An Analysis of the Spectrum of Re-use

A Component of the Remanufacturing Pilot

for

Defra,
BREW Programme

May 2007
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Acknowledgements

This work collates the thoughts and work of numerous others, the quoted original authors, but including our co-workers whose contributions we whole-heartedly acknowledge:

- Joe Darlington
- Andrew King
- Steve Barker
- Doug Marriott
- John Redmayne
- Winnie Ijomah
- Laurie Randall
- Phill Butler
1 Executive Summary

This report is a summary of research exploring remanufacturing in the context of a range of re-use practices. It attempts to differentiate practices by nomenclature and by the corresponding features, processes, and customer relationships. It also presents a general review of research in the field – including knowledge of key practitioners in industry – to gain insight into areas that have been poorly or well researched.

Re-use Terminology

This work, combined with outputs from stakeholder meetings, suggests that terminology in the area of re-use underlies some confusion regarding product standards for remediated end-of-life goods. Efforts to standardise usage within product groups or sectors at least would be beneficial. The following terms related to re-use have been collected and assimilated:

- **Re-use**: A generic term covering all operations where an end-of-life (EoL) product is put back into service, essentially in the same form, with or without repair or remediation. The following terms are also related to the conventional view of ‘re-use’.
  - **Direct re-use**: Placing back into the retail chain returned goods that have no discernable fault.
  - **Redeployment**: Use of a product in the same application, with no assumptions about fitness for purpose or warranty.
  - **Repurposing**: Use of product wholly or partly in another application.

Specific activities under re-use are associated with repair to a greater or lesser extent:

- **Repair**: The correction of specified faults in a product.
- **Refurbishment**: The restitution of major components to a working condition rather than ‘as new’. A level of warranty lower than the Original Equipment Manufacturer performance is characteristic.
- **Reconditioning**: As refurbishment, the restitution of major components to a working condition rather than ‘as new’. A level of warranty lower than the OEM performance is characteristic. Reconditioning may place less emphasis on cosmetic appearance than refurbishment.
- **Remanufacture**: A series of manufacturing steps acting on an end-of-use part or product in order to return it to like-new or better
performance, with warranty to match.

The last category relates to products which are reduced to component raw materials for reprocessing into new artefacts (open or closed loop).

- Recycling: The series of activities by which discarded materials are collected, sorted, processed, and used as raw materials in the production of new products.

**Opportunities for Future Work**

A further development would be the wider adoption of formal codes of practice or standards related to processes, systems and warranties associated with re-used items – remanufactured, refurbished and repaired.

Business processes have been well explored and described. However, remanufacturers perceive the scarcity of effective remanufacturing-specific tools as a key threat to their industry and research shows that there is a need for analytic models of remanufacturing. These might usefully take the form of top-level decision aids that can assist building a wider case for support.

Barriers to purchase have not received as great attention. In particular, issues of trust and risk are common, especially in B2C markets. We suggest that a fuller investigation of risk-mitigation strategies and augmented product offerings is conducted. This could also include ways of increasing product returns to ensure core volumes.

Secondary markets is a little-explored topic, but offers significant potential in the short to medium term in Asian markets, longer term in African markets but uncertain potential in domestic markets. Evidence base research suggests that many export markets are poorly regulated, exploitative and on the verge of illegality. To avoid regulatory and public backlash that could damage legitimate export-for-re-use, we believe that current practice should be explored and frameworks for ethical codes of key sectors, such as electronics, developed.

Much work has been conducted on the subject of product design in the pursuit of various business objectives, remanufacture being just one example. A catalogue of design approaches is useful, but is useful only in the context of specific product and business requirements. If this context is not correctly set to reward e.g. resource efficiency, then desirable and appropriate design methodologies may never be employed. Design is therefore a function of environment and should only be further developed with real-world commercial projects.
There is much activity devoted to promoting recycling and to a lesser extent, re-use and refurbishment within social enterprises. It is apparent that these initiatives could be perceived as competitive and sources of conflict for support. In reality, decisions about end of life options should be taken on the basis of both environmental impact and economic and social benefits, but a means of making these choices does not exist. We believe therefore, that a more detailed model that tackles end of life decisions – re-use and recycling – is required. Initially this will be from a remanufacturing perspective, but should ultimately allow the comparison of many treatment options.

The wider context of design, i.e. the design of macro-economic systems that encourage re-use behaviours, has not been well researched. However, it is the measurement systems that indicate benefits – financial, environmental, social – that ultimately indicate both value and the effect of intervention policies. We suggest, therefore, that further work be conducted to derive business metrics relevant to once-through and re-use that adequately highlight the benefits in categories mentioned. Such general work should be taken forward to examine policy implications.
2 Background

Defra’s BREW programme supports a number of initiatives aimed at business resource efficiency coupled with economic improvement. Landfill tax money is being distributed through a number of established agents each with a different focus on energy or material use. In parallel, Defra seeks to identify novel areas to support, and has selected the industrial practice of remanufacturing for one of its pilot examinations.

Oakdene Hollins has won the contract for the first phase of work in this area, namely the establishment of an evidence base for intervention. This work has lasted around six months and sought to identify remanufacturing potential, the points of intervention, and types of intervention appropriate to BREW, Defra or other government agents.

Remanufacturing is commonly regarded as the return of end-of-life goods to as-new or better condition with warranty to match. In practice, there is a broad variation in the rigour of application of this definition dependent on the complexity of the good, its value, and the demands of the customer. A rather more catholic approach is therefore appropriate in examining the role of remanufacturing as a recovery option.

Accordingly, remanufacturing is one option amongst a number for dealing with end-of-life products. It is therefore important to determine under what circumstances it is an appropriate treatment choice. This choice will ideally present the ‘best’ environmental option, with the proviso that the operation is economic, or could be economic i.e. truly sustainable.

We need to recognise that the factors affecting this choice are dynamic: global economics, technology, policy, customer preferences and education are in constant flux, and cause boundary shifts between viable and non-viable practices. Choice is therefore confusing and, perhaps, inappropriate beyond certain time horizons.

This work has undertaken to ‘map’ the range of re-use options so that the decision to remanufacture a particular product can be properly located within the various factors at work. It illustrates the commonalities and differences between options, and the key factors driving each. A second aspect of the work has considered the specific elements of the remanufacturing cycle in its broadest context, and the motivators and demotivators that need to be addressed at various points in the cycle.
3 Context

Remanufacturing appears within a spectrum of re-use options. Considering the much-described waste hierarchy, it arguably appears at or near the top, entailing maximum preservation of material content, integrity and embedded energy. In favourable circumstances this also equates to high retained economic value. However, it is important to recognise that remanufacturing also requires skilled manual intervention, technical remediation and enhancement, reverse and forward logistics and, not least, a receptive market that matches quality with utility.

These factors can mitigate against economic remanufacture and encourage other treatments such as export to secondary markets, re-use, recycling, energy from waste or even landfill. The latter options have been extensively explored and exploited as responses to the growing waste problem; recycling itself receives substantial Government support. This prompts two questions, namely: When is it appropriate to choose one option over another; and how might appropriate interventions be engineered in, say, remanufacturing to achieve improved benefits?

At the other extreme, we know that certain industries suffer product returns, a high percentage of which have no detectable fault, yet economic structures to remarket these goods are lacking. The question in this case is how could suitable return channels be organised to capitalise as far as possible on common requirements of re-use options.

Answering these questions requires a more holistic approach to end-of-life resource mapping. (In the longer term, a fuller and more sophisticated consideration of new product resource impacts might be required, but this
is not within the scope of this project.) Our work is therefore aimed at creating a decision framework for end-of-life, focusing on re-use options, and this is expanded in the later sections.
4 Methodology

The work has concentrated on the spectrum of re-use, from returns to remanufacture, specifically excluding recycling and other options associated with termination, such as incineration – with or without energy recovery – and landfill. This is because – in general – they are well covered by numerous other agencies and charities such as WRAP, NISP and WasteWatch; and, whilst they are necessary activities, they are unlikely to generate the radical resource effectiveness gains required to achieve so-called Factor 4 changes in production and consumption.

It included the following elements and approaches:

4.1 Produce a Taxonomy of ‘Re-use’

This comprised a literature review and network search for existing definitions, classifications, categorisations of activities falling within the scope of re-use. Further, sub-set activities were analysed in terms of features such as environmental, social and economic impacts, major product-service features. The work entailed some phone-based research, followed by a synthesis of the findings.

4.2 Produce a ‘Map of Re-use’

The information gathered above was re-analysed and augmented by interview with key operators in the field to produce a visual representation of key features. These were mapped in such a way as to show clear commonalities in terms of inputs, process, outputs, barriers and enablers.

4.3 A Register of Previous and Historic Work in Re-use

University of Bristol was responsible for reviewing significant areas of work in the area of remanufacture and re-use, and aligning them to the key issues of interest: logistics, process operation, consumer acceptance, quality etc. A sectoral analysis was included. The work was augmented by research at University of Cambridge by Oakdene Hollins employee, Phillip Butler.

Bristol also compiled a list of companies, by sectors, which are known to be operating in the remanufacturing area (or perhaps have capabilities in
re-use that are relevant to remanufacturing). This captured sectors, products, sites and, for more restricted viewing, particular contacts within the organisations with approximate date of interrogation.

### 4.4 An Analysis of the Motivators and Demotivators of Remanufacture: the ‘Gap Map’

The re-use map (specifically in the area of remanufacture) was overlaid with interest group work on the factors affecting remanufacturing decisions. This was at both the remanufacturer level and the end-user level. Taken in conjunction with other sources of information on remanufacturing priorities – such as the workshops and interest groups – this indicated where beneficial further research might be undertaken. Where possible, suitable stakeholders for this work have been identified.

### 4.5 Synthesis and Write-up

The outputs of the various work packages have been described, the conclusions derived and recommendations made.
5 Taxonomy

In this section we have scanned publicly available literature and web sources for definitions, classifications and exemplifications of re-use activities. In subsequent sections, we have distilled this review into a taxonomy of re-use.

With the evolution of waste treatment legislative landscape, terminology in this area could have developed significantly. The implications of producer responsibility, sector-specific materials treatment constraints and limitations on the trans-national movement of hazardous materials might have been expected to lead to a harmonisation of terminology. However, this does not appear to be the case, with the individual legislative acts using terminology driven by the common parlance of the issues of the sectors being addressed.

The review presented here draws heavily from the work of John Redmayne of Create, the not-for-profit sustainability promoter, who attempted to pull together a definition of re-use in a short review which included the views of Oakdene Hollins, amongst others. In addition, researchers at University of Bristol and Cambridge have provided significant reviews of past and current practice in both philosophical and practical approaches.

A number of opinions on re-use may be gathered from academic, governmental, NGO and industrial sources. Of course, each of these will employ terms suited to their own interests, which may be legal/compliance, fiscal/profitability, systems characterisation, or resource revealing in nature. Subtle degrees of difference in one aspect may be irrelevant to another operator.

Table 5.0: Actor Motives

<table>
<thead>
<tr>
<th>Agent</th>
<th>Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Academic</td>
<td>System description</td>
</tr>
<tr>
<td></td>
<td>Resource flows</td>
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<td></td>
<td>Organisational issues</td>
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<tr>
<td>Government</td>
<td>Economic impact</td>
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<td></td>
<td>Legal frameworks</td>
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<td></td>
<td>Social impacts</td>
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<tr>
<td>NGO</td>
<td>Resource flows</td>
</tr>
<tr>
<td></td>
<td>Social impacts</td>
</tr>
<tr>
<td>Industrialist</td>
<td>Compliance issues</td>
</tr>
<tr>
<td></td>
<td>Profitability impact</td>
</tr>
</tbody>
</table>
'Re-use', broadly defined as the secondary utilisation of products and components, occurs in a multitude of different contexts. The original owner may have no further desire to use a product, cannot afford it, or wishes to replace it with a different product. In such cases the product is either sold on the second-hand market, downgraded to a secondary use (perhaps as toys or in the garden), or given away as a gift. Secondary utilisation may also take the form of hiring and renting, as with car hire and libraries, and retailing products designed for future re-use such as ‘single trip’ cameras.

Re-use may take place with or without a product entering an official waste ‘circuit’ (i.e. a process managed by waste authorities). The extent to which it is properly part of the debate on waste depends on how ‘waste’ is defined, which is subject to considerable controversy. Waste may be defined as products and components which can no longer be used, in which case re-use, like waste reduction, represents a form of waste prevention, whereas recycling, energy recovery and landfill are forms of waste management. On the other hand, waste may be defined more broadly to be ‘any substance or object … which the holder discards or intends or is required to discard’, as in the 1975 [Ref. 155] and 1991 [Ref. 156] European Directives on Waste. In Britain, the term ‘re-use’ is frequently confused with ‘recycling’.

This work considers a range of re-use options, but excludes destructive options such as landfilling and incineration. These may have a role for low value goods, or those with a high calorific value, such as wood, paper, organics and some plastics. It also excludes generic recycling. However, remanufactured items generally have higher durability and are comprised largely – but not exclusively – of metals. As such, they have higher embedded energies and values which exceed any combustion values.

There appears to be no established definition of re-use in the UK although it is frequently referred to in documents, strategies etc. as well as, on occasions, in legislation. In addition a number of other 're-' terms are in usage including remanufacturing, reconditioning, refurbishing, repairing, reusing, reclaiming. This section attempts to draw together available published definitions from the UK, EU and US, and attempt a simple summary.

Firstly, the academic definitions of re-use options have been reviewed.
5.1 Re-use Terminology in the Academic Context

Increased interest in the topic of environmentally conscious design and manufacture has resulted in a somewhat congested field of research in terms of the classifications used to define general recovery activities. Product Re-use/Recovery processes can be mainly grouped under the following headings: Repair, Recondition, Remanufacture, Recycle. Several classifications for such recovery processes exist, and can be found in the literature [Ref. 141, 9, 17]. It is also possible to group recovery process into material recovery (recycling) [Ref. 142] and product recovery (remanufacture) [Ref. 143].

There is also ambiguity in the definitions of remanufacturing, which has caused problems for researchers and practitioners in the field [Ref. 144]. A cross section of definitions can be found summarised in Table 5.1.

Table 5.1: Summary of Recovery Definitions

<table>
<thead>
<tr>
<th>Recovery Processes</th>
<th>References</th>
<th>Consolidated Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair</td>
<td>[Ref. 220, 24]</td>
<td>The correction of specified faults in a product</td>
</tr>
<tr>
<td>Recondition</td>
<td>[Ref. 220, 24]</td>
<td>The rebuilding of major components to a working condition rather than ‘as new’</td>
</tr>
<tr>
<td>Remanufacture</td>
<td>[Ref. 9, 13, 15, 16, 17, 18, 24, 25, 145-152, 220]</td>
<td>The process of recovering an EoL product, and carrying out required restoration to return it to at least OEM original performance condition with a resultant product warranty that at least equals that of a comparable new product.</td>
</tr>
<tr>
<td>Recycle</td>
<td>[Ref. 150]</td>
<td>The series of activities by which discarded materials are collected, sorted, processed, and used in the production of new products</td>
</tr>
</tbody>
</table>

Source: University of Bristol

Various attempts have been made to graphically or verbally differentiate aspects of re-use. The waste hierarchy has commonly been modified to place such options in a value ‘pecking order.’ Such diagrams do not always adequately convey the complexity of options available and others, such as Thierry (1995), [Ref. 9], Figure 5.1 have exemplified using a linear production process applying re-use strategies in the context of reverse logistics.
A notable exception from this analysis, however, is the concept of re-use in an application not as original intent – a cascaded use, or ‘re-purposing’. This then is perhaps the first differentiating characteristic that requires a variation of nomenclature. We shall see that various authorities take different stances on the meaning of re-use, that can therefore cause confusion when translating across analytical contexts.

It can also be seen that re-use can be used to suggest that the good is of sufficient quality for resale as an original\(^a\). This may hide the distinction whereby a re-used item may be treated either:

- In an as-new condition (re-marketed, direct re-use);
- Distinctly in a non-new condition with equivalent effectiveness, or customer utility if not value, perhaps as part of a cannibalisation (conventional re-use, redeployed);
- In a used condition in a different application (in this category, only the simplest of applications spring to mind, such as refillable glass packaging) – (re-purposed);
- Or perhaps simply as a raw material for another product (recycled).

Re-use therefore offers significant subtlety depending on perspectives of the speaker.

\(^a\) There is strong evidence from consumer electronics that many returns are perfectly functional and are replaced directly into the retail stream.
Remanufacture, Repair or Re-use?

Product Recovery and Life Cycle paradigms recognise that the end of use phase does not imply that a product, or its components, are fully used up. It is often the case that a product ceases to fulfil its function because some mechanical or electronic sub-component has failed. In this situation the major components still provide the necessary function and can be returned to service through refurbishment, reconditioning or repair. As a result the conventional product life cycle strategy i.e. one product + one customer with the End of Life (EoL) outcome being waste is no longer as straightforward. EoL can be extended at the product level or at component or material level, which extends the product life much further than the normal service life.

The boundaries between re-use strategies are not always clear, and in reality re-use options often use several strategies simultaneously.

Recovery is associated with a variety of different approaches, all aiming for recovery of the product and its components and parts. The approach of these recovery strategies differs greatly, as does their potential for industrial applications [Ref. 220].

The following sections present a review of the definitions of various re-use terms that arise from academic study. They provide a flavour of the subtle distinctions that may occur, depending on the perspectives and source material of study of the researchers. Our conclusions will consolidate a definition for different uses.

5.1.1 Remanufacture

Context

Remanufacturing is a process where a particular product is taken apart, cleaned, repaired, and then reassembled to be used again. Many different types of products can go through this process, including auto parts, tyres, furniture, laser toner cartridges, computers, and electrical equipment. Essentially any product that can be manufactured can also be remanufactured. In order for a product to be considered remanufactured, most of its components should be used (although some of them can be new if the older parts are too defective to be salvaged).

As society continues to better understand the effects of pollution and the consequences that come with the depletion of our natural resources, attention is focusing on developments that can radically improve resource effectiveness. Remanufacturing is one such development that can generate large energy savings, extend the lives of landfills, and cut down on the
amount of air pollution that would normally occur when a product goes through a reprocessing procedure.

While the basic concept is quite simple, remanufacturing is actually an extensive process. It requires that a used product be completely disassembled in order to assess its actual condition. If it is determined that remanufacturing is worthwhile, various parts of the product are cleaned, restored, repaired, and replaced. Further refinements are then performed and the product is reassembled so that it once again operates in the manner for which it was intended. The product is then ready to be used again. Each step in this process is essential to the entire concept of remanufacturing and careful precautions must be taken to ensure that each step is carried out correctly.

**Terminology**

The term ‘remanufacture’, although widely used in many industries has, until relatively recently, lacked a formal definition with which to classify products. There still exists a degree of uncertainty as to the exact definition of a remanufactured product: Most trade associations and industrial bodies with an interest in remanufacturing will have their own individual definition, and although the vast majority are almost identical, there are subtle differences which may lead to uncertainty. Similarly in academic circles, there exists a debate as to how a remanufactured product should be defined so as to allow for no ambiguity. These definitions are far too great in number to discuss here on an individual basis, but the selected definitions below have been chosen to illustrate the issues that must be considered when assessing a product. The following analysis is based on a paper (Remanufacturing: A Key Strategy for Sustainable Development – Ijomaha, Childe, McMahon) [Ref. 23] written in order to produce a generic model of a remanufacturing business in the UK.

“The process of bringing a product to like-new condition through reusing, reconditioning, and replacing component parts.”

- Amezquita *et al.* [Ref. 54]

The important point to note here is that the product must be ‘like-new’. This is to say that, functionally and cosmetically, the product must be identical to a new product. This definition is ambiguous however, as a *reconditioned* component is by definition of a lower quality than a *remanufactured* component (see Section 5.1.2). This definition describes the use of *reconditioned* components; hence the final product can not be described as remanufactured as it contains components of a lower quality than those with which it was originally manufactured. The following definition does not allow for such ambiguity.
"The process of bringing a product to like-new condition through replacing and rebuilding component parts"

"Products that have been remanufactured have quality that is equal to and sometimes superior to that of the original product."

- Haynesworth and Lyons [Ref.265]

These definitions cover the physical elements of the product. This is insufficient however, as the meta-product must also be considered; customer perception that the product is ‘as new’ is vital. The customer is often not in a position to make a full technical evaluation of the product’s performance. There must therefore be some other method by which the products quality may be gauged. A warranty is the usual mechanism used to re-assure the customer that a product has been manufactured to a particular standard. A remanufactured product, having been manufactured to the same standard, should therefore carry a warranty equal to, or better than, that of the OEM product.

Bringing all these aspects together, the most complete definition of remanufacturing found during the research was as follows:

"The process of returning a used product to at least OEM original performance specification from the customers’ perspective and giving the resultant product a warranty that is at least equal to that of a newly manufactured equivalent."

- Ijomah, Childe, McMahon [Ref. 23]

Although not all academic definitions of remanufacture include all of the points above, they all emphasize the fact that the product must be like-new (or better than new). This is the distinguishing point, academically, between products that have been reconditioned or refurbished to a high standard but yet are not as-new, and products that have been truly remanufactured. It may be very difficult to tell the difference between such products without undertaking meticulous measurement and testing. Every dimension and function should be exactly as stated by the OEM.

5.1.2 Recondition / Refurbish

Context

Reconditioning involves less work content than remanufacturing, but usually more than that of repairing. This is because, unlike remanufacturing, reconditioning only requires the rebuilding of major components to a working condition rather than ‘as new’; yet, unlike repair, all major components that are on the point of failure will be rebuilt or replaced, even where the customer has not reported or noticed faults in those components. The fact that a reconditioned product is clearly not new
(and thus not offering the latest functionality or aesthetic styling of new product) means that it has the same market acceptance issues to products that have been repaired. An example of reconditioning practice comes from a company that reconditions components from white goods and sells them to service agents, and reconditions whole products for sale to low-income families and landlords [Ref. 145]. The reconditioned products tend to have a lower performance specification and associated warranty than the equivalent new product.

**Terminology**

There does not appear to be any properly defined distinction between the words recondition and refurbish, either in academic or industrial terms. Most academic texts will choose one or the other rather than using them together. Only in one academic study did the two terms appear together:

**Reconditioning** – when a product is cleaned and repaired to return it to a ‘like new’ state.

**Refurbishing** – similar to reconditioning, except with perhaps more work involved in repairing the product.

**Remanufacturing** – similar to refurbishing, but requiring more extensive work; often requires completely disassembling the product.

- D. Rodgers, R. Tibben-Lembke [Ref. 53]

This study was concerned with the reverse logistics problems involved in creating a more sustainable manufacturing supply chain. It should be noted that the definition of reconditioning given states that the product should be ‘like new’. This is not consistent with the evidence presented in Section 5.1.1, where it was established that only remanufactured products are considered ‘like new’. As the outcome of study would be in no way affected by the definitions of reconditioning and refurbishing, it is possible that the authors did not fully research the terms, hence the discrepancy with other studies.

Although the meaning of the two words is virtually identical, the context in which they are normally used is not. Large one-off projects such as buildings or ships are said to be refurbished. These involve both cosmetic and mechanical/structural elements. Products that require mainly cosmetic rectification are also said to be refurbished. Both academic and industrial sources are unclear on which term should be used where a product requires technical and cosmetic rectification. The general trend seems to be that products where customers would place a lower value on the cosmetic appearance are said to be reconditioned. Products where the appearance is of equal importance to the functionality are said to be refurbished.

Reconditioning or refurbishing may be defined as:
“The process of returning a used product to a satisfactory working condition that may be inferior to the original specification. Generally, the resultant product has a warranty that is less than that of a newly manufactured equivalent. The warranty applies to all major wearing parts.”

“All major components that have failed or that are on the point of failure will be rebuilt or replaced, even where the customer has not reported or noticed faults in those components.”

- Ijomah, Childe, McMahon [Ref. 23]

The important factor to note here is that the resulting quality of a reconditioned product is deemed to be lower than that of a new or remanufactured product, and the warranty reflects this. The work content of a reconditioning operation is lower than that of a remanufacturing operation. All critical systems will be assessed for wear and tested, but a full component level analysis need not be carried out. The aesthetic finish may be of a lower standard than the OEM product or there may be slight cosmetic imperfections.

5.1.3 Repair

Context

The most logical approach to closing the loop on product use is simply to repair and extend the product’s life. Repairing is simply the correction of specified faults in a product. Generally, the quality of repaired products is inferior to those of remanufactured and reconditioned alternatives. When repaired products have warranties, they are less than those of newly manufactured equivalents. Also, the warranty may not cover the whole product but only the replaced components.

Empirical research [Ref. 220] has shown that appliance ownership within the UK increased by around 60 per cent over a five-year period. In addition, consumer decisions during the ‘use’ phase of a product whether to repair, to pass on or to throw items away accordingly affect product life spans (and thus the rate of waste generation). The E-SCOPE survey found that 68 per cent of respondents cited cost as a reason why they did not get items repaired, a factor borne out by the fact that, while new washing machine prices increased by only 40 per cent during the 1980s–1990s, repair costs over this period increased by 165 per cent [Ref. 24]. This may be because companies have concentrated on designing for cost reduction rather than design for easy repair.
Terminology

The term ‘repair’ appears to be well understood in both academic and industrial circles. It is possibly the simplest process to define here, as it refers to the rectification of a particular fault or symptom; thus the general condition of the product remains unaltered.

“Repairing is simply the correction of specified faults in a product. When repaired products have warranties, they are less than those of newly manufactured equivalents. Also, the warranty may not cover the whole product but only the component that has been replaced.”

- Ijomah, Childe, McMahon [Ref. 53]

Only components that are suspected to be contributing to the particular fault will be examined. The minimum amount of disassembly and inspection will be carried out in order to correct the fault. Components that are worn and nearing the end of their lifetime will not be replaced unless they are causing an immediate problem. It follows then, that the quality of a repaired product will usually be lower than that of a reconditioned/refurbished product.

5.1.4 Re-use

Context

When a product reaches the end of its useful life in a particular environment, it must be disposed of. The method of disposal will determine how much value can be recovered from the product, both in terms of economics and embodied energy. Recycling involves the product being reduced to its constituent materials, which may then be used as a feedstock for further manufacture of new products. Whilst this recovers valuable material and reduces landfill waste, it loses any value added to the product during manufacture. Re-use is a process whereby the value added to a product during manufacture may be fully, or in part, retained.

Re-use often takes place without any alteration to the product except, perhaps, cleaning. If the product was the source of dissatisfaction, however, it may be preceded by repair (correction of fault), refurbishment (servicing), downgrading or upgrading (change in performance capacity). New components may be fitted. In some cases the parts which are replaced may themselves be re-used.

Terminology

Re-use may take place with or without a product entering an official waste ‘circuit’ (i.e. a process managed by waste authorities). The extent to which
it is properly part of the debate on waste depends on how ‘waste’ is defined, which is subject to considerable controversy. Waste may be defined as products and components which can no longer be used, in which case re-use, like waste reduction, represents a form of waste prevention, whereas recycling, energy recovery and landfill are forms of waste management. On the other hand, waste may be defined more broadly to be ‘any substance or object ... which the holder discards or intends or is required to discard’, as in the 1975 [Ref. 155] and 1991 [Ref. 156] European Directives on Waste.

The use of the word academically varies according to the product type under analysis. A common element amongst all authors is that minimal energy should be used in altering the form of the materials contained within the product. Changing the state of a material, melting for example, would not be considered re-use as the original energy used to create the solid object has been lost.

Re-used products can be categorized as either primary or secondary: Primary re-use involves a product being re-used for the same purpose as it was originally intended. Secondary re-use involves finding a new use for an end of life product. The product does not have to remain as one unit for re-use. Indeed, some components may be suitable for primary re-use, whilst others are suitable for secondary re-use or recycling.

The term re-use can be applied to products where no additional processing or rectification work has taken place; the product has merely been transferred to a different environment. This may be a secondary market or a customer with a smaller budget or workload, better suited to a used product. It is also used where products or components have undergone some degree of repair, refurbishment, or remanufacture before re-entering service.

In some texts, the concept of re-use is used as a sub-group of recycling. This is often the case where research has been carried out in the construction industry. Construction materials are often referred to as recycled when strictly speaking, they have been re-used. This is particularly common where secondary re-use is under evaluation.

### 5.1.5 Resale

**Context**

Resale is used as a loose term for the sale of equipment that has been pre-owned by another party. The seller may be either the original owner or a third party broker. It is not generally used for equipment that has been re-
manufactured. Items for resale may have received various degrees of repair / refurbishment, from total functional and cosmetic servicing, to none at all. Resale can also be used in reference to the supply of a commodity from a bulk purchaser to the consumer. Although this situation is analogous with sales of goods other than commodities, it is unusual to find a supplier of new equipment referring to themselves as a resale operation.

**Terminology**

The term resale, when used in reference to consumer or industrial goods, has connotations of used items. An exception to this is when manufacturers, wholesalers, or retailers reduce their inventory of obsolete stock by selling at a reduced price to another trading company. This company will then resell the stock either in secondary markets or to customers with a lower budget than those of the original seller. This is preferable to disposing of the obsolete stock in landfill or recycling.

The resale network provides access to markets that OEM manufacturers may not want to become involved in for fear of customers associating their brand with lower quality used products. It is acknowledged academically as an important channel with which to distribute used products, particularly those organizations which deal in export secondary markets. There are however, also concerns that these secondary markets may be subject to abuse, particularly with regard to the export of obsolete electronic equipment. Due to increasing Landfill Tax, some unscrupulous operators are shipping worthless equipment to developing countries where it is simply dumped, rather than being resold for re-use. This aspect of the resale industry is currently the subject of much concern from environmental and social groups. However, it may also provide fruitful opportunity for future ethical market developments.
5.1.6 Recycling

Although excluded from the main part of this report, this short section provides a brief context for the activity.

Recycling is ‘the series of activities by which discarded materials are collected, sorted, processed, and used in the production of new products’ [Ref. 150]. According to the Northeast Recycling Council [Ref. 25], recycling activity in New York saved 2.7 million tons of iron ore from needing to be extracted to form new materials. However, although it is currently the most mature waste avoidance strategy, with established rates as high as 80 per cent for certain products [Ref. 17], many designers are reluctant to use recycled materials because of uncertain quality or supply standards [Ref. 15]. In addition, while the materials recycled reduce virgin material use, they do still require additional energy to be used to reform them into manufactured products.

Jacobs stated [Ref. 151]: “Wastes can’t turn back into resources unless there is some external source of energy. ‘Recycling’ doesn’t just happen on its own . . . it has to be powered by an energy source.”

5.2 Industrial Usage by Sector

Terminology is examined in respect of the sectors already examined by Oakdene Hollins through Biffaward, Envirowise, BREW and independently contracted work. This is a dynamic list which we expect to update periodically as our product coverage expands.

5.2.1 Remanufacture

Aircraft components:

The term is generally well understood and used in a manner that satisfies the description in Section 5.1.1 (although the generic term ‘rotables’ is common parlance). Due to the strict safety regulations associated with aircraft, only parts of the highest standard will be allowed onto the market, thus any part that is to be re-used must undergo complete disassembly, test and return to the OEM specification. Only approved firms may operate in the market, thus many remanufacturing operations are effectively a closed loop. There is little threat of competition for cores from budget operations as found in the printer cartridge industry for instance.
Automotive:

The term is generally well understood and used in a manner that satisfies the description in Section 5.1.1. The automotive industry has a long history of remanufacturing, and there is a large network of companies specializing in the remanufacture of parts for vehicles. Many OEM producers have their own remanufacturing programs, although often the actual operation is subcontracted to a specialist remanufacturer. Many customers are unaware that a spare part that is fitted to their vehicle may actually be a remanufactured unit.

Consumer electronics:

Very few references were found that referred to remanufactured consumer electronic products. With the exception of toner or ink cartridges, all products that had received some rectification work were described as reconditioned or refurbished. The short product life cycle of consumer electronics and rapid changes in fashion makes full remanufacture of such products unattractive. A six month old product will attract a greatly reduced price that does not justify remanufacture. This is likely to change with the introduction of the WEEE Directive. Future designs will be more likely to facilitate easy disassembly to facilitate remanufacture. The ability to upgrade products will also become more important to increase the products useful lifetime.

Domestic white goods:

There is no significant remanufacturing activity in this sector and thus it is not possible to comment on the use of the term. White goods are usually recycled or reconditioned.

Furniture:

Domestic furniture is generally said to be refurbished rather than remanufactured. There are many companies claiming to sell remanufactured office furniture. The terms remanufacture and refurbish are used interchangeably in the sales literature, and there appears to be little understanding of the difference between the two. Many sites describe their remanufactured stock as ‘almost new condition’ which does not satisfy the definition given in Section 5.1.1.

Industrial and catering equipment:

The term is generally well understood and used in a manner that satisfies the description in Section 5.1.1. There are differences in the exact descriptions that companies involved in the remanufacture of industrial machinery use. Some claim that a remanufactured machine should exceed
the performance of the original, whilst others claim it should match that of the original. Customers in this sector are well informed of the issues involved with purchasing a remanufactured unit as opposed of a new or reconditioned unit.

**Office IT and Reprographics:**

The term is generally well understood and used in a manner that satisfies the description in Section 5.1.1. Customers in this sector are well informed of the issues involved with purchasing a remanufactured unit as opposed to a new or reconditioned unit.

**Vending machines:**

The term is generally well understood and used in a manner that satisfies the description in Section 5.1.1. Customers in this sector are well informed of the issues involved with purchasing a remanufactured unit as opposed to a new or reconditioned unit.

### 5.2.2 Recondition / Refurbish

**Aircraft components:**

The term is generally well understood and used in a manner that satisfies the description in Section 5.1.2. Often, the term ‘overhaul’ is used in place of recondition.

**Automotive:**

The term is generally well understood and used in a manner that satisfies the description in Section 5.1.2. Many smaller firms and garages offer a reconditioning service or offer reconditioned parts at a discounted price in exchange for the old core. Reconditioned parts are a popular choice for motorists with older cars that are no longer under warranty. Engine, electronic, and brake system components are popular candidates for reconditioning.

**Consumer electronics:**

Refurbishment is used to describe products from a wide range of sources and in a variety of conditions. Refurbished products may simply be returns from retailers who do not want to sell stock that has been out of the box or ex-display items but come with a full manufacturer’s warranty. They have been tested but not disassembled. The packaging may be damaged and some accessories may be missing.
Refurbished products may also be units which developed a fault whilst under warranty and were subsequently returned. These are usually repaired and repackaged in the original packaging. They will be sold at a discounted price with a full warranty, which may or may not be endorsed by the OEM.

Older units are also sold as refurbished. These have usually received a full service and come with a 90 day warranty from the refurbishing company. This use of refurbish fits the definition in Section 5.1.2.

**Domestic white goods:**

It is common for white goods to be described as refurbished. This can mean that the units have been serviced and tested or simply cleaned, depending on the item. Such units will often come with a three month guarantee from the refurbisher. This is consistent with the description in Section 5.1.2.

There is a successful refurbishment and redistribution program running in the UK that collects unwanted white goods from households. These are then refurbished and distributed to low income families. However, units do not come with a guarantee as such, but they are fully tested and in clean, working order.

**Furniture:**

Furniture is usually said to have been refurbished after any rectification work has been carried out. Depending on the type of item, it may come with a one or three month guarantee of workmanship for the repair. Office furniture may come with a longer guarantee depending on the item. This use of refurbishment fits the definition in Section 5.1.2.

**Industrial and catering equipment:**

The term is generally well understood and used in a manner that satisfies the description in Section 1.2. Some companies describe reconditioned units to be ‘as new’ but the guarantee distinguishes between these units and a fully remanufactured unit. Both reconditioning and refurbishment are used in this sector. Reconditioning is often used where a full mechanical overhaul has been carried out, where as refurbished items have usually received some cosmetic enhancement or upgrade as well.

**Office IT and Reprographics:**

The term is generally well understood and used in a manner that satisfies the description in Section 5.1.2. Both reconditioning and refurbishment are used in this sector. Some equipment advertised as refurbished may be new equipment that has minor cosmetic damage. This is sold with a full
manufacturer’s warranty. Reconditioned laptops have generally been tested but not dismantled for inspection.

**Vending machines:**

The term is generally well understood and used in a manner that satisfies the description in Section 5.1.2. Some suppliers of refurbished machines only guarantee that the machine will work when it arrives.

### 5.2.3 Repair

**Aircraft components:**

The term is generally well understood and used in a manner that satisfies the description in Section 5.1.3.

**Automotive:**

The term is generally well understood and used in a manner that satisfies the description in Section 5.1.3. A repair is generally guaranteed for 30 days against poor workmanship, but this is dependant upon the nature of the fault. If any components are replaced then these parts only will be guaranteed. The length of the guarantee will depend whether the part is new, remanufactured or reconditioned.

**Consumer electronics:**

The term is generally well understood and used in a manner that satisfies the description in Section 5.1.3. If a repair is carried out under guarantee then the replaced component will usually be guaranteed until the original product guarantee expires. A unit that has been repaired then resold to a second user will usually be described as reconditioned or refurbished rather than repaired.

**Domestic white goods:**

The term is generally well understood and used in a manner that satisfies the description in Section 5.1.3. If a repair is carried out under guarantee then the replaced component will usually be guaranteed until the original product guarantee expires. The workmanship will usually be guaranteed for between one and three months. A unit that has been repaired then resold to a second user will usually be described as reconditioned or refurbished rather than repaired.
Furniture:

It is not common to find furniture described as repaired. Both domestic and office furniture are said to be refurbished when they have been repaired. This reflects the fact that the majority of repairs to furniture are of a cosmetic nature.

Industrial and catering equipment:

The term is generally well understood and used in a manner that satisfies the description in Section 5.1.3.

Office IT and Reprographics:

The term is generally well understood and used in a manner that satisfies the description in Section 5.1.3. A unit that has been repaired then resold to a second user will usually be described as reconditioned or refurbished rather than repaired.

Vending machines:

The term is generally well understood and used in a manner that satisfies the description in Section 5.1.3.

5.2.4 Re-use

The concept of re-use is well understood in the industries above. All employ primary re-use of components and cores. There is also a growing market for secondary re-use of materials contained in the products above, mainly in the construction industry. Whilst there are already well established firms using this resource, the market is relatively undeveloped and new uses are being found for materials that were previously thought only suitable for recycling or landfill.

5.2.5 Resale

This term is well understood in the above industries and in keeping with the definition described in Section 5.1.5.

5.2.6 Summary

The following table summarise the usage of the terms in the context of the core definition presented in Sections 5.1.1/2/3.
### Table 5.2.6a: Sector Use of Term 'Remanufacturing'

<table>
<thead>
<tr>
<th>Sector</th>
<th>Conformance to 5.1.1 Remanufacturing Spec.</th>
<th>Other use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aircraft</td>
<td>Almost exclusively in practice</td>
<td>Safety/legal enforces high quality. Also known as rotables.</td>
</tr>
<tr>
<td>Automotive</td>
<td>Largely in practice</td>
<td>Large operators more conforming. Smaller operators tending to recondition.</td>
</tr>
<tr>
<td>Consumer Electronics</td>
<td>No</td>
<td>Reconditioned/Refurbished is the more common parlance.</td>
</tr>
<tr>
<td>Domestic White Goods</td>
<td>No</td>
<td>Generally recycled or reconditioned.</td>
</tr>
<tr>
<td>Furniture</td>
<td>No</td>
<td>Almost exclusively refurbished.</td>
</tr>
<tr>
<td>Food Processing Equip</td>
<td>Yes</td>
<td>Differences over matching or exceeding OEM specification.</td>
</tr>
<tr>
<td>Office IT</td>
<td>Yes</td>
<td>High standards set by majors such as Xerox.</td>
</tr>
<tr>
<td>Vending Machines</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

### Table 5.2.6b: Sector Use of Term 'Reconditioning'

<table>
<thead>
<tr>
<th>Sector</th>
<th>Conformance to 5.1.2 Reconditioning Spec.</th>
<th>Other use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aircraft</td>
<td>Reconditioned</td>
<td>Often the term ‘overhaul’ is used.</td>
</tr>
<tr>
<td>Automotive</td>
<td>Reconditioned</td>
<td>Typical of medium to small operators as alternative to remanufactured.</td>
</tr>
<tr>
<td>Consumer Electronics</td>
<td>Refurbished</td>
<td>Covers entire range from remarketing of returns with fully warranty, to ex-service with 3 month guarantee.</td>
</tr>
<tr>
<td>Domestic White Goods</td>
<td>Refurbished</td>
<td>Disparity of testing standards. Sometimes no repair, just cleaning.</td>
</tr>
<tr>
<td>Furniture</td>
<td>Refurbished</td>
<td>Almost exclusively refurbished in this sector. Guarantees &lt; 1 year typically.</td>
</tr>
<tr>
<td>Food Processing Equip</td>
<td>Reconditioned/refurbished both used</td>
<td>Sometimes described ‘as new’ but betrayed by short warranty.</td>
</tr>
<tr>
<td>Office IT</td>
<td>Reconditioned/refurbished both used</td>
<td>Refurb = new with cosmetic damage. Full warranty. Recon = fully tested but not dismantled.</td>
</tr>
<tr>
<td>Vending Machines</td>
<td>Refurbished</td>
<td>Limited guarantee.</td>
</tr>
</tbody>
</table>

### Table 5.2.6c: Sector Use of Term 'Repair'

<table>
<thead>
<tr>
<th>Sector</th>
<th>Conformance to 5.1.3 Remanufacturing Spec.</th>
<th>Other use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aircraft</td>
<td>Yes</td>
<td>Guaranteed for 30 days-1 year upwards for the replacement part outside of vehicle warranty.</td>
</tr>
<tr>
<td>Automotive</td>
<td>Yes</td>
<td>Term used within warranty. Otherwise described as refurbished.</td>
</tr>
<tr>
<td>Consumer Electronics</td>
<td>Yes</td>
<td>Term used within warranty. Otherwise described as refurbished, with 1-3 month warranty.</td>
</tr>
<tr>
<td>Domestic White Goods</td>
<td>Yes</td>
<td>Term used within warranty. Otherwise described as refurbished.</td>
</tr>
<tr>
<td>Furniture</td>
<td>Rarely used</td>
<td>Refurbishment is much more common, reflecting cosmetic nature of defects.</td>
</tr>
<tr>
<td>Food Processing Equip</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Office IT</td>
<td>Yes</td>
<td>Term used usually within warranty. Otherwise described as refurb/recon’ed.</td>
</tr>
<tr>
<td>Vending Machines</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>
5.3 Remanufacturing in Detail

The key purpose of this review has been to place remanufacturing in the context of re-use. Therefore, it is core to the study to elucidate the various uses of the term remanufacture, and attempt to provide both a clear definition statement and a list of characteristics associated with true manufacture.

5.3.1 Sectoral and application diversity and term abuse

The specific aspect of re-use related to remanufacture has attracted numerous definitions and qualifications. Various sectors too can elicit differences in both terminology and implied practices associated with their terminologies. For example, automotive is familiar with terms remanufacturing and reconditioning, particularly in relation to the engine sub-sector; they can be used interchangeably, but not all operators are convinced that they represent equal value – or equivalent practices. In the aerospace field, the term ‘rotables’ (i.e. capital items on rotation of use) replaces remanufacture, although it is clear that legal considerations enforce a more consistent, and openly declared, standard of performance.

At the other extreme, to some, remanufacture has become recognised as a new word, a rising fashion that may be used to glamorise otherwise mundane activities. For example, a LDA-supported project in used plastics extrusion referred to this operation as remanufacturing, where in fact it largely fails the tests that all protagonists would set. A provider of water storage equipment claimed to be remanufacturing with no justification for the spurious use of the term. Such abuses signal the need rapidly to define the ‘remanufacturing space’ before its widespread adoption as a degraded descriptor of any process involving recovered materials.

5.3.2 Misconceptions about remanufacturing

Often, the process of remanufacturing gets confused with other similar activities. Rebuilt and recharged products are very close to remanufactured ones and the three terms can often be considered synonymous with each other. Rebuilt products usually refer to auto parts, while recharging is usually performed on imaging products like toner cartridges.

Other types of products are almost completely different from those that have been remanufactured. For example, a remanufactured product is not a recycled one. Recycling involves using a product or its parts as raw materials for a different product and is generally applied to consumable goods like newspapers, bottles, and cans. Very rarely are recycled products
resold to be used as they were originally intended, and when they are, the quality is not as good as a remanufactured product.

In addition, a remanufactured product should not be confused with a repaired one. Usually when a product is repaired, the whole remanufacturing process is disregarded and only defective parts are investigated and replaced. Likewise, restored and reconditioned products are ones that are brought back to their original condition, but these changes are usually cosmetic and apply to things like antiques, rather than mass market consumer products. In addition, remanufactured products should not be classified as ‘used.’ A used product is one that has not been repaired and therefore has no guarantees regarding its performance. Finally, demanufacturing and remanufacturing should not be confused with each other. Demanufacturing is simply the disassembly step that all products that are going to be remanufactured must go through.

5.3.3 Remanufacturing vs. recycling

Although remanufacturing and recycling are two different things, many environmental groups are embracing the concept of remanufacturing over recycling because it cuts down on the use of energy and resources used for processing. While recycled goods are consumed then returned to their original raw material form to be used again, remanufacturing ‘recycles’ the value originally added to the raw material.

Robert Lund [Ref. 147] explained that:

“Remanufacturing differs from recycling also, most importantly because it makes a much greater economic contribution per unit of product than does recycling. The essential difference arises in the recapture of value added. Value added is the cost of labour, energy, and manufacturing operations that are added to the basic cost of raw materials in the manufacture of a product. For all but the most simple durable goods, value added is by far the largest element of cost. Even in a product as simple as a beer bottle, the cost of the basic raw materials (sand, soda, and lime) is much less than 5 percent of the cost of a finished bottle. The rest is value added.

For a product such as an automobile, the value of the raw materials that can be recovered by recycling is only in the order of 1.5% of the market value of the new car. Value added is embodied in the product. Recycling destroys that value added, reducing a product to its elemental value—its recoverable raw material constituents. Further, recycling requires added labour, energy, and processing capital to recover the raw materials. When all of the costs of segregation, collection, processing, and refining are taken into account, recycling has significant societal cost. Society undertakes recycling only because, for all nondurable and many durable products, the societal cost of any other disposal alternative is even greater.”
5.3.4 What is remanufacturing?

Individuals and organisations have attempted to clarify the meaning of remanufacture. This has been as the result of academic study, seeking to differentiate the practice from others, or by trade bodies seeking to achieve some level of conformity amongst a membership. (At this point, we make no judgements about the success or otherwise of this desire.) The following table brings together a number of definitions classified by year of appearance.

Table 5.3.4: History of Remanufacturing Definitions

<table>
<thead>
<tr>
<th>Year</th>
<th>Definition</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>'The process of bringing a product to like-new condition through reusing, reconditioning and replacing component parts.'</td>
<td>Haynsworth &amp; Lyons [Ref. 40]</td>
</tr>
<tr>
<td>1995</td>
<td>'Is the restoration of used products to a like new condition, providing them with performance characteristics and durability at least as good as those of the original product.'</td>
<td>Thierry, Salmon et al. [Ref. 9]</td>
</tr>
<tr>
<td>1996</td>
<td>'Remanufacturing is the practice of disassembling, cleaning, refurbishing, replacing parts (as necessary) and reassembling a product in such a manner that the part is at least as good as, or better than, new.'</td>
<td>Bras and Hammond [Ref. 13]</td>
</tr>
<tr>
<td>1997</td>
<td>'Remanufacturing is one of different product recovery options (others are repair, refurbishing, cannibalization and recycling), which are classified based on the degree of disassembly and the quality level of the recovered product.'</td>
<td>Fleischmann, Bloemhof-Ruwaard et al. [Ref. 17]</td>
</tr>
<tr>
<td>1998</td>
<td>'Remanufacturing is recycling by manufacturing ‘good as new’ products from new products.'</td>
<td>R Steinhilper [Ref. 16]</td>
</tr>
<tr>
<td>2002</td>
<td>'Remanufacturing is the only process where the performance of used products is brought at least to the OEM's performance specification from the customer’s perspective. In addition, remanufacturing gives warranties that are equal to those of equivalent new products.'</td>
<td>W Ijomah [Ref. 14]</td>
</tr>
<tr>
<td>2002</td>
<td>'The process of rebuilding a product, during which: the product is cleaned, inspected and disassembled; defective components are replaced; and the product is reassembled, tested and inspected again to ensure it meets or exceeds newly manufactured product standards’’</td>
<td>E Sundin [Ref. 15]</td>
</tr>
<tr>
<td>2004</td>
<td>'Remanufacturing is the practice of taking end-of-life goods and re-engineering them back to as-new condition, with warranty to match.'</td>
<td>D Parker [Ref. 120]</td>
</tr>
<tr>
<td>2004</td>
<td>'Remanufacturing is the process of disassembling, cleaning, inspecting, repairing, replacing and reassembling the components of a part or product in order to return it to like-new condition.'</td>
<td>Nasr [Ref. 12]</td>
</tr>
<tr>
<td>2004</td>
<td>'An industrial process whereby products referred to as cores are restored to useful life. During this process, the core passes through a number of manufacturing steps e.g. inspection, disassembly, cleaning, part replacement/refurbishment, reassembly and testing to ensure it meets the desired product standard.’’</td>
<td>E Sundin [Ref. 18]</td>
</tr>
<tr>
<td>2005</td>
<td>'Remanufacturing is the generic term that describes the process in which recovered good, or core, is transformed through cleaning, testing, and other operations into a product that is tested and certified to meet technical and/or safety specifications and has a warranty similar to that of a new product.’’</td>
<td>World Trade Organisation (WTO) [Ref. 9]</td>
</tr>
</tbody>
</table>
The Remanufacturing Institute definition provides the most comprehensive overview of what constitutes a remanufacturing process. However, it is not concisely expressed and therefore lacks a certain potency. In addition, the earlier definitions of remanufacturing focus on technical and engineering standards as a benchmark for quality. Later work, as from the Remanufacturing Institute, tends towards outcome measures i.e. ‘working condition’. In our opinion, the requirement from the customer’s point of view is that of guaranteed performance. This might be achieved by improvements to the design of failed components, and even a down-grading of over-engineered components.

The second point is that remanufacturing is a manufacturing process, generally of multiple steps, parallel or sequential. Without being prescriptive, it is necessary to differentiate this from a simply ‘wash-and-brush-up’ or a simple material reprocessing step.

Our preferred definition, although lacking detail, tries to simply capture the essentials, and is based on Ijomah’s and Nasr’s descriptors:

“Remanufacturing is a series of manufacturing steps acting on an end-of-use part or product in order to return it to like-new or better performance, with warranty to match.”
From here, this will be taken as our standard definition of remanufacturing.

5.4 Conclusions

This review, together with the recommendations of industrial practitioners gathered through our stakeholder event, suggest a harmonisation of terminology is required. Although this may be difficult across different sectors, there should at least be references to the salient features of the activities that are consistent with repair, re-use, remanufacture etc. These features will centre on broad issues of:

- **Intent**: the broad nature of re-use, in identical, lower quality, or different applications.
- **Process**: the nature of the steps taken between end of use and next life, and the degree of diagnosis, remediation and replacement undertaken.
- **Warranty**: the nature of the guarantees that are provided by the manufacturer and/or retailer to the re-user.

We propose that this issue be tackled on two fronts:

1. At a high level, by reviewing, adjusting and more widely publicising the efforts to date in establishing ISO standards in the area. The best example of this is that recently achieved by Xerox.

2. At the sector level, working with motivated sectors to rationalise terminology, converge to more centralised definitions and, where necessary and appropriate, define good working practices for Process and Warranty.

Ultimately, some form of labelling or accreditation – even if adopted on a piecemeal basis – may be beneficial in underwriting the value of valid and appropriate re-use options.
6  A Map of Re-use

The simple examples from previous sections indicated the potential complexity of terminology. This would become especially contentious if the legal implications of term use were to become the source of contention, for example, as has been the case with the definition of waste.

As a first step, we have therefore compiled a wide range of terms relevant to re-use, approximately ranked to capture the quality of ‘value retained per unit of recovery effort’. This is not a scientific analysis, merely a framework for further expansion and modification.

Table 6: A Map of Re-use Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Direct re-use (return resale)</th>
<th>Remanufacture</th>
<th>Recondition refurbish</th>
<th>Redeploy (re-use)</th>
<th>Repair</th>
<th>Repurpose</th>
<th>Recycle incineration landfilling</th>
<th>Terminal options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resale of faultless unused goods</td>
<td>Resale of as-good condition</td>
<td>Return to as-good condition with warranty</td>
<td>Lower level of remanufacture</td>
<td>Re-use as-is in same application</td>
<td>Fix a failure</td>
<td>Re-use of all or part in another application</td>
<td>Terminal options</td>
<td></td>
</tr>
<tr>
<td>Disassembly</td>
<td>Selective</td>
<td>Selective</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>Selective</td>
<td>Selective</td>
<td>System</td>
</tr>
<tr>
<td>Testing</td>
<td>System</td>
<td>Selective</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td></td>
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<tr>
<td>Upgrade</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Same Application</td>
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<td></td>
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<td></td>
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<tr>
<td>Secondary Market</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Warranty</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Key:</td>
<td>Present</td>
<td>Absent</td>
<td>May be present</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Testing relates to components of complex assemblies unless stated otherwise. Note: Disassembly relates to components of complex assemblies unless stated otherwise.
6.1 Discussion of the Map

The map presented in Table 6 broadly characterises the similarities and differences of various aspects of re-use. In the upper half of the table, green implies presence of the characteristic, red the absence or inapplicability and orange means a contingent presence.

- **Disassembly:** Remanufacture is the only process that requires systematic disassembly. Reconditioning or refurbishment may require disassembly of between none and all of the item. In repurposing, some or all of the item is put to a different use, hence there is no emphasis on component performance.

- **Testing:** Remanufacture is the only process that requires component-level testing. Reconditioning or refurbishment, applying lower standards, may restrict testing to critical sub-components, the assembled system only, or none at all. Direct re-use will generally involve a whole-item soak test, such as for electronics. Redeployment and repair involve testing to ensure the entire assembly functions acceptably; repurposing involves a similar degree of inspection.

- **Warranty:** Direct re-use and remanufacture, by definition, imply as-new warranties. Reconditioning, redeployment and repair will invoke warranties that are less than for new items and remanufactured. They may extend only to the limit of the warranty on the greater assembly, if they are sub-components. In repurposing, as would be expected of an item moving from original application, warranties will be highly contingent on the criticality of the new use.

In the lower half of the table, the resource inputs have been characterised broadly on a high-low range. It should be noted that these assessments are also assessed bearing in mind also the inputs required for first-use manufacture. This is especially reflected in the remanufacturing characteristics where labour will be higher, but energy and material consumption considerably lower in absolute terms compared to manufacture (but still substantial compared to the other re-use options).

- **Labour content:** In this category, remanufacturing presents a relatively high input option. This is reflection of the fact that the artefact requires considerable work in disassembly, testing and remediation; similarly for reconditioning. Re-use (direct or otherwise) and repair correspondingly require low inputs. The labour needs for repurposing are highly dependent on the use.

- **Energy (and materials) content:** Similar considerations to labour apply.
6.2 Use of the Map

We propose that this map be used as a means of discussing the differences and similarities of options. Further, perhaps requiring extension, it can be used as a basis for generating qualitative and quantitative metrics in one or more dimensions. For example, there have been previous attempts to characterise labour, energy, materials, value, the various ratios of which can reveal extra-ordinary variations in added value per unit mass, labour productivity and energy use per unit value.

This area has not been well examined (in the UK at least) as will be seen from the subsequent literature review. However, it may provide a critical platform for creating fiscal measures that measure and reward materials and energy-efficient practices.
7 A Review of Remanufacturing Literature

Section 5 has drawn heavily on the work of academics in gaining a view of the in-use definition of remanufacturing. This section is oriented towards uncovering which aspects of the remanufacturing environment have been the subject of research.

7.1 Introduction

Remanufacturing is a process that has received increasing interest in the context of the need to ensure that future economic and manufacturing growth is sustainable, that is: “a development that meets the needs of the present without compromising the ability of future generations to meet their own need” (WCED, 1997, [Ref. 260]). The difference between sustainable and industrial agendas was defined by Stahel (1997) [Ref. 255], who described the former as “a long-term societal vision, concerned with the stewardship of natural resources (stock equals wealth) in order to safeguard the opportunities and choices of future generations”; the latter, meanwhile, is described as a ‘short-term optimization of throughput in monetary terms’. The need to move manufacturing onto a ‘greener’ footing, and therefore closer to a sustainable vision is evident in that virgin development uses high levels of both energy and raw materials. The cost ethic, which replaces energy by cheap labour to drive down purchase prices, means that it is often cheapest simply to discard an old product and develop again from new, thus producing waste.

The OECD (Organisation for Economic Co-operation and Development) states that the generation of municipal waste has increased by around 40% since 1980, and is likely to increase by a further 43% in the years to 2020 (OECD, 2001a) [Ref. 237]. This statistic is so alarming that the OECD gives it a code red, indicating that the situation is in need of immediate redress. Such generation of waste material would probably be unsupportable, as the means to dispose of it may well be overwhelmed (King and Burgess, 2005) [Ref. 24].

This has led the drive to ‘Extended Producer Responsibility (EPR)’ and its application in respect of End-Of-Life (EoL) product take-back (Seitz and Peattie, 2004) [Ref. 250], and there have been several recommendations and directives issued in this regard. Examples are: EUROPA (2000) [Ref. 209], which describes EoL requirements for the automotive sector, OECD (2001b) [Ref. 238] which provides guidance for governments on how the EPR issue should be addressed, and EUROPA (2003) [Ref. 210], which regulates the
disposal and re-use of waste from electrical and electronic equipment (WEEE). This last directive is particularly worthy of note because of the specific problems which electrical and electronic wastes pose: A recent UK Update Report (ICER, 2005) [Ref. 217] suggested that a million tonnes – or 93 million items – of electrical and electronic equipment are discarded on an annual basis. This is nearly twice as much as was previously thought, and has the potential to cause a serious threat to environmental sustainability.

The WEEE Directive (EUROPA, 2003) [Ref. 210] is intended to achieve three key objectives:

- Reduction of waste arising from EoL electrical and electronic equipment (defined as being any component powered via either mains electricity supply or batteries);
- Improvement and maximisation of recycling, re-use, and other forms of recovery of EoL electrical and electronic waste materials;
- Minimisation of the impact upon the environment from the treatment and disposal of electronic and electrical EoL equipment.

In order to achieve these goals, it is necessary to gear products toward the EoL scenario. Duflou et al. (2005) [Ref. 208] identified two significant tasks: product re-use, and product disassembly, with optimal re-use of parts and components. Design for disassembly (DFD) is a significant issue in WEEE re-use, as most components and products are not designed with disassembly in mind.

There are several reasons for this ranging from: the additional expense that the DFD process incurs; to the physical quality of certain components, which by EoL may make disassembly extremely difficult – and perhaps not worth doing as the quality of the component may be such that it is not fit for re-use anyway; to the time taken to achieve disassembly, and likely loss of productivity that would result. Subsequent sections of this report examine suitable methods for achieving product re-use, studying suitability and issues regarding implementation.

### 7.2 Methods of Product Re-use

Stahel (1982) [Ref. 253] differentiated between a ‘fast-replacement’ system, or ‘open-loop’ approach, characterised by short-life, incompatible goods and products lacking ‘reparability’, and a ‘self-replenishing’, or ‘closed-loop’ system, characterised by the ability to extend product life expectancy, and the reduction of product waste. This closed-loop approach, adapted from Stahel’s original, is shown in Figure 7.2. The size of the loop determines the amount of energy required to undertake the process.
Figure 7.2: Self Replenishing Loop

Lund (1996) [Ref. 71] and Alonso-Rasgado et al. (2004) [Ref. 200] describe remanufacturing as becoming the generic phrase to describe the process of restoring discarded products to useful life; there are, however, other methods of product re-use: Repair, Reconditioning, and Recycling. Moreover, as Sundin (2004) [Ref. 18] suggests, such terms are by no means universally accepted: automotive component manufacturers describe themselves as ‘rebidders’, whilst road tyre renewal is referred to as ‘retreading’, and revitalising cartridges or batteries is known as ‘recharging’. If product renewal is not extensive and involves the replacement of only a few components, it is often referred to as reconditioning or refurbishing (Sundin, 2004) [Ref. 18]. These terms may also be applied where a product is only restored to its original specifications (Ijomah et al, 1999) [Ref. 218].

Other cultures and countries also use different terms to describe remanufacturing. In Japan, for instance, the process is known as ‘inverse manufacturing’ (Kimura & Suzuki, 1995; Kimura, 1999) [Ref. 222, 224]. In addition to these definitions, the whole process which includes restoration of older products is referred to by Wong (2004) [Ref. 264] as an ‘innovative product service system’. This focus on provision of functional, or ‘Total Care’ products is dependant upon a number of factors. Alonso-Rasgado et al. (2004) [Ref. 200] highlighted these as being the high capital cost of the product, followed by the increasing cost of service and maintenance over time. The maintenance cost is often accepted as being intrinsic to the purchase of a long life-cycle product, but the key purchase decision often rests on the amount of initial financial outlay required. However, this scenario does not take into account after service costs such as disposal / re-use.

The next section examines each of the major four methods for facilitating product re-use: repair, reconditioning, remanufacturing, and recycling in turn, and analyses the positives and negatives of each product as an EoL solution.
7.2.1 Repair

Repairing a product is the process of rectifying a number of given faults with a product and returning it to useful service. King and Burgess (2005) [Ref. 24] describe it as the most logical approach to closing the loop on product use. Stahel (1982) [Ref. 253] describes it as elimination of secondary damage such as worn components, or cosmetic damage (e.g. dents). Repairing a product minimises the energy and material needed to keep it in use at the expense of not offering an updated or improved functionality.

There are a number of disadvantages to this approach. Firstly, the quality of a repaired item tends to be inferior to a newly produced, remanufactured, or recycled version. Warranties for repaired items are also shorter and less comprehensive than those for other methods of EoL re-use. Thus a warranty may cover only the repaired components of the product, rather than the product itself. Cooper and Mayers (2000) [Ref. 206] suggested that consumer decisions on whether to have a product repaired, reconditioned or disposed of were based on age of product, service life remaining, and cost. If the product was relatively inexpensive and was perceived to have a short in-service life remaining, the consumer was unlikely to have it repaired. This is reflected in a four-fold increase in repair costs over as-new purchase costs in the 1980s and 1990s.

7.2.2 Reconditioning

This method of re-use is described by Stahel (1982) [Ref. 253] as the process of putting a product back into prime condition. Examples are overhauls of machinery, and restoring old seals in damp operating environments. King and Burgess (2005) [Ref. 24] describe it as

“Rebuilding of major components to a working condition rather than as-new.”

However, components which have either failed or are on the verge of doing so are replaced or rebuilt.

Whilst this produces a product restored to full working order, the product is clearly second-hand (King and Burgess, 2005) [Ref. 24]. As such, it offers nothing new to the consumer, whilst appearing aesthetically unpleasing, old and possibly outdated. It therefore offers a suitable product to offer to people on benefits and low income families who would otherwise find such goods unaffordable (DARP, 2005) [Ref. 207], but a lower performance specification and warranty than alternative as-new items means that reconditioned products tend to experience serious market acceptance issues.
7.2.3 Remanufacturing

This method of re-use is the only one in which the performance of a used product is returned to at least the Original Equipment Manufacturer’s (OEM’s) performance specification. In addition, remanufactured items possess a warranty which is equal to that of equivalent new products (King and Burgess, 2005) [Ref. 24]. There are many such generic sets of steps throughout the literature (Bras and Hammond, 1996) [Ref. 13]: Stahel (2003) [Ref. 256] describes remanufacturing as ‘service-life extension of goods and components’ and the creation of ‘new products from waste’; Nasr (2004) [Ref. 12] states that remanufacturing is “the process of disassembling, cleaning, inspecting, repairing, replacing, and reassembling the components of a part or product in order to return it to like-new condition”.

Sundin (2004) [Ref. 18] describes it as: ‘an industrial process whereby products referred to as cores are restored to useful life. During this process, the core passes through a number of manufacturing steps, e.g. inspection, disassembly, cleaning, part replacement/refurbishment, reassembly and testing to ensure it meets the desired product standards’. It is a process that is particularly relevant to the re-use of complex electronic equipment, which tends to have a core, which, when recovered will possess an added value that is high in comparison to its actual market value, and to its original value (King and Burgess, 2005) [Ref. 24]. Ijomah et al. (1999) [Ref. 218] describe the remanufacturing process as follows:

1. Receive the core (i.e. the parts of the product to be remanufactured).
2. Strip and clean the core into individual elements. Since used parts may be dirty, they are dismantled and appropriately cleaned; A visual inspection will discard badly damaged elements.
3. Estimate and quote remanufacturing costs. Since many remanufacturing companies are subcontractors to the OEMs, the cost of remanufacturing is often estimated on each product to determine the appropriate re-use strategy.
4. Remanufacture. If the component is suitable, the appropriate machining and fabrication processes will be used to remanufacture the component to ‘as-new’ specification.
5. Build, test, and despatch. Finally, the remanufactured components are reassembled (together with necessary replacement components) to build the new product. After appropriate quality testing, the product will be despatched for sale.

Sundin (2004) [Ref. 18] identifies three distinct sets of actors within the remanufacturing process:
• The Original Equipment Remanufacturer (OER), which is in fact an OEM that undertakes to remanufacture its own products from service centres, trade-in agreements, or end-of-lease contracts.

• Contracted Remanufacturers, which are organisations that are contracted to remanufacture certain products on behalf of other companies. This usually means that the OEM retains ownership of the product, but chooses to outsource remanufacturing rather than undertake the process internally. The OEM is then able to sell the product back to the consumer for a slightly lower price.

• Third Party Remanufacturers. These are organisations that commonly remanufacture independently of the OEM. Their business relies upon sourcing sufficient cores to make the business profitable. Sourcing may be achieved through the collection of redundant products cores from the consumer, and the process is likely to require the purchase of new or replacement components, probably from the OEM.

Sundin (2004) [Ref. 18] emphasizes that these categories are not mutually exclusive, and that some remanufacturing organisations may belong to more than one category.

There are various benefits to remanufacturing as a method of product reuse: the process provides an as-new product with the potential to be upgraded, and added value might render remanufacturing economically viable as an independent process. Jacobsson (2000) [Ref. 220] lists the following benefits for the OEM/OER:

• The OEM owns the only complete set of product specifications, allowing a uniquely qualified viewpoint on the validity of product remanufacture and modification. This information could be sold on to a second tier remanufacturer.

• The consumer network for the remanufactured product is likely to be the same as that for the as-new product.

• Knowledge of consumer patterns provides the OEM with a basis for evaluating remaining values in the discarded product.

• Knowledge of the original product marker may allow the OEM to judge the size of the market for remanufactured goods according to estimated demand. It also enables the OEM to best judge how to place the remanufactured product within the market.

• The OEM may be able to use its reputation to offset perceptions of remanufactured goods as being second hand.
• The OEM has equipment, competencies and infrastructure for manufacturing in place which can be reversed for remanufacturing. Thus the need to invest in a remanufacturing operation is minimised.

• The high volume output of the OEM allows for potential investment in remanufacturing techniques.

• The OEM is able to profit more easily from remanufacturing, as the capability to use recovered parts in the remanufacturing operation exists. This should provide a higher return than if the parts were sold or scrapped.

7.2.4 Recycling

‘Recycling involves the separation and collection of materials for processing and remanufacturing into new products, and the use of the products to complete the cycle’ (Pennsylvania Department of Environmental Protection, 2005) [Ref. 243]. This is the method of re-use most clearly established within the public consciousness, where it is inextricably linked with the concept of waste reduction. The following business benefits of waste reduction appear on the Internet (Business Link, 2005) [Ref. 203]:

“A strategic approach to waste reduction can bring a range of key benefits to your business:

• You can save money through more efficient use of raw materials, packaging and technology.

• It allows you to cut your waste disposal costs

• Compliance with environmental legislation becomes more straightforward and cheaper.

• You can improve your reputation among customers, suppliers, potential employees and insurers, who may want to be sure that you take your environmental responsibilities seriously. You may also boost the morale of existing staff.”

In some product families, recycling rates have reached as high as 80% (EUROPA, 2003) [Ref. 210], recycling being the most easily understood of waste reclamation strategies by the public. However, Chick and Micklethwaite (2004) [Ref. 205] point out that designers tend to be wary of reusing recycled components because such items can have variable quality.
7.3 Consensus: What is the best method of reuse?

In 1982 Stahel highlighted the differences between ‘open’ and ‘closed’ loop systems of manufacturing production, as referred to earlier. His open loop system involved producing an item, whose serviceable life was the same as that of its weakest component. At the point of failure, the item was disposed of, creating waste. An alternative, ‘slow replacement’ approach involves using materials with a longer life span, thus allowing the product a longer useful life, and halving the amount of waste overall. These approaches are characterised by the complete loss of the product materials as waste at the point of disposal.

The alternative ‘closed’ loop “creates an economy based on a spiral-loop system that minimises matter, energy-flow, and environmental deterioration without restricting economic growth or social and technical progress” (Stahel, 1982) [Ref. 253]. The less energy expended during the material reclamation phase, together with minimisation of product waste, should result in a higher profit margin, as highlighted by Stahel (1994) [Ref. 254], who pointed out that the smaller the closed loop cycle, the greater the potential profitability of the system. Therefore, as King and Burgess (2005) [Ref. 24] pointed out, this should mean that repaired or remanufactured products (less energy expended and potentially more profitable) are more common place than recycling, the economic value of which decreases as volume increases (Stahel, 1997) [Ref. 255]; yet, paradoxically, recycling is much more common, and is the method that enjoys the greatest levels of public awareness.

King and Burgess (2005) [Ref. 24] use the first two laws of thermodynamics to substantiate Stahel’s viewpoint. These state (Online Biology Book, 2001) [Ref. 239]:

**Law 1.** Energy can be changed from one form to another, but it cannot be created or destroyed. The total amount of energy and matter in the Universe remains constant, merely changing from one form to another.

**Law 2.** In all energy exchanges, if no energy enters or leaves the system, the potential energy of the state will always be less than that of the initial state.

The first law suggests that energy cannot be lost from a product, but can only alter form. The best way of achieving this in a manufactured product is via a closed loop system, allowing continuity in product redesign whilst excluding potentially harmful waste. Law 2, however, suggests that additional energy is required to transform the system (the waste reduction
process). This is synonymous with entropy: As energy declines, disorder increases, so fresh energy is required to reinvigorate the system. This is also the case in the waste reduction problem, as the high level of energy required to manufacture the product decreases until the low energy waste is expelled in a state of disorder at End of Life (EoL).

If this concept is applied to the four types of feedback loop, then it can be seen that a method with a larger loop, e.g. recycling, requires more energy to transform a disordered mass of recycled comments that either remanufacturing or repair, where the primary shape of the product is maintained (King and Burgess, 2005) [Ref. 24]. This is what is meant by preservation of embedded energy.

Table 7.3 (below) is adapted from King and Burgess (2005) [Ref. 24], and lists the principle advantages and disadvantages of each method of materials re-use.

### Table 7.3: Comparative Benefits of Re-use Options

<table>
<thead>
<tr>
<th>Option</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair</td>
<td>1. It minimises the amount of energy needed to keep product in use</td>
<td>1. Very little infrastructure is in place to provide this service</td>
</tr>
<tr>
<td></td>
<td>2. It minimises the amount of material needed to keep product in use</td>
<td>2. Customers do not receive updated models</td>
</tr>
<tr>
<td>Recondition</td>
<td>1. It allows new low-skilled labour markets to establish new jobs</td>
<td>1. Customers do not receive updated models</td>
</tr>
<tr>
<td></td>
<td>2. Relatively low cost of reconditioning means product is ideal for low income families</td>
<td>2. Few products can be economically reconditioned and then resold at a profit</td>
</tr>
<tr>
<td>Remanufacture</td>
<td>1. As-new product has the potential to be upgraded</td>
<td>1. Difficult to reclaim products efficiently</td>
</tr>
<tr>
<td></td>
<td>2. This may provide sufficient added value to render product economically viable</td>
<td>2. Products tend not to be designed for ease of disassembly</td>
</tr>
<tr>
<td>Recycle</td>
<td>1. Relatively easy to collect waste material through existing disposal routes</td>
<td>1. Existing energy within product is lost during recycling process</td>
</tr>
<tr>
<td></td>
<td>2. Existing wide public understanding</td>
<td>2. Quality and supply of recycled materials is difficult to guarantee</td>
</tr>
</tbody>
</table>
Note also that this analysis is not a comparison in absolute terms of the environmental benefits compared to recycling. Previous work has identified when remanufacture is feasible (in broad terms), but not necessarily when it is desirable. In simple cases it may be clear that re-use is preferable environmentally to recycling, but a fuller life-cycle assessment may often be required. Such a decision process has been the subject of other research work within the Pilot activity, but is not expected to come to fruition until some time into Year 2.

Recycling is widely understood and achievable due to the ease of collecting recycle-suitable waste (Parfitt and Thomas, 2001; Thomas, 2004) [Ref. 240, 258]; As Kimura et al. (2001) [Ref. 225] point out, “due to rapid technological progress, old parts can no longer be used for the next generation products. It may be very difficult and expensive to collect/clean/refurbish used parts, and to make fair quality assurance for them”. Thus a reliable source of quality recyclable parts may be difficult to establish. On the other hand, King and Burgess (2005) [Ref. 24] state that many manufacturers view recycling as an additional cost with little or no financial benefit, since scrap values are often less than recycling costs.

As King et al (2005) [Ref. 24] point out, repairing a product to extend its life is the most logical approach to product/material re-use. In terms of environmental benefit, repair is clearly the better option because less energy is needed and virtually all material is kept. However, its practice is low and, as mentioned earlier, this method suffers from poor market perception.

Reconditioning offers greater potential product performance (Ijomah, 2002) [Ref. 14], but suffers from many of the same problems as repair (King and Ijomah, 2004) [Ref. 227], in that it is frequently seen as being ‘second hand’, and thus has significant market perception issues. It can also be difficult to make a profit from reconditioning activities, particularly in consumer products where there is intense new price competition, often at the expense of durability.

In remanufactured goods, however, the quality of the product can be extremely high (Kimura et al, 1998) [Ref. 223]. Furthermore, King and Burgess (2005) [Ref. 24] suggest that if products can be remanufactured such that the renewed product is up-to-date with market trends and expectations, then a profit can be turned, and the remanufacturing process can be rendered economically viable. Ijomah (2002) [Ref. 14] also states that remanufacturing produces products of a higher performance capability than the other re-use methods. Remanufacturing does suffer from issues such as difficulties in reclaiming parts, partially because products tend not to be designed for ease of disassembly (see Table 7.3). These disadvantages are often shared by other methods of re-use, and the advantages of manufacturing seem to indicate its use is more suitable than other methods.
7.4 Issues with the Implementation of Remanufacturing

Lindahl et al. (2005) [Ref. 30] state that product recovery has traditionally been viewed as an economically beneficial alternative to the ordering of new products. However, there are four principal barriers to the implementation of remanufacturing (King and Burgess, 2005) [Ref. 24]. These are reverse logistics, disassembly, component inspection, and customer demand. In addition, Sundin (2004) [Ref. 18] lists the following factors, drawn from earlier research by Hammond et al (1998) [Ref. 21]:

- The availability and cost of replacement parts.
- Product diversity.
- Cleaning/corrosion.
- Design related issues (complexity, fastening methods, means of assembly and disassembly, increased part fragility).
- Employee skills.

Parlikad et al (2005) [Ref. 242], meanwhile, suggest that amongst the problems faced by ‘demanufacturers’ are a high variety of products, and uncertain product condition after usage. As such, a large quantity of information is required about a product before it can enter the remanufacturing process. Parlikad et al (2005) [Ref. 242] state that this is a major obstacle to the efficient recovery of value from returned products. The following look at barriers to remanufacturing uses the headings proposed by King and Burgess (2005) [Ref. 24], as headings suggested by other authors tend to fit within the broader four heading classification.

7.4.1 Reverse logistics

Traditionally, the supply chain is seen as a one-way structure with a well-defined hierarchy, where goods are used for a certain period, and then discarded. However, remanufacturing inverts this process, reversing the usual logistical approach. The main aim of reverse logistics is to add economic, ecological and legal value to the product returned (Marques and Aguiar, 2004) [Ref. 232]. However, as King and Burgess (2005) [Ref. 24] illustrate, there are several problems in achieving this: The EoL product needs to be transported to the remanufacturing centre, and this can incur substantial costs; the cost can vary significantly between customer and location, which means that costs are difficult to define and predict; there is also the space aspect, as large quantities of products awaiting remanufacture can take up a considerable area. This area may be unavailable, and may incur further costs.
The difficulties mentioned earlier in reclaiming parts for remanufacture also cause a problem, as variability of supply can lead to an unpredictable output, and affect availability to the secondary market. This can affect profit and the economic viability of the remanufacturing process. Finally, the identification and handling of returned goods can present issues, due to the potentially large variety of returned products and components, which could be in a damaged condition. This can render part identification extremely difficult, and cause problems because make and model details are crucial to the successful remanufacture of the product.

### 7.4.2 Disassembly

Disassembly is a particular problem within the remanufacturing process. Many authors address disassembly issues from the point of view of disassembling for material recycling. From a remanufacturing perspective, this is not necessarily sufficient, as it encompasses material re-use rather than whole component or product re-use. For example, Sakai et al (2003) [Ref. 249] propose heating EoL components to release materials which can then be recycled. Whilst this reduces time for disassembly, and associated labour time and costs, it is likely to prove unsuitable for remanufacturing as the heating process could damage the extracted components.

Weiss and Karwasz (2005) [Ref. 261] note that designers should consider disassembly issues in the very early stages of the product design process to target lower waste and energy loss from the product at end of life (EoL). However, they suggest that over 90% of waste from products cannot be utilised because it contains multiple materials and compounds. This would suggest that little thought is currently being given to designing products with EoL recycling or remanufacturing in mind. This point is also made by King and Burgess (2005) [Ref. 24], who citing further reasons why disassembly can prove a significant issue for remanufacturers as: The poor condition of products and components when they reach EoL; and the fact that many products are manufactured overseas, meaning that assembly logic and sequence information is frequently unavailable.

### 7.4.3 Component inspection

Component parts need to be inspected either visually or mechanically in order to confirm their suitability for remanufacturing. These inspections focus particularly on the condition of the component (Kagan et al, 2004) [Ref. 221] as well as the dimensions of the part to ensure that it is suitable for re-use. Certain components which are in good condition can be included in the remanufacturing process, whilst others, which may be either damaged or in generally poor condition, can be recycled (King and
Burgess, 2005) [Ref. 24]. Further checks must also be undertaken to ensure the quality of the remanufactured parts before they can be reintroduced to the market (Franke and Seliger, 2004) [Ref. 212]. King and Burgess (2005) [Ref. 24] suggest that this can be a large cost issue for the remanufacturers, citing:

- Components which will be unsuitable for remanufacturing blocking access to those that have the potential to be remanufactured. Inspection is therefore not always a quick or simple practice.
- Difficulties identifying the degree to which a component has worn or distorted unless there is access to an original as-new component for comparison. This can create problems in judging suitability for remanufacturing.
- The effort needed to inspect physically complex assemblies being disproportionate to the value of remanufacturing. Proxy methods of inspection may permit early identification of critical issues and prevent unnecessary transport of unviable core.

### 7.4.4 Customer demand

"By far the greatest policy barrier to initiate new remanufacturing schemes is having a credible and stable demand for the remanufactured product." (King and Burgess, 2005) [Ref. 24]. It was stated earlier that products created from re-used materials can experience significant market acceptance problems (Cooper and Mayers, 2000; DARP, 2005) [Ref. 206, 207]. King and Burgess (2005) [Ref. 24] outline three key reasons for this:

- A remanufactured product that represents the previous generation of technology, styling, and functionality cannot compete with new products. Cheaper new products may lead to remanufactured products being uncompetitive within the market environment.
- Long-standing customer perceptions of remanufactured goods as second-hand can be extremely difficult to change. Manufacturers are also reluctant to offer guarantees that are all-embracing in case of high product recall costs.
- It is possible that the introduction of a remanufactured product may damage an existing brand in terms of both image and sales. This can make remanufacturers reluctant to introduce remanufactured products. [Recent work by Guide with Bosch suggests that consumers are sophisticated enough to differentiate the offerings on new and remanufactured items, and have a price utility level cut-off (rightly or wrongly). Tests showed that markets were not cannibalised to any economic extent i.e. remanufactured content profitably replaced other repair or supply services.]
7.4.5 Platform design

Platform-based Design is defined by Sangiovanni-Vincentelli et al, (2004) [Ref. 248] as:

- “Laying the foundation for developing economically feasible design flows because it is a structured methodology that theoretically limits the space of exploration, yet still achieves superior results in the fixed time constraints of the design.
- ‘Providing a formal mechanism for identifying the most critical hand-off points in the design chain: The handoff point between system companies and IC (Integrated Circuit) design companies and the one between IC design companies (or divisions) and IC manufacturing companies (or divisions) represent the articulation points of the overall design process.
- ‘Eliminating costly design iterations because it fosters design re-use at all abstraction levels thus enabling the design of an electronic product by assembling and configuring platform components in a rapid and reliable fashion.
- ‘Providing an intellectual framework for the complete electronic design process’.

Sangiovanni-Vincentelli had earlier described platform-based design as “a powerful concept for coping with the increased pressure on time-to-market, design and manufacturing costs” (2002) [Ref. 247], whilst in 2000, he defined a hardware platform as ‘a family of architectures that satisfy set of architectural constraints imposed to allow the re-use of hardware and software components.’

Fanicci et al (2005) [Ref. 211] define platform design for embedded systems as ‘a set of modules, interfaces, services and software that should be as much as possible configurable.’

Goering (2002) [Ref. 213] meanwhile comments that “Platform-based design was introduced several years ago as a concept that would revolutionize chip design and redefine the future of systems-on-chip (SoC). But things haven’t worked out that way. Some platforms are coming into use, but reality has set in: Designing an initial platform hasn’t proven easy and using a platform involves trade-offs. Worse, there isn’t a consistent definition of a ‘platform’

The basic idea behind the platform-based design approach is to avoid designing a chip from scratch. Some portion of the chip’s architecture is predefined for a specific type of application. Depending on the platform type, users might customize by adding hardware, programming logic or writing embedded software. The good news is that a platform limits choices, thereby providing faster time-to-market through extensive design re-use. The bad news is that a platform limits
choices, reducing flexibility and performance compared with a traditional full-custom design methodology.”

Smith (2002, 2004) [Ref. 251, 252] describes platform design thus: “In essence, a platform is a frozen architecture. Once the architecture is frozen, you may standardize the interfaces and give the engineers some choice of building blocks. Actually, the choices range from none (where you make your modifications using software) to multiple choices on multiple blocks. Supposedly, all of the interfaces have been verified for all of the various block combinations. Obviously, the choices are very limited in the beginning of a specific platform and then grow as time goes by, giving the platform builder the time to verify more blocks. That is until the architecture becomes obsolete, which is the main problem with platform-based design.

‘In today’s world of technology, that comes all too quickly. That’s why the word ‘flexible’ is often attached to platform-based design. Unfortunately, flexibility is easier said than done. The best example is the PC platform. Keep in mind that once you change the architecture, you tend to disrupt your interfaces. That calls for a major effort in verification and in setting up the new standards required to keep the platform viable. The dollar cost of Intel’s engineering effort to maintain architectural compatibility — a six-syllable word for disrupting as few interfaces as possible — has been considerable. In design engineering, just as in most everything else, you can’t get something for free.”

Nesci (2003) [Ref. 236] says of platform-based design that “the design process is described as a set of successive refinement steps from a level of abstraction as high as possible all the way down to the details needed for the final implementation. The following layers of abstraction and design steps had been identified:

- System layer: formalization, breakdown and analysis of system specifications;
- Function layer: decomposition of the system in functions and function deployment;
- Operation layer: definition of the functional behaviour in terms of atomic elements referred to as operations (e.g. measurement, control, actuation, transformation, etc.);
- Architecture layer: definition of HW and SW architectures and mechanical components specification;
- Component layer: design of components not available from previous design flows.”

Richter et al suggest that “A platform defines some parts of an implementation while leaving others up to the designer. The system designer therefore has two tasks when using a platform: ensuring that the system specification can be met by the platform; and deriving the specifications for the components not given in the platform. The specifications for the components to be added to the platform during
design must be consistent with the other component specifications and the overall system specification.”

Meanwhile, in 2005, King and Burgess defined platform design as ‘a strategic architecture of common and parametric components that forms the basis for a product family – aimed at meeting either the objective of increased commonality or increased variability. The common components are high-value-added parts to reduce cost and the parametric components vary to suit different customer needs and interface with outer derivative product architecture’. They quote King’s 2002 doctoral thesis in saying “Platform design is an approach to design where a base platform is designed such that it can be used as the basis for a family of derivative products”, and Van Wie et al (2001) [Ref. 259] and Hofer and Gruenenfelder (2001) [Ref. 216] respectively in defining an interface as ‘a spatial region where energy and/or material flow between components’ and a product architecture as ‘the arrangement of component forms to achieve product functions’.

Thus, there are several definitions for platform design across a number of industries, from service providers to systems companies, and from Tier 1 suppliers to chip manufacturers (Sangiovanni-Vincentelli et al, 2004) [Ref. 248]. King and Burgess (2005) [Ref. 24] supply examples of its use in mechanical and electrical design at Volkswagen (Wells, 2001) [Ref. 262], Black & Decker (Lehnerd, 1987) [Ref. 230], Rolls Royce (Rothwell and Gardiner, 1990) [Ref. 245], and Nippon-Denso meters (Whitney, 1993) [Ref. 263].

**Drivers for platform-based products**

The definitions of platform-based design given above suggest a number of qualities that are key drivers for product platforms, namely commonality, which would enable the reduction of cost, and time-to-market, whilst reducing stock holding, and flexibility, which should provide for an increase in market coverage and also customer choice. However, as King and Burgess (2005) [Ref. 24] point out, whilst the optimal solution is a low-cost product with high levels of commonality and flexibility, the reality is that most products are either flexible, or comprised of common components, but seldom both. Bessant and Lamming (1984) [Ref. 201] linked flexibility and cost, and the strong likelihood is that a flexible design will be in some way be mapped to individual customer needs, so reducing product commonality. There is therefore a trade-off between the cost (and opportunity for commonality) and flexibility of a platform-based design (Haubelt et al, 2002) [Ref. 215].

The two extremes each have significant benefits, as King and Burgess (2005) [Ref. 24] pointed out: a commonality strategy can produce significant cost savings, with ‘Volkswagen claiming to save US$1.7 billion annually on
development and production costs by developing a common platform’ (Bremner, 1999) [Ref. 202]. Utilising a flexibility strategy, Honda’s global platform for the Accord car allows three distinct derivatives to be produced for the US, European, and Far East markets. ‘The platform brought savings to allow for the variations in wheelbase, cabin volume, and ride comfort to suit these markets at competitive prices’ (Naughton et al, 1997) [Ref. 235].

The application of platform-based design to remanufacturing

It is possible that the above mentioned principles of commonality and flexibility could be applied to remanufacturing to alleviate certain of the issues described earlier concerning the implementation of remanufacturing. King and Burgess (2005) [Ref. 24] discuss the concept of product utility: “When a consumer buys a product, they relate to it as a single homogeneous product. In other words, it is not viewed as an assembly of individual components but as a single item. Thus, when a product is working and is used it is considered to have a utility value at binary state equal to 1. However, when the product fails or is no longer wanted, the consumer’s perception of the product entirely changes such that its utility value switches to a binary state of 0.” The reason for this is quite often that repair is usually unobtainable or too expensive (Cooper and Mayers, 2000) [Ref. 206].

As such, from the customer’s point of view, the product either has full utility or none at all. The perspective of the manufacturer/remanufacturer differs considerably: A product is an assembly of several different components, each with its own utility, between 0 and 1, depending on factors such as reliability and known failure rate (Parkinson and Thompson, 2004) [Ref. 241]. King and Burgess (2005) [Ref. 24] state that, when a product reaches end-of-life, many of its components will still be fully functional, and therefore potentially reusable in a future product. This is especially the case when the product has fallen victim to ‘the material culture’ (Morello, 2000) [Ref. 233] – a change in fashion or trend. This renders the design obsolete, but not necessarily the functionality of the product, many components of which may not have failed. Indeed, it is possible that the internal functionality is still complete. Even when a product failure has occurred, it is very likely that many components within the system retain a utility and can be re-used in another product.

If this is so, as King and Burgess (2005) [Ref. 24] note, the utility of the components “will lie somewhere between 0 and 1; for example a utility of 0.8 may show that the component only needs cleaning before re-use where 0.5 may show that the product needs to be repaired and recalibrated. Components with a utility of 0.2 may only be useful when cannibalised to reclaim minor parts. Thus, to a producer, an old product should be seen as a collection of discrete components each with different end-of-life utility values.”
As a result of this, King and Burgess argue that where components of a failed or discarded product still retain an intrinsic value, they should be configured in a way to permit ease of identification, disassembly, inspection, and subsequent re-use or remanufacture. As such, the principle of platform-based design is appropriate in the context of product remanufacture, and can be used to solve some of the issues surrounding remanufacture that were mentioned earlier. King and Burgess (2005) [Ref. 24] present two scenarios where this may be the case.

In scenario one, ‘a single complex component could represent a platform if the high-value-added common tooling and manufacturing processes allowed derivative products to be produced at lower cost because the design and production complexity is within the platform. In this case, all other components would be added in a way that would allow easy disassembly without damage to the platform component’.

Alternatively, for scenario two, ‘a platform could contain a large number of smaller components that can either be simply re-used (because their residual quality is still high enough) or be remanufactured. In this case, these components would be designed so that they can be more easily inspected and disassembled, together with other added components also designed for easily removal’.

In the light of this, King and Burgess modified their initial definition of remanufacturing platform design, given earlier, to read ‘a strategic architecture of components that forms a platform of components that are remanufactured for multiple lives on to which a series of ephemeral technology/style components are added’. In so doing, components that retain a high utility value (i.e. towards 1) can be grouped together, forming a base onto which lower-value components can be bolted. Then at the product’s end-of-life, the ephemeral components can be stripped away to reveal a re-useable core that can form the basis of a newly remanufactured product.

### 7.5 Summary: implementation issues

The advent of legislation such as the WEEE Directive (EUROPA, 2003) [Ref. 210] has forced manufacturing organisations to consider after life processing of redundant products. This has brought remanufacturing into focus as a viable method of solving the problem by reusing instead of disposing of end-of-life products and components. However, a number of authors, such as Sundin (2004) [Ref. 18], Parkilad et al (2005) [Ref. 242], and Weiss and Karwasz (2005) [Ref. 261] have illustrated serious technical barriers to the successful implementation of a widespread remanufacturing strategy. Principally, these are: reverse logistics, product disassembly, product inspection, and customer perception. A significant reason behind
these barriers is that at present, remanufacturing is done retrospectively after the design has been fixed (King and Burgess, 2005) [Ref. 24].

A possible partial solution to these issues is the use of platform-based design, which, by means of grouping long-life (higher utility value) components together, provides a base onto which shorter life or disposable components can be attached. This allows the designer to design for disassembly and ease of inspection, so that failed components can be stripped away easily and recycled, whilst the core, re-useable components can be easily checked and sent for re-use or rework. This approach further permits the design of future products to utilise existing component platform, thus increasing commonality and lowering cost. It also allows the manufacturer/remanufacturer to offer an as-new standard warranty with the product, which may go someway to redressing the balance of customer perception.

Design for remanufacture has received moderate attention, but this should be seen in the context of the whole “Design for X” debate: This has received a large amount of attention with relatively small uptake; remanufacture is just one constraint placed on the designer. We interpret the low uptake as the ‘correct’ response to the prevailing legal, social and economic drivers, even if they seem perverse in environmental terms. This simply indicates that the required drivers are not in place. In support of this assertion, we cite the example of Xerox, where platform methods have evolved in response to business demands for re-use exploiting longevity and stability.

However, remanufacturers perceive the scarcity of effective remanufacturing-specific tools as a key threat to their industry ([Ref. 10] Guide, 1999) and research shows that there is a need for analytic models of remanufacturing ([Ref. 11] Guide and Gupta, 1999).

The reviews of work to date suggest a wider view of design is required. Little work has been conducted on the integrated reverse logistics aspects of re-use, and importantly different models of incentivisation of core returns. In addition, the wider context of re-use – the design of the fiscal system to encourage desirable outcomes, has received little attention; some work (e.g. that of Stahel) has addressed macro-economic systems and sector-level productivity metrics, a necessary precursor to any control action.

Consumer issues are more complicated than B2B transactions, and will always be so. Nevertheless, it is productive to understand purchase behaviours in classes of product to understand where re-use might be promoted. Various researchers have uncovered reasons for EoL including technology evolution, peer group pressure, functional under-performance or even emotional rejection. Re-use might therefore explore how owned products might be economically re-energised, and how the risks associated with acquiring another’s discarded products might be overcome.
8 Remanufacturing & Secondary Markets

It is important to acknowledge that consumers are not uniform in their demands of product quality and performance. The property of utility – the perceived overall usefulness, longevity and toleration of goods compared to their price – is a more precise descriptor of the customer’s propensity to buy. Such expectations may be strongly culturally driven, but often seem perverse even within socio-economic groups. This is manifested on the one hand by the clear desire, for example, of developing nations to use hand-me-down technologies such as mobile phones; and on the other, the acceptability in developed countries of handing down (or across) baby cloths and paraphernalia, or FMCG technologies, such as mp3 players, via eBay.

This simply goes to show that consumer behaviour cannot be taken for granted, and that re-use markets can thrive anywhere given appropriate access, information, guarantees and transparency. The fact that much of the activity typified by eBay occurs in a C2C environment also indicates that ‘industrial’ levels of product reprocessing are not required to facilitate re-use. On the other hand, it is not clear to what extent the presence of eBay with its ability to expedite the cascade of functional goods merely results in greater churn and a higher propensity to buy new at the ‘top end.’ These topics have barely been touched in researched, but offer great scope for insight into re-use in action, especially in the hard-to-reach consumer area.

Putting the C2C domain to one side, the idea of cascaded re-use as a large scale retail option has great merit and international precedent. A highly under-exploited mechanism is the example quoted earlier in relation to mobile phones.

This report contains a description of a number of organisations that undertake remanufacturing operations, and describes their perspective on the worth and feasibility of launching remanufactured products into secondary markets. The organisations cover a wide range of goods from mobile phones (Recellular), through ‘white’ electronic goods (Panasonic), to larger, industrial copiers (Xerox).

The organisations are grouped broadly into those who, like Caterpillar, actively seek to create additional markets for their products, and those such as Panasonic, who see the concept of secondary markets as either unfeasible, or as a genuine threat to their business. An Appendix is
provided which contains the transcript of an interview with a remanufacturing manager at Xerox Mitcheldean.

8.1. ‘Pro’ Remanufacturing for Secondary Markets

8.1.1 BT Rolatruc

The typical product flow is broadly circa 4,000 new powered units sold in one year. Approximately 60% of these are ‘sold’ on contract hire - i.e. BTR retains title, typically for a five or six year term. The remaining 40% or so are sold outright to end users and occasionally forklift truck dealers. At the end of the contract hire term, product is returned to us and most is incorporated into our short term rental (STR – also known in the industry as ‘casual’ hire) fleet. Once in the STR fleet, the product will be rented out on non-contract basis for hire periods of at least one week to provide customers with increased handling capacity during their own peak business periods and to cover orders where the new truck lead times are longer than is ideal. This process also helps to recover any residual value position on the product.

The STR fleet is maintained and refurbished at the Fleet Management Centre at Old Dalby, near Melton Mowbray in Leicestershire. Subject to regular reviews, trucks no longer required in the STR fleet are serviced/refurbished to the appropriate standard and released for sale either to forklift truck dealers (there is a trade sales team for used trucks of three people) or released (in a highly refurbished condition) to the field sales team for sale to end users. Some trucks released from the STR fleet are scrapped and some are sold for export to other companies in the BT Group.

8.1.2 Caterpillar Remanufacturing

Caterpillar owns several remanufacturing sites world-wide, including Shanghai, Corinth, Nuevo Laredo, Prentiss, and Shrewsbury, and also incorporates Wealdstone Engineering, Northampton. Caterpillar’s wide scale remanufacturing operation established 7-8 years ago. Development was customer-driven, due to high operating costs of industry.

The remanufacturing system operates in a number of steps, which are as follows:

1. Percentage of profit from remanufacture is returned to partner organisations (e.g. Perkins) as an incentive.

2. Remanufactured parts advertised for sale alongside new parts, the cost of a remanufactured part being approximately 40-60% of new; sales are
made through independent dealers, and parts are stocked in anticipation of demand.

3. The customer purchases a part or product from the dealer, and returns the old product core in return for a discount or partial refund.

4. The dealer pays the ‘as new’ price when buying a product from Caterpillar; when a purchase is made, the dealer receives an ‘entitlement’ – which allows the dealer to return the old product core to Caterpillar to be remanufactured. The remanufacture price difference is repaid upon return of core, as shown by Figure 8.1.2.

Figure 8.1.2: New and Remanufacture Price Differentials

- When dealer orders remanufactured part, they pay full new price ‘n’.
- If they return a composite core within 12 months, they get ‘s’ refund, leaving them with the price ‘r’ paid.

5. Remanufactured part return/exchange based not only on part no. for part no., but also on parts from within the same part ‘family’.

6. Caterpillar’s target is 95% of remanufactured part availability – the Part Shipment Process (PSP) sees Caterpillar receive the product core, and process it to the correct Caterpillar plan; the remanufacturing margin appears to be better than for new products, +90% of core being returned for every remanufactured part sold.
7. The product core is remanufactured, tested, and stocked in readiness for predicted demand.

8. Typically, small customer will tend to by the new product, whilst Industrial-sized organisations, which are more sensitive to operating costs, will purchase remanufactured parts and products.

### 8.1.3 Recellular

The following is taken from Robotis et al [Ref. 140]:

‘ReCellular is a reseller of mobile phones, which procures used and end-of-lease mobile phones from American markets and then resells them in developing markets in the South American or African continents. ReCellular recovered approximately 4 million wireless in 2004 with around 40,000 collection points throughout the United States and Canada. The developing markets do not sell phones based on the latest technologies as the prices charged are too high; hence, there exists a market for these used mobile phones. ReCellular has two options with the phones that it has procured:

- It can either sell these phones directly without any value-adding activities in the developing markets.
- It can add value in terms of remanufacturing the used phones to an as-new condition.

Common problems encountered by remanufacturers in procurement, generally termed ‘heterogeneity of supply’: This can be traced to a large extent to the diversity of sources for collection, and typically manifests itself in the variability in the quality of returns. Social demographics, such as economic class, play an important role.

As an example, consider a region that can be divided into two economically disparate neighbourhoods. The sources of used mobile phones that are collected from regions are typically third parties which are small in size, for example, charity foundations. Used mobile phones that are collected from the region from well-to-do neighbourhoods are more expensive to acquire, and have a higher quality and selling price, compared to phones which are acquired from the less affluent areas. It is suggested that this is due partially to income effects, and partially because people living in affluent neighbourhoods purchase phones of better quality initially. Also, the high quality products have more features and they are made from components of higher quality, hence, the yields associated with the used mobile phones
from affluent neighbourhoods are higher (the average quality of these phones is higher).’

‘ReCellular procures these used mobile phones in bulk quantities from each source like the charitable foundations, and hence pays a common procurement price for all the used phones to each source, as grading them and sorting them at the point of purchase is considered to be time-consuming and expensive. After procuring the used phones, ReCellular sorts out the used phones in terms of quality from the two primary classes of suppliers (this sorting process is done by informal manual testing). ReCellular sells only those used phones in the secondary markets whose quality level is higher than the level required by the market, and it disposes off the rest of the products.’

‘The secondary markets are also heterogeneous, in that there are different classes of customers. These classes are based on the level of quality required by the customer and the prices they are willing to pay. A higher required level of quality is associated with a higher price. In the event of a shortage, used mobile phones of a higher level of quality can be substituted for phones of a lower level of quality.’

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### 8.2 ‘Anti’ Remanufacturing for Secondary Markets

#### 8.2.1 Matsushita Electric Industrial Co Ltd (Panasonic UK)

Matsushita Electric Industrial (MEI) Co. does not consider secondary markets to be a suitable avenue for retail of its products. This is because the brand ‘Panasonic’ is viewed as being synonymous with both quality and corporate identity, but secondary markets are not.

Typically, a Panasonic-brand product – such as a television – is expected to have an operating life of approximately fifteen years, during which it will pass through a number of ‘existences’: From being the main unit for family viewing in the living room, it will be superseded by newer technology, and then will be used in a bedroom or other secondary room. It may then be passed on and used by the children whilst at university, for example. Thus the product gains a reputation for reliability and quality, and MEI hopes that this reputation will lead the consumer to continue to buy Panasonic branded products.

These attributes of quality and reliability are thus of the highest importance to the organisation, and the view is taken that if the product was launched into a secondary market, then control of the brand would be lost. Poor maintenance or repair by a third party leading to substandard product
performance, would likely damage the reputation of the Panasonic brand as a byword for quality and reliability. MEI therefore adopts a risk-averse strategy of brand protection by refusing to place remanufactured products in a secondary market. Instead, products that have been returned and remanufactured are resold to MEI employees at a suitable discount.

8.2.2 A1Mobility

A1Mobility manufactures three- and four-wheeled electric powered mobility scooters and other mobility products such as electric wheelchairs. This organisation would not consider remanufacturing products for a secondary market, because, as a representative explained: “The reason it’s not viable to fix old scooters is the same reason it’s not viable to fix anything these days. A new washing machine / printer / scooter / you name it can be manufactured in the Far East – China/Taiwan/Thailand – for $20 a day (labour cost). Additionally, the Internet has driven retail prices down to ‘trade and a tenner’ so that in order to survive, retailers are helping to ensure that replacement products are reaching the consumer at ‘bargain’ prices. Thus, Western consumer society is creating a mountain of waste products at a rate previously unheard of. This rate is, I believe, set to increase exponentially.”

8.3 Secondary Markets & Ethics

An aspect of secondary markets that has received much attention is that of waste dumping. International trade in waste products has been characterised by pictures of low-wage labour manually ‘disassembling’ western electronics on road-side landfill, or IBCs packed with empty PC carcasses. It is clear that many unscrupulous operators, many associated with waste electronics, are exploiting policing loopholes to move distinctly reject materials – allegedly working or recoverable materials – to low-wage, resource-limited economies. In truth, the percentage of usable and valuable components is low, and the export is a convenient waste export mechanism (for which Rotterdam appears to be a major hub).

This is an area where quite legitimate business is being tarnished by malpractice. Indeed, the diversity of practice within even reputable charitable operators lends confusion to the scene. There is therefore ample scope for exploring and reconciling good practice in this area: systems; acceptable definitions of working goods; usable content; health and safety at destination; treatment of residues at destination; potential re-import etc. This has received little attention academically (although Oakdene Hollins has conducted some research privately), but is undoubtedly a practical barrier to re-use.
In the longer term we must question the current targets for secondary market materials. Our research suggests that Asian countries are rapidly acquiring the expectations of westerners, and the infrastructure to support the lifestyles that go with it. For example, laptops in Tibet may be cheaper than in the UK due to the proximity to the Chinese sources. This means that the demand for used but functional goods in the region is rapidly declining. It is likely that, within ten years, secondary markets will not exist here, and that Africa will present the only opportunity for the activity.

To date, Africa has not seen the level of problem associated with dumping in Asia. Hence, it would be prudent to establish ground rules for good practice that focus on Africa.

### 8.4 Conclusions

The findings of this report suggest that there is a clearly delineated split in organisational perspective where remanufacturing for the introduction of products and services into Secondary Markets is concerned.

Smaller or not-overly-complex products, such as motorised scooters, can be manufactured sufficiently cheaply in other markets that the concept of remanufacture is economically unfeasible. Alternatively, where, as in the case of Panasonic, the brand is so highly prized by the organisation, the fear of losing control over the brand identity is a second reason for avoiding secondary markets.

However, the key to a successful secondary market remanufacturing operation appears to be the ability to influence or control the supply-and-return chain. Where this has been achieved, notably by Caterpillar and also Xerox, a remanufacturing operation thrives, and this in turn makes a secondary market venture feasible both operationally and economically. Arguably, if Panasonic were able to attain such a hold over its supply/return of products, then its entrenched over-protectiveness of its brand would be significantly lessened, and a secondary market operation may become feasible.

The aspect of secondary markets as sinks for lower specification, superseded models has not been well explored, but the allegations and implications of waste dumping are well known. A better definition of ethical operating practices is required. Most of these issues have arisen in Asia, but the markets for second-hand goods from the west are declining as prosperity rises. To date, Africa has not seen the level of problem associated with dumping in Asia. Hence, it would be prudent to establish ground rules for good practice that focus on Africa.
9 The Gap Map

This section draws together what is known about the factors of importance to remanufacturing, and what has been studied to date. The overlap – or lack of it – is an indication of the gaps where there may be either:

- Complete and intuitive understanding: In this case, no further work may be advised, but there may be a role for coding explicit knowledge for wider consumption.
- No clear understanding: In this case, there could be a role for primary research, or reviewing and synthesising disparate prior research, some of which might be contradictory and in need of rationalisation.

The first section reviews what academics and industrialists have said about the state of knowledge in remanufacturing.

9.1 Remanufacturing Factors

To gain some perspective of the weight of research in particular areas, the entire literature review (including the supplement of Appendix D) has been categorised in the following classifications:

- **Political/Legislative (P):** effect of government policy and incentives; definitions of waste; patents; standards for the industry; access to OEM design data; other trade restrictions.
- **Economic ($):** economies of scale; end-of-life values; logistics costs; partnering and supply chain; secondary markets; servicisation.
- **Organisational (O):** parent-subsidiary constraints; structural deficiencies; work flow set-up; skills mismatch; reverse logistics.
- **Social (S):** brand loyalty; convenience; quality perception/attitudes; education, awareness and selling strategies.
- **Technological (T):** design for disassembly; automation; cleaning capabilities; remediation techniques; product diversity; product evolution/obsolescence; upgrading; tracking and tagging.
- **Environmental (E):** environmental/waste benefits; replace/upgrade decisions; recyclability; LCA.

The following statistics illustrate which dimensions have been well-researched and in association with which other factors:
Table 9.1: Topic Coverage in Published Literature

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<td>P</td>
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<td>9 (¬E,5)</td>
<td>3</td>
<td>4 (¬$,$3)</td>
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<td>4 (¬$,$2)</td>
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<td>13 (¬T,5)</td>
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<td>92</td>
<td>56</td>
<td>27</td>
<td>105</td>
<td>87</td>
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Note: light yellow – lone topic in reference
Note: orange – dual topic coverage in reference
Note: ¬X,Y – number of papers (Y) coincidentally with third topic (X) coverage

9.2 Findings and Implications

The bulk of the literature surveyed relates to technological aspects of remanufacturing. To some extent this reflects a particular interest of the authors in design methods. However, this topic appears in association with the topic of Economics ($), Environment (E) and Organisation (O) in large numbers.

- Technology does not operate ‘in a vacuum’; academic research is advanced and intervention should concentrate on practical implementation of learning driven by industry needs.

Economics is strongly represented and associated with all other topics. This may be a reflection of the fundamental recognition of remanufacturing roots in economic benefit, especially discussed by American authors.

- Economics pervades all commercial activity; all interventions need to ensure they are well grounded in profitability as a primary selling point in parallel with wider sustainability benefits.

The topic of Organisation (O) itself appears rarely in isolation, but is highly associated with Economics ($) and, to a lesser degree, Environment (E).

Social issues appear least in number, but are associated almost exclusively with discussions of Economics ($), especially product-service systems, logistics and supply chains. This may reflect remanufacturing as operating at a higher level than the typical social enterprise, which generally deals with refurbishment. However, important – and difficult aspects of customer perception have not been well researched by operators in this domain, but have been identified as key barriers to expansion.
• Greater resource should be directed towards understanding consumer behaviour and how purchase risks and other barriers can be overcome.

Politics is least represented, and to some extent supports the contention that progress in this area needs to move from the technical-systems domain to one in which the wider political and economic environment is primed to be more receptive to the benefits offered.

• Future work in this area should be directed to data and evidence that affects both sector and country level policies; this would include better definition of ‘factor 4’ metrics, standards and fiscal implications.
10 Conclusions

This work, combined with outputs from stakeholder meetings, suggests that terminology in the area of re-use underlies some confusion regarding product standards for remediated end-of-life goods. Efforts to standardise usage within product groups or sectors at least would be beneficial.

A further development would be the wider adoption of formal codes of practice or standards related to processes, systems and warranties associated with re-used items – remanufactured, refurbished and repaired.

Business processes have been well explored and described. However, remanufacturers perceive the scarcity of effective remanufacturing-specific tools as a key threat to their industry and research shows that there is a need for analytic models of remanufacturing. These might usefully take the form of top-level decision aids that can assist building a wider case for support.

Barriers to purchase have not received as great attention. In particular, issues of trust and risk are common, especially in B2C markets. We suggest that a fuller investigation of risk-mitigation strategies and augmented product offerings is conducted. This could also include facilitation of product returns to ensure core volumes.

Secondary markets is a little-explored topic, but offers significant potential in the short to medium term in Asian markets, longer term in African markets but uncertain potential in domestic markets. Evidence base research suggests that many export markets are poorly regulated, exploitative and on the verge of illegality. To avoid regulatory and public backlash that could damage legitimate export-for-re-use, we believe that current practice should be explored and frameworks for ethical codes of key sectors, such as electronics, developed.

Much work has been conducted on the subject of product design in the pursuit of various business objectives, remanufacture being just one example. A catalogue of design approaches is useful, but has utility only in the context of specific product and business requirements. If this context is not correctly set to reward e.g. resource efficiency, then desirable and appropriate design methodologies may never be employed. Design is therefore a function of environment and should only be further developed in the context of real-world projects with commercial drivers.

The wider context of design i.e. the design of macro-economic systems that drive re-use behaviours has not been well researched. However, it is the
measurement systems that indicate benefits – financial, environmental, social – that ultimately indicate both value and the effect of intervention policies. We suggest, therefore, that further work be conducted to derive business metrics relevant to once-through and re-use that adequately highlight the benefits in categories mentioned. Such platform work should be taken forward to examine policy implications.
Appendix A: Reman Supplement

A1 Remanufacturing & small businesses

Aside from environmental benefits, there are many other reasons why remanufactured goods exist. Like many good business decisions, remanufacturing simply saves money by prolonging the economic life of a product. A small business with a tight budget can save money by using remanufactured products because they often cost less (anywhere between 40 and 60 percent less) and come with warranties and extra services that guarantee their performance.

In recent years, remanufacturing has grown into a big business. Recent studies suggest that there are over 70,000 remanufacturing firms employing close to a half million people in the United States. Together, these firms make over $50 billion a year, proving that remanufacturing is a force to be reckoned with in today’s economy. Because of this trend, it would seem that there are many opportunities for small businesses to get in on the action provided by the remanufacturing industry. For example, an auto repair business can easily branch out and start offering remanufactured goods as part of their services, or a small business that repairs office machines will gain the necessary knowledge to remanufacture related products at the same time as it conducts its normal business activities.

If a small business decides to get into the remanufacturing industry, it must first and foremost study and understand the market. Despite the recent success of remanufacturing, there is still a negative perception among consumers regarding products that contain used parts. Many consumers feel that a remanufactured product is not durable as a brand new one and may require additional maintenance in the future. This is a serious issue that must be addressed before a small business decides whether it is worth it to pursue remanufacturing as a vocation.

Like any business venture, remanufactured products must be properly marketed in order for the company producing them to ultimately succeed. Management must target consumers who will appreciate the fact that remanufactured goods are a great financial alternative to new ones, but educate them enough so that they understand they are not sacrificing quality for price. A sound warranty plan and follow-up calls that gauge the product’s performance are also suggested. Like any product or service, a remanufactured product will benefit from positive word of mouth and grow into a solid business because of it.

Inexperienced remanufacturing firms must also be careful not to compete against themselves when marketing remanufactured and new goods at the
same time. In addition, management must work with their own employees so that they understand the many benefits of the remanufacturing process. Many employees may be hesitant to offer remanufactured goods to their customers for fear of potential prejudices regarding the performance of the product.

Most importantly, a small business must have the means at its disposal to locate and recover the products and resources that will be used in the remanufacturing project and ultimately perform the task at hand. Once these products are found, they must be transported to the destination where disassembly will take place. After that, they will most likely be transported to another location that specializes in reassembly. Finally, any unusable parts and products must be collected and transported to recycling centres or other places that specialize in their disposal.

There are many legal and regulatory issues that affect the remanufacturing industry that businesses must be aware of: Intellectual property and anti-trust matters; federal, state and local recycling procedures; and government economic incentives are just a few of them. The Remanufacturing Institute is the watchdog organization for the entire industry and they are constantly monitoring these issues and representing the views of the businesses that are involved in remanufacturing. In addition, the federal government requires that all remanufactured goods must be labelled as such so that they cannot be passed off as new products.

A2 Barriers to Remanufacture

Remanufacturers also perceive the scarcity of effective remanufacturing specific tools as a key threat to their industry [Ref. 10] and research shows that there is a need for analytic models of remanufacturing [Ref. 11].

Remanufacturing operations vary significantly dependant upon the product and market that they are conducted in.

A2.1 Social Barriers to Remanufacture

Social barriers are factors that concern people and their everyday social relationships: demographics, lifestyles, health, and education.

A2.1.1 Brand loyalty

Establishing brand loyalty is purported to be the ultimate goal of marketing. Product sectors that are saturated by strong brands obviously present a significant barrier to the success of independent remanufacturers
breaking through. Brand loyalty is exhibited by a customer’s relative attitude to a specific brand which is then reflected by repurchase behaviour [Ref. 153].

Including remanufactured products can potentially damage the brand either in terms of reducing sales of new products or altering the status or image of the brand [Ref. 24].

A2.1.2 Convenience

Convenience is concerned with the ease of which a product can be disposed of at the EoL. Although awareness of waste is slowly improving, for the average consumer the disposal of a worn out or obsolete product is principally driven by convenience. This is less relevant in business-to-business product recovery as products are often leased or have established take-back infrastructure. Two basic options exist described in the following figure. The waste option reacquires products from waste by sorting and diverting goods from landfill, alternatively the market driven stream offers customers incentives (often financial in the form of discount on new products) to return products the manufacturer.

A2.1.3 Perception/attitudes

Customer association of remanufactured products with second-hand and thus lower quality is very difficult to change. While quality guarantees can be made, manufacturers are reluctant to provide too much in case of large recall charges.
A2.2 Technological Barriers to Remanufacture

Circumstances and (especially) trends concerning the development and application of new knowledge about the world: Scientific and technological developments.

A2.2.1 Access to design data

OEM manufacturers often regard remanufacturers as competitors, and as a consequence intentionally create technological barriers to remanufacturing. An example of this is the Japanese motorcycle industry, given by Lund [Ref. 146], where manufacturers introduce regular design changes that make newer and older models incompatible. Another case is where OEM manufacturers withhold design specifications required for refurbishment in order to limit remanufacturing opportunities [Ref. 154].

A2.2.2 Design emphasis on DFA (disassembly complexity)

When end-of-life products arrive at a potential remanufacturing factory, a manufacturer needs to disassemble the product. This can be difficult and expensive and was found to be a fundamental barrier in a recent review of remanufacturing activity in the UK [Ref. 10]. This can be a large technical barrier to remanufacturing for the following reasons:

- Products are often not designed for disassembly. While certain components are designed to be removed for maintenance, the majority are not. It is thus not always physically possible to remove components (such as those glued, riveted, or welded together).

- The poor condition of some end-of-life products can make it physically difficult to disassemble components that have been damaged or corroded.

- The fact that many products are manufactured overseas (such as in the Far East) often means that the assembly logic and sequence information is not available to the remanufacturer. Thus, having to disassemble a high number of products in order to ‘learn’ the best sequence can be a significant barrier.

A2.2.3 Returns Quality/Inspection

Once the products or parts have been disassembled, the manufacturer needs to find out what condition the products or parts are in. If the parts are suitable for remanufacture they may go to one location; otherwise they would be sent for recycling or landfill. In addition, remanufactured parts need to be quality assured before they can be introduced to the market.
This can be a large cost barrier to remanufacturing for the following reasons.

- As many components will not be remanufactured, these can prevent access to inspect those potentially being remanufactured. It is thus not always possible to assess quickly (and thus economically) the condition of certain components.

- The fact that a component may have distorted or worn is not evident unless an original component is available. Therefore, it can be difficult to judge the level of remanufacturing needed.

- In respect of complex assemblies, the effort needed to inspect physically the assembly may be far more than the benefit of remanufacture. Therefore, it is necessary to develop inspection proxies by which a simple observation can be taken as indicative of more fundamental issues. [Ref. 24]

A2.2.4 Reverse Logistics

In order for remanufacturing to happen, end-of-life products usually need to be returned to a small number of locations. Reverse logistics is the process of collecting back from individual customer’s end-of-life products to a remanufacturing factory. This can be a large cost barrier to remanufacturing for the following reasons:

- The cost involved in the transportation of individual items can often be the most expensive part of the whole activity. This is a particular difficulty as the cost can vary significantly between customer locations and the available transport solution; it is thus difficult to predict and therefore to afford.

- In addition to cost, the space requirements needed to store returned products (whether on route or at the destination factory) are also a barrier. Whilst it can be interpreted as another cost, it can simply be the unavailability of space that makes the reverse logistics difficult.

- Thirdly, the variability of return flow is also an issue as this has a direct effect on the output and thus availability of remanufactured products to customers entering the new market sector. This exposure to unmet demand (which loses revenue and damages customer satisfaction) stems from the low incentive for customers to return products. While the choice is between the household bin and hassle of return (often with very little financial reward), return rates are likely to be difficult to guarantee.
Finally, identification and handling returned products can be difficult. With a huge variety of products potentially returned, often in a damaged condition, quickly identifying each product in terms of make and model is not a trivial matter. Most customers no longer have the original packaging and thus handling the products for optimal storage without further damage is difficult.
Appendix B: The Application of Platform-based Design

From the customer’s point of view, a product either has full utility (it is working) or none at all (it has failed). The perspective of the manufacturer/remanufacturer differs considerably: A product is an assembly of several different components, each with its own utility, between 0 and 1, depending on factors such as reliability and known failure rate (Parkinson and Thompson, 2004) [Ref. 241]. King and Burgess (2005) [Ref. 24] state that, when a product reaches end-of-life, many of its components will still be fully functional, and therefore potentially reusable in a future product. This is especially the case when the product has fallen victim to ‘the material culture’ (Morello, 2000) [Ref. 233] – a change in fashion or trend. This renders the design obsolete, but not necessarily the functionality of the product, many components of which may not have failed.

Indeed, it is possible that the internal functionality is still complete. Even when a product failure has occurred, it is very likely that many components within the system retain a utility and can be re-used in another product. If this is so, as King and Burgess (2005) [Ref. 24] note, the utility of the components ‘will lie somewhere between 0 and 1; for example a utility of 0.8 may show that the component only needs cleaning before re-use where 0.5 may show that the product needs to be repaired and recalibrated. Components with a utility of 0.2 may only be useful when cannibalised to reclaim minor parts. Thus, to a producer, an old product should be seen as a collection of discrete components each with different end-of-life utility values’.

As a result of this, King and Burgess argue that where components of a failed or discarded product still retain an intrinsic value, they should be configured in a way to permit ease of identification, disassembly, inspection, and subsequent re-use or remanufacture. As such, the principle of platform-based design is appropriate in the context of product remanufacture, and can be used to solve some of the issues surrounding remanufacture that were mentioned earlier. King and Burgess (2005) [Ref. 24] present two scenarios where this may be the case.

In scenario one, ‘a single complex component could represent a platform if the high-value-added common tooling and manufacturing processes allowed derivative products to be produced at lower cost because the design and production complexity is within the platform. In this case, all other components would be added in a way that would allow easy disassembly without damage to the platform component’.
Alternatively, for scenario two, ‘a platform could contain a large number of smaller components that can either be simply re-used (because their residual quality is still high enough) or be remanufactured. In this case, these components would be designed so that they can be more easily inspected and disassembled, together with other added components also designed for easily removal’.

In the light of this, King and Burgess modified their initial definition of remanufacturing platform design, given earlier, to read ‘a strategic architecture of components that forms a platform of components that are remanufactured for multiple lives on to which a series of ephemeral technology/style components are added’. In so doing, components that retain a high utility value (i.e. towards 1) can be grouped together, forming a base onto which lower-value components can be bolted. Then at the product’s end-of-life, the ephemeral components can be stripped away to reveal a reusable core that can form the basis of a newly remanufactured product.
Appendix C: XEROX 2ndary Market Experiences

General Background Information

1 What products are remanufactured in your business?
   • Large volume mono and colour printers.
   • Returned equipment which has been under utilised e.g. because of loss of contract etc.
   • Components across the whole equipment range e.g. fuser rolls, circuit boards etc.

2 How long has ‘remanufacturing’ been a part of your business?
   • 25 years – Xerox started refurbishing copying equipment in the early 1980’s at it’s plant in Mitcheldean, Gloucestershire.

3 Could you quantify the size of remanufacturing: (i.e. tonnage of remanufactured goods, value of the business in sales?)
   • I only have figures for 2004: In the UK market, Xerox remanufactured / recycled 3,745 tonnes of printing equipment

Dimensions of Remanufacturing Industry

1 What remanufacturing recovery strategy best describes your business?
   • Over the last 2 years Xerox has reduced it’s remanufacture of whole equipment but raised the remanufacture of components. The reasons for this are:
     1. The cost of maintaining older design equipment in the field is higher than for the new generation of printers – Xerox leases equipment on all maintaining leases and therefore must keep the cost of maintenance to a minimum
     2. New energy consumption standards are more difficult to achieve
     3. Manufacture is being carried out by 3rd party companies in the far east etc making the cost of returning equipment for refurbishment is too high
   • The Xerox strategy has moved to re-use / recycle of components in order to reduce cost of raw materials, however if it is viable to remanufacture equipment in certain product ranges then this will continue. Xerox currently remanufactures its large volume printers as this has proved to be the most cost efficient way of maintaining products in the field.
2 Please describe the type of secondary markets that remanufactured goods are sold too (i.e. developing countries, lower cost second life consumers etc)

- Xerox has sold and leased remanufactured equipment to not only developing countries but to many high profile companies who are looking for the best solution to their printing needs – I do not believe that you can compartmentalise remanufactured sales in the 2 examples above – in today’s financial climate companies are looking for cost savings and if the provision of remanufactured equipment satisfies their requirements then any organisation will take up the opportunity.

3 From your knowledge how many other ‘remanufactures’ are competing in your market?

- Other companies remanufacturing copying / printing equipment on a large scale include OCÉ, OKI and Hewlett Packard

4 What are the benefits of remanufacturing for your business?

- Ability to offer a product at a reduced price to customers who couldn’t afford new products
- Reduces waste disposal in terms of less waste to landfill and reduced costs
- Component remanufacturing reduces the requirement for raw materials
- Keeps Xerox brand name synonymous with ‘green manufacturing’

5 Please describe the major factors/aspects for the following barriers that inhibit remanufacturing for secondary markets in your business? (Those highlighted
in red are the factors that you indicated as being a major concern.)

Xerox Barriers to Remanufacturing

### Social
- Many potential customers are not aware of the specification of ‘remanufacture’ and currently there is no standard – an ISO standard would do much to give customers the metrics with which to compare and provide the comfort feeling as does ISO 14001 and 9001 for environment and quality.

### Technological
- Xerox has been designing for disassembly for some years now, however the main technological stumbling blocks are the need to reduce warm up times and energy consumption – all customers are looking for the latest low energy products

### Economic
- As the WEEE and RoHs regulations take hold across Europe, the concerns we have are with cross border shipments of ‘waste’. In order to maximise remanufacture Xerox needs to be able to return it’s equipment to central sources e.g. Venray in Holland. We have been returning equipment using TNT logistics for many years but are encountering more and more obstacles to cross border shipping.

### Environmental
- As above – the main stumbling blocks are the need to reduce warm up times and energy consumption – all customers are looking for the latest low energy products
Political

• The RoHs directive has banned the re-use of a large amount of items such as circuit boards, fuser modules etc. Xerox has applied for exemptions but so far with little success – our argument is that end of life and obsolescence would finally bring these items back into the hazardous waste stream in a steady flow rather than dumping large quantities.

6 Finally, what do you consider to be the future developments in remanufacturing in your business?

• Increased concentration on the re-use and remanufacture of components.
• I would suggest that the EU should have introduced a directive to force manufacturers to use a minimum of 25% recycled parts, materials in all new equipment when it introduced the WEEE and RoHs directives – this is something which needs to be looked at, otherwise the availability of large amounts of recycled materials such as ABS plastics will reduce the opportunity for resale. A recent illustration of this occurred following the clean up of the World Trade Centre – the sudden increase in availability of steel caused the US steel works to request Government aid to stay in business – Xerox has been recycling equipment for some considerable time and has forged relationships with many customers, following the introduction of the WEEE Directive the market will be swamped by the availability of materials and the waste streams we currently have will dry up making it too costly to continue – unless there is some legislative requirement placed on manufacturers to use recycled materials.
Appendix D: Supplementary literature review

Taken from Majumder and Groenevelt (2001) [Ref. 25]:

Literature related to remanufacturing comes from many sources. The recycling literature includes consumer behaviour about recycling, and competition in recycling. Remanufacturing is also related to secondary markets in durable goods. Many authors have documented the economics of remanufacturing and value recovery. Technical issues regarding remanufacturing have been studied from the engineering perspective. Finally, the operations management perspective has examined remanufacturing with respect to production control, inventory, and multi-echelon/supply chain issues.

There is an extensive body of recycling literature from socio-economics, environmental studies and resource management. While remanufacturing is different from recycling in terms of the specificity of use of the used items, some research merits mention. Clarke, Stavins, Breeno, and Bavaria (1994) [Ref 56] as well as Daniel, Diakoulaki, and Pappis (1997) [Ref. 58] document the challenges of reengineering existing manufacturing and supporting processes to make them more environmentally friendly. Hornik, Cherian, Madansky, and Narayana (1995) [Ref. 70] summarize the determinants of recycling behaviour from sixty-seven empirical studies. They conclude that the strongest predictors of recycling behaviour are internal facilitators: consumer knowledge and commitment to recycling, followed by external incentives, monetary rewards, and social influence.

The durable goods literature is relevant because of the similar effect of endogenous competition due to used items that have been sold earlier. Anderson (1984) [Ref. 55] considers a monopolist selling goods to price-taking customers in the presence of a competitive secondary market. Purohit (1992) [Ref. 122] considers the relationship between the markets for new and used automobiles from a marketing perspective. He concludes that depreciation of used cars is strongly influenced by the types of changes in the new models. Ferrer (1996d) [Ref. 63] has also looked at market segmentation in situations where a manufacturer sells both original and remanufactured goods.

Research on the specific cost structure of remanufacturing has been done by Ferrer (1996b) [Ref. 61] for tyres and Ferrer (1997) [Ref. 64] for PCs. Ferrer (1996c) [Ref. 62] also formulated a generalized cost model drawing on remanufacturing costs in various industries in Europe. de Ron and Penev
(1995) [Ref. 59] look at considerations in the recycling and remanufacturing of electronic components, while Ferrer (1996a) [Ref. 60] examines practices in remanufacturing for a variety of industries in Europe.

From an engineering and design standpoint, the research has focused on the impact of engineering design on remanufacturability. Amezquita, Bras, and Hammond (1998) [Ref. 52] have surveyed remanufacturers about the issues in automotive parts remanufacturing. Amezquita, Bras, Hammond, and Salazar (1995) [Ref. 54] have attempted to characterize the remanufacturability of engineering systems. Bras and Hammond (1996) [Ref. 13] have studied the issue of designing a component for remanufacturability and formulating metrics for assessing remanufacturability.

From the operations management perspective, the literature includes production control, inventory policies, and capacity planning research. Guide and Srivastava (1997b) [Ref. 67] review models in repairable inventory from the 60s onwards. They examine a number of papers that model repairable inventories in terms of classic theory in operations management including stocking policies, multi-echelon models and others. Guide (1994) [Ref. 65] looks at capacity planning for remanufacturing. Guide, Kraus, and Srivastava (1997a) [Ref. 66] look at order release strategies. Guide, Kraus, and Srivastava (1997) [Ref. 69] outline scheduling policies for remanufacturing. Van der Laan and Solomon (1997) [Ref. 76] consider production planning and inventory control for remanufacturing. Except for Toktay, Wein, and Zenios (1997) [Ref. 75], who consider inventory management of remanufacturable products in the entire supply and distribution chain, all the other operations management authors concentrate on the manufacturing facility.

In addition to these, in recent work Savaskan (1999) [Ref. 73] looks at the benefits of channel coordination between the OEM and the reverse logistics chain. This is relevant since we study the effect of competition between remanufacturers and OEMs. Anecdotal evidence from companies indicates that many local remanufacturers start out as reverse logistics chain operators, or operate with them to divert used items from the OEM.

Majumder and Groenevelt (2001) [Ref. 25] (this paper) model the effect of competition in remanufacturing and outline the impact of different parameters [such as (re)manufacturing costs and availability of returns to each player] on the competitive equilibrium.
### Appendix E: References

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<th>Ref.</th>
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Art 3(e) Recycling  
in the context of WEEE |
| Ref 2 | European Parliament and Council Directive 94/62/EC of 20 December 1994 on packaging and packaging waste, Art.3(5) | 'Re-use’ shall mean any operation by which packaging, which has been conceived and designed to accomplish within its life cycle a minimum number of trips or rotations, is refilled or used for the same purpose for which it was conceived, with or without the support of auxiliary products present on the market enabling the packaging to be refilled; such re-used packaging will become packaging waste when no longer subject to re-use; |
| Ref 3 | Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles, Art. 2(6) | Art 2(6): ‘re-use’ means any operation by which components of end-of life vehicles are used for the same purpose for which they were conceived;  
Art 2(7): ‘recycling’ means the reprocessing in a production process of the waste materials for the original purpose or for other purposes but excluding energy recovery. Energy recovery means the use of combustible waste as a means to generate energy through direct incineration with or without other waste but with recovery of the heat; |
| Ref 4 | OECD/Eurostat Joint Questionnaire on waste                             | Re-use shall mean any operation by which end of life products and equipment (e.g. electrical and electronic equipment) or its components are used for the same purpose for which they were conceived. |
| Ref 5 | Office of Solid Waste: Measuring Recycling: A Guidance for State and Local Governments. Appendix A: Glossary          | Refers to the use of a product or component of municipal solid waste in its original form more than once. Examples include refilling glass or plastic bottles, repairing wood pallets, using corrugated or plastic containers for |
To clean or repair something old and use it again instead of throwing it away.

Using a product or component of municipal solid waste in its original form more than once; e.g. refilling a glass bottle that has been returned or using a coffee can to hold nuts and bolts.

Any waste trader can coin a new phrase other than ‘disposal’ or ‘recycling’ to evade Basel’s jurisdiction. For instance, a waste trade can claim that an EoL vessel is destined for ‘re-deployment’, ‘re-conversion’, ‘associated applications’, etc. and since these terms are not found in Basel, it can be claimed that the treaty does not apply. This similar tact is employed in the ‘re-use’ rumours of the SS BLUE LADY.

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<thead>
<tr>
<th>Ref</th>
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<th>Term Detail</th>
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<tr>
<td>6</td>
<td>Office of Solid Waste: Glossary</td>
<td>storage, and returning milk crates.</td>
</tr>
<tr>
<td>7</td>
<td>Office of Communications, Education, and Media Relations : Terms of Environment: Glossary, Abbreviations, and Acronyms (Revised December 1997) Term Detail</td>
<td>To clean or repair something old and use it again instead of throwing it away.</td>
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<td>8</td>
<td>Taking Back the SS BLUE LADY: Malaysia’s Legal Obligation under the Basel Convention</td>
<td>Using a product or component of municipal solid waste in its original form more than once; e.g. refilling a glass bottle that has been returned or using a coffee can to hold nuts and bolts.</td>
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<td>9</td>
<td>Thierry (1995) in Seitz: Thierry, M., M. Salmon, J. Van-Nunen and L. Van-Wassenhove. (1995), ‘Strategic Issues in Product Recovery Management’ California Management Review, 37 (2), 114.</td>
<td>Any waste trader can coin a new phrase other than ‘disposal’ or ‘recycling’ to evade Basel’s jurisdiction. For instance, a waste trade can claim that an EoL vessel is destined for ‘re-deployment’, ‘re-conversion’, ‘associated applications’, etc. and since these terms are not found in Basel, it can be claimed that the treaty does not apply. This similar tact is employed in the ‘re-use’ rumours of the SS BLUE LADY.</td>
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<td>Ref 23</td>
<td>Ijomah, W., Childe, S., McMahon C. ‘Remanufacturing: A Key Strategy for Sustainable Development’</td>
<td>This study firstly defines remanufacture, reconditioning and repair, then goes on to try and design a framework for a generic remanufacturing business process.</td>
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<td>Ref 25</td>
<td>Majumder, P. and Groenevelt, H. (2001) ‘Competition in Remanufacturing’, Production and Operations Management, Summer 2001</td>
<td>This study examines the competition between OEM who wish to remanufacture and independent operators seeking to acquire cores for remanufacture. Research on competition in recycling differs from this; in recycling the manufacturer does not recycle, and the recyclers are price takers. In this paper, OEM may also remanufacture, and both players set prices. The determinants of consumer behaviour for recycling are relevant, since similar determinants may influence the rate of returns for used items. Remanufacturing also differs from durable goods markets since the remanufactured items are functionally similar to original items and may be sold as such. The competition stems from other remanufacturers, not a secondary market created by goods sold earlier by the original manufacturer. The engineering and operations literatures do not consider competition at all.</td>
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<td>26</td>
<td>Kulkarni, A.G., Parlikad, A.K., McFarlane, D.C. &amp; Harrison, M.G.</td>
<td>‘Networked RFID Systems in Product Recovery Management’</td>
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<td>27</td>
<td>Rodger, D. &amp; Tibben-Lembke, R.</td>
<td>‘Going Backwards: Reverse Logistics Trends and Practices’</td>
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<td>28</td>
<td>Jackson, T. &amp; Leach,</td>
<td>‘Industrial and Social Ecology of Urban Resource Flows’</td>
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<td>31</td>
<td>Barthel, M. and Hughes, H. for WRAP</td>
<td>‘Promoting Sustainable Innovation in UK Retail’</td>
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<td>Ref 36</td>
<td>Boothroyd, G. and Dewhurst, P. (1991), ‘Product Design for Assembly’, Boothroyd and Dewhurst, Inc., Wakefield. Using this approach a product’s development is to be completely optimized based on simplifying assembly process costs by minimizing the number of components used within the product, possible directions used to assemble components together, and assessment of the required annual unit production volumes.</td>
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To satisfy legal requirements and address environmental issues, manufacturers have started to think about product designs which allow the re-use of components and the recycling of materials. Such designs have special requirements with respect to materials, fixings, and assembly and disassembly techniques. Costs, and working conditions of employees involved in disassembly and dismantling need to be optimised.


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<td>68</td>
<td>Ketzenberg, M.E., Souza, G.C., and Guide, V.D.R. (2003) ‘Mixed Assembly And Disassembly Operations for Remanufacturing’, Production and Operations Management, Fall 2003.</td>
<td>This paper considers the problem of designing a mixed assembly-disassembly line for remanufacturing. Two main configurations are studied, under the assumption that the disassembly sequence is exactly the reverse of the assembly sequence.</td>
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<td>73</td>
<td>Savaskan, C. (1999) ‘Channel Choice and Coordination in a Remanufacturing Environment’, Working Paper series 99/14/TM INSEAD.</td>
<td>This paper addresses the problem of choosing the appropriate channel structure for the recollection of post-consumer products from customers. It</td>
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find that agencies that are closer to the customer, e.g. retailers, are the most effective undertakers of the recollection effort for the manufacturer.

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<td>74</td>
<td>Silva, G.C., Ketzenberg, M.E. and Guide, V.D.R. (2002) ‘Capacitated remanufacturing with service level constraints’, Production and Operations Management, Summer 2002.</td>
<td>This research examines production planning and control for a remanufacturer that can sell returned items on a graded as-is basis or remanufacture the returned items. The results provide key insights into the decision-making process required to maximize profits and minimize average flow times for remanufactured products.</td>
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The market for remanufactured medical equip. is well established, particularly in the U. S. and seems set to grow in Europe. This article discusses some of the concepts involved and sets out some factors that make it viable. Example are drawn from the medical imaging sector.

Basic criteria for deciding whether rebuilding or remanufacturing an ailing machine tool is worth the effort. Shops can accurately diagnose their situations, know when to rebuild or remanufacture a machine tool, which machines are good candidates and how to evaluate and select a rebuilding/remanufacturing source.

This study proposes a remanufacturing enterprise as an economic development vehicle in the inner city. It focuses specifically on the dental chair as a primary product.
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the Environment, Dallas, TX, IEEE.

| Ref 154 | Bunuel, M., ‘The Effectiveness of a Take-back Policy to Avoid the Non-optimal exclusion of Remanufacturing’. |

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<td>265</td>
<td>Haynsworth, H.C. and Lyons, R.T. (1987) ‘Remanufacturing by design, the missing link’, Production &amp; Inventory Management; Second quarter, pp. 24 - 28</td>
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