determine the fibre composition.

Fibre identification by FTIR spectroscopy is complicated by the presence of dyes and any chemicals incorporated in the fibres during use (such as dirt, deodorants, detergents perfumes and oil). Some of these issues can be resolved by broadening the spectrum to include visible light, ultra-violet light and X-rays, but this greatly increases the cost and complexity of the instrument.

FTIR spectrometry is essentially a non-contact and instantaneous analytical technique, and the instrument head can accommodate a wide range of sample presentations. FTIR identification of textiles in a recycling facility has been demonstrated, but is not yet available commercially<sup>2</sup>.

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<sup>2</sup> <http://textiles4textiles.eu/>

A recent innovation in spectroscopy is hyper-spectral imaging<sup>3</sup>. This is essentially a solid state camera that is able to capture images at a broad range of wavelengths simultaneously. The technology combines the high resolution of spectrometers with the speed and spatial resolution of a camera. Although not yet a commercial technology, it could be a very good technology for this application.

### Solubility characteristics

An old-fashioned method for identification of an unknown fibre sample is the 'solubility test'. This involves exposing samples of the material to a range of acids, bases and organic liquids, and noting whether or not a response occurs. Fibre identification by solubility is considered to be a reliable method of analysis and is incorporated in the ASTM Standard D276.

However, it is not conducive to automation, is slow to undertake and requires multiple samples of the textile and appropriate chemical handling facilities. Also, a solubility test cannot easily be adapted to determine dye colour. Consequently, the solubility test was not considered further in this study.

#### A1.4. Machine-readable marker technologies

A machine-readable marker is a coding scheme that either contains the requisite information itself, or refers to it via a look-up table. The marker is applied to the textile at the point of manufacture and travels with it through its life. There exist a variety of marker technologies potentially suitable for this application. They may be categorised according to the domain in which the code is stored:

Domain	Technology
Physical	Present (e.g. dummy button) Absent (e.g. punch card)
Electronic	Contact (aka chip-and-pin) Contactless (radio frequency identification, RFID) Contactless (RFID chip-less)
Magnetic	Magnetostrictive (e.g. security tag) Stripe (e.g. airline boarding card) Electrostrictive Magnetic ink character recognition (MICR)
Optical	Character/symbol recognition (label reading) Bar code / matrix code Optical mark reader (OMR)
Chemical	UV/fluorescent stain (e.g. envelopes)
Nano	Engineered DNA Smart water Quantum dots Nano particle signature

<sup>3</sup> [http://www2.imec.be/be\\_en/research/image-sensors-and-vision-systems/hyperspectral-imaging.html](http://www2.imec.be/be_en/research/image-sensors-and-vision-systems/hyperspectral-imaging.html)

## Physical

Physical markers are coded by the presence or absence of material. For example, a dummy button could provide a simple coding scheme based on shape, number of holes, thickness, diameter, colour etc. An established coded marker technology based on the absence of material is the (now obsolete) punch-card.

Physical markers are limited in the quantity of information they can carry in a sensible form-factor. Due to reasons of cost and aesthetics, the useable limit probably about four permutations for each of four variables (e.g. four permutations each of diameter, shape, colour, hole count). This means that the resolution of sort cannot exceed 256 bins, which is too small for this application.

## Electronic

Electronic markers use a similar technology to computer memory. Data is stored in an integrated circuit that can be 'read' and in some cases changed ('written') as well. The device that accomplishes this is a speck of silicon (the chip) that measures <0.1mm per side. Silicon chips are capable of carrying large amounts of information, potentially permitting unique identification of every item of clothing and household textile. However, environmental concerns have been raised over the proliferation of e-textiles (electronic textiles) because valuable materials will be dispersed in large amounts of heterogeneous textile waste. Moreover, the electronic components can act as contaminants in the recycling of textile materials as well as in landfill or on incineration.

Electronic data storage systems are differentiated by the interface between the chip and the reader.

### *Contact*

In a contact system, the interface is a direct electrical connection between two pieces of metal. Often one of the metal pairs is a spring contact to allow for physical tolerance variations. The 'chip-and-pin' security system used on bank and credit cards is a widespread example of a contact interface device.

### *Contactless (RFID)*

Another method of communicating with the chip is by electromagnetic waves i.e. radio or an induction loop. Generally the latter are known as near-field communication devices, of which the contactless smart card and RFID tags are common examples.

For any given system there is a direct relationship between the dimensions of the device and the operating range. Likewise, the operating frequency and data capacity are linked. Put simply, long-range transfer of a significant quantity of data requires a physically large, high frequency device. This limitation can be removed by providing a power source, such as a battery, but the weight, thickness and cost of the device increase substantially from the addition of this component.

Simple RFID tags just return a unique identification number (UIN) when interrogated. This number is truly unique to that tag, permitting tracking of the item to which it is attached. Advanced RFID tags can hold additional data about the item.

Because RFID tags permit unique item tracking, consideration needs to be given to the confidentiality of this information. Since 2002, over 700 academic papers have been presented on this subject. It should be noted that some organisations, such as civil liberties

groups, have concerns over the proliferation of RFID tags since they potentially could be a means to compromise personal privacy<sup>4</sup>.

A generic problem of using electronic devices with textiles is the need to make them compatible with laundering - generally, electronics and water do not mix. This largely rules contact devices out of consideration, since the contacts must be exposed in order to interrogate the chip. Even for RFID tags, the chips require hermetic encapsulation to survive multiple wash cycles - although the antenna does not, as it is simply a conductive element. At least one RFID product exploits this attribute by using conductive thread for the antenna. More typically, machine-washable RFID tags are encapsulated in plastic or silicone rubber, making them bulky items. Very short-range, machine-washable, RFID tags can be disguised as clothing buttons but, as they are essentially a contact device, a person must then be employed to find and present the tag to a reader.

The base cost of semiconductor-based RFID tags is seen as a barrier to their widespread adoption. Consequently, much effort has been expended to develop 'chipless RFID' technologies. It is a subject of significant research with over 30 projects funded in the EU 7th Framework Programme, and a number of products are available commercially. However, the weakness of virtually all chipless RFID technologies is that it is not possible to interrogate more than one tag at a time so the use environment needs to be considered carefully.

### **Magnetic**

Information can be encoded as local magnetic fields. This principle underpins tape-recorders, computer hard drives and swipe cards. It involves modifying the magnetism of tiny iron-based magnetic particles on a band or area of magnetic material. The information is read by moving the magnetic material past a reading head or vice versa. Very high data densities can be achieved, but the reading/writing head must then be positioned with corresponding precision. The read-head is effectively a contact device.

Magnetic swipe cards are a mature technology. When printed on paper they are sufficiently cheap to be a single-use item (e.g. airline boarding cards, London Underground tickets). The magnetic stripes used on bank credit and debit cards will survive multiple laundry cycles provided the temperature is below 60°C. Owing to this restriction, swipe card tags are not considered further in this study.

Another use of magnetic coding is in the ink characters at the bottom of cheques. Banks use magnetic ink character recognition (MICR) to read these numbers to obtain data such as account numbers and bank sort codes. The E13B MICR font is based on a 3.25 mm character grid and is designed to also be readable by people. The information carrying capacity is too low for this technology to be useful in identifying textiles.

### **Optical**

Machine vision systems, comprising an electronic camera coupled to a computer, can capture and read information originally intended to be read by people. The best known example is optical character recognition (OCR) of documents. For example, modern cars can now read roadside speed limit signs as part of the driver informatics system<sup>5</sup>.

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<sup>4</sup> *Privacy, Data Protection Law, and RFID Irreconcilable Differences?*, M. Langheinrich, Institute for Pervasive Computing ETH Zurich, 2006

<sup>5</sup> [http://www.conti-online.com/www/automotive\\_de\\_en/general/chassis/safety/safety\\_sicherheit\\_leben\\_en/hidden/verkehrszeichenerkennung\\_en.html](http://www.conti-online.com/www/automotive_de_en/general/chassis/safety/safety_sicherheit_leben_en/hidden/verkehrszeichenerkennung_en.html)

### *Optical character recognition (OCR)*

Textiles in the UK are required by law to carry labelling which indicates their composition. While these labels are intended to provide information to consumers, they can also be read by machine (using OCR). The required information about the textile could therefore be recovered from a label provided the label is still attached, is still readable at the end of life and can be located and presented to a camera. Many existing laundry care labels do not have sufficient contrast or adequate character precision to permit OCR at high accuracy.

### *Bar/matrix code*

Vision systems can also be used to capture data from barcodes and matrix codes. There exists a wide variety of 1D and 2D bar codes, defined by multiple standards. The information that can be stored depends on the symbology used. Sustaining a sensible aspect ratio limits the length of 1D bar codes to 20 characters. The data capacity of 2D bar codes varies with the type of information. Taking the 2D 'QR code' as an example:

<b>Data format</b>	<b>Capacity</b>
Numeric only	7,089 numbers
Alphanumeric only	4,296 characters

With appropriate illumination, bar- and matrix-codes can be read from a significant distance and interrogation is instantaneous. Readers are available as an 'App' for many smart phones. A QR code can even contain a web-link, so scanning it takes the customer to a website landing page relevant to the item.

### **Chemical**

Several mail delivery services use a UV-fluorescent dye code to uniquely identify each piece of mail for one month. While this technology is mature it is not used elsewhere, so suitable printers, dyes, readers etc. would need to be developed for use with textiles.

### **Nano**

There exist a number of nanotechnology tagging and identification technologies. One commercial product uses a chemical that fluoresces under UV to provide a general indication of its presence, but the chemical signature is unique to each batch. The chemical is claimed by the manufacturer to be resistant to removal by washing, "remaining indefinitely on clothing". Another uses engineered DNA as the information carrier. Other possibilities include nano-materials of unique composition, and quantum dots.

These approaches are all able to carry a very large quantity of information. However, to read the code generally requires a sample of the material and access to sophisticated laboratory equipment such as a GCMS. Consequently these technologies do not merit further consideration for use with identification of textiles.

#### **A1.5. Comparison of identification technologies**

None of the identification technologies reviewed is ideal. All have merits and limitations. The key variables that need to be taken into account when selecting an identification technology are:

- Presentation - how the textile must be presented in order for identification to proceed. For identification technologies that do not use markers, these are the equivalent to the more favourable case of a hidden marker since presentation to a reader is not required in order for identification to proceed.
- Reading distance - typical maximum separation between the textile and the reader.

- Speed - the number of items that can typically be processed per second. For markers that require a person to locate and present it to a reader, the speed is always restricted by this step rather than by the time taken by the machine to read and decode the marker.
- Accuracy - the ability to correctly deduce the make-up of a textile. Where this information is encoded in a marker, it is the ability to read the marker without error (assuming the marker is fully functional). Note that, for RFID technologies, a null response does not distinguish between no tag being present and a failure to read, which accounts for the accuracy rate being below 100%. For other marker technologies, which require a person to present the marker to a reader, the 'false negative' issue does not occur.
- Resolution - is the number of textile types it is possible to identify. Many marker technologies use some of the information carrying capacity for functions such as headers or error correction so the table presents the resolution available for identification.
- Marker dimensions - the dimensions of markers can vary over a wide range depending on the exact form implemented. Typical measurements are indicated.
- Laundry cycle compatibility - the laundry cycle is taken to be the equivalent of 50 washes at 60°C over the lifetime of the textile. Of the identification technologies under consideration, only the OCR and bar/matrix codes printed on labels are likely to wear out due to the wash temperature and number of survivable cycles.
- Quality indication - whether or not the identification technology is able to deduce other information about the condition of the textile (worn etc.). In practice, only manual inspection is able to do this, but any marker that requires a human to find and present it could potentially incorporate this function as well.
- Complex textile description - many clothing and household textiles comprise several fibre types used in different areas; for example, a wool jacket might have a polyester lining. This parameter reflects the ability of the technology to describe such a situation. Mostly it is a direct consequence of the data capacity of the identification technology.

These variables are tabulated over-page for each of the candidate technologies.

Their economic viewpoint of the technology options is discussed in Annex 2.

Identification technology

Parameter	Identification technology									
	Manual sort	FTIR	Physical marker	Electronic contact	RFID	Magnetic stripe	OCR	1D/2D bar code		
Presentation	hidden	hidden	visible	visible	hidden	visible	visible	visible		
Reading distance	<1 m	<1 m	0-1 m	0 m	0-5 m	0 m	<1 m	<1 m		
Speed, items/sec	2	4-10	2	2	20	2	2	2		
Accuracy	92%	95%	95%	100%	98%	100%	95%	100%		
Resolution	8 per stage 500 max	1,000	250	unlimited	unlimited	10,000	10,000	1D – up to 35 characters 2D – up to 4,250 characters		
Marker size, mm	zero	zero	10 x 10 x 2.5	10 x 7	60 x 20 x 2 thick if encapsulated	85 x 13	30 x 30	1D – 40 x 10 2D – 20 x 20		
Laundry cycle compatibility	yes	yes	yes	no	no unless encapsulated	no	degrades each cycle	degrades each cycle		
Quality identification	yes	no	yes	yes	no	yes	yes	yes		
Complex textile description	yes	no	no	yes	yes	yes	yes	yes		
Marker and presentation cost, p/item	0	0	1.1 – 2.0	50 - 250	3 base 6 covered 75 encapsulated	6.0	1.2	1.0		
Identification and sorting cost, p/item	5.2-6.7	1.4	2.1 – 3.0	50-250	4 base 7 covered 75 encapsulated	7.0	2.2	2.0		
Quality, identification and sorting cost, p/item	6.0-7.5	2.6	2.9 – 3.8	50-250	4.8 base 7.8 covered 75 encapsulated	7.8	3.0	2.8		

#### **A1.6. Singulation and sorting technologies**

Used textiles delivered to a reprocessing facility need to be prepared before being presented for identification. Because used textiles often arrive at collection facilities in plastic bags, the first step is to open the bag and grab the plastic film. Commercial machines are available for this purpose. Bags are opened by blunt 'knives' fixed a distance above a conveyor. Un-bagged material passes underneath the knives while bags are caught and split open. After tumbling to extract the textiles, the bag remnants are removed by an air blast and caught on tines.

With the textile stream fully accessible, the next step is to remove rubbish and non-textiles (e.g. shoes). This task is done manually because of the wide variety of contaminants that could be present.

Performing any type of machine-based identification ideally requires the textiles to be presented as a stream of single items. 'Singulators' perform the functions of unstacking, side-by-side eliminating, aligning and managing pace. For textiles, an inclined plane conveyor is often used as a singulator. Friction between the belt and an item is sufficient to it carry upwards while stacked and edge items tumble back and are re-circulated.

One of the difficulties of mechanised handling of clothing and household textiles is their widely ranging size, weight and compactness, and the propensity for items to tangle and get attached together by hooks, buttons and other fasteners. Often human intervention is necessary to guarantee singulation.

Following identification, individual textiles can be routed to a sorting bin by a variety of interventions such as diverters, scalpers, drop gates and throwers (air-jets), the latter being the most common.

#### **A1.7. Conclusions**

Of the available technologies that could be used to identify clothing and household textiles in a waste stream, only four satisfy enough parameters to warrant further study. They are manual sorting, FTIR spectroscopy, RFID tags and 2D bar codes.

Economic analysis of each of these technologies is presented in Annex 2.

## Annex 2: Economic assessment

This Annex provides an economic assessment of four candidate technologies that could be used to identify and sort clothing and household and textiles. The technologies are:

- manual sorting;
- Fourier transform infra-red spectroscopy;
- radio frequency identification tags; and
- 2D bar codes.

The economic assessment is conducted from the viewpoints of retailers, consumers and reprocessors/recyclers.

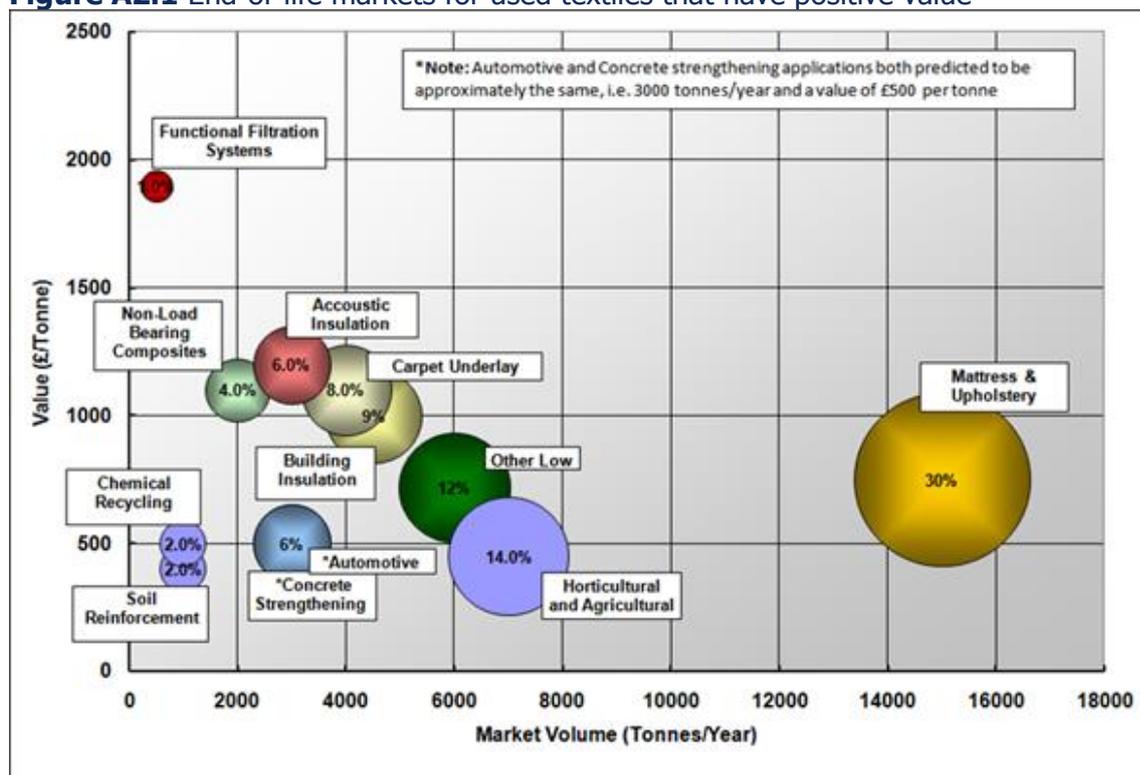
### A2.1. Markets for end-of-life textiles

At end of life, textiles have four outcomes. In most Western economies, the principal end-of-life application, particularly for clothing textiles, is re-use; often in other countries. This option offers relatively high value. It is well studied, but outside the scope of this project and so will not be considered further.

#### A2.1.1. Positive value opportunities

A study conducted in 2009 analysed the positive markets for end-of-life textiles (excluding re-use):

**Figure A2.1** End-of-life markets for used textiles that have positive value



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

No new markets or significant relative price changes have been identified that substantially alter this picture. It should be noted that this could be a 'chicken and egg' scenario. Currently it is impossible to sort reliably to single material streams, so applications that could use such a feedstock do not exist. On the other hand, no end-use applications for tightly defined waste textiles exist because suitable feed stocks are unavailable. There are some

possible intermediate possibilities – for example, mattress fillers must contain a minimum wool content to meet flame retardant specifications, so that better knowledge of the wool content of blends would permit more material to be re-used in this application.

### A2.1.2. Negative value opportunities

For a complete picture on the market for end-of-life clothing and household textiles, the financially negative value must also be considered. These are disposal routes that incur a fee. Currently there are three options. These markets and the associated gate fees are presented in the table below.

Material	Value £/t
Landfill	-£93
Refuse-derived fuel	-£50
Compost	-£44 anaerobic composting -£24 windrow digester

### A2.1.3. Legislative drivers

Legislative considerations can override economic criteria. For example, infectious medical waste must be incinerated. The European Landfill Directive<sup>6</sup> aims to reduce the amount of biodegradable waste going to landfill, which includes many textiles, to 75% of the 1995 figures by 2010 and to 35% by 2020.

## A2.2. Developments in fibre-to-fibre recycling

An undeveloped market for waste textiles is the 'circular economy', in which end-of-life products are rendered back to fibres that can be re-spun then woven into new textiles. This market is not new. A large shoddy industry was operating in the UK over 100 years ago and has since migrated to India and North Africa. However, the quality of the resulting products is poor (resulting in the term 'shoddy' entering the vernacular).

There are two principal routes for fibre-to-fibre recycling. They are mechanical recovery and chemical recovery.

### A2.2.1. Mechanical recovery

All industrial methods of mechanical recovery decrease the fibre length, which adversely affects a number of important properties of yarn. Even when mixed with a proportion of new fibre, 'shedding' and 'slubs'<sup>7</sup> are problems that are exacerbated if the fibre composition of the input stream is not well controlled.

There have been a number of reasonably successful trials to mechanically recycle cotton denim. While denim is easily distinguished from other textiles it can be adulterated with other yarns, particularly to provide elasticity<sup>8</sup>. Because of this, a consumer take-back arrangement is often a pre-requisite to achieving the necessary specificity of the waste stream required for successful recycling. The short length of mechanically recovered denim fibres makes subsequent handling difficult and reduces the robustness of the resulting textile. For this reason, the proportion of recycled fibre in the new textile is often restricted to below 10%, although this figure is rising as the technology improves and there are examples of textiles with 20-30% recycled content being offered to consumers<sup>9</sup>. As currently implemented, the recycling process is usually more expensive than using virgin cotton<sup>10</sup>. This

<sup>6</sup> Council Directive 99/31/EC of 26 April 1999

<sup>7</sup> 'Shedding' is the loss of fibres, 'slubs' are lumps in the fabric due to lengths of increased thickness of yarn

<sup>8</sup> <http://eatsleepdenim.com/>

<sup>9</sup> H&M closes loop with recycled denim, *EcotextileNews*, 2014, 59, p.6

<sup>10</sup> <http://sentbyromy.wordpress.com/2013/09/30/recycled-denim-collection-by-scoth-soda/>

due to a combination of high transport costs for the end-of-life textiles from the recycler to the processing facility and then to the weaver, who is usually in Asia, together with the endeavour required to manage this reverse supply chain.

A number of open-loop recycling markets exist for short-fibre products, such as automotive sound insulation, but the feedstocks are all low value applications and often there is competition from virgin fibre similarly rejected because of short staple length. The process of recycling waste textiles is at a commercial disadvantage to virgin, due to the cost of the transport of the recycled material back to the manufacturer, which is usually located closer to the virgin fibre producers.

Wool has the merit that the staple is longer than many fibres and the yarn is less tightly spun, making mechanical recovery a more promising proposition. In the case of sheep's wool, virgin apparel wool costs around £5,000/tonne<sup>11</sup>. Gate prices for shoddy feedstock are around £150/tonne for high-grade material sorted by colour, down to £20/tonne for unsorted wool<sup>12</sup>. Even these prices make processing of shoddy uneconomic in Europe. It now takes place in India/North Africa, where the output is mostly blankets. A number of small companies in Europe are manufacturing building insulation products based on recycled wool.

Recycling specialist wools is more a workable proposition due to their rarity and consequent high price. A well-established wool recycling industry persists in Italy, due to a combination of technical investment and concentration on fashionable/superfine wool products. For example, hand recovered and recycled cashmere yarn has a retail price equivalent to £20,000/tonne<sup>13</sup>. The virgin price is in the region of £90,000/tonne. Not only does this make recovering specialist wool products economically worthwhile; for certain species it can provide environmental benefits through keeping herd sizes appropriate for the environment. Even then, the imperfections in the recycled yarn mean re-use is largely limited to products and weave patterns in which defects are more tolerable (e.g. scarves). This industry is restricted in its development by the small volume of specialist wools produced commercially. Consequently it will likely remain a niche activity.

While the above is the historical perspective, one recent innovation in mechanical processing appears to make it possible to render cotton textiles back to fibres while preserving the length of a useable majority. The process is apparently patented and it is claimed "the staple length can be equivalent to virgin cotton" and "regenerated cotton comes at a lower cost than virgin cotton". However there are no patents assigned to the company and it does not have a web presence. Furthermore, the company appears to have ceased trading following a law suit stemming from failure to fulfil contracts to supply recycled cotton<sup>14</sup>. Although no reason for the "failure to supply" is given in the court documents, one might speculate whether it was due to difficulties associated with establishing the process on an industrial scale.

#### A2.2.2. Chemical recovery

Chemical recovery of fibres is the process of reducing the textile to a lower chemistry, then using further chemical treatments to construct new fibres.

#### **Chemically re-processed cellulose**

Production of man-made cellulosic fibres from wood is well developed and now accounts for 8% of the global market for man-made fibres<sup>15</sup>. By contrast, cellulose recycling from waste

<sup>11</sup> Price schedule 2013, The British Wool Marketing Board

<sup>12</sup> Global Recycling Network – Wool waste, 2013

<sup>13</sup> <http://www.etsy.com/uk/shop/ThoughtfulRoseSupply>

<sup>14</sup> United States District Court, E.D. Wisconsin., Case No. 11-CV-00400, 02 April 2012

<sup>15</sup> <http://textileexchange.org/node/993>

textiles is still at the developmental stage with R&D projects having been undertaken at e.g. Manchester University (England), Renewcell and Chalmers University (Sweden) and Saxion University (Netherlands). The aim is to recycle used cotton clothing into either a chemically modified (e.g. viscose) or pure cellulosic (e.g. lyocell) fibre. These projects are mostly based on the concept of pulping the textile followed by chemical treatment to perform selective extraction. For example, the cotton in polycotton can be separated by treatment with dilute sulphuric acid, followed by washing in water. Cyclohexane dissolves the man-made fibre from a cotton/lycra mix. Some of these projects are reportedly progressing to demonstration plants; however, none is yet operating at a significant scale or on a full commercial basis. The Chalmers project also addressed the recycling of polycotton blends through the recycling of the polyester component.

Some of the problems related to chemically re-processing cellulose relate to the pre-treatments necessary to deal with 'contaminants' such as dyes, textile finishes (e.g. flame retardants) and mechanical objects (zips, buttons etc.). This nascent industry might benefit considerably from textile sorting technology that could deliver a tightly specified feedstock. Initially this would probably be pure cotton textiles, free from dyes, treatments and fasteners.

Placing a value on this feedstock can be done by comparison with the feedstocks for viscose (softwood dissolving pulp) and Tencel (eucalyptus pulp), since there must be an element of economic competitiveness. Softwood dissolving pulp is currently in the region £530/tonne and eucalyptus pulp £800-£1,000. Yarn prices are roughly double that of the raw material pulp. These fibres have to compete with cotton, the price of which is around £1,150/tonne<sup>16</sup>.

### **Chemically re-processed polyester**

Chemical re-processing of polyester is done by means of either thermal or de-polymerisation engineering.

#### *Thermal*

Polyester is stable in the environment and accounts for roughly one fifth of all textile waste (excluding floor coverings), so there would be significant sustainability benefits if recycling of this material from textiles were possible<sup>17</sup>. However, a competing waste resource for thermal re-processing is drinks containers. Most 'plastic' water bottles are made of polyester. These are easily collected, melted and extruded into fibres, whereas polyester textiles require chemical decomposition before being converted back into new polyester raw material. Polyester textiles are also far more likely to be contaminated with dyes and other undesirable ingredients. For comparison: baled, clear, bottle scrap - of which around three quarters ends up being re-spun as fibre<sup>18</sup> - commands a price of around £300/tonne<sup>19</sup>. It is presumed that if a textile waste stream of relatively pure polyester could be produced by sorting, it would have to undercut this price by a significant margin to allow for the additional processing involved. Virgin polyester fibres first used as filling/stuffing materials are by and large chemically untreated so might be the basis of a suitable feedstock. Camira Fabrics Group recycles polyester taken from wastes associated with the extrusion process, amounting to 1.2 million kilos/year. Other large players include Unifi, Advensa and Trevira.

#### *De-polymerisation*

Re-processing of polyester is simplified if the polyester is chemically engineered with this objective in mind. However, this requires manufacture/retailer engagement and take-back schemes for the very specific products that contain the special grade of recyclable polyester.

<sup>16</sup> <http://www.indexmundi.com/commodities/?commodity=cotton>

<sup>17</sup> *Environmental Improvement Potential of Textiles, April 2012, JRC Scientific and Technical Reports*

<sup>18</sup> *Conversion of PET-bottle-flakes to added value products, Ulrich K. Thiele, Polyester Technology, May 2003*

<sup>19</sup> *Materials Recycling World, WRAP materials pricing report*

The *ECO CIRCLE*<sup>20</sup> polyester recycling initiative is based on this principle, but remains a niche endeavour.

Waste polyester fibres are a major problem in the environment because of their stability. In addition to the landfill problem, short polyester fibres are being washed out to sea and causing difficulties for marine ecosystems. Chemical engineering to make polyester biodegradable would deliver major benefits. Some progress has been made in this area for packaging materials, but with prices around £3,500/tonne and densities of 1.22-1.35 g/cm<sup>3</sup>, this material is at an economic disadvantage compared with established alternatives<sup>21</sup>. To make significant changes, legislation requiring polyesters to be biodegradable may be needed.

### **Chemically re-processed Nylon**

Chemical re-processing of Nylon is well established<sup>22</sup>. In essence, formic acid is used as a recyclable solvent. Other constituents are captured in sludge. The process can yield Nylon with >99.8% purity. However the capital and running costs are high, which is acting as a barrier to its widespread deployment. Currently, carpet recycling is the target application. Another candidate recycling technology for Nylon is a patented process that converts carpet fibres into a feedstock that can be further processed into oil for use as a refinery feedstock. As a commodity, Nylon exhibits appreciable price volatility. Chip prices are in the region of £1,800/tonne and are predicted to climb by 10-15% through 2014<sup>23</sup>.

Separation of Nylon products from the textile waste stream is a reasonably well developed activity since there exists an easily identifiable source of material, in the form of hosiery. At least one company in the USA encourages consumers to post end-of-life hosiery to a recycling facility where it is processed into items such as park benches and garden compost containers. Blending of nylon with other man-made fibres, notably elastane, limits the options for recycling.

A recent study estimated that the size of the UK hosiery market in 2014 will be £900 million (retail price) and the average selling price will be £12/item<sup>24</sup>. Given an average item weight of 10g this implies annual UK consumption of 750 tonnes, classifying this as a niche market.

#### **A2.2.3. Complex textiles**

Complex textiles are especially difficult to recycle since, by definition, they are made of multiple fabrics each of which may contain several fibre types. Several research projects are endeavouring to find solutions to this problem. Generally the approach is to join the fabrics with an adhesive or thread that can be selectively degenerated, permitting separation of the individual fabric panels<sup>25,26</sup>. While this approach has some merit, it will cause problems for a recycling process that relies on a marker, unless one is attached to every panel of the textile. This is unlikely to be economic.

### **A2.3. Stakeholder cost-benefit analysis**

From the study presented in Annex 1, four candidate identification and sorting technologies were identified, namely: manual sorting, FTIR, RFID and bar code. A cost model has been prepared which is used to provide input to the sections which follow. Note that it is based on **100% utilisation of the technology by textiles in the waste stream**, a scenario that will not be achieved for many years.

<sup>20</sup> <http://www.teijin.com/solutions/ecocircle/>

<sup>21</sup> *Textiles flow and market development opportunities in the UK, September 2012, WRAP*

<sup>22</sup> <http://www.aquafil.com/>

<sup>23</sup> <http://www.fibre2fashion.com/textile-market-watch/nylon-chips-price-trends-industry-reports.asp>

<sup>24</sup> *Hosiery opportunity, 2012, The Retail Practice Jacques Vert Group*

<sup>25</sup> <http://www.ecometex.eu/>

<sup>26</sup> <http://www.wear-2.com/>

### A2.3.1. Retailer perspective

#### Manual sorting

Both pre- and post-sale, the retailer has no influence or dependencies on manual sorting. This may change in the future if producer responsibility legislation is applied to textiles, as it has for other consumer products such as waste electrical and electronic equipment (WEEE). There may be small second-order interactions; for example, some retailers receive detailed reports from reprocessors on the quantities of their product in the waste stream. This provides valuable post-sale information on fashion trends, gender preference, durability, wardrobe life etc.

Occasionally a retailer will run a take-back scheme for specific textiles that it originally sold. Mostly the schemes target either specialist wools or pure cotton denim. Usually they operate through the retailer collecting the waste textiles in store, often in conjunction with some purchasing incentive such as a discount voucher. On receipt the textiles are checked to verify compatibility with the scheme, so the resulting waste stream is pure and high quality. It is then sent directly to a dedicated re-processing facility. In this case, the manual sorting operation is effectively undertaken by the retailers' staff and is hidden in the store operating cost. Take-back is usually only undertaken in conjunction with a marketing campaign under the guise of a CSR initiative.

#### Identification by FTIR

FTIR can be viewed as an automated aid to manual sorting that permits accurate 'binning' by fibre type and colour. Hence there is no connection between whether or not a reprocessor has FTIR identification technology installed and either the pre- or post-sale business of the retailer.

#### RFID tags

Pre-sale RFID tags are purported to offer many direct benefits to a retailer, often associated with improved stock management. Several post-sale benefits are also postulated (see table below). The technology has been adopted by a few high end retailers<sup>27,28</sup>. However, no published study has been located that quantifies the benefits other than in the most general terms. Seldom are any drawbacks mentioned and none are quantified. For the immediate future it would appear that in many instances the incumbent technology (bar codes) offer an adequate cost/benefit ratio and at no risk.

Pre-sale benefits	Post-sale benefits
Supply chain accuracy	Customer preferences/profile
Supply chain confidence in accuracy (<1/5000 error rate)	Duplicate sales (do you still sell these?)
Store -warehouse stock distribution	Wardrobe life – fashion cycle
Stock location on shop floor	Whole life cycle Corporate Social Responsibility
Item/set pairing (e.g. shoes, scarf and gloves)	Item/set pairing (e.g. shoes, scarf and gloves)
Faster stocktaking	Guarantee verification
Reduced theft by stock handlers	Assist in theft conviction / stolen goods recovery
Reduced employee turnover (more customer time and positive interaction)	Low volume, high recycling value capture (e.g. Vicuna wool)
Item traffic through fitting rooms	
Smart (electronic) mirrors	Smart (laundry care label) washing machines
Identification of counterfeiting	Producer responsibility

<sup>27</sup> <http://www.rfidjournal.com/>

<sup>28</sup> <http://www.texttrace.ch/en/use-cases/index.php>

The RFID industry has been predicting a rapid uptake of the technology since the 1980s, but it always seems to be 1-2 years away. After 10 years endeavour the giant US retailer Walmart has abandoned efforts to manage its supply chain using RFID tags, returning instead to bar codes.

Since 2013, there has been a hiatus in the adoption of RFID technology, at least in the USA, due to a lawsuit in which Round Rock Research is suing a number of US retailers and manufacturers of RFID tags and systems for patent infringement. This follows the purchase of a suite of RFID-related patents by Round Rock Research from Micron Inc. The defendants include American Apparel, Dole Food, Fruit of the Loom, Hanes brands, JC Penney, Macy's, Pepsi Co, Gap, VF Corp., Walmart, and Impinj. Meanwhile Avery Dennison, Alien Technology, Checkpoint Systems, Invengo, Motorola Solutions, Smartrac and IBM have reached agreement with Round Rock Research on undisclosed terms. The case is currently awaiting reports from the US Patent and Trademark Office on the validity of the 10 patents in question. There is neither deadline for completion, nor a date for trial continuation. Usually in such cases the patent holder seeks to extract a royalty fee for each use of the technology, which will increase the cost of RFID tags to industry.

The price of RFID tags varies considerably with the type and price. A detailed breakdown looking at all the materials and assembly steps suggests the cost of a basic RFID tag is around 3p in high volume, while a laundry-compatible tag ranges from 50p to £2.30.<sup>29</sup> Given that more than 80% of the cost is mature materials that are already used in large quantities by the semiconductor packaging industry, it is difficult to foresee a significant reduction in price without some currently unknown innovative development. The cost of attaching an RFID tag to a textile is likely to be similar to that of a fabric label - somewhere in the region of 2p. However, an association needs to be made between the unique identifier number (UIN) of the tag and the textile. The accuracy of the connection depends on the rigor of traceability required. If the factory is producing one garment in a single style then blocks of numbers could be pre-assigned for, say, each size. For a more bespoke product, traceability to the seamstress may be desirable. Whatever the approach, there will be an additional cost associated with the tag management that needs to be included. Industry estimates are that an RFID inventory system adds £122,000 in middleware capital costs alone<sup>29</sup>.

### **Bar codes**

It is a legal requirement that all textiles carry a permanent label to inform the consumer of the fibre content and country of origin. This, and additional information such as dye colour and how to recycle the textile, could be carried by a bar code in machine-readable form. One implementation might be silk-screen printing on a polyester label. Such information has value to the reprocessor, but the cost of providing it falls to the retailer. While there might be corporate social responsibility benefits to the retailer in attaching bar code labels, the value of this is difficult to quantify.

Bar code labels are unlikely to be of use in stock control of textiles simply because they are too inaccessible for rapid scanning - the reprocessor has the luxury of tumbling and turning a textile to find a hidden label since the garment is no longer on a hanger and creasing does not matter.

A recent study has identified a potential new business model for retailing of textiles. The premise is that a fashion retailer offers an incentive for their customers to return their used garments (bought from that same retailer) to a store. Following varying degrees of remanufacture, they are returned to flagship stores carrying a 'pre-owned' label. A business model such as this should be able to benefit from detailed information about the garment,

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<sup>29</sup> 2011 *Passive UHF RFID Tags & Smart Labels Buyer's Guide, The RFID network, October 2011*

provided by a bar code or RFID tag. Thus far, this business model has only been developed successfully for branded clothing that retails at high margin.

It is not known whether a bar code printed directly on fabric will be machine readable at the end-of-life. If this proves not to be the case and improvement is required, one option might be a label manufactured using the same printing and substrate technology used for polymer bank notes. These will survive immersion in liquid, heating in a microwave, washing and tumble drying. According to the Bank of England, the cost of the polymer and multi-stage printing of a 140mm x 70mm polymer bank note (£10 size) is 12.5p<sup>30</sup>. This area could accommodate 10-20 2D bar codes, depending on the reading distance required, suggesting the cost to the retailer should be under 1p each since the printing requirements are far less onerous than on a bank note.

If the bar code is used to carry a UIN to associate with the textile, the same traceability and logging requirements apply as with RFID tags. However, if the bar code carries information for the consumer/recycler about the textile, then it may be possible to affix a more generic and mass produced label.

For both bar codes and RFID tags there are additional costs associated with any labelling or tagging system. These include the cost of the management system to make sure the right tag goes on the right garment, and the potential impact of the tagging supply chain on the textile manufacturing process in terms of lead times. From the retailer perspective, tagging errors or the decision to release a batch of textiles without a full set of labels is less critical where the sole function is provision of post-sale benefits.

#### A2.3.2. Consumer perspective

There is no direct cost or benefit to consumers from the application of identification and sorting technologies to waste textiles. While there are undoubtedly second-order socio-economic benefits arising from improved waste handling, these are beyond the scope of this project. Of the candidate technologies, bar codes and RFID might have negative benefits. These arise from the presence of a tag, the form or physical bulk of which may or may not be acceptable depending on the type of tag, the textile to which it is attached and its location.

According to a UK consumer study on attitudes to RFID conducted in 2005, 46% view it favourably, 18% had no opinion, 32% didn't know and 4% had an unfavourable opinion<sup>31</sup>. Overall, 41% of those surveyed thought RFID would increase the price of the goods and 69% had concerns over data privacy.

2D bar codes are interesting from a consumer perspective since many smart phones can run an 'App' that can decode them. This raises the possibility of the consumer being able to scan the bar code and receive information on local organisations where it can be sold or donated. Likewise, the retailer could use the bar code as a direct marketing channel.

#### A2.3.3. Reprocessor perspective

Each of the candidate technologies potentially benefits the recycler in different ways and has different merits and draw-backs.

### Manual sorting

Manual sorting costs £175-£235/tonne, depending on the resolution of the activity<sup>32</sup>. The overall cost of manual sorting scales linearly with the size of the operation. Taking the

<sup>30</sup> <http://www.gtglobaltrader.com/news/canada-switches-plastic-money>

<sup>31</sup> <http://events.iaik.tugraz.at/RFIDSec06/Program/slides/009%20-%20Invited%20Talk%20-%20Marc%20Langheinrich.pdf>

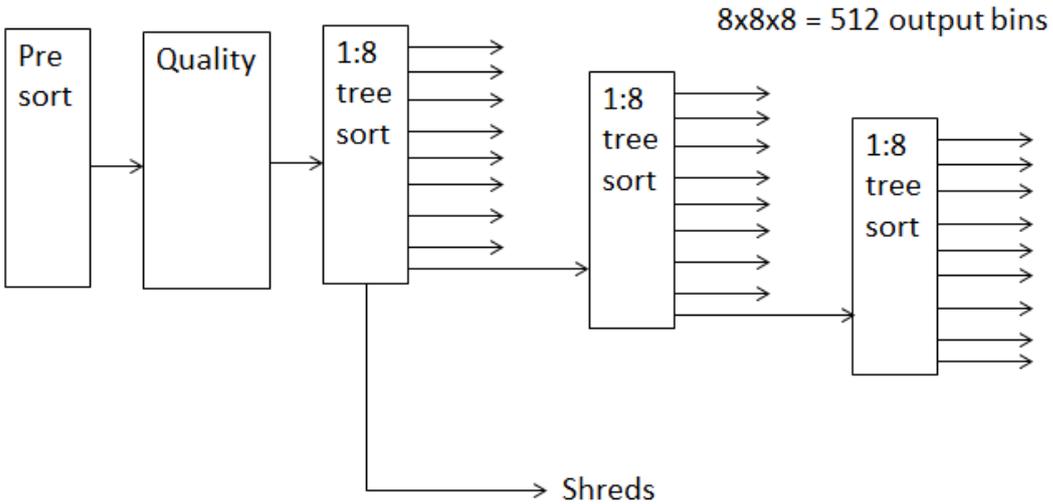
<sup>32</sup> *Textiles flow and market development opportunities in the UK, September 2012, WRAP*

sorting cost to be £200/tonne and making some additional assumptions about a manual sorting process it is possible to derive a number of parameters, as follows:

Parameter	Value
Fully burdened staff cost	£20,000
Working time	236 days x 7.5 hours / annum
Staffing cost	0.31p per second
Manual sorting cost	£200 / tonne fully burdened
Throughput per person	100 tonnes / annum
Throughput rate	25 seconds per item (aggregate handling time)
Staffing for 7,500 tonnes per annum	25 per shift on 3 shifts

A manual sorting operation can be divided into a number of operations, as indicated below. The first step is a pre-sorting operation in which textiles are separated from non-textiles (including shoes, belts, rubbish). Next there is a quality sort where shredding grades are separated. For the export and wiper grades a 'tree-sort' is used to populate the output bins being targeted.

**Figure A2.2** Process flow for manual sorting cost model



A typical reprocessor in the UK has a throughput capability that ranges between 5,000 and 30,000 tonnes/annum<sup>33</sup>. The textile recovery process delivers benefits in the form of aggregate sales value of £1,140/tonne. However, if (as is usually the case) most high quality items have been removed before being sold to the reprocessor, which represents roughly one quarter the waste stream by weight, the aggregate sales value decreases accordingly:

Application	Value, £/tonne	Whole waste stream distribution, %	Distribution on receipt by reprocessor, %
UK re-use	2,600	21	1
Export re-use	1,100	51	65
Wipers	175	11	14
Shreds	90	14	17
Waste	(-75)	3	3
<b>Average value</b>		<b>£1,140/tonne</b>	<b>£780/tonne</b>

Source: Textiles flow and market development opportunities in the UK, September 2012, WRAP

<sup>33</sup> Textiles flow and market development opportunities in the UK, September 2012, WRAP

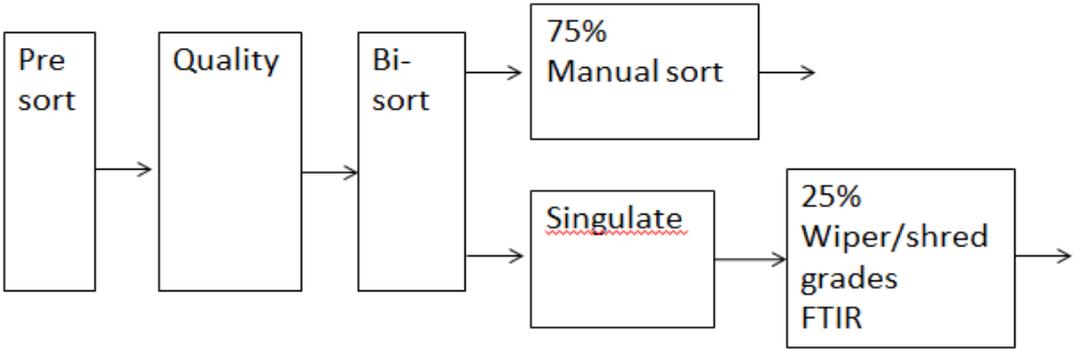
The cost of securing feedstock is constant in this analysis, and is estimated at £550/tonne. Including this cost reveals that the business margin for textile recycling by manual sorting is small; estimated at 4%, roughly equal to £30/tonne.

Parameter (manual sorting)	Value
Feedstock cost	£550/tonne
Sorting cost	£200/tonne
<b>Subtotal costs</b>	<b>£750/tonne</b>
Sales price	£780/tonne
<b>Subtotal sales</b>	<b>£780/tonne</b>
<b>Profit</b>	<b>£30/tonne</b>
<b>Margin (% of sales price)</b>	<b>4%</b>

**Identification by FTIR**

FTIR is only able to sort textiles by fibre type and colour. Consequently the technology is most effectively utilised when working with wiper and shred grades, which represent around 25% of the throughput. Accordingly it is presumed only 25% of the waste stream is sorted by FTIR, the remainder is processed manually. The process flow used for the cost model is given below:

**Figure A2.3** Process flow for FTIR augmented manual sorting



Note: The 75/25 division is based on the waste stream content of the various grades.

The Textiles 4 Textiles business case is the only published cost estimate for an automated sorting machine and the figures have the benefit of independent review<sup>34</sup>. The machine capacity was 12,500 tonnes per annum, on three-shift working. To fit into a manual sorting process with a 25/75 split, the plant capacity would have to be 50,000 tonnes/annum. This is larger than any reprocessor operation currently running in the UK. Consequently, the Textiles 4 Textiles business case has been reworked, assuming the FTIR equipment operates at one third maximum throughput, giving a total reprocessing operation of 16,500 tonnes per annum.

Included in the Textiles 4 Textiles business case is the cost of pre-sorting and singulation for the FTIR machine, so these two steps have been sized to meet the tonnage of the manual sorting stream only.

<sup>34</sup> A review of commercial textile fibre recycling technologies, WRAP, 2012

Parameter	Value	Notes
FTIR staff costs	£60,000	3 staff on one shift
Space costs	£40,000	1,000 m <sup>2</sup> at £40/m <sup>2</sup>
Energy costs	£17,200	1 shift
Overheads	£20,000	
Maintenance	£10,400	0.25 staff plus spares
FTIR equipment	£22,000	£220,000 10 yr depreciation
Sorting equipment	£12,400	£124,000 10 yr depreciation
Other equipment	£8,000	Conveyors etc.
<b>Sub-total FTIR</b>	<b>£190,000</b>	
Manual sort	£2,500,000	12,500 tonnes at £200/tonne
Bi-sort	£61,875	0.5 seconds per item
Minus ¼ pre-sort costs	-£10,000	Included in FTIR cost above
<b>Total</b>	<b>£2,764,000</b>	<b>for 16,500 tonnes/annum</b>
	<b>£168</b>	<b>£/tonne</b>

Although this business case assumes 10 year depreciation on the capital, because this element is small in relation to the other costs, the business case is not markedly altered by using a 3 year depreciation period.

A realistic implementation of FTIR in a UK facility could potentially decrease the sorting costs to £170/tonne. In addition an analysis of the Textiles 4 Textiles study claimed the better precision and accuracy of sorting made possible by the technology could increase the value of the resulting wiper grades by £50/tonne<sup>35</sup>. This increases the value of recycled material by a maximum of £8/tonne, allowing for their proportion in the feedstock. A more conservative number of £5/tonne has been used for this cost model.

Parameter (manual sorting supported by FTIR)	Value
Feedstock cost	£550/tonne
Sorting cost	£170/tonne
<b>Subtotal costs</b>	<b>£720/tonne</b>
Sales price	£790/tonne
<b>Subtotal sales</b>	<b>£790/tonne</b>
<b>Profit</b>	<b>£70/tonne</b>
<b>Margin (% of sales price)</b>	<b>9%</b>

Despite the partial utilisation of the FTIR equipment, the margin of the operation increases over solely manual sorting to 9%, or approximately £70/tonne.

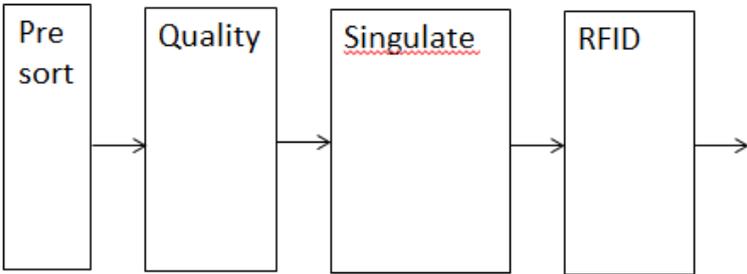
### Identification by RFID

RFID tags provide a means describing the exact makeup of a textile, either directly or indirectly. However, rubbish still needs to be removed from the waste stream and the quality of the textile determined. These steps can only be performed manually; waste removal is difficult to automate owing to its unpredictability and the need to guard against damage to

<sup>35</sup> Textiles flow and market development opportunities in the UK, September 2012, WRAP

downstream equipment, while quality is too subjective to automate. Similarly the RFID reader will require the items to be singulated before presentation, and this is also currently a manual operation. Thus the process flow for the cost model is as follows:

**Figure A2.4** Process flow for automated sorting by RFID



The running cost of an RFID reader and associated computer system is modest if the system is passive. However one use scenario is where the unique identification number of the tag is used as a look up pointer to a data base entry containing the description of the textile. Given that these data bases may exist in several forms and be constantly updated by the retailers, it would be prudent to allow for one full-time engineer to maintain this aspect of the system. A salary of £40,000/annum is assumed for the role. The recycler does not pay for the cost of the RFID tag since this is borne by the retailer. An RFID reader system will incur some capital cost. A fully-equipped scanning gantry and associated computer systems might cost £220,000 for the design and installation costs<sup>36</sup>. In addition there will be the sorting machinery that responds to the command derived from reading the tag, for which the capital cost is £124,000. This process step is common with FTIR sorting so has been assigned the same unit price, but has been multiplied by three to allow for the substantially faster operation required (see below).

In theory, many hundred RFID tags can be interrogated per second. However, in a recycling environment the tags must be physically separated so one tag can be associated with each textile. Assuming each textile occupies 0.5m length on the conveyor and the minimum spacing is 1m, it is possible to relate the tag 'read rate' to the line throughput and conveyor speed, assuming three shift working:

Tags reads per second	Throughput, tonnes/annum	Conveyor speed, mph
0.1	255	0.3
1	2,549	3
6.5	16,567	21
10	25,488	33
100	254,880	330

Reading 6.5 tags per second results in a similar throughput to the FTIR sorting case examined previously. While the resulting conveyor speed is fast, at 21mph, it is not unreasonable so for a fully automated system.

Thus the cost for identification and sorting by RFID is calculated to be around £80/tonne when the capital is depreciated over 10 years:

<sup>36</sup> Going for (not so) broke: The true cost of RFID, July 2005, Inbound Logistics

Parameter	Value	Notes
RFID station staff costs	£60,000	1 staff on 3 shifts
Computer engineer	£240,000	1 staff on 3 shifts
Management staff	£80,000	1 staff
Space costs	£40,000	1,000 m <sup>2</sup> at £40/m <sup>2</sup>
Energy costs	£52,000	T4T business case
Overheads	£20,000	T4T business case
Maintenance	£10,000	0.25 staff plus spares
RFID equipment	£15,000	£150,000 10 yr depreciation
Sorting equipment	£37,500	£124,000 10 yr depreciation 3x T4T case due to higher speed
Other equipment	£12,000	Increased due to higher conveyor speed
<b>Sub-total RFID</b>	<b>£562,500</b>	
Manual pre-sort	£127,875	1 second per item
Manual quality sort	£511,500	4 seconds per item
Manual singulation	£127,875	1 second per time
<b>Total</b>	<b>£1,329,750</b>	
	<b>£80</b>	<b>£/tonne</b>

The principal benefit to the recycler of being able to accomplish precise and accurate sorting is to access higher value markets for the products, such as the premium of up to £50/tonne for wiper grades referred to above. In addition, it is likely that RFID will identify items that meet the premium grades having re-use value as well. This could be in response to market dynamics or fashion. For example, a dress that is a copy of one worn by the Duchess of Cambridge could be profitably diverted from the export re-wear to the UK-resale bin, but as an item would be extremely difficult to identify in the waste stream without a descriptive tag. Each 1% of the waste stream diverted from export re-wear to UK re-use adds a further £26 to the process margin. An allowance of £10/tonne has been included in the cost model as it is uncertain how big an opportunity this represents.

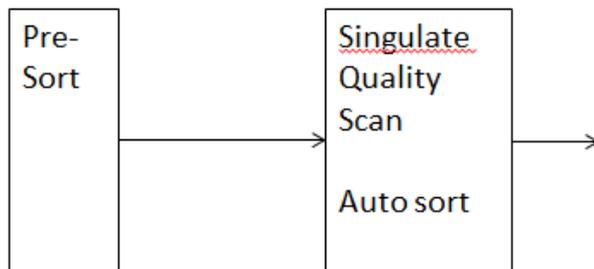
Parameter (sorting by RFID)	Value
Feedstock cost	£550/tonne
Sorting cost	£80/tonne
<b>Subtotal costs</b>	<b>£630/tonne</b>
Sales price	£785/tonne
<b>Subtotal sales</b>	<b>£785/tonne</b>
<b>Profit</b>	<b>£155/tonne</b>
<b>Margin (% of sales price)</b>	<b>20%</b>

The margin of the operation is higher than manual sorting at 20%, or around £155/tonne. It is instructive to test the sensitivity of the cost model to the capital depreciation period. Reducing the return period to three years increases the cost of sorting by £20/tonne.

## Identification by bar code

Identification by bar code adds cost to the RFID model since a human operator is required to find and present the tag to a reader. However, at the same time the operator can also perform the singulation and quality check. The sorting can be done by machine in response to a decoded bar code. Thus the process flow assumed for the cost model is:

**Figure A2.5** Process flow for automated sorting by bar code



The pre-sorting is likely to be done at a separate station. Five seconds per item are allocated for the integrated manual step, based on time-action analysis of the steps involved. This timing is based on the Smart Innovations Clothes Sorting Machine<sup>37</sup> that operates on exactly this basis, but with the operator punching a number into a keyboard. For consistency with the other sorting technologies a throughput of 16,500 tonnes/annum is presumed.

An interesting aspect of this process flow is that multiple stations must be operated in parallel to achieve a similar throughput. When operating three shifts, each is essentially only capable of processing 70 tonnes/annum, so that 235 stations are required to sort 16,500 tonnes per annum. In the cost model the size of the facility, conveyors, automated sorting equipment etc., are scaled accordingly.

Parameter	Value	Notes
Computer engineer	£240,000	3 shift
Management staff	£160,000	3 shift
Maintenance	£10,000	x5 T4T business case
Space costs	£40,000	T4T business case
Energy costs	£52,000	3 shift
Bar code equipment	£10,000	£100,000 over 10 years
Sorting equipment	£62,000	x5 T4T business case
Other equipment	£40,000	x5 T4T business case
Manual pre-sort	£123,700	1 second per item
Manual scan etc.	£639,375	5 seconds per item
<b>Total</b>	<b>£1,423,250</b>	<b>100% utilisation</b>
	<b>£85</b>	<b>£/tonne</b>

<sup>37</sup> [http://txrecycler.com/automation\\_system.php](http://txrecycler.com/automation_system.php)

While the total capital cost of a bar code system is higher than for an RFID system, when amortised over several years the cost differential is small compared with other variables. The cost of identifying and sorting textiles using bar codes is £85/tonne making it very similar in price to RFID.

As with RFID tags, it is presumed scanned bar codes will access higher value markets for wipers and potentially some UK re-use applications as well. From the reprocessor perspective, the economic cases for sorting by RFID and bar codes are very similar.

Parameter (sorting by bar code)	Value
Feedstock cost	£550/tonne
Sorting cost	£85/tonne
<b>Subtotal costs</b>	<b>£635/tonne</b>
Sales price	£785/tonne
<b>Subtotal sales</b>	<b>£785/tonne</b>
<b>Profit</b>	<b>£150/tonne</b>
<b>Margin (% of sales price)</b>	<b>19%</b>

### Comparison of options

The capital costs of each technology and operating margin for a plant throughput of 16,500 tonnes/annum are estimated to be as follows:

Technology	FTIR	RFID	Bar code
Capital investment	£344,000	£525,000	£224,000
<b>Margin</b>	<b>9%</b>	<b>20%</b>	<b>18.5%</b>

The cost model assumes depreciation of capital occurs over 10 years but as it is a small in relation to the operating cost, particularly labour, reducing the return period to three years has only a small effect on the short-term profitability. In general, the benefits of sorting by technology are reduced costs and higher sales value that combine to increase margin. For comparison, the cost model predicts manual sorting operates at a margin of 4%.

At high operating margin and throughput the period required to break even on the capital investment is exceedingly short. However it is predicated on the unrealistic assumption that the whole feedstock is suitable for sorting by technology. Because manual and automated sorting use different topologies, in reality there will be a long period where there will be a requirement to separate the feedstock into two streams depending on how it is to be processed. The cost of this operation and the necessity to run both manual and automated processes in parallel will decrease the margin and greatly extend the break-even period.

### End markets

The different identification and sorting technologies affect different end markets in different ways. For recycling organisations where the primary goal is to identify textiles that can be sold for re-wear in the UK, RFID and bar codes that carry a description of the textile could have a major influence on the operation. It would permit items to be grouped in a variety of interesting classifications, for example by manufacturer/retailer, identical styles, identical items differing only by size, matched sets etc. Some of these categories would likely command higher prices (e.g. matched sets) while others would decrease the retail life (e.g. current fashion season style/colour). Scanning tags/bar codes would also provide a route into an inventory management system that few retailers of this type currently operate.

For the reprocessor, the target market is also the UK re-use market since this offers the highest value in terms of pounds per tonne. However, without a change in the current collection infrastructure most of the choice items will have been removed by the recycling organisations, particularly if they are using the same technology to identify textiles as they enter the recovery process. The ability to sort by different classifications could permit higher prices to be commanded for the export re-wear market for textiles. This could be in response to regional nuances, seasonal variation, or otherwise customised bales. Currently around 65% of the product from textile reprocessing targets this end use so any change in market value has a direct correlation with on the process margin.

For wiper and rag grades, a previous study estimated that the accessible market price could increase by up to £50/tonne on account of the precision and accuracy of sorting that is achievable. This is corroborated by the retail price differential between virgin and reclaimed pure cotton wipers which, at that later point in the supply chain, is £84/tonne.

One market for recycled pure cotton is the manufacture of knitting yarn. Typically the cotton is mechanically reprocessed and blended with 30% acrylic. The cotton feedstock is garment cutting waste since the colour is consistent. In particular a combined visible-IR wavelength system can determine the actual colour of a textile (allowing for fading during wear) so that accurate sorting on this basis may provide a new market opportunity for reprocessors, the price being comparable to white cotton wiper-grade material.

Fibre-to-fibre recycling, particularly for cotton, is not yet developed on an industrial scale. One of the difficulties with the technology is the wide variation in feedstock that the process is expected to accommodate when fed from a manual sorting process. Textile identification by FTIR, RFID and 2D bar codes all offer the prospect of delivering highly specified and controlled supply of textiles so might help in simplifying the process development required.

#### A2.3.4. Other case studies

A study published in 2010 modelled the cost of item-level tagging of product for sale in (US) pharmacies, using either RFID or 2D bar codes.

Summarising, the study found that for RFID technology manufacturers have high initial and on-going costs because they bear the on-going cost of tagging. Wholesalers benefit the most, showing positive ROI because they can leverage the tagged products for internal operations with relatively little investment and almost no on-going costs. Retailers would have major initial costs due to the need to outfit hundreds or thousands of outlets with RFID reading systems. For them, on-going costs and savings roughly balance. For 2D bar codes, the manufacturer's recurring costs drop considerably because ink for barcodes is a lot cheaper than RFID tags. But the wholesaler gains little because they can't read every serial number without manually manipulating each unit to read the bar code. For the pharmacy, the setup costs are lower, but the on-going benefits are not as substantial. Based on this analysis the study concluded "*2D bar codes will likely take the largest share of serialization approach in the pharmaceutical supply chain*".

## A2.4. Comparison of prospects

### A2.4.1. Retailer perspective

There have been a number of studies of the benefits of using RFID in the retail environment<sup>38</sup>. However, the nature of the reported results and publications in which they are presented raises questions over the impartiality of the work. Draw-backs are seldom reported and mostly the benefits are described qualitatively.

The difficulty of quantifying the benefits of RFID technology to the retail industry has been studied and the reasons determined<sup>39</sup>. The EU BRIDGE (Building Radio frequency IDentification for the Global Environment) project concluded *"it is very difficult, rather impossible, to present reliable data for the measurement and the analysis of the economic impact of RFID"*<sup>40</sup>. Without this, information businesses are understandably cautious about adopting the technology.

There is no producer responsibility on textile retailers at present. Schemes that take back textiles for recycling are uneconomic for the retailer, compared with using virgin fibre, largely due to the cost of transporting the recycle back to the manufacturer, often located in Asia. The incentive for take-back for recycling time is therefore limited to CSR and product marketing, which is a finely judged calculation between consumer engagement and cost. However, many textiles that are returned to store are in good condition so are prized by recovery organisations for the re-sale and re-wear markets. Sometimes the retailer will donate the collected clothing to charitable organisations as this helps minimise the cost of transport for disposal and accrues a tax benefit.

### A2.4.2. Reprocessor perspective

Reprocessors have interest in sorting textiles by fibre type. The cost of providing fibre information varies with the use case. FTIR does not require any information to be added to the textile. Neither can it carry this information, so there is zero cost in both instances.

RFID tags and 2D bar codes can carry fibre information. Programming an RFID tag takes several seconds (to perform the write and verification cycles). This means investment in a modest facility will be required to deliver programmed tags at the rate necessary to keep up with the rate of textile production. Based on imports to the UK of 1,700 million tonnes of textiles per annum, it is estimated the annual demand for tags for this application could be as high as 4,000,000,000 units to satisfy the UK market.

Both RFID and bar codes can provide a unique identification number which then points to a database containing this information. The retailer then incurs the cost of populating and maintaining this database and possibly working through other organisations to make it available to reprocessors. This raises issues of commercial confidentiality, legal agreements, access fees, etc., all of which have an associated cost. Obviously, a reprocessor must have access to the database if the information it contains is to be useful in directing the sorting process.

While the adoption of common standards for RFID tags and bar codes that carry or link to an item description clearly has functional advantages, the opportunity for cost reduction is probably small. Indeed, the opposite may well be true. If the standard is defined and maintained by an independent trade body or organisation, it is often the case that a fee will

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<sup>38</sup> RFID Journal

<sup>39</sup> Performance Measurement and Cost Benefit Analysis for RFID and Internet of Things Implementations in Logistics, D. Uckelmann, Springer, 2012

<sup>40</sup> Economic Impact of RFID Report, European Commission contract No: IST-2005-033546, P. Schmitt and F. Michahelles, 2008

be payable in some form to support that work. Even if this work is done internally by the retailer, some resource is still required to set up, document and maintain it. The principal beneficiaries are the consumer and recycler since common data standards permit the broadest range of tags to be read at best speed.

#### A2.4.3. Stakeholder preferred solutions

- **Retailer.** Of the technology options, only RFID tags potentially provide benefits to the retailer pre-sale. However, the high price of a complete RFID inventory tracking system currently limits use to high value, low volume items. There does not seem to be an reason why the roll-out should not be gradual, starting with high value items in a limited number of stores and slowly propagating the technology. Initially there will be an additional cost in that some items will carry tags that are not used, for example because they end up in a store that does not yet have readers, but this will diminish as the rollout proceeds.

Textile bar codes might provide CSR benefits to the retailer both pre- and post-sale, but are unlikely to be a better option for inventory management than the existing paper swing tags.

- **Consumer.** There is some consumer resistance to RFID tags. Bar codes are generally acceptable provided the size and location of the label is appropriate for the item. A limited number of consumers may engage more favourably in the end-of-life determination for textiles if the bar code can be read by an App to help with the process.
- **Recycler.** The recycler can benefit by substituting some manual sorting operations by FTIR to achieve more precise binning by fibre type and colour. FTIR technology will likely improve in performance and decrease in cost over time, while labour rates will probably only increase, making the case for investment more compelling.

RFID tags and bar codes are potentially more valuable to the reprocessor than FTIR identification. But, until these are routinely present on textiles, the business case for investment in readers is low owing to the high throughput required to achieve breakeven. Consumer concerns over 'live' tags, means the reprocessor may be denied the option to use RFID technology as the basis for identification and sorting even if it is widely adopted by retailers.

In conclusion, economic analysis of the four technologies that could be used to identify and sort textiles (manual sorting, FTIR spectroscopy, RFID tags and 2D bar codes) reveals that their relative merit varies with the viewpoint of the stakeholder.

1. The retailer incurs cost through using RFID tags or 2D bar codes but the ability to profit is uncertain.
2. The consumer does not experience direct cost from any option and only 2D bar codes are likely to provide benefit to the circular economy.
3. The reprocessor benefits most from RFID tags and 2D bar code labels, but only when a significant proportion of the textiles passing through the facility carry such markers.



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