Justification for remanufacture in the lighting industry

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Remanufacture: *return a used product to at least its original performance, from a customer perspective, with a warranty at least equal to that of a newly manufactured equivalent.*

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Justification for the remanufacture of lighting equipment: Summary

The lighting industry has begun embracing circularity to tackle environmental impacts derived from the production, use and disposal of lighting equipment. The authors propose that the circular strategy of remanufacture can make an important contribution to the lighting industry by joining together the ‘waste management’ of lighting with contemporary attitudes to design and manufacture. Remanufacture is the process of *‘returning a used product to at least its original performance, from a customer perspective, with a warranty at least equal to that of a newly manufactured equivalent’* (British Standards Institution, 2019).

Assessing the state of circularity in the lighting industry found that the legal pathway for collecting and treating used lighting equipment, the WEEE scheme, is operating at concerningly low levels of collection for recycling – below 10% of the annual placed-on-market weight. The authors propose that remanufacture could improve collection rates and complement recycling operations by adding to, not reducing, the residual value of used equipment.

Addressing the technical aspect of remanufacture, the authors identify some key design and engineering factors which help enable products produced today to be remanufactured, not recycled, after their first lifecycle. This also offers preliminary guidance on which existing products have the most potential for remanufacture. It is suggested that lighting design should begin to encompass the ‘re-design’ of used lighting equipment, as well as the design of products which can be remanufactured.

Drawing on case study evidence from other related sectors it is found that remanufacture can provide significant environmental, social and economic benefits. Across the EU, 192,000 people are directly employed in remanufacture (European Remanufacturing Network, 2015); 19,000 in Scotland (Zero Waste Scotland, 2021).

Some general terminology and processes are introduced. There are three ‘macro’ models for remanufacture: Original Equipment Manufacturers/Remanufacturers (OEMs/OERs), Contracted Remanufacturers (CRs) and Independent Remanufacturers (IRs). Collected used products to be remanufactured are termed ‘cores’ (British Standards Institution, 2019) and while each industrial sector has evolved remanufacture to their specific requirements, the fundamental process for the remanufacture of lighting equipment is proposed to be (1) core collection, (2) inspection, (3) disassembly, (4) component reprocessing, and (5) reassembly and testing.

Finally, the prospect for remanufacture in the lighting industry is briefly explored. The moderate level of standardisation of key components, both mechanically and electrically, as well as relatively low levels of product complexity are encouraging factors. The variability of lighting equipment design and lack of processes, standards, methodologies and legislation which formally support the remanufacture of lighting equipment are the most significant barriers. The authors highlight a number of potential benefits arising from the remanufacture of used equipment; especially reduced environmental impacts, increasing the residual value of used equipment, creating employment opportunities and encouraging end-users to view lighting as a long-term purchasing decision.

The authors identify the most remanufacture-supportive strategies to be designing new lighting equipment to be remanufactured and the development of an Open Data Standard for lighting. These strategies could provide the confidence prospective remanufacture operators need to start developing a collaborative ecosystem like those identified in other sectors.

Introduction, context and aims

The lighting industry is in a period of change. Legislators, researchers, designers, providers and end-users of lighting increasingly recognise the importance of lighting equipment which is not just energy-efficient but also low-waste and sustainable in a broader sense. This period of reflection and positive change provides an opportunity to develop not just "better" versions of existing lighting equipment but new attitudes to product design, manufacture and ownership models for lighting which have environmental, social and commercial benefits. Circularity is however a collection of concepts – not one specific, implementable strategy. This paper makes a case for remanufacture as an essential and valuable part of a material-efficient lighting industry.

Remanufacture is recognised as the most sophisticated method in the circular economy (Ijomah, 2019) and is increasingly successful in sectors including tech, automotive, industrial and furniture. Remanufacture, however, remains a largely neglected technique in the lighting industry.

EGG Lighting, an SME based in Glasgow, Scotland, is among those advocating the remanufacture of lighting equipment and this paper introduces evidence of the economic, environmental and social benefits of remanufacture, as well as proposing the key parameters for remanufacture in the lighting industry.

We hope to encourage awareness and consensus in the lighting industry around the merits of remanufacturing. It is clear that industry collaboration is an important enabler for remanufacture and successful implementation of circularity in general (Earley, 2017). We therefore encourage all individuals and organisations to view this paper as a starting point to consider how the remanufacture of lighting equipment can be encouraged in their sector.

It is important to note at the outset that the majority of through-life environmental impacts are incurred during the use phase of lighting. It is therefore important to increase the lumen-per-watt efficacy of all lighting and the industry correctly devotes much attention to this aim. The importance of improving light-source efficacy does not however reduce the importance of improving the circularity of lighting equipment. Indeed, the authors propose that implementing remanufacture could *accelerate* the timely adoption of ever-advancing LED technology, without waste as a prerequisite. New technology need not mean new products.

The state of circularity in the lighting industry

The collection and treatment of all used lighting equipment is essential minimise material waste and to prevent the release of hazardous substances into other resource flows or the environment. Unfortunately the legal framework for ensuring collection and proper treatment - the WEEE (Waste Electrical and Electronic Equipment) regulations - has had limited success.

Figure 1 shows that in 2019 over 40,000t of lighting equipment were placed on the UK market, with only 2,700t collected by WEEE scheme operators. The annual collected weight expressed as a percentage of the annual retailed weight is just 7% as shown on Figure 2. While this does not mean that only 7% of lighting equipment is collected for recycling, it indicates that a very high proportion of lighting equipment is being disposed of in sub-optimal and possibly illegal ways. In the 5 years between 2015 and 2019, 218,400t more lighting was placed on the market than was collected by the WEEE scheme.

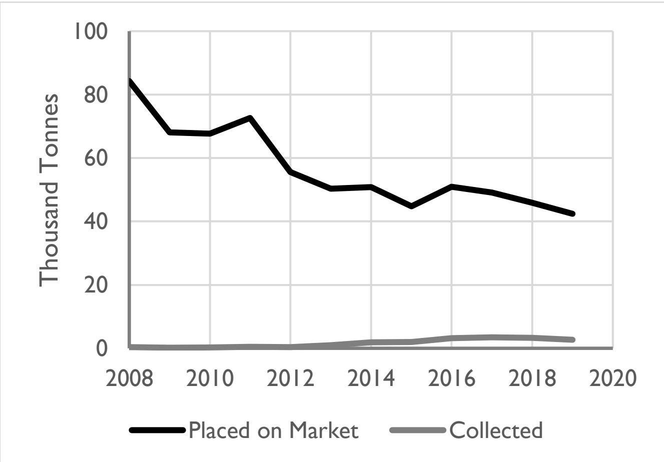

Figure 1: Lighting Equipment placed on the UK Market and collected as WEEE (tonnes) (Office for National Statistics, 2020)

Note that the trend of decreasing weight placed on the market shown on Figure 1 is the result of more lightweight LED products replacing fluorescent and other heavier technologies. The total value of lighting sold in the UK market has tended to increase year-on-year since at least 1997 (Office for National Statistics, 2020).

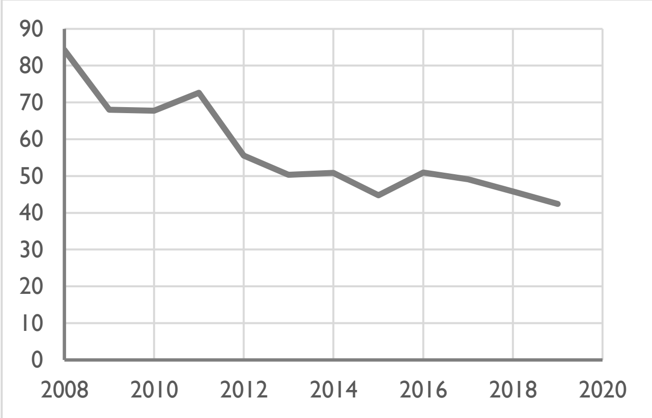

Figure 2: Lighting Equipment collected as WEEE as % of Lighting Equipment placed on UK market (Office for National Statistics, 2020)

The limited success of the WEEE scheme requires urgent attention because:

- Lighting equipment may contain hazardous materials which require specialist treatment
- Non-specialist treatment (for example, treating whole luminaires as scrap metal) is likely to result in downgrading or contaminating resource flows
- The low collection rate of lighting equipment makes it more difficult to progress to more advanced circular economy models

It is essential to note that the limited success of the WEEE scheme is not the responsibility of a single stakeholder; circularity is most easily introduced through the collaboration of stakeholders across the industry (Earley, 2017).

A significant factor in the limited success of the WEEE scheme is that *the end-user is likely to incur an expense to arrange collection and proper treatment of used lighting equipment*. Remanufacture is able to influence this issue because it increases the valuation of used equipment whereas recycling reduces it. The authors propose that remanufacture could thus encourage higher collection rates of used equipment through collection financing or buyback schemes. Recycling is essential but limited and should be considered a last-resort technique.

Remanufacture and its distinction from recycling, reuse and repair

The 'circular economy' has been adopted by industry and legislation as a framework for mitigating environmental impacts resulting from production. Circularity encourages the development of closed-loop resource flows where, put simply, 'waste becomes food' (Braungart & McDonough, 2009). Circularity primarily relates to the removal of waste and associated environmental impacts from a system rather than reducing them.

Waste reduction strategies, though entirely valid, are therefore not strictly 'circular'; examples include reducing the overall flow of materials (light-weighting, downsizing, reducing consumption), extending the lifetime of products (durability) (Bocken, et al., 2016) and maintaining materials in their highest-value state (Blomsma & Tennant, 2020).

Remanufacture has a specific definition and is distinct from recycling, reuse and repair.

Recycling
Recycling reduces a product to its constituent materials to be used in the manufacture of a new product (Blomsma & Tennant, 2020). Recycling is generally the least preferable technique for circularity and incurs a number of limitations (Ijomah & Danis, 2019):

- Recycling is energy and resource intensive (collection, cleaning, sorting, shredding, processing, transporting)
- Recycling reduces the value of the product to that of its raw materials
- Recycled materials are often lower-grade than equivalent virgin materials
- Recycling can be difficult to track due to international and complex supplychains
- Recycling can result in the increase in overall production (rebound), especially where recycled materials are not used to manufacture similar new products

Reuse
Reuse is the process through which a fully functional product is put back into use in a similar environment without modification. The WEEE regulations use a much broader definition of reuse (WEEE Regulations, 2013).

Repair
Repair is returning a faulty or broken product or component back to a usable state (British Standards Institution, 2009). Any warranty or quality assurance, if provided, is likely to be less than a new product or be specific to the repaired component(s).

Remanufacture
Remanufacture is: 'The process of returning a used product to at least the original equipment manufacturer's performance specifications from a customer perspective and giving the resultant product a warranty at least equal to that of a newly manufactured equivalent.' (British Standards Institution, 2019)

While hierarchical circular economy and waste treatment models often prioritise reuse (Ellen Macarthur Foundation, 2014) (Stahel, 1982), the authors propose that decision-making should be led by product specific impact-assessment rather than heuristic assumptions. It is proposed that in many cases remanufacture is more suitable than reuse and repair in the lighting sector because:

- Lighting technology and efficiency continues to advance at a significant rate, requiring the upgrade of key components and therefore more than just repair or reuse
- Diligent testing and documentation is an important sectoral requirement, which is aligned with remanufacture practice
- Customer expectations for performance, reliability and warranty are important and therefore the product must be comparable in these respects to a new product

Figure 3 communicates the generalised change to product value for each circular technique, demonstrating that a remanufactured product regains more value than other circular treatment methods.

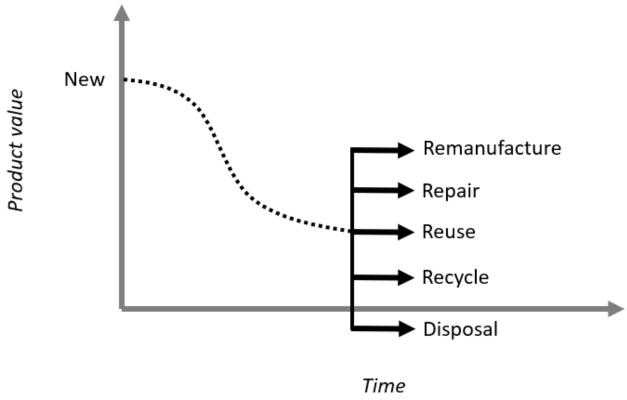

Figure 3: Circular techniques and their relationship to product value

For remanufacture, a used product is referred to as a "core". This term reflects that the used product is an incomplete starting point with future potential. The remanufacture process generally involves (1) core collection, (2) inspection, (3) disassembly, (4) component reprocessing, and (5) reassembly/testing.

During the *component reprocessing* stage, if a core is not suitable for remanufacture (for example, due to extensive damage) then functional components from the core can be removed, tested and reutilised in the reassembly of another core – this is referred to as 'component reuse'.

While recycling reduces the value in a product to that of its constituent materials (the commercial viability of which is limited by the work and costs involved), remanufacture increases the value of a product towards its 'new' value as represented by Figure 4. This increase in value could be used to finance collection or 'buyback' in order to improve collection rates of used lighting equipment.

Figure 4 conveys three observations: (1) lighting equipment depreciates quickly after initial purchase; (2) lighting equipment loses more value over its lifetime as the result of degrading performance and technical or perceived obsolescence; (3) remanufacture aims to return the value of lighting equipment towards its 'new' value. In general with these observations, the authors propose that maintaining product value is a key objective to encourage the circularity of lighting equipment.

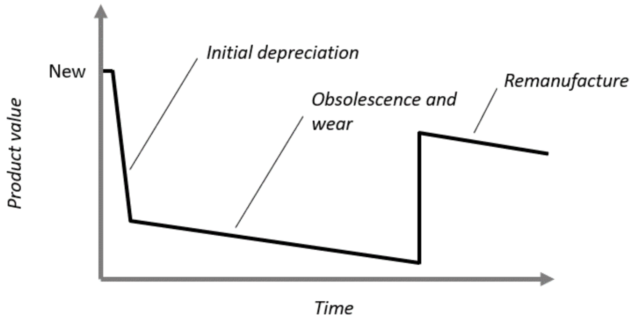

Figure 4: Remanufacture value proposition

In remanufacture the mindset of 'separate manufacture and waste management' is advanced to 'combined manufacture and waste management'. At this point, used lighting equipment ceases to be 'waste' and instead become 'cores' which have a residual value that can be increased through design and the remanufacture process. The ease of remanufacture is influenced by the original design and characteristics of a core.

Design for a circular lighting sector

The previous section stated that *maintaining product value is a key objective to encourage the circularity of lighting equipment*.

Currently 'design' commonly refers to the development of a new product, whereas in the circular context, design includes both the development of new products which can be remanufactured and the development of remanufactured products from used ones (Tam, et al., 2019).

To produce good cores for future remanufacture, 'designers will need to embrace designing for disassembly and make remanufacture a primary consideration in the design of new products' (Zero Waste Scotland, 2021). With reference to Figure 4, design can encourage the ease of remanufacture in two main ways:

- Reducing the depreciation and wear rate, thereby increasing residual value of used equipment;
- Improving the technical or commercial feasibility of remanufacture

The depreciation and wear rate of lighting equipment is composed of technical factors such as durability and rate of change of technology, as well as 'market' factors such as rate of change of aesthetic preference and how application-specific a product is. In brief, design for remanufacture could include production of durable equipment without aesthetic qualities likely to be fleeting and which is suitable for many end-users.

The technical feasibility of remanufacture is influenced by the geometry, material, quantity and other factors relating to the product. Notably, the core should be easily collected, disassembled, cleaned and re-assembled. This implies the avoidance of certain assembly techniques in favour of standard and durable fasteners; the use of internal modularity and standardisation of components likely to require replacement; and the use of reworkable materials which do not age poorly (rust, decolour, delaminate, scratch, degrade).

Table 1 introduces some techniques under these categories which may encourage the development or selection of equipment best suited to remanufacture. The interactions between factors are not developed, however some should be self-evident (for example, rate of change of technology and use of standard mounting technology).

Table 1: Design or technical and commercial/market factors influencing remanufacture

Depreciation and wear rate of lighting equipment	
Technical factors	*Market factors*
• Durability • Rate of change of technology • Ability to upgrade without obsolescence (physical or software)	• Rate of change of aesthetic preference • Warranty/support duration • Applicability for a broad use case • Presence of demand • Adherence to product performance standards • Customer trust in the equipment
Feasibility of remanufacture	
Technical factors	*Market factors*
• Reversable construction techniques • Use of component modularity and standardisation • Reduction of component count • Avoidance of unnecessary small tolerances • Use of standard and durable fasteners and connectors • Use of reworkable and durable materials • Ease of failure diagnosis • Use of simple internal geometries • Dimensional factors which encourage collection and rework	• Mass-manufacture or commonality of the design • Availability of relevant documentation • Availability of spares • Avoidance of proprietary technology • Degree of industry collaboration

Table 2: Turnover and prevalence of remanufacture in different EU sectors (European Remanufacturing Network, 2015)

Sector	**Turnover (€bn)**	**Firms**	**Employment**	**Annual volume**	**Product complexity**	**% of sector**
Aerospace	12.4	1,000	71,000	5,160,000	High	11.50%
Automotive	7.4	2,363	43,000	27,286,000	High	1.10%
Electronic and Electrical	3.1	2,502	28,000	87,925,000	Moderate	1.10%
Furniture	0.3	147	4,000	2,173,000	Low	0.40%
All-terrain vehicles	4.1	581	31,000	7,390,000	High	2.90%
Machinery	1	513	6,000	1,010,000	High	0.70%
Marine	0.1	7	1,000	83,000	Moderate	0.30%
Medical equipment	1	60	7,000	1,005,000	High	2.80%
Rail	0.3	30	3,000	374,000	Moderate	1.10%
Total	**€29.8bn**	**7,204**	**192,000**	**132,405,000**	**-**	**1.90%**

Remanufacture in other sectors

Remanufacturing has been of increasing interest in recent decades due to its environmental, economic and social benefits. Table 1 demonstrates the prevalence of remanufacture in a variety of sectors (European Remanufacturing Network, 2015), showing that 7,204 remanufacture operators turn over **€30bn** each year.

The benefits of remanufacture are easier to explore through case studies rather than theory, so this and the following section will use case studies to explore the environmental, social and economic impact of remanufacture.

In the automotive sector, the French manufacturer Renault has been one of the leading remanufacturing and circular economy organisations, with initiatives spanning some 70 years. In total 30,000 engines, 20,000 gearboxes and 16,000 fuel injections systems are remanufactured at the Choisy-le-Roi plant each year. These assemblies are 30-50% less expensive to remanufacture than to manufacture new (Smets, 2016). The process employs 345 workers (The Danish Environmental Protection Agency, 2016) and therefore has a strong social impact on local communities. The process results in an 80% reduction in energy and water consumption and 70% less waste production than conventional manufacture methods (The Ellen Macarthur Foundation, 2013) (PBL Netherlands Environmental Assessment Agency, 2017).

In a more general study of remanufacture, with findings drawn from nine automotive remanufacturers based in Europe, cost reductions amount to 10-65%, energy reductions to 75-85% less and CO2 emissions reductions 70-90% less when comparing to an equivalent new part (Sundin, 2016).

From a social perspective, those nine remanufacturers directly employ more than 1200 workers, providing economic and social stability in their local communities (Sundin, 2016). In many cases the social impact is a main driver for remanufacture, such as in Grundfos, a danish pump manufacturer with a total of 18,000 personnel. Grundfos developed its remanufacturing and recycling department as part of a goal to create jobs, enhance diversity among the workforce and create opportunities for workers with physical, mental or social challenges (The Danish Environmental Protection Agency, 2016). In total, Table 2 shows that nearly 200,000 workers across the EU are employed in remanufacturing roles - including 19,000 in Scotland alone (Zero Waste Scotland, 2021).

The reduced cost of remanufacturing rather than manufacturing new products enables more individuals or businesses to access good-quality equipment. For example, engine turbine blades have been successfully remanufactured at 30% lower cost than new, with identical expected service life (Sundin, 2016). This cost reduction raises the question of whether remanufactured lighting equipment may be able to encourage businesses operating fluorescent or outdated lighting to upgrade to modern LED technology. Capital cost can be a significant barrier to the adoption of efficient technology, especially in retrofit scenarios which are often the poorest performers in terms of electricity consumption.

While cost breakdowns vary between sectors, the cost of raw materials is often a significant factor in the profitability of manufacture and there are national-scale benefits associated with the resource efficiency remanufacture offers. At a national scale the annual cost savings from even a partial implementation of circularity in the USA has been estimated at US$340 to $380 billion (Ellen Macarthur Foundation, 2014).

Remanufacture Models

The specific way in which remanufacture is organised varies between sectors, with three distinguishable models, shown on Figure 5: Original Equipment Remanufacturers (OERs), Contracted Remanufacturers (CRs) and Independent Remanufacturers (IRs).

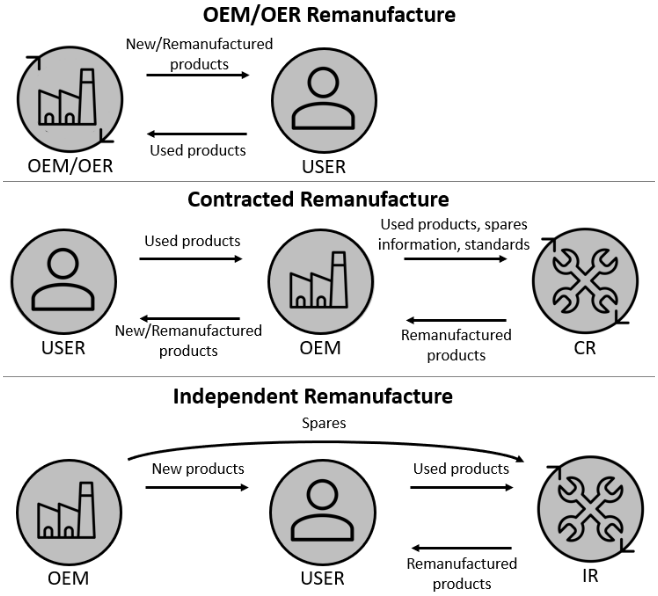

Figure 5: Remanufacture models

Original Equipment Manufacturers/Remanufacturers (OEM/OERs)

Manufacturers that collect and remanufacture their own products are termed Original Equipment Remanufacturers (OERs) and typically source cores directly from end-users at the end of lease contracts or via retailers. This may be part of a close commercial relationship between the end-user and OEM/OER.

The OEM/OER has complete information and ability to influence product design, availability of spare parts, performance and may have some influence on upstream and downstream supplychain/retail practices. The OEM/OER is also able to mitigate challenges with supply fluctuation through their knowledge of placed-on-market quantities and models. One benefit of inhouse remanufacture for the OEM/OER is the ability to retain control of the reputation of their equipment, particularly where there exists an informal or unprofessional reuse market.

Prominent examples of OEM/OERs include Renault, IBM and HP. The Dutch OEM/OER furniture (re)manufacturer DESKO implements a buy-back scheme to ensure a steady and predictable supply of cores, based on an understanding of the duration of use cycles which last 4-7 years. Additionally, it keeps an inventory of spare parts from partially-rejected cores and applies pricing models based on the number of lifecycles a product has completed.

Contracted Remanufacturers (CR)

CRs are remanufacture operators with a direct partnership or agreement with an OEM. The main characteristic of this model is that remanufacture is performed based on a contract; as a service for the owner of the core. The CR is therefore not responsible for resale of the remanufactured equipment.

Contracted Remanufacturers benefit from a close relationship with the OEM, enabling access to technical information, spare parts and official logistical arrangements for collection and distribution. This collaboration insulates the remanufacturer from market factors, requires less investment and allows them to focus on a specific capability (Lund, 1985).

The greatest challenges for CRs are ensuring commercial success with limited influence over product and process design as well as market factors (Sundin, 2016).

An example Contracted Remanufacturer is the Swedish company UBD Cleantech (Sundin, 2016). UBD Cleantech collects, remanufactures and returns callipers and other equipment under contract for a large variety of automotive OEMs. In this model the OEM has chosen not to develop the capability to remanufacture products inhouse, but specifies standards and requirements to UBD Cleantech to protect their brand reputation.

Independent Remanufacturers (IR)

This category includes third party remanufacturers that are independent of and have limited contact with the OEMs. This limitation of interaction with the OEM results in increased uncertainty in the supply of cores as well as the availability of replacement components. Additionally, Independent Remanufacturers usually process a variety of cores with different designs and of various quality which may result in operational and technical challenges.

One of the key benefits for Independent Remanufacturers is increased potential profitability due to the unsaturated market they operate in. This profitability comes with increased operational risks due to limited access to technical and market information; IRs are therefore often small and agile companies that retain a close relationship with the end customer.

An example Independent Remanufacturer is Vector Aerospace, a UK-based independent remanufacturer focussing on engine components and parts for fixed-wing aircraft (Sundin, 2016). The OEM manufacturer is only contacted if new spare parts are required, and during the remanufacturing process the owner of the core stays the same.

Remanufacture Process

The remanufacture process is implemented by operators in a case-specific manner depending on industry, business model, product attributes, market size and other factors (Sundin, 2016). Despite this variety the main stages of remanufacturing are: core collection, cleaning, inspection, disassembly, component reprocessing, and reassembly/testing.

Core collection
Most OEMs involved in remanufacture operate collection schemes either directly or via retailers to maximise return rates. However, the majority of remanufacturers in Europe are IRs with limited to no interaction with OEMs and therefore obtain cores directly from end-users or retailers (European Remanufacturing Network, 2015).

Cleaning
The selection of a cleaning/preparation method is usually experience-based rather than methodical (Nee, 2013). Cleaning costs contribute significantly to the total remanufacturing costs and cleaning performance has a large effect on the quality and yield rate of components (Sitcharangsie, et al., 2019). Table 3 provides an introduction to cleaning techniques and their applications.

Inspection and Testing
Inspection is the process by which the performance and quality of a core is determined. In most cases the core's quality is directly linked to its viability for remanufacture. Inspection ranges from a quick external visual inspection to the detailed examination of key components. The performance of a core and all components is tested and compared to standards set either by the OEM, the market or legislation, allowing remanufacturers to guarantee quality and performance of the remanufactured core.

Disassembly
The disassembly of a core is often a labour-intensive task and thus a number of methods have been developed to estimate the time needed to dis- and re-assemble a core, summarised by Table 4. Disassembly time can either be directly measured or calculated based on product parameters (Vanegas, 2018). The main methods to calculate disassembly time are: U-effort (Sodhi, et al., 2004) which focuses on connector types, the Philips ECC (Boks, 1996) which uses a database of timed tasks, Maynard Operation Sequence Technique (MOST) which is used for time estimation of a variety of products (Maynard, et al., 2001) and a method developed by Desai & Mital which identifies five key factors; force, material handling, tool utilisation, accessibility of components and fasteners, and tool positioning, to estimate disassembly time (Desai & Mital, 2003).

Component reprocessing
Component reprocessing consists of all the necessary tasks for maintaining, repairing, reconditioning, or replacing a used component. Components may be reused, replaced or improved, with components being sourced from the same core, other cores or being new. It is common practice to upgrade key components in products that age or become obsolete quickly, for example laptops.

Reassembly and testing
Reassembly typically follows the reverse sequence of the disassembly process and is involves bringing together tested components, which may have been collected from cores or new, into a remanufactured product. Following reassembly each product or batch must be tested according to safety, quality, consistency and performance standards which may originate from the remanufacturer, market, OEM or legislation.

Table 3: Comparisons of cleaning methods (Sitcharangsie, et al., 2019)

Cleaning Technique	Suitable surface	Application
High-Temperature decomposition	Cast iron	Oil, grease and other organic matter
Supercritical CO2 cleaning	Heat-sensitive metal parts which are heat sensitive or precise, e.g. aluminium	Oil, grease and other organic matter
Liquid blasting	Most types of surface except when contaminated with grease	Rust, paint
Shot blasting	Cast surfaces	Rust, paint, scale
Ultrasonic cleaning	Most hard and non-absorbent materials; metals, glass, plastic, aluminium or ceramic, including delicate products	Oil, grease and other organic matter
Chemical solvents	Almost all types of surface	Rust, scale, oil, grease

Table 4: Methods for disassembly timing and analysis (Vanegas, 2018)

Method	Calculation approach
U-effort	Based on properties of connectors
Phillips ECC	Database with actual disassembly times
Desai & Mital	Factors affecting disassembly time are evaluated with Method Time Measurement (MTM)
Kroll	Base time for fasteners and difficulty scores based on Maynard Operation Sequence Technique (MOST)

Remanufacture in the lighting industry: barriers, drivers, benefits

This section will explore the potential for remanufacture in the lighting industry and suggest the benefits it may offer, drawing upon previous sections.

Barriers to remanufacture

A significant barrier to remanufacture is the design of existing products. Most lighting equipment is not designed with remanufacture (or recycling etc.) in mind and therefore the feasibility of developing new products from these cores will vary - or will require new methods and problem-solving (Tam, et al., 2019). Therefore, the authors propose that developing methodology to determine the technical and commercial feasibility of remanufacturing existing products is crucial. This may lead to the identification of remanufacture-viable products or classes.

The variability of products themselves is a challenge, because it limits economy of scale and consistency in the remanufacture process. As with recycling, the commercial viability of remanufacture can be improved through sorted and high-quality collection streams of remanufacturable products. Isolating these from collections of used equipment will be another critical task for the lighting industry and the authors suggest this can be best done through the use of 'digital passports'; asset tags which make information about a product available to a machine or human operator.

Particularly for the Independent Remanufacturer, information about collection rates, valuations and demand for each product type is valuable but difficult to obtain. Streamlined communication channels between stakeholders in remanufacture would enable the transfer of information relating to technical factors, quantities, quality and condition. The authors support the aforementioned 'digital passport' to be connected with an open data standard for lighting. This could provide the required information to independent remanufacturers to enable forecasting, process planning, technical information transfer and environmental impact and warranty tracking. The broad availability of this information would encourage cross-industry collaboration and de-risk the development of remanufacture.

The performance and safety of lighting equipment is essential and regulated by a number of standards and pieces of legislation. While remanufacture is more formally developed in other sectors, there is presently little recognition of remanufacture in the lighting industry. This creates a grey-area while the methods and processes for carrying out and assessing remanufacture are not defined or tested, which hinders end-user trust and supplychain confidence. To address this, existing standards should be reviewed for their applicability to remanufacture and any opportunities for new standard methods identified. This process should be informed by evidence from practical research and pilot studies.

Drivers for remanufacture

The principal driver for remanufacture is the pressing need to improve the environmental performance of the lighting sector. This includes the collection rate of used lighting equipment, the timely adoption of improved-efficiency light-source technology and reduction of manufacture and end-of-life impact of lighting equipment.

Remanufacture production costs tend to lie between 34% and 60% lower than the manufacture of new products (Zero Waste Scotland, 2021). This cost saving may enable remanufacturers to subsidise the collection of used equipment through buyback schemes, increasing collection rates. It may also enable price reduction to be offered to end-users, which carries the benefit of enabling more businesses to access good-quality efficient lighting. The penetration of low-quality equipment into the market and the continued prevalence of fluorescent lighting in existing installations demonstrates the need for high-quality, affordable lighting. If it can provide this, remanufactured lighting equipment could play a part in encouraging end-users to adopt modern LED technology while creating significantly less waste in the process.

Figure 6 shows the inflation-adjusted import and export of lighting equipment from the UK market. Over twice as much lighting equipment is imported than exported. While the overall trade in lighting has been increasing for 2 decades, the proportion of this equipment that originates in the UK has diminished. As part of a broader debate, it is sensible that the circulation of equipment and resources within a smaller geographic footprint would reduce transportation emissions and enable greater oversight and scrutiny of supplychain practices.

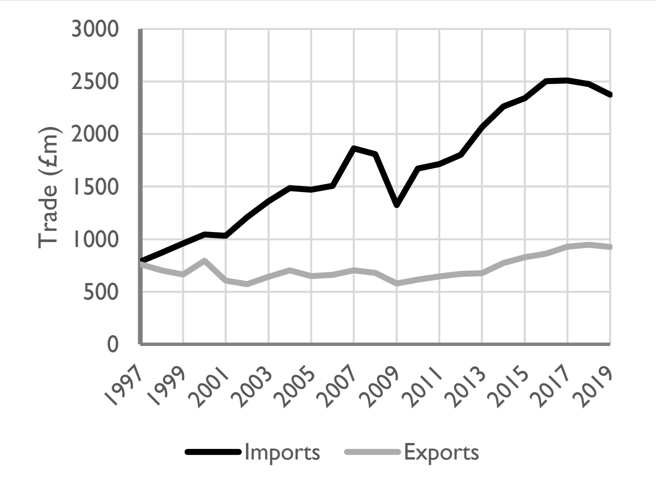

Figure 6: UK Trade in electric lighting equipment (£m, worldwide, NSA, CVM) (Office for National Statistics, 2020)

There are drivers for remanufacture in the direction of legislative travel. The WEEE regulations will be reviewed in 2023 and may include 'eco-modulation' to incentivise environmentally responsible design. The EU Eco-design directive now mandates the straightforward removal, supported by publicly-accessible instructions, of light sources and control gears (European Commission, 2019). The EU energy labelling of light sources regulation requires the provision of some technical information to be publicly digitally available through a QR code (European Commission, 2019). Similarly, recent political events indicate that the transportation of waste plastic will become increasingly regulated (CIWM, 2021), which may influence the commercial viability of recycling lighting equipment.

Benefits of remanufacture

Table 5 summarises the benefits of remanufacture which have been identified throughout this report.

Table 5: Benefits of remanufacture

Benefits of remanufacture
Environmental
• Reduction of new-manufactured products and demand for material extraction and processing • Significantly improved environmental outcome over recycling • Improved collection rate of used lighting equipment • Reduced transportation of products where these are currently mainly imported • Overall reduced environmental impact of remanufacture • Improved transparency of remanufacture over supplychain, ensuring environmental legislation is adhered to • Encourage timely adoption of latest LED efficiency to cost-driven businesses
Social
• Creation of jobs in circular sector – 19,000 jobs presently relate to remanufacture in Scotland, 192,000 in the EU • Improved trust between end-users and lighting industry
Economic
• 34-60% reduction in production cost versus new equipment, in general (Zero Waste Scotland, 2020) • Greater insulation from international supply disruption and tariffs • Development of a remanufacture process could increase the residual value of used lighting equipment • Realisation of residual value of lighting equipment could encourage long-term purchase decisions based on quality and longevity rather than cost alone • Reduced exposure to warranty risk • Increased relationship with end users • Potential synergy with new ownership models, such as lighting as a service

References

Blomsma, F. & Tennant, M., 2020. Circular economy: Preserving materials or products? Introducing the resource states framework. *Resources, Conservation & Recycling.*

Bocken, N., de Pauw, I., Bakker, C. & van der Grinten, B., 2016. Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering,* pp. 308-320.

Boks, C. B., 1996. Disassembly modeling: two applications to a Philips 21" television set. *IEEE International Symposium on Electronics & the Environment,* pp. 224-229.

Braungart, M. & McDonough, W., 2009. *Cradle to Cradle.* New York City: Random House.

British Standards Institution, 2009. *BS EN 8887-2:2009: Design for manufacture, assembly, disassembly and end-of-life processing (MADE). Terms and definitions,* s.l.: s.n.

British Standards Institution, 2019. *BS ISO 8887-1:2017: Technical product documentation - Design for manufacturing, assembling, disassembling and end-of-life processing.* London: s.n.

CIWM, 2021. *UK criticised for not following EU over plastic waste export ban.* [Online] Available at: https://www.circularonline.co.uk/news/uk-criticised-for-not-following-eu-over-plastic-waste-export-ban/

Desai, A. & Mital, A., 2003. Evaluation of disassemblability to enable design for disassembly in mass production. *International Journal of Industrial Ergonomics,* p. 265–281.

Earley, R., 2017. Circular Design Futures. *The Design Journal,* pp. 421-434.

Ellen Macarthur Foundation, 2014. *Towards the Circular Economy : Accelerating the scale-up across global supply chains,* s.l.: s.n.

European Commission, 2019. *ecodesign requirements for light sources and separate control gears.* [Online] Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2019.315.01.0209.01.ENG&toc=OJ:L:2019:315:TOC

European Commission, 2019. *energy labelling of light sources.* [Online] Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1575537561243&uri=CELEX:32019R2015

European Remanufacturing Network, 2015. *Remanufacturing Market Study.* [Online] Available at: http://www.remanufacturing.eu/assets/pdfs/remanufacturing-market-study.pdf

Ijomah, W. & Danis, M., 2019. Refurbishment and reuse of waste electrical and electronic equipment. In: *Waste Electrical and Electronic Equipment (WEEE) Handbook.* s.l.:Elsevier, pp. 264-279.

Maynard, H., Bright, Zandin. & B., K., 2001. *Maynard's Industrial Engineering Handbook.* New York: McGraw-Hill Standard Handbooks.

Nee, A., 2013. Re-engineering Manufacturing for Sustainability. *Proceedings of the 20th CIRP International Conference on Life Cycle Engineering.*

Office for National Statistics, 2020. *UK trade in goods by classification of product by activity time series.* [Online] Available at: https://www.ons.gov.uk/businessindustryandtrade/internationaltrade/datasets/uktradeingoodsbyclassificationofproductbyactivity

PBL Netherlands Environmental Assessment Agency, 2017. *Circular Economy: Measuring innovation in the product chain - Policy report,* s.l.: s.n.

Sitcharangsie, S., Ijomah, W. & Wong, T. C., 2019. Decision makings in key remanufacturing activities to optimise remanufacturing outcomes: A review. *Journal of Cleaner Production.*

Smets, A.-S., 2016. Evolution de l'économie circulaire au sein des TPE et PME wallonnes.

Sodhi, R., Sonnenberg, M. & Das, S., 2004. Evaluating the unfastening effort in design for disassembly and serviceability. *Journal of Engineering Design,* p. 69–90.

Stahel, W., 1982. *The Product-Life Factor,* s.l.: s.n.

Sundin, E., 2016. Map of Remanufacturing Business Model Landscape.

Tam, E., Soulliere, K. & Sawyer-Beaulieu, S., 2019. Managing complex products to support the circular economy. *Resources, Conservation & Recycling,* Volume 145, p. 124–125.

The Danish Environmental Protection Agency, 2016. *Best Practice Examples of Circular Business Models.* [Online]
Available at: https://www2.mst.dk/Udgiv/publications/2016/06/978-87-93435-86-5.pdf

The Ellen Macarthur Foundation, 2013. *TOWARDS THE CIRCULAR ECONOMY,* s.l.: s.n.

Vanegas, P., 2018. Ease of disassembly of products to support circular economy strategies. *Resources, Conservation and Recycling,* p. 323–334.

Zero Waste Scotland, 2021. *The Future of Work: Baseline Employment Analysis and Skills Pathways for the Circular Economy in Scotland,* s.l.: s.n.