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End-of-life decision tool with emphasis on remanufacturing

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ABSTRACT

Remanufacturing is a product recovery strategy resulting in end-of-life products being returned to as new condition or better and receiving a warranty at least equivalent to the original. To differentiate remanufacturing from other forms of product recovery, a clear definition of a remanufactured product is essential. At present two distinct methods for understanding end-of-life recovery strategies exist; a) the use of tools and b) definitions. These current methods fall short however of categorically stating what is and what is not a remanufactured product. Therefore, the responsibility of classifying a product as remanufactured is left to individuals and organizations and so potential exists for products to be incorrectly labelled. By firstly examining the problems associated with using existing methods to determine the status of end-of-life product, and why product identification is important, this paper then goes on to present a new simple innovative method to quickly and accurately determine the status of a product which has undergone an end-of-life recovery strategy, by virtue of a bespoke tool. The tool presented is the result of two rounds of academic and industrial feedback; an initial tool was presented, and underwent critique, at the International Conference on Remanufacturing 2015 with an updated tool then subject to another independent review from academic and industrial stakeholders. The main benefits associated with this tool are, a) a quick way to identify the status of a product, b) a method for researchers to quickly determine the best terminology for end-of-life products which have received a recovery treatment, c) a quick and reliable method to check whether a remanufactured product is labelled as something else, d) an additional way to ensure compliance with existing legislation and standards, and e) an identification of only the essential characteristics of a remanufactured product.

1. Introduction

An end-of-life (EOL) product may be put back into the market place as a result of being remanufactured, reconditioned, repaired, or re-used, or may be recycled to create a new product (from this point on known as a recycled product). All these processes are distinct from one another, with different levels of product quality. It is therefore clear that correct product terminology is extremely important. Considering specifically remanufacturing, for a successful industry to take root, an industry which can bring increased employment opportunities, allow manufacturers to obtain product failure information, deliver energy savings, and which can provide a cheaper supply of products, (Giuntini and Gaudette, 2003; Lund and Hauser, 2010), then any ambiguity in definition is not desirable and can lead to a variety of problems.

In remanufacturing, a notable problem with incorrect terminology is the potential to overestimate the size or impact of the industry; consider, Lund and Hauser (2010) who documented that an earlier study, (Lund, 1996), had overestimated the size of the remanufacturing industry in America by virtue of a very liberal definition of remanufacturing and reliance upon external organizations reporting their practices. Further, there is also evidence to support the public's desire to engage with remanufactured products, in terms of how much they are willing to pay, can depend on issues such as ambiguity in remanufacturing process, (Hazen et al., 2012), and also with branding and product category, (Abbey et al., 2014; Hamzaoui-Essoussi and Linton, 2014). On a wider scale, a similar study into customer willingness to pay for reuse and recycled goods documented a similar complex relationship taking into account issues such as brand and product type, (Hamzaoui-Essoussi and Linton, 2010). Additionally, correct terminology not only provides a platform to allow for public perception and industry size to

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be gauged more accurately, but also serves to allow organizations to comply with existing and new legislation; consider for instance the European Union's strict recycling and waste treatment polices (European Parliament and Council, 2012; 2008, 2000). Note, while examining carbon fibre reinforced plastic (CFRP) Paterson et al. (2016) expand on these themes and further discuss the importance of correct terminology.

Currently, there are two methods within literature to define EOL recovery practices; one is by providing a written definition and the other is via using tools. Despite these existing techniques some researchers and industrialists who are involved with EOL recovery (but who are not necessarily aware of the acute differences in the various forms of EOL recovery) have been found to use both incorrect and very liberal terminology to describe their practices. For instance, it has been documented that researchers and industry practitioners in the field of carbon fibre and CFRP product recovery, routinely use remanufacturing, or re-manufacturing, to describe a process that is not remanufacturing, while also using the terminology recycled CFRP to describe a product that is not always recycled (Paterson et al., 2016). Thus, a new tool has been devised to help both researchers and industrialists from various sectors to more accurately describe their practices and products. While the existing tools and definitions of EOL processes provide much insight into EOL recovery strategies, they fall short of explicitly identifying a recycled, remanufactured, reconditioned, repaired or re-used product. The tool presented in this work fills this gap in knowledge, and for the first time within literature a clear identification of a product in terms of which EOL recovery process it has received is presented. Further, no knowledge of product or material recovery is required prior to using the tool, and so researchers and industrialists involved in product and material recovery now have a very quick, direct and easy method to more accurately describe their practices and products.

Moving forward within this text, the definitions used for recycled, remanufactured, reconditioned, repaired and re-used are presented to allow for a frame of reference to be established; this is presented as section 2.1. Additionally, to allow for the gap in knowledge, and ultimately the novelty, to become apparent, section 2.2 presents a review of the current tools and techniques used by industry and academia. Section 3.0 documents a research methodology for the tool, which includes two rounds of independent validation.

Section 4.0 presents the final tool (the contribution to knowledge of this work), and also the discussion. The discussion identifies the advantages and benefits of the tool along with while also identifying the scope of the tool. Finally section 5.0 presents the conclusion to this work.

2. Remanufacturing domain

2.1. Definitions

The practices defined in this work are formed from various sources, which are listed in Table 1, and are all in keeping with the United Kingdom's national standards body, (BS 8887-2, 2009). This British Standard definition was selected for various reasons, 1) the definition is the official definition as adopted by Britain, noting that members of British industry were partly used for tool validation 2) the research was conducted at the University of Strathclyde, Glasgow, United Kingdom and 3) the BSI agrees for the large part with wider remanufacturing definitions offered by powerful institutions, such as the United States Government - Federal repair cost savings act of 2015 (Federal Act, 2015) and with the European Union Action Plan for the Circular Economy, (European Action Plan, 2015). It should be noted however that although British standards are used to provide a frame of reference, the scope of this work is not limited strictly to Britain; additional definitions of practices/operations from outside of the United Kingdom are presented as necessary. For instance, case study 1 highlights feedback of the original work from an American delegate at the International Conference on Remanufacturing (ICoR) 2015; the critique in that instance being dealt with by slightly altering the flow chart to allow for an American definition(s) of a remanufactured product. It is also of merit to state the term refurbishment is classed the same as recondition under the standard (BS 8887-2, 2009), hence refurbishment is not discussed in this research. Looking at the definitions of practices in keeping with (BS 8887-2, 2009) standards it should be noted that only a definition of remanufacture has been directly taken from literature, (Ijomah, 2002). Rationale as to why (BS 8887-2, 2009) is not used directly for the remaining definitions is drawn from the fact that using external references, in conjunction with British standards allows the practices to be defined more succinctly. These are given in Table 1.

It is important to highlight a small caveat. In this paper, no distinction is made between re-use and repurpose. While going by (BS 8887-2, 2009) re-use states that a product is used again for the same purpose and repurpose is re-using a product for a different purpose in a role that it was not originally designated to perform, in terms of this work, there is no requirement to distinguish between these two terms. Having now presented a frame of reference, in that recycle, remanufacture, recondition, repair and reuse have been explained, attention is drawn to the existing mechanism and tools used to differentiate between these practices.

2.2. Existing mechanism and tools and contribution to knowledge

As stated, two clear methodologies, which are very often presented in conjunction with one another, are used to describe and understand the differences between EOL recovery strategies; these methodologies being a definition based approach and a tool based approach. The definition approach, typically where the processes involved in the different forms of EOL recovery are listed and may be compared against each other, is almost ubiquitous for obvious reasons and is by far the most favoured method found within literature; attention may be drawn to section 2.1 for references in this regard. The tool based approach, which leads to the contribution to knowledge of this work, is noted with not having any formal written definitions of recovery practices, and thus is often used in conjunction with the definition based approach. Further, there are in general two different tools which are used to understand EOL recovery processes. The first tool, as presented within the literature by Ijomah (2002), and which documents a hierarchy based system, in which remanufacture sits atop, with reconditioning beneath remanufacture and repair beneath recondition is presented as Fig. 1. Table 2 highlights various authors who use this tool, or a variant of this tool, and the rationale as to why they used the tool.

As seen from Table 2, even with the literature having a different focus in each case, the tool is predominately used in the same way. That is, when discussing remanufacturing, the tool is used to highlight the differences between remanufacture, recondition and repairing. The tool is clearly effective in doing so, but, it is indeed the case that the tool does not inform the user as to whether a product is remanufactured, reconditioned, repaired. The user, would have to digest the available literature, including using the tool outlined above and still have to form a decision themselves as to the correct status of a product. Note however, the process of allowing the user to independently form a decision allows for a potential scenario in which a user could make an incorrect decision to arise. An additional tool focused on highlighting the differences, from a cradle to grave standpoint, between recycle, remanufacture,

Table 1
Definitions of EOL operations.

Term	Definition	References
Remanufacture	*'remanufacturing is the only end of life process where used products are brought at least to Original Equipment Manufacturer (OEM) performance specification from the customer's perspective and at the same time, are given warranties that are equal to those of equivalent new products'* (Ijomah, 2002)	(BS 8887-220:2010, 2010; European Action Plan, 2015; Federal Act, 2015; Gray and Charter, 2007; Hatcher et al., 2014; Ijomah, 2002; Ijomah et al., 2007, 2004; King et al., 2006; Matsumoto and Ijomah, 2013; Nasr and Thurston, 2006; Parker, 2010; Paterson et al., 2016; Steinhilper and Weiland, 2015; Sundin, 2004; Sundin et al., 2009)
Recondition	Reconditioning involves taking a product and restoring/replacing all components parts which have failed or are on the verge of failure resulting in the product being returned to an acceptable standard (typically less than virgin standard). Any warranties issued are typically less than a warranty given to a virgin product. Recondition involves less work than remanufacture but more than repair	(Gray and Charter, 2007; Ijomah, 2002; Ijomah et al., 2007, 2004; King et al., 2006; Matsumoto and Ijomah, 2013; Parker, 2010; Sundin et al., 2009)
Repair	For a given fault within a product, if an operation has been conducted to correct the fault the product has said to have been repaired. Almost certainly all repaired products are not restored to original standard and any guarantee issued will generally only cover the corrected fault. This process involves less work than remanufacture and recondition	(Gray and Charter, 2007; Ijomah, 2002; Ijomah et al., 2007, 2004; King et al., 2006; Matsumoto and Ijomah, 2013; Parker, 2010; Sundin et al., 2009)
Recycle	Recycling is a series of processes where waste products are collected, processed and returned to raw material format. This process differs from all others in that the energy used to create the pre-recycled product is completely lost. Future products may be created from the raw materials and are denoted as, in the case of a plastic bottle for instance, a recycled bottle.	(European Commission, 2012; European Parliament and Council, 2008, 2000; Gray and Charter, 2007; Ijomah, 2002; King et al., 2006; Nasr and Thurston, 2006; Parker, 2010; Paterson et al., 2016; Sundin et al., 2009)
Reuse (denoted as re-use in this work without loss of meaning)	Re-use is the process of re-using a product for the same purpose without conducting any significant repair to the product.	(European Commission, 2012; European Parliament and Council, 2008, 2000; Gray and Charter, 2007; Ijomah, 2002; King et al., 2006; Nasr and Thurston, 2006; Parker, 2010; Paterson et al., 2016)

recondition, repair and re-use is also found within literature. Fig. 2, documents this tool, with Table 3 identifying literature which uses this tool.

Note, that not all the authors in Table 3 include recondition in the tool, only (Khor and Udin, 2012; King et al., 2006; King and Barker, 2007; King and Gu, 2010) incorporate recondition.

As with Table 2, upon examining Table 3, it can be seen that the tool presented in Fig. 2 is used within literature in generally the same way. That is, Fig. 2 is used to highlight the differences in EOL recovery strategies with reference to a cradle to grave production process. Further, similar to Fig. 1, no definitive answer as to whether a product has been remanufactured, reconditioned, repaired, re-used or recycled, is provided and therefore, the user must again form a decision themselves as to the status of a product.

At this point it can be said that the tools in both Figs. 1 and 2 have been used in different ways; Fig. 1 has been used to highlight the differences between reconditioning, remanufacturing, and repairing, with respect to labour content, level of warranty, and product performance. Fig. 2, on the other hand, has been used to understand at which point recycling, remanufacture, recondition, repair and re-use is implemented in the context of a cradle to grave production process. It is therefore the case that both tools do not explicitly state or determine if a product has been recycled, remanufactured, reconditioned, repaired or re-used. That is, to determine the correct status of a product, the user must consult both definitions and tools, and then use their own judgement. The tool presented in this work fills this gap in knowledge and for the first time within literature, a tool which accurately determines whether a product has been recycled, remanufactured, reconditioned, repaired or re-used is presented.

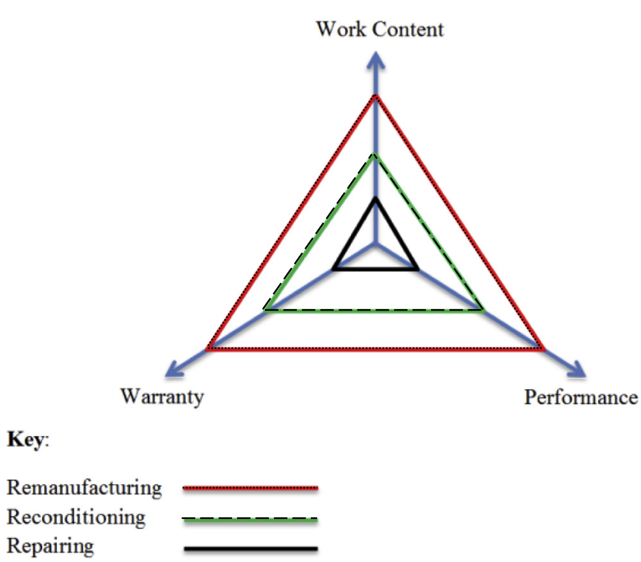

Fig. 1. Highlighting the difference in content of remanufacturing reconditioning and repair when considering work content, warranty and overall performance. *Reproduced with permission from* Ijomah, 2002, *"A model-based definition of the generic remanufacturing business processes", Plymouth University,*

3. Methodology

The development process for the new bespoke tool is now discussed, with Fig. 3 documenting the approach taken. Following this, an explanation of stages A, B and C is given. The strongest focus is placed upon section C, the tool development phase.

3.1. Section A and B

A: Case study analysis which included speaking with/visiting industrialists and academics, to find out how identification of used

Table 2
—Literature, and focus of that literature, which documents the use of EOL tool presented in Fig. 1.

Focus of literature	How tool was used	Tool documented within literature
To determine a robust definition of remanufacturing	To emphasis the differences between remanufacturing, reconditioning and repairing, in terms of labour content, warranty and product performance.	(Ijomah, 2002)
To highlight alternative strategies for EOL waste	See (Ijomah, 2002)	(King et al., 2006)
The role of remanufacturing in economic and ecological growth	See (Ijomah, 2002)	(Ijomah, 2009)
A case study to explore how some Swedish companies currently incorporate product/service systems into their products, and identify new ways which they could do so, with an additional focus on remanufacturing.	See (Ijomah, 2002)	(Sundin et al., 2009)
To discuss remanufacturing and problems facing remanufacturing	See (Ijomah, 2002)	(Gurler, 2011)
To identify remanufacturing and typical remanufacturing processes	See (Ijomah, 2002)	(Matsumoto and Ijomah, 2013)
To investigate terminology surrounding CFRP recovery operations	See (Ijomah, 2002)	(Paterson et al., 2016)

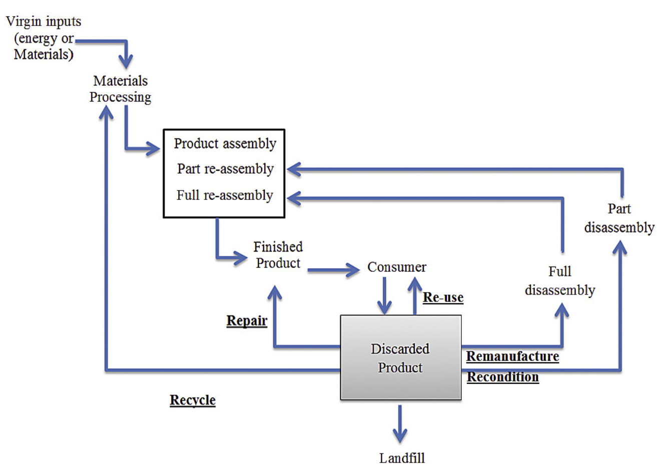

Fig. 2. Product cradle to grave tool highlighting end-of-life processes, adapted from (King et al., 2006) and (Paterson et al., 2016).

products status/classification was undertaken.

- Companies visited – Mackie Automatic Transmissions Ltd, Autocraft Drivetrain Solutions, Concept group, Cummins, and ZF, and Turbo guy

B: Literature review to record state of the art and thus identify a gap in knowledge.

- Identification that to correctly identify the status of a secondary market product, consumer is required to form their own decision by using existing definitions or via existing tools.
- Gap identified – lack of a method that can be used to easily identify secondary market products that is easy and inexpensive and does not require the user to have advance knowledge of the differences between the various processes

Note that consultation with industrialists and academics occurred both prior to and during the literature survey, hence, the two way arrows documented in Fig. 3.

3.2. Section C

3.2.1. Initial tool development

- Based on the information taken from the literature and case studies, a prototype tool to determine if a product has been recycled, remanufactured, reconditioned, repaired or re-used was developed. The tool consists of both a question set and a flow chart. The question set details both the processes involved

Table 3
—Literature, and focus of that literature, which documents the use of EOL tool presented in Fig. 2

Focus of literature	How tool was used	Tool documented within literature
To identify and discuss remanufacturing, the processes of remanufacturing and benefits of remanufacturing	To present hierarchy of expected economic value associated with recycle, remanufacture, repair and re-use, in the context of the a cradle to grave production process	(Lund, 1985)
Effect of fastening and joining mechanisms on remanufacture	To demonstrate the strategies available for products to avoid landfill, in the context of a cradle to grave production process	(Shu and Flowers, 1995)
Product design that impacts on remanufacturing	See (Shu and Flowers, 1995)	(Shu and Flowers, 1999)
To highlight that a key enabler to sustainable growth is to close the loop on the manufacture to landfill production cycle	See (Shu and Flowers, 1995)	(Nasr and Thurston, 2006)
To determine the views of remanufacturing academics on various issues relating to remanufacturing	See (Shu and Flowers, 1995)	(King and Barker, 2007)
Environmental benefits of remanufacturing	See (Shu and Flowers, 1995)	(King and Gu, 2010)
Analysis of reverse logistics for electronic goods in Malaysia with a focus on business performance in terms of EOL recovery strategies	To highlight the reverse logistics processes, in the context of a cradle to grave product production process	(Khor and Udin, 2012)
Development of a conceptual design framework which incorporates EOL thinking	To demonstrate a conceptual framework for a more sustainable form of aircraft design	(Ribeiro and Gomes, 2014)
Design for multiple life cycles	To highlight the consideration of material flow during cradle to cradle design process	(Go et al., 2015)

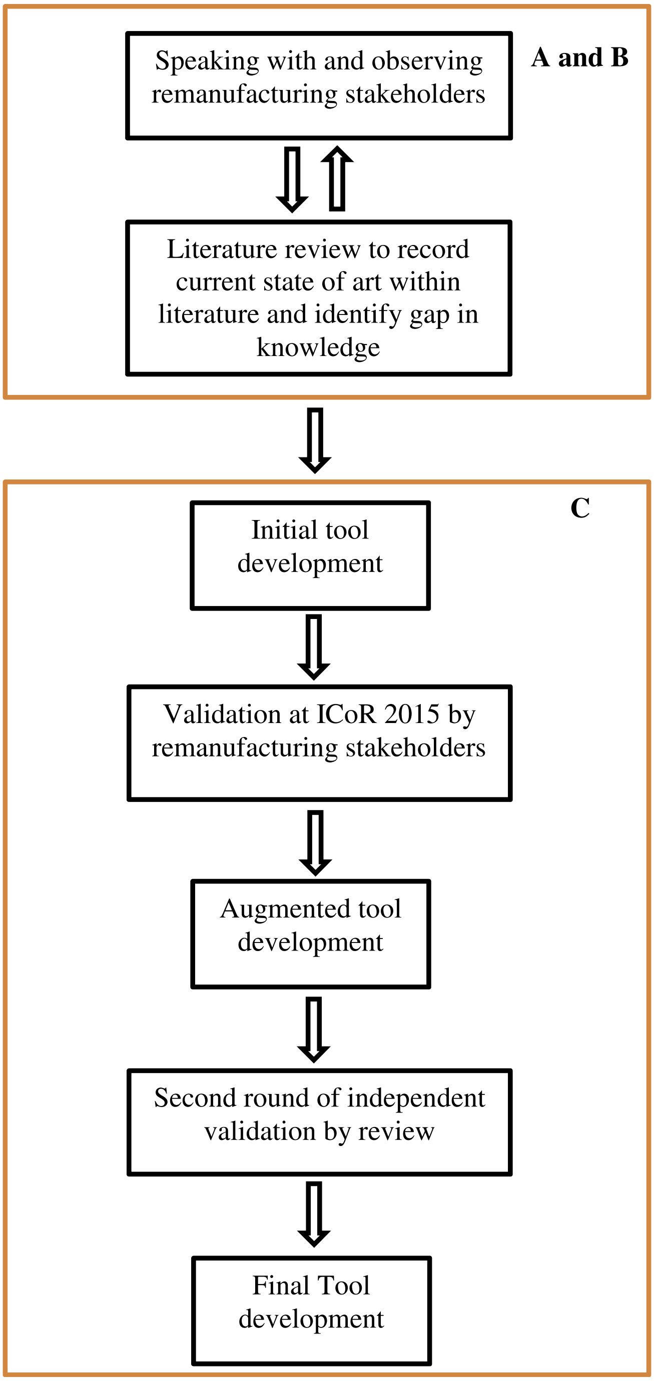

Fig. 3. Graphical depiction of the methodology adopted in this research.

in remanufacturing as documented by Ijomah (2002) and the essential characteristics of a remanufactured product; noting that movement through the flow chart is via answering yes or no to the questions provided. The initial tool is presented as Fig. 4 and Table 4.

The principal behind the tool is that the user would start at position 1, answer yes or no to question 1, and then progress through the flow chart and question set accordingly - noting that each question only has a yes or no answer. In terms of Fig. 4, a yes answer is denoted as a green arrow and a no answer is denoted as a red (dashed) arrow.

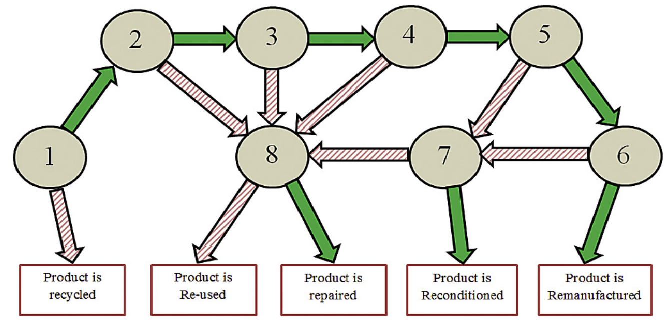

Fig. 4. Original flow chart presented at ICoR 2015

3.2.2. Validation at ICoR 2015 by remanufacturing stakeholders

- The prototype tool was presented at the ICoR 2015 (Paterson et al, 2015). This venue was chosen for the initial validation stage as demonstrating the tool at an international conference on remanufacturing would allow for many members of the wider remanufacturing and sustainability community to be directly exposed to the tool and thus allow the authors to gauge the general response to the tool. Further, the delegate list at this conference was composed of academics and operational remanufacturers from various countries and backgrounds and so feedback obtained from such a rich environment would of great benefit to the development of the tool. As part of the initial validation stage, verbal feedback was obtained from three conference delegates, each from different vocations. Table 5 documents both the position and relevancy of each reviewer along with the observations and concerns raised.

3.2.3. Augmented tool development

- As a result of the initial validation stage, it was found that no changes were required for either the flow chart or the question order. However, to incorporate the concerns raised in Table 5, questions 1, 5, and 6 were updated. A detailed discussion of the concerns raised in Table 5, along with the specific changes required is given in appendix A. The augmented question set is given in Table 6.

In comparison to Table 4, changes to question 1, question 5, and question 6, may be found. Note the flow chart was unaltered and so Table 6 may be used in conjunction with Fig. 4.

3.2.4. Second round of validation by independent review

- The augmented tool was then subject to another round of independent review. In this instance, the tool was reviewed by representatives from research institutions who are engaged with industrial bodies. With both academic and industrial affiliations it was envisaged that feedback obtained from these reviewers would be well grounded from both an academic and industrial standpoint. In this instance, the reviewers provided independent written reviews of the augmented tool. Table 7 documents both the position and relevancy of the reviewer along with the observations and concerns raised.

Table 4
Original question set presented at ICoR 2015

Question No	Question
1	Is emergy (energy expired to create product from raw materials) retained from original EOL product?
2	Does the product have a core?
3	Is core capable of being disassembled?
4	Has the core been disassembled?
5	Is warranty of product equal to or better than the original?
6	Have all core components been cleaned, inspected, replaced/repaired to original standard and had its core reassembled such that the product is in like new condition?
7	Have all major broken components and components on the verge of failure been replaced or repaired?
8	Has the product been restored to an acceptable level in any significant way (and core reassembled if applicable)?

3.2.5. Final tool development

- The concerns raised in the second validation process were taken into consideration. Thus, a final new version of the tool, and contribution to knowledge of this research, was developed; section 4 documents and discusses this. Similar to the first validation stage, the flow chart and order of questions were unaltered. A detailed discussion of the concerns raised in Table 7, along with the specific changes required to the question set is given in appendix B.

4. Final tool and discussion

A bespoke tool to determine if a product is recycled, remanufactured, reconditioned, re-used or repaired is given as Table 8 and Fig. 5 — with an alternative version of the final tool, which merges Table 8 and Fig. 5 together, given as Fig. 6. The tool validation was by 'review' (Landry et al., 1983) technique. The validity of the tool was ensured by the robustness of research design which included thorough analysis by stakeholders on two occasions. The tool stood up well to both rounds of validation in that only the wording of some of the questions was altered and so the original interactive flow chart and order of the questions was not changed during both rounds of the validation process. It is also the case that no suggestion that the flow chart or question order should be changed occurred during the validation process, thus strengthening the case that no definitions of processes were violated using this tool.

4.1. Discussion

As stated in section 2.2 the general method to determine if a product has been recycled, remanufactured, reconditioned, repaired or re-used is to interpret the existing definitions of these process and, possibly with the help of existing tools, come to a conclusion by oneself as to the status of the product. This strategy however, allows for the possibility of confusion, which can lead to errors when forming a decision as to the status of a product. The tool developed in this paper seeks to eliminate any potential confusion and thus allows one to quickly and efficiently determine if a product is recycled, re-used, repaired, reconditioned, or remanufactured. Also, considering the negative role that ambiguity in the remanufacturing process can have, also included in this tool is a full definition of a remanufactured product. Put simply, this system allows for clear identification of what type of EOL treatment a product has received without having intimate knowledge of the subtle differences between EOL treatments. For example, to determine if a product is recycled, the system presented in this work only requires one question to be asked, namely, 'Is the emergy retained from original product?' That is, investigating whether emergy has been retained or not gets to the heart of a recycling (in that emergy has been lost) and so a quick determination of a recycled, or not recycled, product is made. Noting that this system allows for identification of a recycled product without entering into any discussion regarding the particular processes involved in recycling. Further, the concept of a core is also used to determine quickly if a product can be reconditioned or remanufactured, for

Table 6
Augmented question set arising as an output from first validation stage.

Question No	Question
1	Is emergy (see N.B.) retained from original EOL product?
2	Does the product have a core?
3	Is core capable of being disassembled?
4	Has the core been disassembled?
5	For British remanufacture - Is warranty of product equal to or better than the original? For American remanufacture - Is the product fully warranted?
6	Have all core components been cleaned, inspected, replaced/repaired to original standard and had its core reassembled such that the product is in like new condition or better?
7	Have all major broken components and components on the verge of failure been replaced or repaired?
8	Has the product been restored to an acceptable level in any significant way (and core reassembled if applicable)?

N.B. To create a product of out raw materials then various processes/actions have to be performed. These various processes and actions all require (to some degree) energy to be expired. The total amount of energy expired in creating a product is known as emergy or embodied energy. When recycling a product, the product is returned to raw materials and so this emergy is lost and therefore new energy must be expired to create a new product from the raw materials.

Table 5
Identifying the position and relevancy of reviewers, along with the observations and concerns raised in relation the initial tool, at ICoR 2015.

Reviewer	Position	Relevance to subject matter	Observations from Reviewers
A	Academic from G-SCOP laboratory within the University of Grenoble France, whose research interests including remanufacturing and sustainability	Expert in the field of remanufacturing and sustainability. Academic is not based in the United Kingdom	No direct mention of product being returned to better than new quality and that this issue was only implied.
B	Representative of an American company directly involved in the remanufacture of hydraulic components	American operational remanufacturer of hydraulic components. Representative is not based in the United Kingdom	In some instances, remanufactures in America are on occasion unaware of the quality of the original product. Thus by insisting that the product should be returned to like new condition then the scope of the research may be limited to areas outside America
C	Representative from a company involved in large construction programme devised in association with the British Government	Significantly large manufacturing based construction programme which has its own sustainability policy.	Emergy, while the correct term, it is an unusual term from a public perspective and thus the public may struggle to understand its meaning

Table 7
Identifying the position and relevancy of reviewers, along with the observations and concerns that were raised during the validation process for the augment tool.

Reviewer	Position	Relevance to subject matter	Observations from Reviewers
A	Representative from a Government sponsored remanufacturing institution	The remanufacturing body has a focus on developing the remanufacturing industry within Scotland	Clarity required on whether all emergy or just some of emergy should remain It may be the case that not everyone is aware of the concept of a core, and so clarity on the difference between a product and a core, in this context, is required
B	Representative of a national manufacturing research institution	Institution involved in cutting edge manufacturing processes and bridging the goals between industry and academia	Clarity required on question 2 as it was felt that all products would contain a core if they are returned as a whole. Further, it was also felt that the way the question was written could imply products were being returned in parts or in component form. If this was the intention, the question should be written to reflect this. Clarity required on question 6, as the way in which it is written would be perhaps too ambiguous for manufacturers to answer. The way in which the question is written possibly implies that the remanufacturing steps should mirror the manufacturing steps and that the focus should be on a remanufactured product being at least as good as original standard. The term 'significant way' in question 8 was possible vague The word expire is not applicable in this context Possible merge the question set and flow chart into one tool to improve usability

example, question 2 inquires whether the product has a core, if the answer is no, then immediately reconditioned and remanufactured are eliminated and product must be at this point, re-used or repaired. Considering now re-used and repair, the ruling out either of these two treatments is not possible in the proposed system. Why? Consider the following; examining the definitions of end-of-life treatments, a case could be made that significant cross over between remanufacture, recondition, repair and re-use exists, which, if left unchecked, has the potential to greatly increase confusion levels and possibly overcomplicate the flow chart. For instance, while it is true that a reconditioned or remanufactured product requires a product core, it is not true that a product with a core is always required to be reconditioned or remanufactured, i.e. products with cores can still be repaired or just re-used. This aspect forces the flow chart to have a degree of flexibility such that, even though a product has a core, the core cannot be used to eliminate repair or re-use. Thus, after navigating question 1, owing to the cross over between definitions of practices, from any stage in the flow chart there is always a path back to question 8. For instance, even though a product has a core and even though the core may have been disassembled and reassembled, the product at hand may still fall under repair or re-use. The cross over between remanufacture, recondition, repair and re-use leads to the realisation that singling out individual product characteristics that a product must have to be called re-used, repaired, reconditioned or remanufactured is fraught with difficulty. However, the system presented in this work manages to do so. It does so by virtue of asking leading questions and using the definition of remanufacture to eliminate recovery treatments leaving the only probable answer remaining as

Table 8
Final version of the question set.

Question No	Question
1	Is the vast majority of emergy (see N.B.) retained from original EOL product?
2	Is the product constructed through a manufacturing assembly process involving different parts (such products typically denoted as cores)? Noting that items constructed from a single piece of material, for example some hardware tools, do not have to be assembled and thus are not classed as cores in this instance.
3	Is core capable of being disassembled?
4	Has the core been disassembled?
5	For British remanufacture - Is warranty of product equal to or better than the original? For American remanufacture - Is the product fully warranted?
6	Have all the core components been inspected and subsequently rebuilt or replaced and been reassembled and tested such that the overall product and core components are at a standard equalling that of like new condition or better?
7	Have all major broken components and components on the verge of failure been replaced or repaired?
8	Has the product been restored to an acceptable level in any significant way (and core reassembled if applicable)?

N.B. To create a product of out raw materials then various processes/actions have to be performed. These various processes and actions all require (to some degree) energy to be consumed. The total amount of energy consumed in creating a product is known as emergy or embodied energy. When recycling a product, the product is returned to raw materials and so this emergy is lost and therefore new energy must be consumed to create a new product from the raw materials.

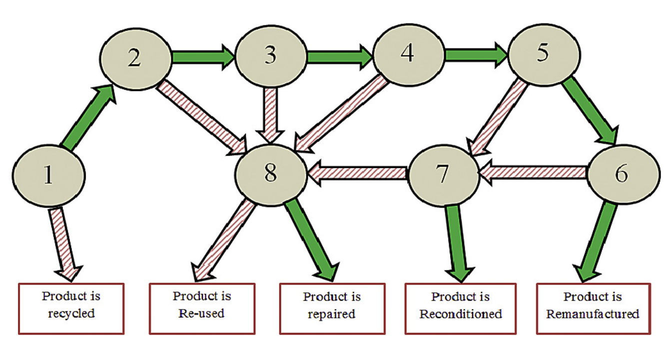

Fig. 5. Final version of the flow chart. Unchanged from original design.

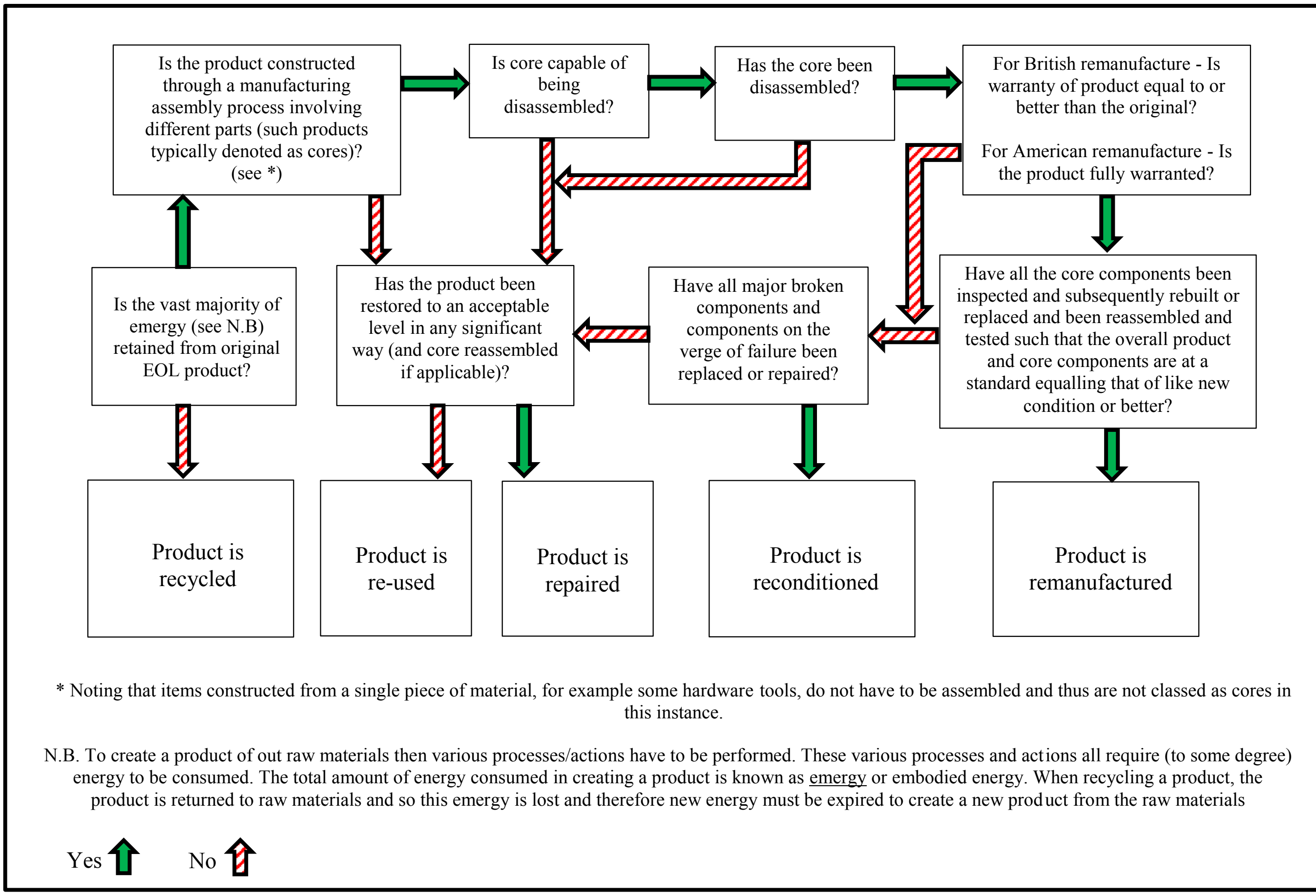

Fig. 6. Flow chart (Fig. 5) and question set (Table 8) are combined to create an alternative version of the tool.

the recovery treatment performed. Thus, the issue highlighted with existing methods, i.e. the user must always form their own opinion as to whether a product has been recycled, repaired, re-used, reconditioned or remanufactured, has been removed; the new system presented here informs the user directly.

4.2. Scope of the tool

It is important to point out that the system devised in this paper does not present a deep understanding of the various operational requirements and processes involved in successfully recycling, remanufacturing reconditioning, repairing and re-using products – this analysis has been previously conducted in the many works cited thus far. For instance, the system presented here omits the fact that in order to successfully and continually remanufacture, a company/organization would require a steady supply of cores and that the product should fail from a functionality standpoint and not from a dissipative standpoint. Specifically, the system presented in this work is not designed to be used by companies or individuals to form a decision as to whether they should begin remanufacturing processes or if a product should be remanufactured. The goal of the tool presented in this work is to allow for a decision to be made as to which type of product treatment has been given, not as a tool to determine which recovery is best suited to an organization's needs. Thus, by limiting the scope of the tool to one in which an identification of product status is the main focus, a simple and easy to use tool is developed.

For a deeper knowledge on recycle, re-use, repair, recondition and remanufacture, there are multiple texts presented in the references.

4.3. Advantages and tool applications

Currently, both definitions of practices and existing tools have been shown as legitimate ways to better understand product recovery and material recovery in terms of recycle, remanufacture, recondition, repair and re-use. However, it has also been shown that these existing mechanisms do not explicitly identify a recycled, remanufactured, reconditioned, repaired or re-used product. The novel tool in this work builds on existing knowledge and for the first time within literature, a method to determine both quickly and accurately whether a product has been recycled, remanufactured, reconditioned, repaired or re-used is presented. Further, the tool presented in this work is able to determine the correct product status in situations in which the user has little or no knowledge of EOL recovery (i.e. no knowledge of recycle, remanufactured, recondition, repair or re-use) and thus has direct applicability to various researchers and the general public. For instance, Paterson et al. (2016) found that researchers involved in recovery strategies for composites, but who were unaware of the specifics involved in each recovery operation, were incorrectly, and inadvertently, labelling products as remanufactured. Considering that global composite consumption is growing year on year (Kraus and Kühnel, 2015), if left unchecked this practice could give rise to the impression as to the existence of a CFRP remanufacturing industry. Using the tool presented in this paper, no such mistake would have occurred. That is, by using this tool, remanufacture would be immediately eliminated as these products can neither be successfully disassembled nor reassembled. Thus, for an operational recycler of CFRP with no knowledge of the subtle differences in recovery strategies, this tool serves as a quick and easy way to better articulate their final product. Similar to this, a key barrier to the successful implementation of remanufacturing in the UK in terms of consumer engagement is through the false labelling of 'remanufactured' products, (Spelman and Sheerman, 2014). Thus, given that the definitions and remanufacturing practices used as a basis to develop this tool, are in keeping with (BS 8887-2, 2009) and (BS 8887-220:2010, 2010), the tool presented in this work may be used as a quick, reliable and robust test to determine the correct status of secondary market products by both consumers and stakeholders involved in EOL recovery. Further, the tool identified in this work may also be used along with existing methods as an effective mechanism to help gauge the wider remanufacturing industry. That is, owing to the simple design and execution of the tool, the tool may be sent to companies involved in EOL recovery processes. In this way, a quick test of the products that are being produced by the company would be enough information for a researcher to determine if the company can be called a remanufacturer. This is of particular interest in the cases in which remanufacturers use different terminology to describe remanufacturing. For instance, the term 'overhaul' in the aerospace industry has been documented as being equivalent to remanufacture (Gray and Charter, 2007). Using this tool, it would quickly and effortlessly become apparent to both the company and the researcher that overhaul and remanufacture can describe the same process. Additionally, the literature identified in Tables 2 and 3, noting that each work has a different research focus, has been shown to use existing tools to develop the concept of remanufacturing or to highlight the different recovery strategies in terms of a cradle to grave production process. Thus, these researchers now have an additional tool, presented in this work, to assist them in reinforcing the concept of a remanufactured product, while also allowing the reader to interactively determine the difference between a recycled, remanufactured, reconditioned, repaired and re-used product. Further, and focusing on the characteristics of a remanufactured product, an additional benefit from the proposed tool is that only the essential characteristics of a remanufactured product are presented. Expanding on this point, attention may be drawn to a list outlining the general characteristics that a remanufactured product should have, (Andreu, 1995). This list is outlined below.

1. The product has a core that can be the basis of the restored product. A core is the used equipment to be remanufactured.
2. The product is one which fails functionally rather than by dissolution or dissipation.
3. The core is capable of being disassembled and of being restored to original specification.
4. The recoverable value added in the core is high relative to both its market value and its original cost.
5. The product is one that is factory built rather than field assembled.
6. A continuous supply of cores is available.
7. The product technology is stable.
8. The process technology is stable.

Note that since its original publication, this list has either been replicated or cited directly by various authors as a way to identify the characteristics of a remanufactured product, (Barquet et al., 2013; Go et al., 2015; Ijomah et al., 2007; Linder and Williander, 2015; Matsumoto and Ijomah, 2013; Sundin et al., 2009; Winkler, 2010).

Evaluating this list, it is the authors' opinion that only points 1), 2) and 3) are truly indicative of a remanufactured product. That is, a remanufactured product must by definition meet the first three points only. From the authors' perspective the remaining points are not considered essential for a product to be remanufactured and are only included in the list for reasons stemming from an economic standpoint. Consider point 4) which focuses upon the economic value of the core. This point has no bearing on whether a product can be remanufactured – it only has a bearing of whether or not it would be economical advantageous to remanufacture. Consider point 5), again this finding has no bearing on whether a product can be remanufactured and owing to evolving technology and processes it may not be required at all even from an economic standpoint. Points 6), 7) and 8) again are not relevant when considering if a product can be remanufactured - they are only generally relevant when forming a decision on the economic advantages of a remanufacturing operation.

Thus the case is made that points 4–8) are best described as criteria that one would expect from a product that has been remanufactured from an economical/industrial view point. The system presented in this paper states a remanufactured product's characteristics in isolation of whether it should or should not be remanufactured, and from the characteristics that one would generally expect from an economically driven remanufactured product, a quality that the list by (Andreu, 1995) fails to do.

Removing the economically driven element from the list provided by Andreu, allows a less complicated list of the characteristics associated with a remanufactured product to be expressed. That is, an output from this tool is that a list of only essential product characteristics, characteristics that are not debatable, can be presented within literature. Unlike the current list by Andreu, the new list gets to the basis of a remanufactured product directly and may be used as a more realistic and fundamental checklist to both reinforce the concept of a remanufactured product and also to identify a remanufactured product. For clarity, the essential qualities of a remanufactured product as outlined in the question set and flow chart are expressed, similar to that by Andreu, in a list. This list is given below as points 1–5.

Essential Characteristics of a Remanufactured product.

1. Product emergy is retained
2. The product has a core
3. The core is capable of being disassembled and reassembled
4. The product has a warranty equal or better than original
5. All core components have been replaced or restored to their original standard.

5. Conclusion

It has been shown that the current tools and definitions within literature, while providing much insight into EOL recovery, fail to explicitly state the status of a product which has received a recovery operation. Thus, a reader must digest existing definitions and tools and form their own opinion as to whether a product has been recycled, remanufactured, reconditioned, repaired or re-used. Therefore, a gap in knowledge was found for a tool which quickly and accurately determines the status of a secondary market product. The tool presented in this work filled this gap in knowledge, such that, for the first time within literature, a tool to quickly and accurately determine if a product has been recycled, remanufactured, reconditioned, repaired or re-used, is presented. Additionally, problems associated with using incorrect terminology to describe secondary market products were also discussed, including; the accurate gauging of the remanufacturing market, the benefits of a remanufacturing industry, an identification that ambiguity in definition has an effect on consumer engagement with secondary market products, and successful compliance with existing, and possible involvement in drafting new, legislation and standards. The tool presented in this work was shown to have applicability in these areas, and was also shown to act as an easy and quick method to check for a remanufacturing synonym such as overhaul. Further, an additional output of this tool was that a clear and inviolable list of the characteristics of a remanufactured product was presented, a list that builds on existing knowledge and which documents only the essential characteristics of a remanufactured product.

The tool documented in this work was born out of two independent rounds of validation from both industry and academia. An initial tool was presented at ICoR 2015 for validation, with an augmented tool then presented to industry stakeholders. Both the validation process and the tool development process are outlined in this work - noting, that through both rounds of validation only the questions were altered. That is, the original flow chart and ordering of questions survived two rounds of cross examination, thus strengthening the position that no definitions were violated using this tool (i.e. no errors in product classification were recorded in the validation process).

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Appendix A. Analysis of the observation and concerns that were raised at ICoR 2015

An examination of the constructive feedback is now presented. That is, discussion is provided on each issue raised with any changes arising to the flow chart and question set also outlined.

In relation to comment from reviewer A

This point was taken on board with a decision, in this instance, taken to rewrite question 6. Question 6 was rewritten as,

> 'Have all core components been cleaned, inspected, replaced / repaired to original standard and had its core reassembled such that the product is in like new condition or better?'

In relation to comment from reviewer B

In relation to point 2, it was felt that no changes would be initially made subject to an investigation into what currently could be classed as a remanufactured product within the United States. That is, working definitions of remanufacturing products were consulted prior to altering the flow chart and question set. To this end, two useful sources which documented existing working definitions of a remanufacturing product from an American perspective were consulted. The first sourced definition was from the aforementioned American Federal Repair Cost Savings Act of 2015 (Federal Act, 2015) and the second source definition of remanufacturing was from the Remanufacturing Industries Council (RIC, 2016). Looking first at the federal repair cost saving act of 2015, (noting that this act was signed into law on the 10/07/2015) a remanufactured vehicle component is defined as,

> *"vehicle component (including an engine, transmission, alternator, starter, turbocharger, steering, or suspension component) that has been returned to same-as-new, or better, condition and performance by a standardized industrial process that incorporates technical specifications (including engineering, quality, and testing standards) to yield fully warranted products"*

Looking now at the Remanufacturing Industries Council, which is an American National Standards Institute (ANSI) accredited standards developer, and whose members compose remanufacturers such as Caterpillar and Xerox, the current remanufacturing definition put forward by them is given as,

> *"Remanufacturing is a comprehensive and rigorous industrial process by which a previously sold, worn, or non-functional product or component is returned to a "like-new" or "better-than-new" condition and warranted in performance level and quality."*

It can be seen that both definitions state clearly that a remanufactured product must be returned to original equipment specification or better. Thus the point raised at ICoR i.e. 'determining if a product has been returned to like new condition is sometimes impossible', may be correct from certain members of the delegation point of view, bears no relation on how a remanufactured product should be defined. That is, official legislation and an ANSI accredited standards developer, the RIC, have both shown that American remanufactured products are required to be returned to at least as new condition. However, it is the case that the documented definitions for American products are slightly out of sync with the British standard definition (BS 8887-2, 2009), when it comes to the concept of a warranty. The British standard stipulates remanufactured products should have a warranty that is at least equal to the original, whereas the Federal Repair Act states that remanufactured products should be fully warranted and RIC state that remanufactured products should be warranted in performance level and quality. Taking both the issue of like new condition and quality of warranty into account, to allow for the range of this tool to cover American remanufacture, the decision was made to alter question 5 of the question set. It should be noted however, this alteration is for warranty purposes only, i.e. the like new condition issue raised at ICoR 2015 has been shown not to affect the flow chart of question set scope. Question 5, was rewritten, with the inclusion of the following text,

For British remanufacture - Is warranty of product equal to or better than the original?

For American remanufacture - Is the product fully warranted?

In relation to comment from reviewer C

This point was taken on board in this instance. As such, the view was taken to provide an altogether more comprehensive explanation of what emergy is. To facilitate this, question 1 is rewritten as,

> 'Is emergy (see N.B.) retained from original EOL product?'

With, the N.B being included under question 8 and containing the explanation of what emergy is, which is given as,

> 'To create a product of out raw materials then various processes/actions have to be performed. These various processes and actions all require (to some degree) energy to be expired. The total amount of energy expired in creating a product is known as emergy or embodied energy. When recycling a product, the product is returned to raw materials and so this emergy is lost

and therefore new energy must be expired to create a new product from the raw materials.'

Appendix B. Analysis of the observations and concerns that were raised during second validation stage

In relation to the first concern from reviewer A

Depending on the complexity of the product undergoing an EOL process the term emergy can be a difficult concept to tie down. For example, in reviewing the practices of CFRP recycling, Paterson et al. (2016) stated that even though a composite recycling process recorded small amounts of losses in terms of carbon fibre emergy, the majority of the emergy remained and so the carbon fibre could not in general be called recycled. Thus, the point is taken on board with a statement that small losses of emergy are in general ok included in the question set and also with the assumption that in almost all cases the decision as to whether a product has been recycled is a fairly simple one to make. Question 1 is rewritten as,

'Is the vast majority of the emergy (see N.B) from the original EOL product remaining?'

In relation to the second concern from reviewer A the first concern from reviewer B

Concerns surrounding the concept of a core were raised by both Review A and Review B. The rationale behind question 2 was to ensure that no single component items slipped through the net such as, say a single piece of metal for instance. However, as both reviewers expressed interest in question 2 both points are taken on board in this instance and changes were made to the original question. Question 2 was rewritten as follows,

'Is the product constructed through a manufacturing assembly process involving different parts (such products typically denoted as cores)? Noting that items constructed from a single piece of material, for example some hardware tools, do not have to be assembled and thus are not classed as cores in this instance'.

The rewritten question addresses both reviewers concerns. In terms of reviewer A, any confusion over the terms product and core have now been removed by identifying that cores are products which have to be assembled using different parts. In terms of reviewer B, the reason to why the question was asked becomes apparent, i.e. to remove the possibility of products which are not in general able to be described as a cores, i.e. a stand-alone plant pot or a simple spanner or mug for instance, from slipping through to the later stages.

In relation to second concern from reviewer B

The point is taken on board and the question rewritten to accommodate the concern that was raised. Question 6 is rewritten as,

'Have all the core components been inspected and subsequently rebuilt or replaced and been reassembled and tested such that the overall product and core components are at a standard equalling that of like new condition or better?'

The question now focuses less on specific remanufacturing process such as cleaning and more on ensuring the global remanufacturing characteristic of 'like new' performance.

In relation to third concern from reviewer B

The review suggested that the term significant was a vague term to use in this instance. The review comment is noted, rational, reasonable and totally understandable; however the decision taken in this instance is that the term 'significant' should remain in the question set. The reason that the term 'significant' remains in the question set is that there is in general a grey area between repair and re-use. For instance, after the publication of the Waste Framework directive (European Parliament and Council, 2008), additional guidance on this directive was also issued, (European Commission, 2012). When describing re-use, point 1.4.3 of this guidance allows for *"some repairing"* to be conducted on a re-used product. Thus, the term 'significant' while not crystal clear, owing to the already existing grey area, does allow for at least some distinction between a re-used product and a repaired product.

In relation to fourth concern from reviewer B

The review's point is taken on board in this instance. The wording was changed from "expired" to "consumed".

In relation to fifth concern of reviewer B

The review's point was taken on board. Both the question set and flow are indeed able to be merged into one document.

References

Abbey, J.D., Meloy, M.G., Guide, V.D.R., Atalay, S., 2014. Remanufactured products in closed-loop supply chains for consumer goods. Prod. Oper. Manag. 24, 488–503. http://dx.doi.org/10.1111/poms.12238.
Andreu, J., 1995. The remanufacturing process. In: Internal Paper from Manchester Metropolitian University. Manchester.
Barquet, A.P., Rozenfeld, H., Forcellini, F.A., 2013. An integrated approach to remanufacturing: model of a remanufacturing system. J. Remanufacturing 3, 1–11. http://dx.doi.org/10.1186/2210-4690-3-1.
BS 8887-2, 2009. BSI Standards Publication Design for Manufacture, Assembly, Disassembly and End - of - Life Processing (MADE) Part 2: Terms and Definitions.
BS 8887-220:2010, 2010. Design for Manufacture, Assembly, Disassembly and End-of-life Processing (MADE). The Process of Remanufacture. Specification.
European Action Plan, 2015. European Union Action Plan for the Circular Economy [WWW Document]. URL http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614 (accessed 10.17.16).
European Commission, 2012. Guidance on the Interpretation of Key Provisions of Directive 2008/98/EC on Waste. [WWW Document]. URL http://ec.europa.eu/environment/waste/framework/pdf/guidance_doc.pdf (accessed 10.17.16).
European Parliament and Council, 2012. Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE). Off. J. Eur. Union L 197, 38–71. http://dx.doi.org/10.3000/19770677.L_2012.197.eng.
European Parliament and Council, 2008. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain directives (Waste framework. Off. J. Eur. Union L 312, 3–30. http://dx.doi.org/10.2008/98/EC.; 32008L0098.
European Parliament and Council, 2000. Directive 2000/53/EC - End-of-Life Vehicles. Off. J. Eur. Communities L 269, 34–42.
Federal Act, 2015. United States Government – Federal Repair Cost Savings Act of 2015 [WWW Document]. URL. https://www.congress.gov/bill/114th-congress/senate-bill/565/text/pl (accessed 10.17.16).
Giuntini, R., Gaudette, K., 2003. Remanufacturing: the next great opportunity for boosting US productivity. Bus. Horiz. 46, 41–48. http://dx.doi.org/10.1016/S0007-6813(03)00087-9.
Go, T.F., Wahab, D. a, Hishamuddin, H., 2015. Multiple generation life-cycles for product sustainability: the way forward. J. Clean. Prod. 95, 16–29. http://dx.doi.org/10.1016/j.jclepro.2015.02.065.
Gray, C., Charter, M., 2007. Remanufacturing and Product Design [WWW Document]. URL http://cfsd.org.uk/Remanufacturing and Product Design.pdf

(accessed 10.17.16).
Gurler, I., 2011. The analysis and impact of remanufacturing industry practices. Int. J. Contemp. Econ. Adm. Sci. 1, 25–39.
Hamzaoui-Essoussi, L., Linton, J.D., 2014. Offering branded remanufactured/recycled products: at what price? J. Remanufacturing 4, 1–15. http://dx.doi.org/10.1186/s13243-014-0009-9.
Hamzaoui-Essoussi, L., Linton, J.D., 2010. New or recycled products: how much are consumers willing to pay? J. Consum. Mark. 27, 458–468. http://dx.doi.org/10.1108/07363761011063358.
Hatcher, G.D., Ijomah, W.L., Windmill, J.F.C., 2014. Design for remanufacture: a literature review and future research needs. J. Clean. Prod. 19, 2004–2014. http://dx.doi.org/10.1016/j.jclepro.2011.06.019.
Hazen, B.T., Overstreet, R.E., Jones-Farmer, L.A., Field, H.S., 2012. The role of ambiguity tolerance in consumer perception of remanufactured products. Int. J. Prod. Econ. 135, 781–790. http://dx.doi.org/10.1016/j.ijpe.2011.10.011.
Ijomah, W., 2009. Addressing decision making for remanufacturing operations and design-for-remanufacture. Int. J. Sustain. Eng. 2, 91–202. http://dx.doi.org/10.1080/19397030902953080.
Ijomah, W., 2002. A Model-based Definition of the Generic Remanufacturing Business Process. Plymouth University. http://dx.doi.org/10.026.1/601.
Ijomah, W., McMahon, C., Hammond, G., Newman, S., 2007. Development of design for remanufacturing guidelines to support sustainable manufacturing. Robot. Comput. Integr. Manuf. 23, 712–719. http://dx.doi.org/10.1016/j.rcim.2007.02.017.
Ijomah, W.L., Childe, S., McMahon, C., 2004. Remanufacturing: a key strategy for sustainable development. In: Proceedings of the 3rd International Conference on Design and Manufacture for Sustainable Development. Cambridge University Press. http://dx.doi.org/10.1016/j.buildenv.2006.10.027.
Khor, K., Udin, Z., 2012. Impact of reverse logistics product disposition towards business performance in Malaysian E&E companies. J. Supply Chain Cust. Relatsh. Manag. 1–19. http://dx.doi.org/10.5171/2012.699469.
King, A., Barker, S., 2007. Using the Delphi technique to Establish a robust research Agenda for remanufacturing. In: 14th CIRP Conference on Life Cycle Engineering. Japan, pp. 219–224.
King, A., Burgess, S., Ijomah, W., Mcmahon, C., 2006. Reducing Waste: repair, recondition, remanufacture or recycle? Sustain. Dev. 267, 257–267. http://dx.doi.org/10.1002/sd.
King, A., Gu, J., 2010. Calculating the environmental benefits of remanufacturing. In: Proc. ICE - Waste Resour. Manag, vol. 163, pp. 149–155. http://dx.doi.org/10.1680/warm.2010.163.4.149.
Kraus, T., Kühnel, M., 2015. Composites market Report 2015. In: Federation of Reinforced Plastics (AVK) and Carbon Composite e.v. (CCeV).
Landry, M., Malouin, J.-L., Oral, M., 1983. Model validation in operations research. Eur. J. Oper. Res. 14, 207–220. http://dx.doi.org/10.1016/0377-2217(83)90257-6.
Linder, M., Williander, M., 2015. Circular business model innovation: Inherent Uncertainties. Bus. Strateg. Environ. http://dx.doi.org/10.1002/bse.1906. Online prepublished version.
Lund, R., 1996. The remanufacturing industry: Hidden giant. Boston University press, Boston.
Lund, R., Hauser, W., 2010. An American perspective. In: 5th International Conference on Responsive Manufacturing - Green Manufacturing. http://dx.doi.org/10.1049/cp.2010.0404.
Lund, R.T., 1985. Remanufacturing: the experience of the United States and implications for developing countries. World Bank. Tech. Pap. 31, 1–126.
Matsumoto, M., Ijomah, W., 2013. Remanufacturing. In: Kauffman, J., Lee, K. (Eds.), Handbook of Sustainable Engineering, pp. 389–408. http://dx.doi.org/10.1007/978-1-4020-8939-8.
Nasr, N., Thurston, M., 2006. Remanufacturing: a key Enabler to sustainable product systems. In: Proceedings of the 13th CIRP International Conference on Life Cycle Engineering, pp. 15–18.
Parker, D., 2010. Briefing: remanufacturing and reuse – trends and prospects. Proc. ICE - Waste Resour. Manag. 163, 141–147. http://dx.doi.org/10.1680/warm.2010.163.4.141.
Paterson, D.A.P., Ijomah, W., Windmill, J., 2016. An analysis of end-of-life terminology in the carbon fiber reinforced plastic industry. Int. J. Sustain. Eng. 9, 130–140. http://dx.doi.org/10.1080/19397038.2015.1136361.
Paterson, D.A.P., Ijomah, W., Windmill, J., 2015. Carbon fibre reinforced plastic EOL: protecting remanufacturing status and life cycle route analysis. In: International Conference on Remanufacturing, pp. 1753–1759. http://dx.doi.org/10.1016/j.buildenv.2006.10.027.
Ribeiro, J.S., Gomes, J.D.O., 2014. A framework to integrate the end-of-life aircraft in preliminary design. In: 21st CIRP Conference on Life Cycle Engineering. Elsevier B.V., pp. 508–513. http://dx.doi.org/10.1016/j.procir.2014.06.077
RIC, 2016. Remanufacturing Industries Council [WWW Document]. URL http://www.remancouncil.org/educate/impact-of-remanufacturing/what-is-remanufacturing (accessed 08.04.2016).
Shu, L.H., Flowers, W.C., 1999. Application of a design-for-remanufacture framework to the selection of product life-cycle fastening and joining methods. Robot. Comput. Integr. Manuf. 15, 179–190. http://dx.doi.org/10.1016/S0736-5845(98)00032-5.
Shu, L.H., Flowers, W.C., 1995. Considering remanufacture and other End-of-Life Options in selection of fastening and Joining methods, in: Electronics and the Environment, 1995. In: ISEE., Proceedings of the 1995 IEEE International Symposium on. IEEE, pp. 75–80. http://dx.doi.org/10.1109/ISEE.1995.514953.
Spelman, C., Sheerman, B., 2014. Triple Win: the Social, Economic and Environmental Case for Remanufacture, a Report by the All-party Parliamentary Sustainable Resource Group and the All-party Parliamentary Manufacturing Group. United Kingdom.
Steinhilper, R., Weiland, F., 2015. Exploring new Horizons for remanufacturing an up-to-date Overview of Industries, products and Technologies. In: The 22nd CiRP Conference on Life Cycle Engineering. Elsevier B.V., pp. 769–773. http://dx.doi.org/10.1016/j.procir.2015.02.041
Sundin, E., 2004. P. Roduct and Process Design for Successful Remanufacturing. Linkoping Univeristy.
Sundin, E., Lindahl, M., Ijomah, W., 2009. Product design for product/service systems. J. Manuf. Technol. Manag. 20, 723–753. http://dx.doi.org/10.1108/17410380910961073.
Winkler, H., 2010. Sustainability through the implementation of sustainable supply chain networks. Int. J. Sustain. Econ. 2, 293–309. http://dx.doi.org/10.1504/IJSE.2010.033396.