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VDI ZRE publications:

Resource efficiency through remanufacturing

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The brief analyses of VDI ZRE provide an overview of current developments related to resource efficiency in research and industrial practice. They each contain a compilation of relevant research results, new technologies and processes as well as examples of good practice. The brief analyses thus provide a broad audience from business, research and administration with an introduction to selected areas of resource efficiency.

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VDI ZRE publications

Resource efficiency through remanufacturing

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ABBREVIATION INDEX

APRA	Automotive Parts Remanufacturers Association
bil.	billion
BS	British Standard
b2b	Business to Business
CFRP	Carbon fibre-reinforced plastics
CO_2	Carbon dioxide
CR	Contracted remanufacturer
DfRem	Design for Remanufacturing
DIN	German Institute for Standardisation
EEE	Electrical and electronic equipment
ElektroG	German act governing the sale, return and environmentally sound disposal of electrical and electronic devices
EoL	End of Life
ERN	European Remanufacturing Network
EU	European Union
IPA	Fraunhofer Institute for Manufacturing Engineering and Automation
IPRI	International Performance Research Institute GmbH
IR	Independent remanufacturer
IT	Information technology
kg CO_2-eq	Kilogram of CO_2 equivalents

km	Kilometer
KrWG	German Waste Management Act
LAGA	German federal/Laender working group on waste
LCA	Life Cycle Assessment
MessEV	German regulation on the sale and provision of measuring instruments on the market as well as their use and calibration (Measurement and Calibration Act, or 'MessEV' for short)
MJ-e	Megajoule equivalents
MRO	Maintenance, Repair and Overhaul
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
OER	Original Equipment Remanufacturer
P	original product
P_R	Refabricated product
PLC	Programmable logic controller
PT	Original product part
PT_R	Refabricated product part
RAM	Random-Access Memory
Reman	Remanufacturing
SME	Small and medium-sized enterprises
SSD	Solid State Drive

t	Tons
tecXL	Own brand of the remanufacturer bb-net
USD	United States Dollar
VVA	Regulation (EC) no. 1013/2006 of 14 June 2006 on shipments of waste
WWII	World War II

1 INTRODUCTION

Remanufacturing[1] is a central measure for increasing resource efficiency. The material and energy expenditure for the manufacture of a product and the associated costs are lowered. Through remanufacturing the original high level of value added is retained and the dependence on import of critical raw materials is reduced.

Remanufacturing is defined as treatment for reuse of a used product which through various process steps is brought to at least the quality level of a new product.[2] For this the collected used parts, so called cores[3], are disassembled, cleaned, inspected, rebuilt and reassembled.

Remanufacturing as a key component of a circular economy is viewed as being the preferred option for closing material loops, particularly compared with recycling, and possesses a high resource efficiency potential (Figure 1).[4]

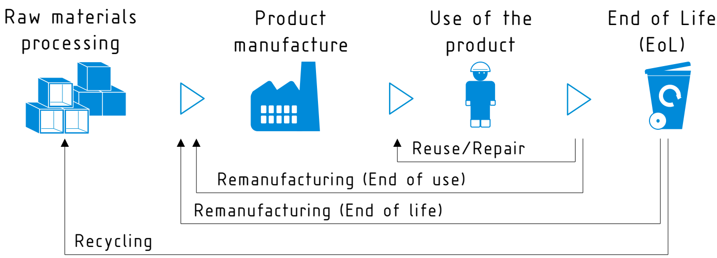

Figure 1: Instruments of a circular economy

The remanufacturing industry already experienced a dramatic upswing in WWII. Sinking production capacities in favour of military production led to

1 Editorial note: In the present brief analysis, apart from the usual term "remanufacturing", the German version "refabrication" along with the verb form "refabricate" as well as the verb "rebuild" and the phrase "industrial rebuilding" are used.
2 Cf. BUMB (2016), pp. 36 and 48.
3 "A core part is a used part intended to become a remanufactured product." cf. Parker et al. (2015), p. 0; in the present brief analysis the terms "core" and "used part" are used for collected and returned products and product units.
4 Cf. Graedel and Allenby (1998), Ryding et al. (1995), Jacobssen (2000), Steinhilper (1998) in Lindahl et al. (2006), p. 448.

the rebuilding of used goods.[5] Today the remanufacturing industry has a share of approx. 2 % of the overall European manufacturing sector. The German remanufacturing industry generates annual turnover of some 8.7 billion euros. This already corresponds to one-third of the entire European turnover.[6]

Corporations such as Bosch, Liebherr, Ricoh and Caterpillar make use of the advantages of remanufacturing and rebuild their own products in in-house remanufacturing divisions. However, remanufacturing also offers numerous options for small and medium-sized enterprises. Remanufactured products can be used in place of new makes, or remanufacturing can be integrated into the company workflows. For manufacturers this means lowered production costs, increased profit margins and strategic competitive advantages, whereas customers can profit from more flexible pricing policies.

The present brief analysis delivers an industry overview and is particularly intended to provide an impetus to small and medium-sized enterprises

- for implementing remanufacturing processes,
- creating incentives for use of remanufactured products,
- raising the awareness of the ecological and economic efficiency potential of remanufacturing and
- provoke further discussion on the topic.

To that end, in this brief analysis the legal framework is staked out, relevant actors in the value chain are introduced and the necessary process steps are described. Ecological and economic effects as well as effects of targeted product design are discussed and the European and German markets are characterised according to countries and industries. Finally, practical examples are presented to point out the possibilities of how remanufacturing companies act or how remanufacturing is integrated into original equipment manufacturers' company workflows.

5 Cf. APRA (2016).
6 Cf. Parker et al. (2015), pp. 1 and 50.

2 REMANUFACTURING OF CORES

2.1 Definition and demarcation

Remanufacturing is the industrial rebuilding of used parts and is defined uniformly in the literature with respect to its key characteristics. Based on the following definitions and demarcations, remanufacturing is understood and used in the present brief analysis as follows:

Definition of remanufacturing for the purposes of the present brief analysis:

(1) Remanufacturing is an **industrial rebuilding process used on** cores.

(2) A core is subjected to **standardised process steps** to rebuild it and restore its original function.

(3) The product performance given back to the core **is at the same level as or a higher level** than that of an equivalent new part.

(4) By means of the same **quality assurance measures** as for new parts production and a **warranty** it is ensured that the refabricated product or the refabricated product unit[7] has the quality of a new product or product unit.

Sundin summarises remanufacturing as an industrial process through which cores are rebuilt for reuse. At the end of the process it must be ensured that the refabricated product meets the standards of the original.[8]

British standard BS 8887-2:2009 defines remanufacturing as the restoration of the product performance to the same level as or a higher level than that of

[7] Editorial note: In the present brief analysis the phrases “refabricated product“ and “refabricated product unit” are grouped into the phrase “refabricated product”. The term “product” accordingly also includes product units such as product assemblies and product subsystems.

[8] Cf. Sundin (2004), p. 2.

a newly manufactured product. The standard also demands that a warranty of the restored performance be provided for the refabricated product. [9]

This definition is also adhered to by the Centre for Remanufacturing & Reuse[10] and the Automotive Parts Remanufacturers Association (APRA) which has agreed upon a common definition with four other European automotive and supplier industry associations. This additionally determines that the cores are rebuilt using standardised industrial processes and are visibly marked as refabricated products.[11, 12]

Some enterprises hold that refabrication is the industrial repair of products after their use cycle.[13, 14] The term 'repair' is described in accordance with DIN 31051:2012-09 as a physical measure which re-establishes the function of a defective unit (element, device, subsystem etc.). The wear parts are not renewed in the process, unlike in remanufacturing. The term 'defective unit' describes the condition in which a unit is incapable of performing a required function.[15] However, the general process of remanufacturing is not limited to defective units. All cores, functional and defective, are included (Figure 2).[16] This is in agreement with the definition in the technical guidelines of the Basel Convention which define the process of refurbishment as modification of used equipment to re-establish the function. Definition of a functional or defective condition or classification as waste is not made.[17] The term 'refurbishment' is equated to the term 'remanufacturing'.[18] Therefore repair is excluded as a definition for the determination of remanufacturing in the context of the present brief analysis.

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9 Cf. BS 8887-2:2009 (2009).
10 Cf. Parker and Butler (2007), p. 3.
11 Cf. APRA (2014).
12 Cf. Weiland (2014), p. 13.
13 Cf. Buecker + Essing (2009).
14 Cf. Knorr-Bremse (2015).
15 Cf. DIN 31051, (2012-09), p. 4.
16 Cf. Lindahl et al. (2006), p. 447.
17 Cf. Basel Convention (2015), p. 18.
18 Cf. Ernst (2016).

2.2 Classification in the legal frameworks

A core can be classified depending upon the application as a used product or as waste according to the German Waste Management Act (KrWG). The classification is independent of whether the product is in functional or defective condition (Figure 2).

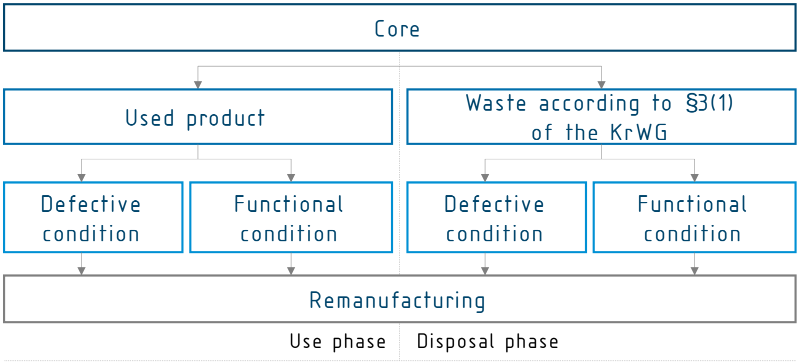


Figure 2: Classification of the term 'core'

The waste term plays a crucial role in the classification: According to §3(1) of the KrWG 'waste is [...] any substance or object which the holder discards or intends or is required to discard'. Therefore the discarding intention of the owner decides on the waste status if rebuilding of the product is still possible.

A product to be refabricated which does not fall under the waste definition – for which there is thus no discarding intention – remains in the use phase or is fed back into the manufacturing phase. The legal waste framework is not applicable in this case. The responsibility and liability for the product remain with the manufacturer. According to §3(1) clause 2 of the German Product Liability Act anyone 'who claims to be a manufacturer through attachment of a name, a brand or another differentiating mark' can be considered to be a manufacturer.

Products which fall under the definition of waste in accordance with the German Waste Management Act can only lose their waste status again under certain conditions. According to §5 of the KrWG the waste characteristic ends if a material or an object has gone through a recovery process and is made in such a way that

(1) it is usually used for specific purposes,

(2) a market for it or a demand for it exists,

(3) it meets or complies with all technical requirements applicable for its respective purpose as well as all legal requirements and applicable standards for products (e.g. DIN EN 62309 and VDI 2343) and

(4) its use does not on the whole lead to harmful effects on humans or the environment.

In this case remanufacturing is a recovery process and can be assigned to the second level of the waste hierarchy, preparation for reuse, according to §6(1) of the KrWG.

Manufacturers placing, e.g., electrical equipment on the market are obliged to ensure proper collection and recovery of their products in accordance with the statutory producer responsibility (§23 of the KrWG). If the original equipment manufacturer carries out rebuilding or has rebuilding carried out, the producer responsibility remains with the original equipment manufacturer.

The producer responsibility can be passed on to an enterprise which is independent of the original equipment manufacturer if this enterprise rebuilds the respective product and, e.g., markets it under its own brand name.[19]

The Electrical and Electronic Equipment Act (ElektroG) makes specific demands on actors who directly or indirectly influence the preparation for reuse:

- According to §4(1) of the ElektroG, manufacturers should design 'their electrical and electronic equipment *if possible* such that reuse and disassembly [...] are considered and facilitated'.
- Preliminary treatment facilities for old electrical and electronic equipment are obliged according to §20(1) of the ElektroG to check through visual and functional tests whether the old equipment can be fed into a

[19] **Cf. Arbeitskreis Elektrogeräte und Ressourceneffizienz (2016), p. 46.**

process for preparation for reuse – insofar as is technically possible and economically feasible.

- Preliminary treatment facilities, thus remanufacturing enterprises, which rebuild old electrical and electronic equipment, must also be certified by an expert according to §21 of the ElektroG.[20]

Waste intended for remanufacturing is often treated internationally and is then subject to the Regulation on Shipments of Waste (VVA) and the requirements set forth in the Basel Convention. These are extremely strict in order to prevent illegal shipments. Waste can thus be shipped, dependent on the severity of the hazard (hazard category) and the recipient country, without being subject to approval or being subject to approval – if no general export prohibition exists (Table 1).

Table 1: Requirements pertaining to shipment of waste[21]

	Export to EU countries	Export to OECD-countries	Export to Non-OECD countries
Non-hazardous waste[22]	not subject to approval, but subject to notification in accordance with §18 of the VVA*	not subject to approval, but subject to notification in accordance with §18 of the VVA*	depending upon the communication from the recipient state, not subject to approval, subject to approval or prohibited
Hazardous waste[21]	subject to approval	subject to approval	subject to approval if no export prohibition exists

* VVA = regulation (EC) no. 1013/2006 of 14.06.2006 on shipments of waste

20 Cf. LAGA M31 (draft 2016), p. 77 et sq.
21 Cf. Aiblinger-Madersbacher (2016), p. 331 et sqq.
22 Hazardous waste is waste which has hazardous properties and represents a potential danger to the environment. Non-hazardous waste is all other waste.

2.3 Relevant actors in remanufacturing

In the remanufacturing industry three actors carrying out the rebuilding process for cores can be distinguished:[23]

- original equipment manufacturers (OEMs) or original equipment remanufacturers (OERs)
- contracted remanufacturers (CRs)
- independent remanufacturers (IRs).

Original equipment manufacturers and remanufacturers (OEMs/OERs) take their own products back via a so-called reverse supply chain, a backwards-oriented logistics chain, e.g. through a service centre, leasing agreements, deposit systems or trade-in by dealers. The cores are disassembled and rebuilt in-house and re-assembled either on the same production lines as are used for production of new parts or at separate production locations.[24] Remanufacturing enables original equipment manufacturers to offer customers a broader product range with greater pricing flexibility. Another advantage is the already existing knowledge related to product design and the availability of parts, allowing the rebuilding process to be completed cost-effectively and with efficient use of materials.[25]

External remanufacturing enterprises (CRs) can be commissioned to carry out the rebuilding of the cores by original equipment manufacturers on a contract basis. The possession of the cores remains with the original equipment manufacturer, whereas the process is outsourced. With this variant the original equipment manufacturer can also offer a wider range of products and has flexibility in terms of pricing. For the contracted remanufacturer the constant order situation over the contract period and the simple access to information concerning product design and inspection specifications as well as to spare parts are of importance.[26]

23 Cf. Sundin et al. (2016), p. 12.
24 Cf. Knorr-Bremse (2015).
25 Cf. Sundin et al. (2008), p. 538.
26 Cf. Sundin et al. (2008), p. 539.

In contrast, independent remanufacturers (IRs) act without or with only minimal contact to the original equipment manufacturers. This means they are responsible for procurement of the cores, procurement of any necessary spare parts and redistribution of the refabricated products themselves. The refabricated products are often marketed under their own brand names.[27]

The boundaries between the three actors presented above can be fluid (Figure 3).

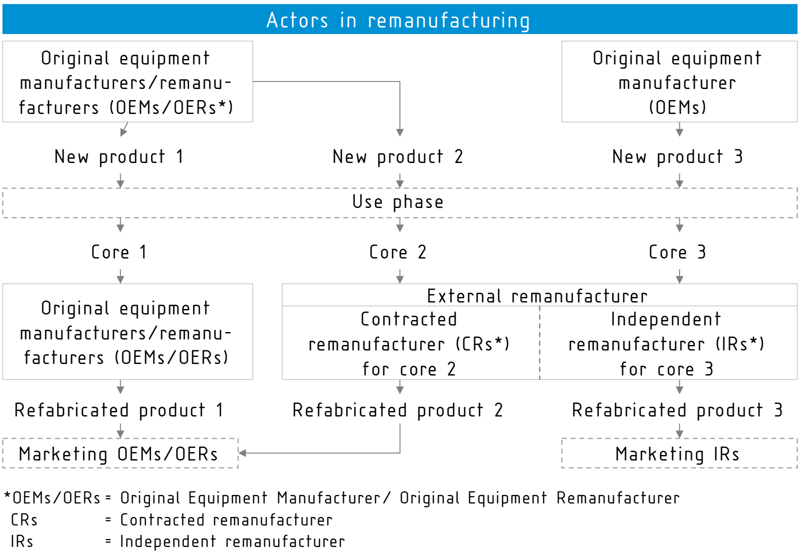


Figure 3: Relevant actors in remanufacturing

An external remanufacturer can rebuild cores on a contract basis for an original equipment manufacturer and at the same time restore another or the same used parts assortment and market it under its own brand name as an independent remanufacturer. The original equipment manufacturer can also rebuild an assortment of its products in-house while the rebuilding of another product assortment is contracted out to an external contracted remanufacturer.

[27] Cf. Sundin et al. (2008), p. 539.

The core broker is an additional actor who comes in before the rebuilding process begins.[28] The core broker is a professional service provider who handles cores and who carries out pre-sorting upon the request of the customer prior to shipment so that used parts can be shipped in an unmixed fashion.

2.4 Remanufacturing process chain

Remanufacturing takes place in manufacturing plants which are organised like industrial enterprises. This includes mass production or standardised industrial processes as well as a uniform quality level for the rebuilt products.[29]

The remanufacturing process is divided into five main process chain steps as well as possible upstream and downstream process steps (Figure 4).

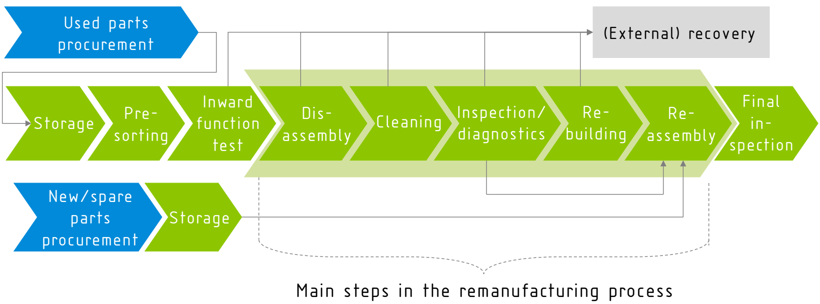


Figure 4: Remanufacturing process chain[30, 31]

The order of the process chain steps depends upon the used parts to be rebuilt, among other things. Mechanical, electrical, electromechanical and hydraulic systems (e.g. clutches, starters or alternators) are usually immediately disassembled and follow the further process steps of cleaning, inspection, rebuilding and reassembly.[32]

28 "Core = used part intended to become a remanufactured product", cf. Parker (2015), p. 0; Corebroker = Used parts dealer.
29 Cf. Bullinger et al. (2009).
30 Following Steinhilper (1998) in Butzer (2016a).
31 Following Bullinger et al. (2009), p. 287.
32 Cf. Steinhilper (1998) in Butzer (2016a).

The upstream goods inward function test is primarily carried out on mechatronic, electronic and hybrid systems.

Vehicles, for instance, may contain up to 100 electronic assemblies for which reliable testing and fault diagnostics must be performed. For this a behaviour test can be used by means of a characteristic curve analysis[33], subsequent thermographic diagnostics and manual visual diagnostics before the product is sent in rebuildable condition to the disassembly section.[34]

During disassembly the cores are broken down into their individual constituents and sorted. Constituents which cannot be reused or refabricated are removed and fed into adequate recovery systems. Disassembly usually requires manual breaking down as various degrees of corrosion and contamination exist and the associated rebuilding or reuse can only be estimated by trained personnel, there is a large variety of differing and in part disassembly-unfriendly old equipment structures and the quantity arising is difficult to calculate.[35, 36]

In the subsequent cleaning step the disassembled parts which have been segregated for rebuilding are de-greased, de-oiled, de-rusted or stripped of paint. This is done by wet cleaning (e.g. washing station systems or chamber washing systems with spray-float-immersion technology) or dry cleaning systems (e.g. furnaces for removing coats of paint or dry blasting systems with blasting media of the usual type such as sand, glass beads or corundum).[37] There is a need for development of product- and material-specific cleaning technologies in order to reduce surface attack and better protect the functional properties of the used parts.[38] At the same time consideration

33 Characteristic curve = characteristic multidimensional representation of two mutually dependent physical quantities for a part or an assembly. The characteristic curve analysis of a mechatronic system uses signal measurements to examine the system's performance capabilities which should lie in a predetermined performance range.
34 Cf. Steinhilper and Freiberger (2010), p. 95 et sq.
35 Cf. Butzer and Schötz (2016), p. 4.
36 Cf. VDI 2343 Blatt 3, p. 3.
37 Cf. Universität Bayreuth (2017).
38 Cf. Bullinger et al. (2009), p. 287.

should be paid to resource efficiency aspects such as preparation and circulation of the cleaning media or use of programmable logic controllers (PLCs) enabling cleaning based on the component contamination depth (e.g. adjustable blasting intensity).[39]

The cleaned parts are subjected to a further condition check and are categorised according to the defects found as follows:[40]

- reusable without rebuilding,
- reusable after rebuilding,
- not reusable.

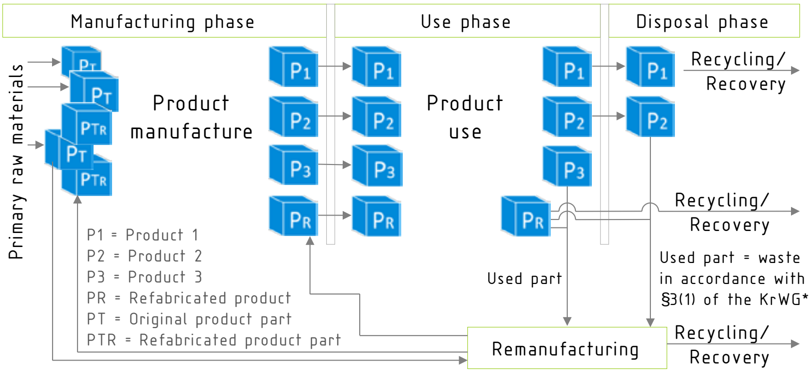
Used parts which do not require rebuilding are sent directly to the reassembly section. Used parts which must be rebuilt are rebuilt using typical procedures such as drilling, milling, honing, grinding or welding, inspected and assembled in the reassembly section to form the output product. The method of mechanical rebuilding depends on the used part and is already defined during process design. Non-reusable parts are supplied to an adequate recovery system and can be replaced by new parts or spare parts.[41] Reassembly can partly take place after the rebuilding of the components on the production lines used for the new parts if the used parts are refabricated by the original equipment manufacturer.[42]

Quality assurance measures are operated intensively and continuously after the production of the rebuilt product as well as over the entire rebuilding process.[43] The final inspection ultimately serves towards checking of the performance and functionality and ensures that they are at the same level as or a higher level than that of a new product. Quality assurance measures are carried out on every refabricated used part – unlike with newly produced parts.[44]

39 Cf. Universität Bayreuth (2017).
40 Cf. Butzer and Schötz (2016), p. 4.
41 Cf. Butzer and Schötz (2016), p. 4.
42 Cf. Knorr-Bremse (2015).
43 Cf. Bullinger et al. (2009), p. 287.
44 Cf. Butzer and Schötz (2016), p. 4.

2.5 Ecological effects and resource savings through remanufacturing

Remanufacturing circulates products. A used part is fed into a rebuilding system either at the end of the use phase or at the beginning of the disposal phase. The use of primary raw materials and the employment of, among other things, energy as well as raw, auxiliary and operating materials for new production are hence done away with for at least one life cycle (Figure 5).



* § 3 (1) KrWG: Waste in the sense given in this act is any substance or object which the holder discards or intends or is required to discard.

Figure 5: Classification of remanufacturing in the product life cycle

The question of whether remanufacturing actually requires fewer materials and less energy than new production has already been investigated in several studies using the method of life cycle assessment (LCA). The comparative assessment of ecological effects over the entire life cycle thereby determines the alternative which is favoured from an environmental point of view. Selected results of five LCA analyses for different remanufacturing case examples are listed in Table 2.

Table 2: LCA results for new and remanufactured product parts – case examples[45]

	New production	Remanufacturing	Savings in %
Case example 1: DIESEL MOTOR[46]			
Energy consumption in megajoules	6,016.68 MJ	3,620.16 MJ	**40 %**
Resource consumption of coal in kilograms	2,200 kg	590 kg	**73 %**
Resource consumption of crude oil in kilograms	59.5 kg	48.5 kg	**18 %**
CO_2-emissions in tonnes	3.9 t	1.02 t	**74 %**
Case example 2: CYLINDER HEAD[47]			
Resource consumption of coal in kilograms	320,175 kg	71,182 kg	**78 %**
Resource consumption of crude oil in kilograms	6,468 kg	9,237 kg	- **43 %**
CO_2-emissions in tonnes	534 t	126 t	**76 %**
Case example 3: COMPRESSOR[48]			
Emissions in kilograms of CO_2 equivalents	1,590 kg CO_2-eq	168 kg CO_2-eq	**89 %**
Case example 4: GEAR BOX[49]			
Energy consumption	Not specified	Not specified	**33 %**
Case example 5: STARTER[50]			
Energy consumption in megajoule equivalents	281.03 MJ-e	122.73 MJ-e	**56 %**
Material consumption in kilograms	3.49 kg	0.43 kg	**88 %**
Emissions in kilograms of CO_2 equivalents	17.01 kg CO_2-eq	8.03 kg CO_2-eq	**53 %**

Up to nearly 90 % less emissions and material and up to 56 % less energy are consumed in the presented examples by remanufacturing of cores. For instance in the 'cylinder head' case the process steps of cast iron production and cylinder head casting are avoided. In addition the rebuilding of a used cylinder head requires less energy resources and generates less emissions than machining of a new cylinder head.[51]

This case example also shows that consideration of the entire life cycle is indispensable. Through this the crude oil consumption for the used cylinder heads increases by 2,800 kg. This is due on the one hand to the transport path to the rebuilding location (remanufacturing centre) which is lengthened by more than 750 km. On the other hand approximately 4.5 kg of crude oil

[45] The case examples possess different system limits and cannot be compared with one another.
[46] Cf. Dias et al. (2013), p. 676.
[47] Cf. Liu et al. (2013), p. 1031.
[48] Cf. Biswas et al. (2013), p. 7.
[49] Cf. Warsen et al. (2011), p. 67 in Peters (2016), p. 33.
[50] Cf. Bartel (2015), p. 7.
[51] Cf. Liu et al. (2016), p. 1031.

per cylinder head is employed for pyrolysis for removal of paint in the cleaning process. Refabrication of the cylinder head thereby increases the crude oil consumption by a total of 43 %. Nevertheless, the remaining savings compensate for the increased transport path and crude oil consumption in the cleaning process and decrease the overall environmental impact by some 40 %.[52]

Remanufacturing is hence assessed to be a circulation option with one of the highest resource efficiency potentials and has a lower environmental impact than recycling, for instance.[53, 54] The amount of energy employed for rebuilding an used part is usually less than the amount of energy used for recycling the product and for renewed product manufacture from the resulting secondary raw materials.[55, 56] Both variants are loop closing strategies which promote independence from critical raw materials.[57]

In summary the use of refabricated products has clear advantages from an environmental point of view.[58] However, the assessment should take into account all criteria and life phases.

Ecological advantages of remanufacturing:

- Extension of product service life
- Sustainable option for closing material loops
- Lower material and energy consumption in comparison with new parts production for greater resource and energy efficiency
- Resource-efficient alternative to recycling (preparation for reuse)
- Promotes independence from critical raw materials

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52 Cf. Liu et al. (2016), p. 1031.
53 Cf. Graedel and Allenby (1998), Ryding et al. (1995), Jacobssen (2000), Steinhilper (1998) in Lindahl et al. (2006), p. 448.
54 Cf. Dando (2016).
55 Cf. Lund (1996) in Lindahl (2006), p. 448.
56 Cf. Nasr and Thurston (2006), p. 16.
57 Cf. BMUB (2016), p. 36 and 48.
58 Cf. Sundin and Lee (2016).

2.6 Economic effects of remanufacturing

Rebuilding of cores retains the resources introduced and the energy used for manufacture – that is, the original added value.[59]

Manufacturers in the manufacturing industry assume on average more than 40 % for material costs which thus represent the largest cost centre within a company.[60] Through remanufacturing material and energy expenditures can be lowered. This accordingly leads to cost savings or higher profit margins which can possibly be passed on to the customers via reduced selling prices. In this case remanufacturing results in a win-win situation for the manufacturer and the customer.

Using the example of mechatronic systems it could be determined that used parts under certain conditions (Figure 6, Table 3, Table 4) could in part be rebuilt at a cost of less than 50 % of the original new price. The break-even point is thereby already attained with low parts volumes.[61] Consequently refabricated products can be offered on a case-by-case basis for around 40 % to 80 % of the price for procurement of an equivalent original product and represent a major cost advantage for the customer.[62]

However, the resulting savings for manufacturers and customers only ensue under certain market conditions. In the United States the remanufacturing industry, which had a market size of approx. USD 43 billion in 2011, became established not because of ecological motives or due to legal requirements, but rather for purely economic reasons.[63, 64] The necessary conditions for this are listed in Figure 6 and can be assigned to three areas: the collection system for cores (a), the remanufacturing process (b) and the marketing of the refabricated products (c).

59 Cf. Walther (2010), p. 189.
60 Cf. VDI ZRE (2017).
61 Cf. Steinhilper and Freiberger (2010), p. 92.
62 Cf. Sahni et al. (2010) in Xing and Gao (2014), p. xiii.
63 Cf. Parker et al. (2015), p. 23.
64 Cf. Nasr and Thurston (2006), p. 16.

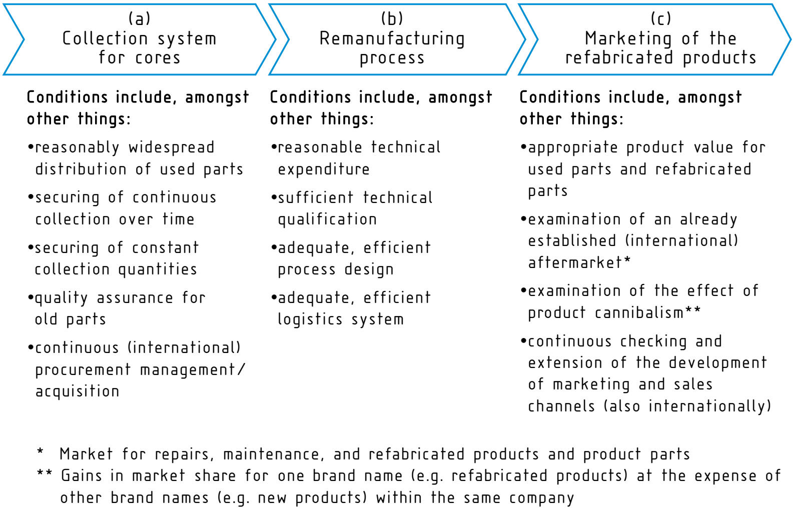

Figure 6: Conditions for economic viability of remanufacturing[65]

(a) Collection system for cores

An adequate collection system is one of the basic conditions for an economically functioning remanufacturing company or a remanufacturing division in a company.[66] The continuous supply of constant quantities of cores over time with the most constant quality possible and at reasonable prices must be secured via procurement management and acquisition.[67] This depends crucially upon how widespread the original product is on the market. A small quantity of products on the market makes collection logistics more difficult, whereas market (over)saturation causes the demand for refabricated products to drop in the marketing phase. Potential core collection routes or systems can be divided into the following groups:[68]

- *Ownership-based collection:* During use of the product by the customer the ownership constantly lies with the manufacturer (leasing and rental models, amongst others).

65 Following Guide and Wassenhove (2009), p. 12.
66 Cf. Nasr and Thurston (2006), p. 16.
67 Cf. Guide and Wassenhove (2009), p. 12.
68 Cf. Östlin (2009) in Sundin et al. (2016), p. 18.

- *Collection based on a service agreement:* Collection is based on a service agreement between the manufacturer and the customer which includes rebuilding.
- *Order-based repair:* A customer transfers the used part to the remanufacturer with a direct rebuild order. The customer gets the same product back in rebuilt condition.
- *1:1-Collection*: With the purchase of a rebuilt product the customer is obliged to return an identical, used part.
- *Collection via discount on refabricated products:* With the return of a used part the customer receives a discount which he or she receives as a price reduction for the purchase of refabricated products.
- *Collection via purchase of used parts:* The rebuilder buys used parts from offerers (scrap yards, core brokers and end consumers, amongst others).
- *Voluntary return:* The offerer (scrap yard, core brokers, end consumer or customer, amongst others) returns the used part voluntarily to the rebuilder.

A study surveyed 30 European remanufacturing companies about their collection routes. Of 44 responses the most frequently mentioned collection type was the purchase of used parts (34 %, Table 14 in Appendix).[69]

(b) The remanufacturing process

The process design for rebuilding must be adapted to the type and variety of used parts[70] and must be economically oriented, meaning that the costs of the technical work should not exceed the income obtained from the refabricated products. In particular the inspection of the used parts can currently not yet or hardly be carried out via automated process steps, but rather requires manual visual diagnostics and specific know-how, thus sufficient qualification of employees. Moreover the logistics system and the associated

[69] Cf. Sundin et al. (2016), p. 18.
[70] Cf. Butzer and Schötz (2016a), p. 7 et sqq.

transport expenses must efficiently network the collection channels, the remanufacturing locations and the available marketing channels.

(c) Marketing of the refabricated products

The refabricated products must possess an appropriate product value; i.e. there should be a constant demand for them. It is hence more difficult to refabricate short-lived electronics articles than, e.g., automobile products such as starters or alternators which are required over longer time phases.[71] An already established aftermarket – a market on which repaired, reusable and rebuilt products are traded – is also helpful.

The sales channels through which the refabricated products are offered must always be readjusted and adapted to the requirements of the customers and the current market trends. One example is the principle of 'using rather than possessing' which represents a new marketing route for refabricated products. The scepticism shown by the customer towards refabricated products can be restrained through buying of the product performance by the customer without the customer being in possession of the product.

Within the enterprise further effects such as product cannibalism effects can occur. Here refabricated products counteract the market share gains of other newly manufactured products within the company. Dell, for example, prevented this effect on the American market by separating the Internet presences for new products and refabricated products.[72, 73]

The economic effects of remanufacturing can thus positively affect the balance of an enterprise if the market conditions are met and considered.

71 Cf. Allwood et al. (2011), Chapman et al. (2009) and Lundmark et al. (2009) in Brüning et al. (2014), p. 27.
72 Cf. Ovchinnikov (20f10), p. 824.
73 Cf. Dell (2016).

Economic advantages of remanufacturing:

- Retention of original resources and energy – thus the original added value – for the most part
- The usually lower manufacturing costs compared with those for new production of an equivalent product
- Cost advantages for users: Procurement costs for refabricated products which are approx. 40 % to 80 % lower than for equivalent new products
- Competitive advantages through higher profit margins and strategic advantages

2.7 Design for Remanufacturing

The economic and ecological advantages of remanufacturing can be strengthened if the product design is already adapted to refabrication. 'Design for remanufacturing' (DfRem) is a component of the Ecodesign which can lower the environmental impacts over the entire life cycle of a product.[74, 75]

Design for remanufacturing (DfRem) can be applied at two leverage points: in the strategic design, e.g. sales, marketing, service support, the collection system or analysis of the aftermarket, and on the technical level.[76] Focus in the last few years has almost exclusively been on the analysis and development of the technical level, i.e. the physical product design, to the benefit of remanufacturing.[77] This includes easy disassembly, modular design or wear resistance of components (Table 3, derivation in Table 11 in Appendix).[78]

74 Cf. Sundin et al. (2008), p. 46.
75 Cf. UBA (2016).
76 Cf. Nasr and Thurston (2006), p. 17.
77 Cf. Prendeville et al. (2016), p. 3.
78 Cf. Nasr and Thurston (2006), p. 17; Yang et al. (2016), p. 149; Gray and Charter (2006), p. 25 et sqq.; Prendeville, S. and Bocken, N.; p. 5.; Prendeville et al. (2016), p. 40.

Table 3: Elements of DfRem – technical level

DESIGN FOR REMANUFACTURING – TECHNICAL LEVEL		
PRODUCT DESIGN in consideration of adaptive or adequate		
TECHNOLOGY	MATERIALS	CONSTRUCTION
• use of durable technology extending beyond a life cycle • use of exchangeable technologies with the same product design	• corrosion resistance • wear resistance • durability • surface stability (functional and decorative layers)	• ease of disassembly • ease of cleaning • modular product design with low complexity • adequate joining processes (using pins, screws etc.) • standardisation of design for product families, amongst others

The planned product should be designed according to Figure 6 under the aspects of adaptive technology, adequate materials and efficient construction. The manufacturers/designers thereby obtain the greatest benefit from a lasting product design if the producer responsibility, thus the product ownership, remains with the manufacturer over the entire life cycle.[79] Under certain circumstances conflicting aims could thereby arise in product development. In lightweight construction, for example, saving of as much weight as possible can influence the durability of the materials used and hence oppose product use over multiple life cycles and hence remanufacturing (e.g. in the automotive sector for reduction of petrol and diesel consumption). Comprehensive consideration of the product life cycle and precise definition of aims are thus indispensable.

Apart from the life cycle consideration as a key recommendation, assignment of a greater role to the strategic design, thus the design of the operational and organisational factors to the benefit of remanufacturing, is suggested.[80] This contains the definition of the strategy regarding, amongst other things, the customer needs and/or the consumer behaviour, appropriate communi-

[79] Cf. Nasr and Thurston (2006), p. 17.
[80] Cf. Hatcher et al. (2011), p. 2004.

cations and public relations work, optimal pricing strategies, efficient collection systems or analysis of existing markets for rebuilt used parts (Table 4).[81, 82]

Table 4: Elements of DfRem – strategic level[83]

DESIGN FOR REMANUFACTURING – STRATEGIC LEVEL			
ORGANISATIONAL DESIGN in consideration of the factors			
MARKET ANALYSIS	CONSUMER BEHAVIOUR / CUSTOMER STRUCTURE	MARKETING STRATEGY	LOGISTICS
amongst other things, analysis • existing aftermarkets • market volume and market potential • market growth and dynamics • market shares • legal framework	amongst other things, analysis of • consumer categories (sex, income etc.) • main purchasing motives/ purchasing intentions of consumer categories • factors influencing existing purchasing motives/ intentions • effect of product category on willingness to pay • effect of type and form of information retrieval on willingness to pay	Definition of (amongst other things) • pricing policy • product policy • sales policy • advertising policy	amongst other things, analysis of • efficient design of collection systems • efficient design of transport and infrastructure • suppliers

The organisational and operational design significantly affects the success of remanufacturing. VDI standard 2343 Blatt 2 presents, e.g., the collection and disposal logistics, but investigations on this are currently still rare and require intensification in order for design for remanufacturing to be advanced on a strategic level.[84, 85]

81 Cf. Prendeville and Bocken (2016), p. 4.
82 Cf. Prendeville et al. (2016), p. 8.
83 Cf. Govindan (2016).
84 Cf. VDI 2343 Blatt 2, (2010).
85 Cf. Govindan (2016).

Key aspects of design for remanufacturing:

- Technical level: Employment of durable and adaptable technologies, processing of long-lasting and reliable materials and easily disassembled, modular, partly standardised product design
- Strategic level: Comprehensive analysis of market and consumer behaviour regarding the products to be refabricated as well as definition of a marketing strategy and an efficient collection system

3 REMANUFACTURING MARKET STRENGTH AND MARKET TREND

3.1 The European market

3.1.1 Characterisation by country

The remanufacturing industry has a share of about 2 % of the overall European manufacturing sector and generates turnover of some 30 billion euros annually.[86]

In a Europe-wide comparison the countries Germany, the United Kingdom and Ireland as well as France and Italy are market leaders and generate over two-thirds of the total turnover. German companies generate around one-third of the total gross receipts in the remanufacturing industry (Figure 7).

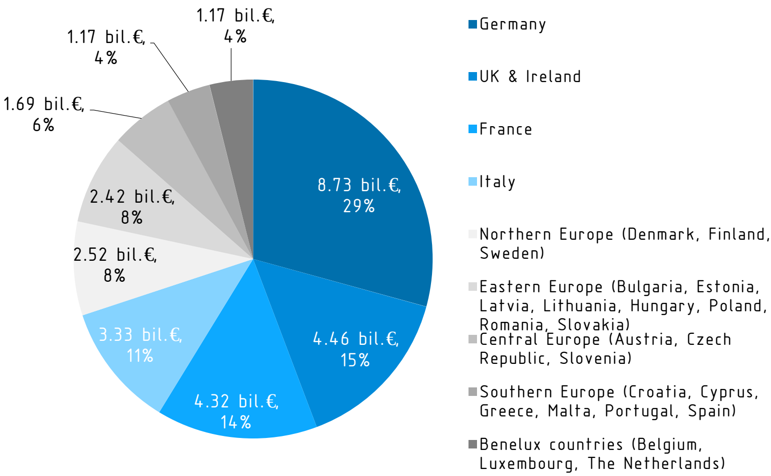

Figure 7: Turnover in remanufacturing industry in billions of euros per year by country[87]

Most of the remanufacturing activities take place in Germany, going hand in hand with the high level of turnover generated in Germany. The European Remanufacturing Network (ERN) asked remanufacturing companies operating in Europe about their rebuilding locations. Of 188 respondents with a

86 Cf. Parker et al. (2015), p. 1.
87 Following Parker et al. (2015), p. 1.

total of 506 responses, there were 73 responses indicating activities taking place at German production locations. This corresponds to a share of 14 % (Figure 8).[88]

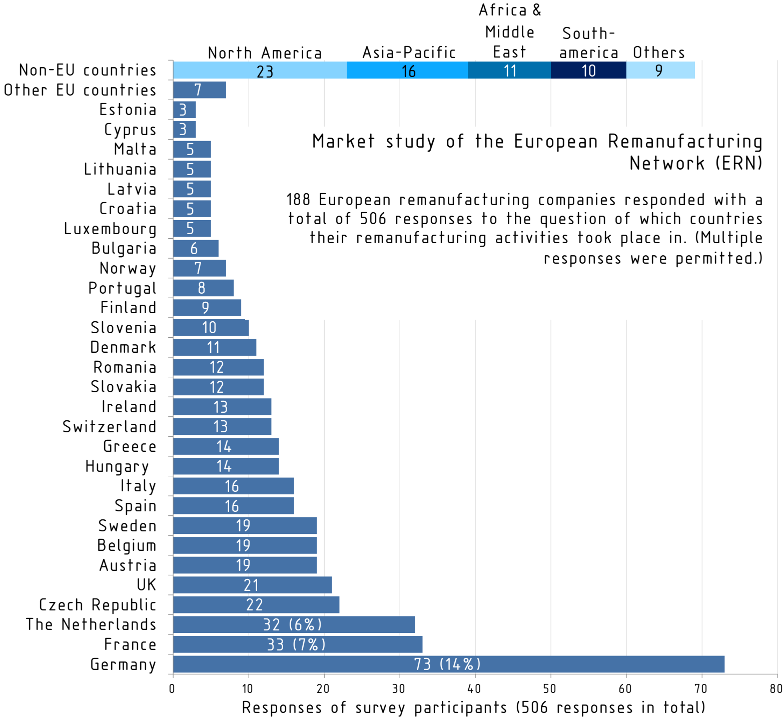

Figure 8: Remanufacturing activities by country[89]

Nearly 50 % of the European remanufacturing activities take place in the countries Germany, France, the Netherlands, Czech Republic, the UK, Austria, Belgium and Sweden. The head offices of the surveyed companies are situated in Germany in 61 cases, in the U in 37 cases, in the Netherlands in 24 cases and in France in 12 cases. There are either no or a maximum of seven head offices of remanufacturing companies in the remaining countries (Table 12 in Appendix). [90]

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[88] Cf. Parker et al. (2015), p. 32.
[89] Following Parker et al. (2015), p. 32.
[90] Cf. Parker et al. (2015), p. 27.

In some cases the country-specific turnover (Figure 7) does not correspond to the country-specific number of companies (Figure 8). This applies, for example, to the Netherlands. Together with Belgium and Luxembourg, the Netherlands has approximately 1.2 billion euros in annual turnover, but count amongst the countries with the highest number of company locations (32) in a country comparison. This can be attributed to, among other things, a different company size which was likewise surveyed in the market study of the European Remanufacturing Network and measured by means of the company turnover (Table 5).

Table 5: Distribution of enterprise sizes as measured by turnover[91]

Company size	Responses	In per cent	
< 2 million Euro	59	32.4 %	71 %
2–10 million Euro	55	30.2 %	
10–50 million Euro	15	8.2 %	
50–100 million Euro	11	6.0 %	
100–500 million Euro	10	5.5 %	
> 500 million Euro	32	17.6 %	
Responses	182	100 %	

Approximately 71 % of the survey participants (182 responses in total) are small to medium-sized enterprises (SMEs) with annual turnover of up to 50 million euros. Of all of responses, microenterprises (< 2 million euros) and small enterprises (2–10 million euros) make up the largest share with approx. 30 % each.[92, 93] Approximately 18% of the enterprises generate turnover of more than 500 million euros per year, with 5.5 %, 6 % and 8 % of the enterprises being in the three successively lower turnover segments. The remanufacturing industry can thus be characterised as showing a tendency towards micro- and small enterprises and a share of large corporations with their own remanufacturing divisions.[94]

Regarding the actors of remanufacturing it was found that the small enterprises and microenterprises operated as independent remanufacturers (IRs) in up to 80 % of the cases. Large corporations with turnover of more than 100

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[91] Cf. Parker et al. (2015), p. 28.
[92] Cf. Parker et al. (2015), p. 28.
[93] Classification of different company sizes recommended by EC 2003/361/EG in Parker et al. (2015), p. 28.
[94] Cf. Parker et al. (2015), p. 27.

million euros are original equipment manufacturers or remanufacturers (OEMs or OERs) with in-house rebuilding operations in more than 80 % of the cases (Figure 9).[95]

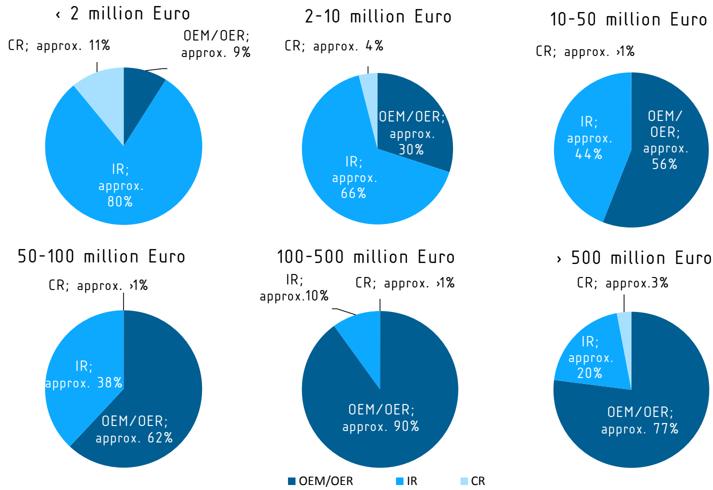

Figure 9: Distribution of remanufacturing actors by turnover[96]

In comparison, contracted remanufacturers (CRs) hardly play a role or play a subordinate role as companies with less than 10 million euros in turnover.

3.1.2 Characterisation by industry sector

The greatest share of the total European turnover of approx. 30 billion euros is taken up by the aerospace (42 %) and automotive (25 %) industry sectors. Together they produce more than two-thirds of the entire European turnover in the remanufacturing industry (Figure 10).

[95] Cf. Parker et al. (2015), p. 30.
[96] Following Parker et al. (2015), p. 30.

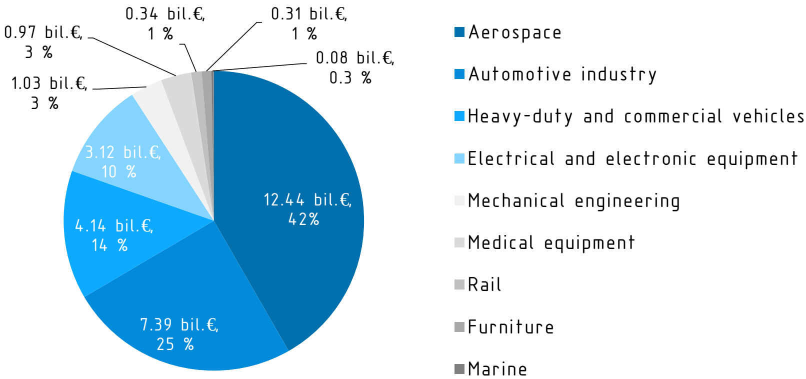

Figure 10: Turnover in the remanufacturing industry in billions of euros in Europe by industry [97]

Annual turnover of between one and four billion euros is achieved in the heavy-duty and commercial vehicles, electrical and electronic equipment (EEE), mechanical engineering and medical equipment industry sectors. The industry sectors of rail, furniture and marine play a much lesser role, together achieving a share of 2.5 % of the total turnover in the remanufacturing industry.

Over two-thirds of the European companies are active in the automotive industry and in the industry for rebuilding of electrical and electronic equipment. These are also the industries rebuilding the most cores, as indicated in the table as quantities (Table 6).

[97] Following Parker et al. (2015), p. 44.

Table 6: Number of companies, employee count and quantity of rebuilt used parts by industry[98]

Branch	Company		Employee count		Remanufactured used parts	
Aerospace	1,000	13.9 %	71,000	37.0 %	5,160,000	3.9 %
Automotive	2,363	32.8 %	43,000	22.4 %	27,286,000	20.6 %
Heavy-duty and commercial vehicles	581	8.1 %	31,000	16.1 %	7,390,000	5.6 %
EEE	2,502	34.7 %	28,000	14.6 %	87,925,000	66.4 %
Mechanical engineering	513	7.1 %	6,000	3.1 %	1,010,000	0.8 %
Medical equipment	60	0.8 %	7,000	3.6 %	1,005,000	0.8 %
Rail	30	0.4 %	3,000	1.6 %	374,000	0.3 %
Furniture	147	2.0 %	4,000	2.1 %	2,173,000	1.6 %
Marine	7	0.1 %	1,000	0.5 %	83,000	0.1 %
Total	7,204	100 %	192,000	100 %	132,405,000	100 %

In contrast, most jobs are found in aerospace, more than twice as many as in the electrical and electronic equipment industry. The lower number of rebuilt used parts with more than twice as many employees in the aerospace industry can be explained by, among other things, the sizes of the used parts which are, as is to be expected, larger than in, e.g., the electrical and electronic equipment industry.

The European market can thus be summarised on the basis of the country and industry analyses as follows:

The European remanufacturing market:

- The Reman industry makes up 2 % of the European manufacturing sector and has annual turnover of approximately 30 billion euros.
- The branches of industry with the highest turnover levels are aerospace, automotive, electrical and electronic equipment (EEE) and heavy-duty and commercial vehicles.
- In an EU-wide comparison Germany has the highest turnover with the most company head offices and rebuilding locations.
- The remanufacturing market is characterised by a majority of micro-enterprises and small enterprises for the most part operating as independent remanufacturers.

98 Following Parker et al. (2015), p. 0.

3.2 The German market

The German remanufacturing industry generates annual turnover of some 8.7 billion euros. The greatest share of this is contributed by aerospace with 44 %, followed by automotive with a turnover share of 27 % (Figure 11).[99]

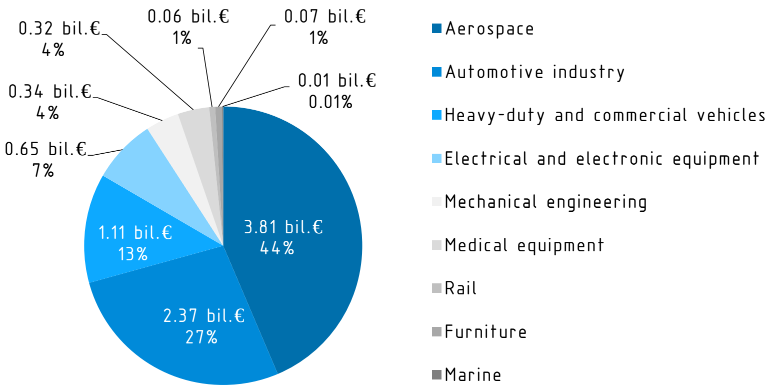

Figure 11: Turnover by industry in Germany[100]

The rail, furniture and marine industries play a subordinate role, together making up approx. 2 %. The heavy-duty and commercial vehicles (13 %), electrical and electronic equipment (7 %), mechanical engineering (4 %) and medical equipment (4 %) industries contribute nearly one-third of the annual turnover.

Except for furniture and marine, the German remanufacturing industries lead in terms of turnover in Europe (Table 7).

99 Cf. Parker et al. (2015), pp. 58, 64, 73, 81, 87, 92, 98, 104 and 109.
100 Following Parker et al. (2015), pp. 58, 64, 73, 81, 87, 92, 98, 104 and 109.

Table 7: Comparison of turnover between Germany and the second-placed country[101]

Branch	Turnover in the EU (1)	Turnover BRD (2)		Turnover second-placed country (3)		Difference (2)-(3)	
	Total in billions of euros	in billion euros	% of total	in billion euros	% of total	In billion euros	Percentage points
Aerospace	12.44	3.81	31 %	2.7 (UK & Ireland)	22 %	1.11	9
Automotive	7.39	2.37	32 %	0.79 (South Europe*)	11 %	1.58	21
Heavy-duty and commercial vehicles	4.14	1.11	27 %	0.63 (France)	15 %	0.48	12
EEE	3.12	0.65	21 %	0.59 (Italy)	19 %	0.06	2
Mechanical engineering	1.03	0.34	33 %	0.2 (Italy)	19 %	0.14	14
Medical technology	0.97	0.32	33 %	0.12 (UK & Ireland)	12 %	0.2	21
Rail	0.35	0.06	17 %	0.05 (amongst others, UK & Ireland)	14 %	0.01	3

* Southern Europe = Croatia, Cyprus, Greece, Malta, Portugal, Spain

In the automotive sector and in the medical equipment industry Germany's share of the total European turnover is more than 20 percentage points higher than that of the second-placed country. In the remaining industries the obtained turnover levels lie between 2 and 14 percentage points higher.

The industry in Germany with the most employees is the aerospace sector with a total of 17,400 employees, followed by the automotive industry with around 10,400 jobs (Table 8).

101 Following Parker et al. (2015), pp. 58, 64, 73, 81, 87, 92, 98, 104 and 109.

Table 8: Number of employees and number of refabricated used parts per industry and year in Germany[102]

Branch	Employee count	Rebuilt used parts	Number of used parts per employee
Aerospace	17,400	1,580,000	91
Automotive	10,400	8,510,000	818
Heavy-duty and commercial vehicles	6,400	1,550,000	242
EEE	4,000	10,420,000	2,605
Mechanical engineering	1,600	330,000	206
Medical equipment	2,000	330,000	165
Rail	400	70,000	175
Furniture	500	470,000	940
Marine	70	12,400	177
Total	**42,770**	**23,272,400**	

The highest number of refabricated cores can be found for a staff count of 4,000 in the electrical and electronic industry. This corresponds to a ratio of 2,600 remanufactured used parts for each employee per year. In comparison, the ratio of refabricated used parts to employees is approx. 90:1 in the aerospace industry.

In summary the German remanufacturing market can be characterised as follows:

The German remanufacturing market:

- The German remanufacturing industry generates annual turnover of some 8.7 billion euros.
- More than two-thirds of turnover is obtained in the aerospace and automotive sectors and approx. 98 % in the aerospace, automotive, electrical and electronic equipment, heavy-duty and commercial vehicles, mechanical engineering and medical equipment sectors.
- Remanufacturing in Germany leads Europe in terms of turnover in all sectors except for furniture and marine.
- The remanufacturing industry employs approx. 43,000 people and rebuilds approximately 23 million cores a year.

[102] Following Parker et al. (2015), pp. 58, 64, 73, 81, 87, 92, 98, 104 and 109.

3.3 Market trend

Remanufacturing offers a high resource efficiency potential. It is experiencing broad promotion and extensive interest, particularly in research and development[103, 104] and will become increasingly anchored in political instruments, for instance directly via continuation of the German Resource Efficiency Programme or indirectly via the Ecodesign Directive.

Evaluation of the remanufacturing market has yielded a prediction of steady growth in the coming years to at least 43 billion euros in 2030.[105] In the aerospace industry, for example, an annual growth rate of 2.9 % in the maintenance, repair and overhaul (MRO) sector is expected for Europe.[106] For Eastern Europe the annual growth rate is even estimated to be 6.2 % as primarily older, maintenance-intensive fleets are in use.[107]

The greatest challenges affecting growth or that need to be overcome for growth are thereby:

- the progressing electrification of the products,
- the availability of (high-quality) spare parts and cores management,
- the image of remanufacturing and
- the availability of well trained personnel.[108, 109]

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103 Cf. Matsumoto et al. (2016), p. 131.
104 Cf. Govindan (2016).
105 Cf. Parker et al. (2015), p. 1.
106 "overhaul" is the technical term for remanufacturing processes at airline industries, cf. Parker et al. (2015), p. 55.
107 Cf. European Commission (2015), p. 194.
108 Cf. Butzer and Schötz (2016), p. 36.
109 Cf. Sundin et al. (2016), p. 24.

Further current and future strengths, weaknesses, opportunities and barriers were recorded by 42 remanufacturing actors in a workshop (Table 9, Table 10).[110]

Table 9: Current and future strengths and weaknesses in the remanufacturing industry[111]

Strengths		Weaknesses	
Current	Future	Current	Future
• specialised technical knowledge • achieved resource efficiency • good price-to-performance ratio of refabricated products • well trained • personnel	• specialised technical knowledge • established networks • stable and efficient processes • partially established design for remanufacturing	• image problems availability of high-quality spare parts legal framework • variety of product and part variants • access to product information	• availability of well trained personnel • rising product complexity • knowledge in the field of rebuilding of electronics • Digitalisation

The specialised technical knowledge is evaluated by the actors as a constant strength in the remanufacturing industry, whereas, for example, the availability of well trained personnel in the future is estimated to be problematic. This can be due to the much discussed lack of experts, particularly in the technology-related sectors of the economy.[112] This can cause additional high personnel costs (Table 10) as the remanufacturing processes often require manual disassembly as well as technical know-how.

Rising product complexity necessitates continuous adjustment and specialisation of the remanufacturing processes which is detrimental to economic viability. This can be countered by design for remanufacturing (DfRem) which is estimated by the actors as a future strength of the remanufacturing industry and at the same time as a current opportunity (Table 10). Thus, for example, one of the future megatrends in German mechanical engineering lies in the establishment or intensification of non-price-related competitive factors such as quality, reliability and in particular sustainability.[113]

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[110] Cf. Butzer (2016b).
[111] Cf. Butzer and Schötz (2016), p. 36.
[112] Cf. DIHK (2016), p. 7.
[113] Cf. Auer (2014), p. 3.

Table 10: Current and future opportunities and barriers in the remanufacturing industry[114]

Opportunities		Barriers	
Current	Future	Current	Future
• Design for Remanufacturing • increasing awareness, improved image • new products • growing market	• 3D printing • Digitalisation/ Big Data • technological developments • increasing awareness, improved image • new products • growing market	• legal framework • no access to software • electrification • competition with low-priced new parts	• market intervention by OEMs • legal framework • no access to software • high personnel costs

Digitalisation and electrification of products require specialised competencies and present the remanufacturing industry with current and future challenges. At the same time they yield a significant growth potential if these challenges are faced, e.g., with a modular product design or use of exchangeable technologies with the same product design (Table 10).

In the future 3D printing will be a promising way of producing spare parts which are currently estimated as being problematic with respect to availability. Research projects are currently being carried out to link the technology and spare parts production[115] which can become more important for remanufacturing enterprises as well as for workshops or repair cafes, amongst other things.

The trade sees a constant barrier in the legislative framework which causes a high administrative expenditure due to the case-based definition of used parts as waste. For example the minimum requirements for shipment of used electrical and electronic equipment are extremely tightly regulated by the ElektroG and the VVA so that illegal shipments can be prevented. However, this is assessed as endangering global remanufacturing processes[116] because economically viable supply of the necessary know-how or spare parts

114 Cf. Butzer and Schötz (2016), p. 36.
115 Cf. IPRI (2015).
116 Cf. Hieronymi (2016).

on a national scale is often difficult to guarantee, particularly in light of the fact that the remanufacturing centres are in part close to the manufacturing plants, e.g. in China or Malaysia.[117] If the competitiveness of remanufacturing is restricted by this, then the competitiveness of (low-priced) new parts is increased.

The market trend in the remanufacturing industry can thus be summarised as follows:

Key aspects of the market trend for remanufacturing:

- The remanufacturing market will grow in the coming years.
- The main challenges to be overcome in the remanufacturing industry are
  - the continuing electrification of products,
  - the availability of high-quality spare parts,
  - the image of the sector and
  - the availability of well trained personnel.
- Future opportunities for remanufacturing are seen to lie in the areas of 3D printing and digitalisation, amongst others.

117 Cf. ZVEI/Bitkom (2015), p. 14.

4 PRACTICAL EXAMPLES OF REMANUFACTURING

4.1 Remanufactured water meters

In general a water meter consists of a plastic counter and a brass hydraulic element through which the water flows. In the last few years the raw material prices for brass, amongst other things, has shown strong fluctuations, with brass being replaced by plastics in the production of water meters. The disadvantages of this lie in the energy-intensive manufacture of the plastic as well as the plastic's comparatively low durability.[118]

In Annex 7 clause 5.5 of the Measurement and Calibration Act calibration intervals of between five and eight years are defined for measuring instruments for flowing water.[119] For cold water meters with supplementary mechanical devices, for example, recalibration after six years is necessary. This causes the exchange of the entire water meters for economic reasons.

Based on this relatively reliable return rate for water meters Lorenz GmbH, a mid-sized manufacturer of water meters, developed a collection concept. Water meters replaced by measuring services and water suppliers are taken back or bought by Lorenz GmbH and fed into an in-house remanufacturing process. This includes efficient disassembly of the water meters, in the process of which worn, used or contaminated components such as batteries and strainers are partly replaced. The brass hydraulic component with usually minimal signs of wear is rebuilt and in part reassembled with new material to form a refabricated water meter (Figure 12).[120, 121]

118 Cf. Schmidt et al. (2017), p. 182.
119 Regulation governing the sale and provision of measuring instruments on the market as well as their use and calibration (Measurement and Calibration Act – MessEV)
120 Cf. Schmidt et al. (2017), p. 184.
121 Cf. Mauß (2016).

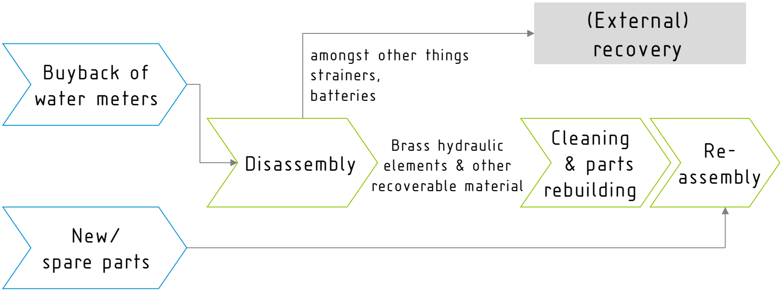

Figure 12: Buyback of water meters [122]

Because, amongst other things, the entire forging process in the production of the hydraulic component is eliminated, Lorenz GmbH saves approximately 30 % on new material, in particular brass, and reduces annual energy consumption by approximately 150,000 kWh. At present approximately 75% of the returned water meters are reused; approximately 25 % of manufactured water meters are made from rebuilt material.

The reduced material expenditure is reflected in lowered material costs which do not exceed the increased personnel costs for the rebuilding process. Through an approximately 30 % unburdening of hydraulic manufacture the same production volume can be achieved with lower expenditures and production growth can be realised without additional investments.[123, 124]

4.2 Remanufactured PCs and notebooks

In the b2b area in 2013 approximately 40,700 tonnes of waste IT and telecommunications devices occurred, whereby 97 % was recovered.[125] According to Chapter 2.2 remanufacturing of waste is a recovery process and may only be carried out in certified disposal or preliminary treatment facilities. An SME is specialised in rebuilding of IT products, specifically PCs and notebooks, and as a certified preliminary treatment enterprise rebuilds some 65,000 IT units for reuse (Figure 13).[126]

122 Following Mauß (2016).
123 Cf. Schmidt et al. (2017), p. 184 et sq.
124 Cf. Mauß (2016).
125 Cf. Wagner et al. (2016), p. 31.
126 Cf. bb-net (2017).

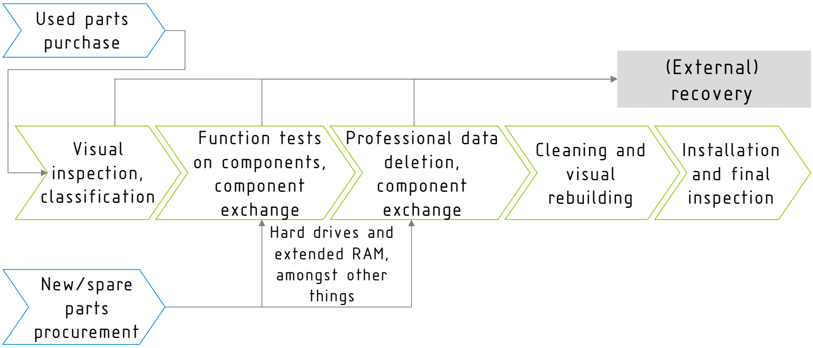

Figure 13: Process chain for IT products[127]

The products usually collected via an IT purchase are visually inspected and classified in the first step of the rebuilding process. The devices are classified according to the damage and signs of wear found. The first class covers visually immaculate products, whereas second-class products are no longer used for resale under the own brand name.[128]

In the second step the products undergo a technical check. If the functionality is impaired and cannot be restored by the replacement by hardware components, the product is discharged from the rebuilding process. Functioning devices are additionally equipped with new SSD hard drives or extended RAM to correspond to the state of the art.[129]

Professional data deletion is then carried out using special software tools. In this step as well larger hard drives (new ware) are used, for example, to secure the technical status quo.[130]

After the technical inspection and equipping the product is prepared for sales through cleaning and visual rebuilding. Intensive cleaning is carried out, broken or missing parts such as keys are replaced and worn areas are treated. If the device corresponds to the credo of the SME of providing ‘like-

[127] Cf. tecXL (2017).
[128] Cf. tecXL (2017).
[129] Cf. tecXL (2017).
[130] Cf. tecXL (2017).

new technology', then the operating system and further software are installed. The product is packaged and sold under the company's own brand name through dealers.[131]

The company reduces the natural resources requirement by 80 % and thereby reduces CO_2 emissions by around 70 % by rebuilding the IT products. In addition ecologically degradable cleaning agents, pollution-free packaging solutions and carbon-neutral parcel delivery are used.[132]

4.3 Remanufactured industrial robots

Industrial robots have an average service life of five years.[133] In order to extend the service life and avoid cost-intensive new investments an SME offers individual rebuilding services for robots. In 90 % of the cases rebuilding is done at the request of customers; in only 10 % of the cases are the industrial robots purchased by the SME.[134] The general procedure is shown in Figure 14.[135]

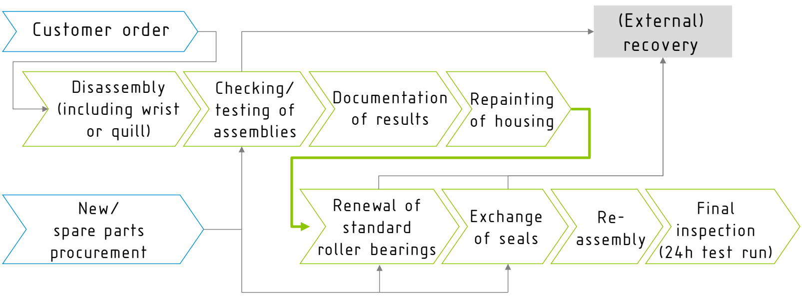

Figure 14: Process chain for industrial robots[136]

[131] Cf. tecXL (2017).
[132] Cf. bb-net (2017).
[133] Cf. Meister (2012).
[134] Cf. ERN (2015).
[135] Cf. robotif GmbH (2017).
[136] Cf. robotif GmbH (2017).

The greatest challenges for the rebuilder lie in procuring of the spare parts. Particularly for industrial robots which are no longer manufactured on a regular basis, spare parts must be taken from existing robots.[137] In this case 3D printing could offer an interesting option in the future.

4.4 Remanufactured printers

Remanufacturing of printers and printer modules is a common process in the industry. Via leasing agreements, particularly for companies, the manufacturers get their printers back after the use period has elapsed and can supply them again for reuse after successful rebuilding.

An SME carries out remanufacturing of printers designed especially for company needs. At the end of the leasing period the printers frequently do not attain the designed print volumes or the estimated service life. The company purchases the collected devices from the manufacturers, rebuilds them and sells them to other companies (Figure 15).[138]

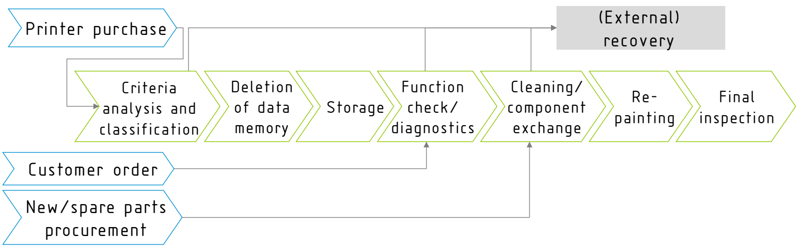

Figure 15: Process chain for printers[139]

In the first step of the remanufacturing process the product is analysed with respect to various criteria. If the criteria are met the memory is deleted and the product is stored. Only after an order has been received from a customer is the product tested for functionality and thoroughly cleaned. Wear parts are replaced and the printer can optionally be repainted.[140] The company additionally offers untested devices to external remanufacturers.

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137 Cf. ERN (2015).
138 Cf. ERN (2015a).
139 Cf. Büroservice Hübner (2017).
140 Cf. Büroservice Hübner (2017).

4.5 Remanufactured laser cartridges

The Clover Technologies Group offers remanufacturing of laser cartridges for printing systems. Collected empty laser cartridges are inspected and subjected to sorting and classification according to stringent criteria. Only cartridges meeting the standards specified by the company are sent to the further remanufacturing process. The remaining cartridges are fed into an adequate recycling system.[141]

The cartridges designated for remanufacturing are separated, disassembled and cleaned with a partially automated system before digital filling up to the precisely calculated toner weight is carried out. A seal is affixed to the cartridge and the cartridge is assembled with original manufacturer components (Figure 16).

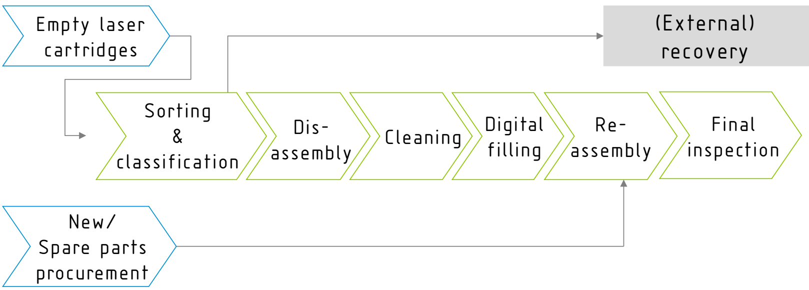

Figure 16: Process chain for laser cartridges[142]

At the end of the process up to 75 % of the cartridge consists of new components. Each cartridge undergoes a final test and upon passing the test is made available for reuse.

4.6 Remanufactured starters and alternators

The average age of passenger cars has been rising for several years. The service life of passenger cars was seven years in 2004, but by 2014 it was nearly nine years. With increasing age come increasing defect and consequently repair rates.[143]

141 Cf. Clover Technologies Group (2017).
142 Cf. Clover Technologies Group (2017).
143 Cf. Deutschlandfunk about TÜV Report (2014).

Remanufacturing of passenger car spare parts such as starters and alternators has been an established process in the automotive industry for years. An example company rebuilds up to 300 to 450 starters and alternators a day. Each core is run through the same standardised process (Figure 17).

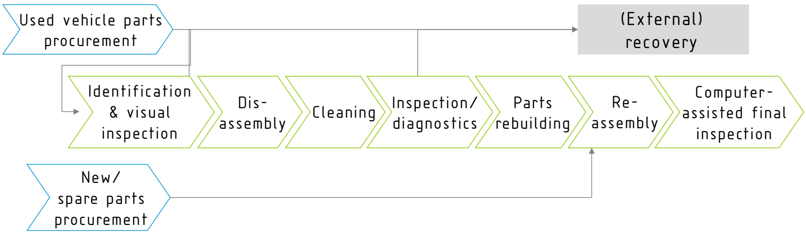

Figure 17: Process chain for starters and alternators[144]

The cores are identified, visually inspected and completely disassembled. Following thorough cleaning by means of hot washing machines and sandblasters, amongst other things[145], the disassembled parts are checked. The rebuildable parts are separated from the non-rebuildable parts and remanufactured. This is followed by assembly to form the finished aggregate and a computer-assisted performance check.[146]

Remanufacturing of starters can save up to 88 % of the material costs for new production, lower CO_2 emissions by up to 53 % and slash energy consumption by more than half.[147]

4.7 Remanufactured braking systems

A braking system manufacturer has been remanufacture parts for 60 years and estimates remanufacturing to be an increasingly relevant area in the automotive sector, particularly in light of rising demand for fair value-based repairs.[148]

The company receives used parts through a deposit system. The parts are manually disassembled, whereby disassembly of compressors, for example,

144 Cf. Andre Niermann (2017).
145 Cf. Niermann (2014), p. 73.
146 Cf. Andre Niermann (2017).
147 Cf. Bartel (2015).
148 Cf. Heerwagen (2015).

takes about 20 minutes. The parts are then thoroughly cleaned using spray washing machines, pyrolysis furnaces, blasting systems and ultrasonic baths, amongst other things. Remanufacturing of the cleaned parts includes exchange of spare parts such as seals and bearings. The remanufactured spare parts are reassembled using work steps corresponding to those used for the original parts. Some of the rebuilt components are assembled on the production lines for new parts. Each remanufactured product is subjected to more than 100 testing and measurement steps for ensuring the quality and functionality (Figure 18).[149]

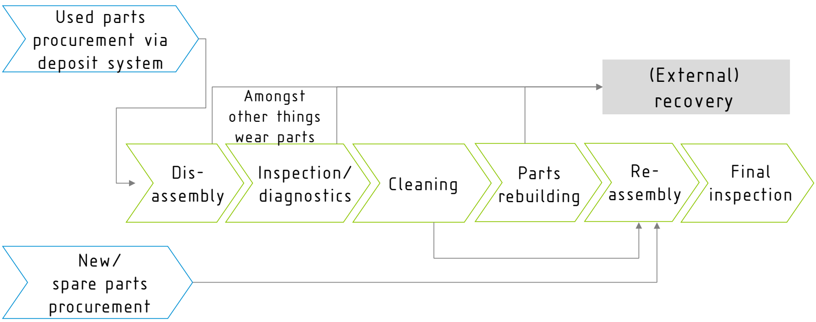

Figure 18: Process chain for braking systems[150]

Through the remanufacturing process for used parts savings in carbon dioxide emissions of up to 75 % compared with those associated with manufacture of a new product are possible. In addition the refabricated products can be offered at an up to 20 % lower selling price.

4.8 Remanufactured carbon fibre-reinforced plastic components

The manufacture of carbon fibre-reinforced plastics (CFRPs) involves high energy consumption which can be justified by the return or recirculation of

[149] Cf. Heerwagen (2015).
[150] Cf. Knorr-Bremse (2015).

the CFRP.[151] However, current recycling technologies for CFRP (e.g. pyrolysis) are neither economically viable nor resource-efficient and shorten the reclaimed fibres.

Recycled CFRPs thus are of lesser quality and are only used for parts with low requirements.[152] Thus remanufacturing represents an economically viable variant for retaining the high quality of the CFRP components.

A company produces CFRP components for bicycles, motorsport and medical equipment. Because the company serves a niche market it has close relationships with customers by means of whom used or defect products get back to the company. The returned products are disassembled and undergo testing. Often the defective CFRP element, usually a tube or CFRP surface, is removed from the rest of the product and replaced by a new CFRP part. The challenge lies in the renewed joining of the existing and new CFRP elements, a task requiring a great deal of know-how and technical experience (Figure 19).[153]

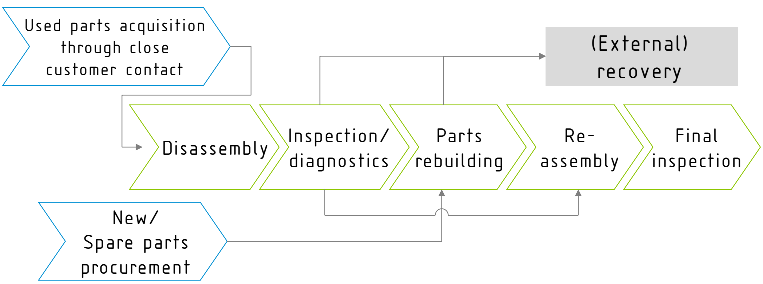

Figure 19: Process chain for carbon fibre-reinforced plastic components

In the remanufacturing process the rebuilt components are continuously inspected. At the end of the process the components undergo a final check for ensuring the function and performance of the remanufactured product; the manufacturing costs can be reduced by 70 % to 80 % in some cases.[154]

[151] Cf. Meiners and Eversmann (2014), p. 374.
[152] Cf. Kaiser et al. (2016), p. 95.
[153] Cf. ERN (2015c).
[154] Cf. ERN (2015c).

4.9 Remanufactured tunnel boring systems

Tunnel boring machines, or moles, are often unique pieces of machinery which have been designed according to the specific project requirements. Nevertheless, further use in other projects cannot be ruled out given the appropriate adaptations.[155]

A company disassembles the tunnel boring machine – following delivery and identification – into its components and carries out an initial analysis of the technical condition. The reusable components are prepared for storage, stored and only upon request by the customer considered for rebuilding and reassembly. The company calculates the price for the tunnel boring machine requested by the customer in consideration of stored rebuildable components and can thus flexibly respond to the customer in terms of pricing (Figure 20).[156]

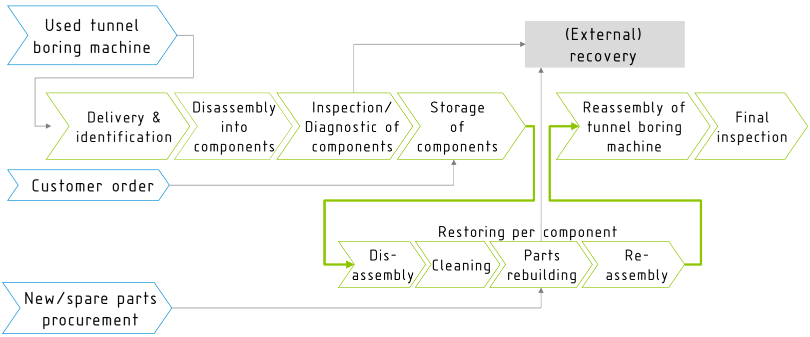

Figure 20: Process chain for tunnel boring machine[157]

When the customer issues the order the tunnel boring machine including the components to be remanufactured is planned. The mole is fed into the remanufacturing process (further disassembly, cleaning, rebuilding, sandblasting, painting and assembly) and finally into the final tunnel boring machine assembly process. Following completion, inspection and certification of the tunnel boring machine are carried out after which the machine is ready for use.[158]

155 Cf. Herrenknecht AG (2017).
156 Cf. ERN (2015b).
157 Cf. Herrenknecht AG (2017).
158 Cf. ERN (2015b).

5 CONCLUSION

The brief analysis shows that remanufacturing of products under adequate conditions holds tremendous resource efficiency potential and can lead to reduced material consumption and cost savings, and hence to competitive advantages, in small and medium-sized enterprises – as procurers as well as providers of refabricated products.

Remanufacturing describes a standardised industrial rebuilding process. The performance of rebuilt products is the same as or higher than that of new products. The remanufacturer provides a warranty.

Material and energy expenditures in production of materials and parts as well as at end of life are saved through the avoidance of new product manufacture. Examples and analyses show that through remanufacturing of used parts up to 80 % of the manufacturing costs[159] could be saved and material consumption could be reduced by up to nearly 90 %[160] in some cases. This allows manufacturers to pass some of the resulting profit margins on to the customers. Remanufactured products can thus be offered at approx. 40 % to 80 % of the procurement price for a new product. This results in improved competitiveness of the companies due to more variable pricing with a simultaneously wider range of products.

The positive economic and ecological effects can be enhanced even more if design for remanufacturing is heeded in the product design. This includes, for example, modular design as well as easy disassembly, high corrosion resistance and wear resistance of materials used or accommodation for technological leaps.

However, it is precisely the increasing prevalence of electronics in products and the rising complexity that present challenges to the remanufacturing industry. The availability of high-quality spare parts, the image of the remanufacturing sector and the availability of well trained personnel are also being considered to be current and in part future weaknesses.[161] At the same time

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159 Cf. ERN (2015c).
160 Cf. Bartel (2015), p. 7.
161 Cf. Butzer and Schötz (2016), p. 36.

the remanufacturing industry sees, for example, 3D printing as an opportunity for reacting to the limited availability of spare parts. The increasing positive perception of the industry too is already being recognised as an opportunity to boost market growth. Thus the remanufacturing industry is being met with keener interest precisely in the area of research and development.[162, 163] The German Resource Efficiency programme II, for example, defines the conceptual consideration of the topic in substitution research.[164]

The European remanufacturing industry is expected to grow by more than 50 % to 46 billion euros by 2030 given the current conditions. With more favourable political and economic conditions the industry is even predicted to more than triple.[165] This underscores the rising significance of remanufacturing for industrial production and unlocks further resource efficiency potential.

162 Cf. Matsumoto et al. (2016), p. 131.
163 Cf. Govindan (2016).
164 Cf. BMUB (2016), pp. 36 and 48.
165 Cf. Parker et al. (2015), p. 50.

LITERATURE CITED

Aiblinger-Madersbacher, K. (2016): Grenzüberschreitende Verbringung von Elektro- und Elektronikgeräten [online]. In: Recycling und Rohstoffe, Volume 9, TK Verlag Karl Thomé-Kozmiensky, [retrieved on 21 February 2017], available at: http://www.vivis.de/phocadownload/2016_rur/2016_RuR_327-344_Aiblinger_Madersbacher.pdf.

Allwood, J. M., Ashby, M. F.; Gutowski, T. G. and Worell, E. (2011): Material Efficiency: A white paper. In: Resources, Conservation and Recycling, 55 (3), Elsevier Verlag, pp. 362-381.

Andre Niermann (2017): Research, Development & Remanufacturing [online]. Andre Niermann – automotive electrical products GmbH & Co. KG. [retrieved on 22 February 2017], available at: http://www.niermann-electric.com/index.php?id=43.

APRA (2014): Common Definition of Remanufacturing [online].Automotive Parts Remanufacturers Association, 11 February. 2014, [retrieved on: 26. September 2016], available at: http://www.apra-europe.org/dateien/RemanufacturingDefinition/APRA_Definition_Division.pdf.

APRA (2016): Design for Remanufacturing [online]. Automotive Parts Remanufacturers Association [retrieved on: 17 January 2017], available at: https://apra.org/?page=Remanufacturing.

Arbeitskreis Elektrogeräte and Ressourceneffizienz (2016): Abschlussbericht des Arbeitskreises Elektrogeräte und Ressourceneffizienz [online]. Niedersächsisches Ministerium für Umwelt und Klimaschutz (Ministry of the Environment, Energy and Climate Protection, State of Lower Saxony), November 2016, [retrieved on: 28 February 2017], available at: www.umwelt.niedersachsen.de/download/112456/Abschlussbericht_des_Arbeitskreises_Elektro-Altgeraete_und_Ressourceneffizienz.pdf.

Auer, J. (2014): Neue Wachstumschancen für den deutschen Maschinenbau – Technologieführerschaft & Auslandinvestitionen [online]. tti Technologietransfer und Innovationsförderung Magdeburg GmbH. [retrieved on: 21 February 2017], available at: http://www.cluster-smab.de/de/component/phocadownload/category/13-branche.html#.

Bartel, P. (2015): Aktuelle Herausforderungen und Strategien des Remanufacturing von Automobilteilen [online]. In: Spieth, H: Vom Jetzt in die Zukunft. Remanufacturing – Ein zweites Leben für Investitionsgüter. Ressourceneffizienz- und Kreislaufwirtschaftskongress 2015 [retrieved on 21 February 2017], available at: http://www.ressourceneffizienzkongress.de/sites/default/files/2016-07/151007_ressourcen_forum_4.pdf.

Basel Convention (2015): Technical guidelines on transboundary movements of electrical and electronic waste and used electrical and electronic equipment, in particular regarding the distinction between waste and non-waste under the Basel Convention (adopted by COP.12, May 2015) [online]. Basel Convention [retrieved on: 27 January 2017], available at: http://www.basel.int/Implementation/Publications/TechnicalGuidelines/tabid/2362/Default.aspx.

bb-net (2017): Ein Unternehmen stellt sich vor [online]. bb-net – The IT Lifecycle Company, [retrieved on: 20 February 2017], available at: http://www.bb-net.de/unternehmen/.

Biswas, K. W.; Duong, V.; Frey, P. and Islam, M. N. (2013): A comparison of repaired remanufactured and new compressors used in Western Australian small- and medium-sized enterprises in terms of global warming. In: Journal of Remanufacturing 3 (4), Springer Open Journal, 2013.

BMUB (2016): German Resource Efficiency Programme II. Programme for the sustainable use and conservation of natural resources. 1. edition, BMUB, Berlin, [retrieved on: 12 January 2017] available as PDF at: http://www.bmub.bund.de/fileadmin/Daten_BMU/Pools/Broschueren/progress_ii_broschuere_bf.pdf.

Brüning, R.; Ebelt, S. and Regenfelder, M. (2014): Solide Grundlage. Das Blatt ReUse der VDI-Richtlinie 2343 zeigt Potentiale und Erfolgsfaktoren der Wiederverwendung von elektr(on)ischen Geräten auf. In: ReSource, January 2014, Rhombos-Verlag, pp. 25-31.

BS 8887-2:2009: Design for manufacture, assembly, disassembly and end-of-life processing (MADE) – Terms and definitions. British Standard Institute, 30 April 2009.

Bücker + Essing (2009): Gemeinsame Forschung mit Fraunhofer-Projektgruppe [online]. Bücker + Essing GmbH, press release, 22 April 2009 [retrieved on: 26 January 2017], available at: http://www.buecker-essing.de/index.php?module=viewer&index[viewer][page]=about_us_management.

Bullinger, H.-J.; Spath, D.; Warnecke, H.-J. and Westkämper, E. (2009): Handbuch Unternehmensorganisation – Strategien, Planung, Umsetzung. 3. edition, Springer-Verlag, Berlin Heidelberg, ISBN 978-3-540-72136-9.

Büroservice Hübner (2017): Druck & Kopie – Aufarbeitung [online]. Büroservice Hübner GmbH, [retrieved on 22 February 2017], available at: http://www.druckerboerse.com/impressum.

Butzer, S. (2015): Remanufacturing und Remanufacturing-Beispiel aus der Praxis [online]. Rohstoffdialog Baden-Württemberg, Fraunhofer IPA, 1 December 2015, [retrieved on: 26 September 2016], available at: http://download.steinbeis-europa.de/2015-11-30_cluster_ws_rohstoffdialog/01_marktchancen_remanufacturing_butzer.pdf.

Butzer, S. (2016a): Remanufacturing – Ein wichtiger Beitrag zur Circular Economy [online]. Ressourceneffizienz Kongress BW Kreislaufwirtschaft, 6 October. 2017, ZKM Karlsruhe [retrieved on: 21 February. 2017], available at: http://www.ressourceneffizienzkongress.de/sites/default/files/2016-10/ReKo-16_Forum_8.pdf.

Butzer, S. (2016b): Networking Event: Challenges and Perspectives in Remanufacturing [online]. Workshop-Agenda, European Remanufacturing Network, Bayreuth, 21 January 2016 [retrieved on: 21 February 2017], available at: http://www.lup.uni-bayreuth.de/documents/universitaere_forschung/Event-Agenda.pdf.

Butzer, S. and Schötz, P. (2016): D3.3 – D3.4 Map of Remanufacturing Processes Landscape [online]. European Remanufacturing Network, [retrieved on: 26 January 2017], available at: https://www.remanufacturing.eu/wp-content/uploads/2016/07/ERN_DeliverableReport_WP3_Processes_final_for_upload.pdf.

Butzer, S. and Schötz, P. (2016a): Industry Sector Specific Remanufacturing Processes [online]. The European Conference on Sustainability, Energy & the Environment 2016, Conference Proceedings, International Academic Forum, [retrieved on 10 March 2017], available at: http://papers.iafor.org/papers/ecsee2016/ECSEE2016_30698.pdf.

Chapman, A.; Bartlett, C.; McGill, I.; Parker, D. and Walsh, B. (2009): Remanufacturing in the UK - A snapshot of the remanufacturing industry in the UK [online]. Centre for Remanufacturing and Reuse, Oakdene Hollins, Aylesbury, United Kingdom, August 2010 [retrieved on: 21 February 2017], available at: http://www.remanufacturing.org.uk/pdf/story/1p342.pdf.

Clover Technologies Group (2017): Ten-step laser toner remanufacturing process. [online]. Clover Germany GmbH, [retrieved on 21 February 2017], available at: http://www.clovertech.de/ten-step-laser-toner-remanufacturing-process.

Dando, R. (2016): Remanufacturing Opportunities for Home Appliances. In: Make-New-Again by Remanufacturing, Rebuilding or Refurbishing, Fernand J. Weiland (2016).

Dell (2016): US Internet presence for remanufactured products: www.dell.com; US Internet presence for remanufactured products: www.delloutlet.com.

Deutschlandfunk (2014): Autos werden immer älter – und anfälliger [online]. Deutschlandfunk on TÜV Report 2014 [retrieved on 21 February 2017], available at: http://www.deutschlandfunk.de/tuev-report-2014-autos-werden-aelter-und-anfaelliger.697.de.html?dram:article_id=271110.

Dias, A. S.; Kim, H.; Sivakumar, P. K.; Liu, Z.-C. and Zhang, H.-C. (2013): Life Cycle Assessment: A Comparison of Manufacturing and Remanufacturing Processes of a Diesel Engine. In: Re-engineering Manufacturing for Sustainability, Proceedings of the 20th CIRP International Conference on Life Cycle Engineering, Singapore 17-19 April, 2013, Springer Singapore, pp. 675–678.

DIHK (2016): Digitalisierung der Arbeitswelt – Unternehmen vor neuen Herausforderungen [online]. DIHK Arbeitsmarktreport 2016. DIHK, Berlin, [retrieved on: 22 February 2017], available at: http://www.dihk.de/ressourcen/downloads/dihk-arbeitsmarktsreport-2016/at_download/file?mdate=1474963698219.

DIN 31051 (2012-09): Fundamentals of maintenance. German Institute for Standardisation, September 2012, Beuth Verlag, Berlin.

Commission Recommendation 2003/361/EC: Commission Recommendation of 6 May 2003 concerning the definitions of microenterprises as well as small and medium-sized enterprises. In: Official Journal of the European Union, L 124/36, 20.05.2003.

ERN (2015): robotIF (Case study) [online]. European Remanufacturing Network, [retrieved on: 20 February 2017], available at: https://www.remanufacturing.eu/case-studies/robotif-gmbh/.

ERN (2015a): Büroservice Hübner GmbH (Case study) [online]. European Remanufacturing Network, [retrieved on: 20 February 2017], available at: https://www.remanufacturing.eu/case-studies/bu%CC%88roservice-hu%CC%88bner-gmbh/.

ERN (2015b): Herrenknecht AG (Case study). European Remanufacturing Network, [online] [retrieved on 21 February 2017], available at: https://www.remanufacturing.eu/case-studies/herrenknecht-ag/.

ERN (2015c): ax-lightness composites GmbH & Co.KG (Case study) [online]. European Remanufacturing Network, [retrieved on 21 February 2017], available at: https://www.remanufacturing.eu/case-studies/ax-lightness-composites-gmbh-co-kg/.

Ernst, M. (2016): Recent developments at the level of the Basel Convention. Talk given during the UNEP International Resource Panel Stakeholder Workshop: Assessment of Resource Efficiency and Innovation in Circular Economy through Remanufacturing, Refurbishment, Repair and Direct Reuse, 10. Oct. 2016, Berlin.

European Commission (2015): Annual Analyses of the EU Air Transport Market 2013 [online]. European Commission, Mott MacDonald, 24 April 2015, [retrieved on: 22 February 2017], available at: http://ec.europa.eu/transport/sites/transport/files/modes/air/internal_market/observatory_market/doc/annual-2013.pdf.

Gray, C. and Charter, M. (2009): Remanufacturing and Product Design – Designing for the 7th Generation. The Centre for Sustainable Design, University College for the Creative Arts, Farnham UK, 2009.

Guide, V. D. R. and Wassenhove, L. N. V. (2009): The Evolution of Closed-Loop Supply Chain Research. In: Operation Research, 57(1), pp. 10-18.

Govindan, K. (2016): Marketing issues for remanufactured products (Call for Paper) [online]. Elsevier [retrieved on 27 January 2017], available at: https://www.journals.elsevier.com/journal-of-cleaner-production/call-for-papers/marketing-issues-for-remanufactured-products.

Hatcher, G. D.; Iljomah, W.L. and Windmill, J.F.C. (2011): Design for remanufacture: a literature review. In: Journal of Cleaner Production, 19 (17-18), Elsevier, Nov.-Dec. 2011, pp. 2004-2014.

Heerwagen, M. (2015): Remanufacturing von Teilen der Bremsanlage - Ersatzteile fürs zweite Leben [online]. Eurotransport.de, 15 December 2015 [retrieved on 22 February 2017], available at: http://www.eurotransport.de/news/remanufacturing-von-teilen-der-bremsanlage-ersatzteile-fuers-zweite-leben-6817464.html.

Herrenknecht AG (2017): Sanierung – In Rekordzeit fit für den nächsten Einsatz [online]. Herrenknecht AG, [retrieved on 21 February 2017], available at: https://www.herrenknecht.com/de/services/tbm-dienstleistungen/sanierungen.html.

Hieronymi, K. (2016): Remanufacturing and Circular Economy on the IT Industry. In: Make-New-Again by Remanufacturing, Rebuilding or Refurbishing. Fernand J. Weiland, (2016).

IPRI (2015): Ersatzteil 3D [online]. International Performance Research Institute IPRI [retrieved on 21 February 2017], available at: http://www.ipri-institute.com/ersatzteil3d/.

Kaiser, O.; Krauss, O.; Seitz., H. and Kirmes, P. (2016): Ressourceneffizienz im Leichtbau. VDI Zentrum Ressourceneffizienz (Ed.), Berlin, November 2016.

Knorr-Bremse (2015): Genuine Remanufacturing [online]. Knorr-Bremse Group, [retrieved on: 26 January 2017], available at: http://www.knorr-bremse.com/media/documents/press/press_releases/2015/06_09_kb_remanufacturing_eac1/Remanufacturing_Broschuere_d_2015.pdf.

LAGA M31 (draft 2016): Umsetzung des Elektro- und Elektronikgerätegesetzes – draft [online]. Communication of the German federal/Laender working group on waste 31, 9 June 2016 [retrieved on: 27 January 2017], available at: http://www.laga-online.de/servlet/is/29187/M31_Entwurf_9_06_16.pdf?command=downloadContent&filename=M31_Entwurf_9_06_16.pdf.

Lindahl, M.; Sundin, E. and Östlin, J. (2006): Environmental Issues within the Remanufacturing Industry [online]. In: Proceedings of LCE2006. 13th CIRP International Conference on Life Cycle Engineering, pp. 447-452.

Liu, Z. Jiang, Q.; Li, T.; Dong, S.; Yan, S.; Zhang, H. and Xu, B. (2016): Environmental benefits of remanufacturing: A case study of cylinder heads remanufactured through laser cladding. In: Journal of Cleaner Production, Elsevier, 1 October 2016, Volume 133, pp. 1027-1033.

Lund, R. (1996): The remanufacturing Industry: Hidden Giant. Boston Massachusetts: Boston University, 1996.

Lundmark, P.; Sundin, E. and Björkman, M. (2009): Industrial Challenges within the Remanufacturing System [online]. In: Proceedings of Swedish Production Symposiums. Stockholm, pp. 132-139, 2009, [retrieved on 22 February 2017], available at: https://www.diva-portal.org/smash/get/diva2:375722/FULLTEXT01.pdf.

Matsumoto, M.; Yang, S.; Martinsen, K. and Kainuma, Y. (2016): Trends and Research Challenges in Remanufacturing. In International Journal of Precision engineering and manufacturing – Green Technology, 3 (1), Springer Verlag, Jan. 2016, pp. 129-142.

Mauß, W. (2016): Wiederaufbereitung von Wasserzählern – von der Einzelmaßnahme zum ganzheitlichen Unternehmenskonzept [online]. In: Ressourceneffizienz- und Kreislaufwirtschaftskongress Baden-Württemberg [retrieved on 22 February 2017], available at: http://www.ressourceneffizienzkongress.de/sites/default/files/ 2016-10/ReKo-16_Forum_8.pdf.

Meiners, D. and Eversmann, B. (2014): Recycling von Carbonfasern. Thomé-Kozmiensky, K. J.; Goldmann, D. (Ed.): Recycling und Rohstoffe, Volume 7. Neuruppin: TK Verlag Karl Thomé-Kozmiensky, 2014, pp. 371-378.

Meister, A. (2012): Auch Roboter werden alt [online]. Die Welt, published on 14 October 2012. [retrieved on 20 February. 2017], available at: https://www.welt.de/print/wams/muenchen/article109822136/Auch-Roboter-werden-alt.html.

Nasr, N. and Thurston, M. (2006): Remanufacturing: A Key Enabler to Sustainable Product Systems [online]. In: Proceedings of the 13th CIRP International Conference on Life Cycle Engineering (LCE), 2006, Leuven, Belgium, [retrieved on 22 February 2017], available at: http://www.mech.kuleuven.be/lce2006/key4.pdf.

Niermann, A. (2014): Heavy Duty Remanufacturing a Book with seven seals? In: Remanufacturing of Heavy Duty Vehicle Components – A Hidden Giant. Fernand J. Weiland, (2014).

Östlin, J.; Sundin, E. and Björkmann, M. (2009): Product life-cycle implications for remanufacturing strategies. In: Cleaner Production, 17 (11), Elsevier, Jul. 2009. pp. 999-1009.

Ovchinnikov, A. (2010): Revenue and Cost Management for Remanufactured Products. In: Production and Operations Management, 20(6), Nov.-Dec. 2011, School of Business University of Baltimore, pp. 824-840.

Parker, D. and Butler, P. (2007): An Introduction to Remanufacturing [online], Centre for Remanufacturing & Reuse, [retrieved on: 26 September 2016], available at: http://www.remanufacturing.org.uk/pdf/story/1p76.pdf.

Parker, D.; Riley, P.; Robinson, S.; Symington, H.; Tewson, J.; Jansson, K.; Ramkumar, S. and Peck, D. (2015): Remanufacturing Market Study [online]. European Remanufacturing Network, October 2015, [retrieved on 22 February 2017], available at: https://www.remanufacturing.eu/wp-content/uploads/2016/01/study.pdf.

Peters, K. (2016): Methodological issues in life cycle assessment for remanufactured products: a critical review of existing studies and an illustrative case study. In: Journal of Cleaner Production, 10 July 2016, Volume 126, pp. 21-37.

Prendeville, S. and Bocken, N. (2016): Design for Remanufacturing and Circular Business Models. In: Sustainability Through Innovation in Product Life Cycle Design, Part III, Springer Singapore, pp. 269–283.

Prendeville, S.; Peck, D; Balkenende, R.; Cor, E., Jansson, K. and Karvonen, I. (2016): Map of Remanufacturing Product Design Landscape [online]. European Remanufacturing Network, [retrieved on: 22 February 2017], available at: https://www.remanufacturing.eu/wp-content/uploads/2016/11/D3.2_FINAL.pdf.

robotif GmbH (2017): Reparatur Pakete, [online], robotif GmbH [retrieved on: 20 February. 2017], available at: http://www.robotif.de/cms/werkstatt-reparatur/reparatur-pakete.php.

Schmidt, M.; Spieth, H.; Bauer, J. and Haubach, C. (2017): 100 Betriebe für Ressourceneffizienz, Band 1 – Praxisbeispiele aus der produzierenden Wirtschaft. Springer Spektrum, Berlin Heidelberg, 2017.

Steinhilper, R. (1998): Remanufacturing: The Ultimate Form of Recycling. Fraunhofer-IRB-Verlag, Stuttgart, 1998.

Steinhilper, R. and Freiberger, S. (2010): Neue Qualifikation zur Kfz-Ersatzteilversorgung durch Austauschteileproduktion (Remanufacturing) von mechatronischen Baugruppen [online]. Berufsbildungswissenschaftliche Schriften, Leuphana-Seminar-Schriften zur Wirtschaftspädagogik, Band 4: Die BBS Friedenstraße auf dem Weg zu einer nachhaltigen Entwicklung, [retrieved on 21 February 2017], available at: http://bwp-schriften.univera.de/Band4_10/steinhilper_freiberger_Band4_10.pdf.

Sundin, E. (2004): Product and Process Design for Successful Remanufacturing [online]. Dissertation, Linköpings Universitet, ISBN 91-85295-73-6, [retrieved on: 14 December 2016], available at: https://www.diva-portal.org/smash/get/diva2:20932/FULLTEXT01.pdf.

Sundin, E.; Östlin, J.; Öhrwall Rönnbäck, A.; Lindahl, M. and Sandström G. (2008): Remanufacturing of Products used in Product Service System Offerings. In: Manufacturing Systems and Technologies for the New Frontier: The 41st CIRP Conference on Manufacturing Systems, 26–28 May 2008, Tokyo, pp. 537–542.

Sundin, E. and Lee, H. M. (2016): Remanufacturing and the Environment. In: Make-New-Again by Remanufacturing, Rebuilding or Refurbishing. Fernand J. Weiland (2016).

Sundin, E.; Sakao, T.; Lindahl, M.; Kao, C. and Joungerious, B. (2016): Map of Remanufacturing Business Model Landscape [online]. European Remanufacturing Network, [retrieved on 11 January 2017], available at: https://www.remanufacturing.eu/wp-content/uploads/2016/05/ERN-D-3-1-Map-of-Remanufacturing-Business-Model-Landscape.pdf.

tecXL (2017): tecXL Aufbereitung – So wird „gebraucht“ zu Technik wie neu [online]. bb-net media GmbH, [retrieved on: 20 February 2017], available at: http://www.tecxl.de/ueber-tecxl/tecxl-aufbereitung/.

UBA (2016): Mit Produktdesign Umweltbelastungen reduzieren [online]. Umweltbundesamt (German Federal Environment Agency), 18 August 2016 [retrieved on: 26 January 2017], available at: https://www.umweltbundesamt.de/themen/wirtschaft-konsum/produkte/oekodesign.

Bayreuth University (2017): Reinigungstechnik [online]. Bayreuth University [retrieved on: 26. January 2017], available at: http://www.lup.uni-bayreuth.de/de/fhg/01_arbeitsgebiete/reinigungstechnik/index.html.

VDI 2343 Blatt 2 (2010): Recycling of electrical and electronic equipment – Logistics. Beuth Verlag GmbH, Berlin.

VDI 2343 Blatt 3 (2009): Recycling of electrical and electronic equipment – Disassembly. Beuth Verlag GmbH, Berlin.

VDI ZRE (2017): Kostenlose Service-Hotline hilft Unternehmen [online]. VDI Zentrum Ressourceneffizienz [retrieved on: 8 February 2017], available at: https://www.vdi.de/artikel/vdi-zre-neue-servicestelle-ressourceneffizienz/.

Wagner, J.; Lange, U. and Günther, M. (2016): Analyse der Datenerhebung nach ElektroG über das Berichtsjahr 2013 zur Vorbereitung der EU-Berichtspflicht 2016 [online]. Umweltbundesamt (German Federal Environment Agency), Dessau-Roßlau [retrieved on: 13 February 2017], available at: https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/texte_24_2016_analyse_der_datenerhebung_nach_elektrog.pdf.

Walther, G. (2010): Nachhaltige Wertschöpfungsnetzwerke – Überbetriebliche Planung und Steuerung von Stoffströmen entlang des Produktlebenszyklus. Springer-Verlag, Berlin Heidelberg, 2010.

Warsen, J.; Laumer, M. and Momberg, W. (2011): Comparative life cycle assessment of remanufacturing and new manufacturing of a manual transmission. In Hesselbach, J.; Herrmann, C.: Proceedings of the 18th CIRP International Conference on Life Cycle Engineering. Springer-Verlag, Berlin Heidelberg, pp. 67-72.

Weiland, F.J. (2014): European Remanufacturing of Heavy Duty vehicle components – A Hidden Giant? In Remanufacturing of Heavy Duty Vehicle Components – A Hidden Giant! Fernand J. Weiland, (2014).

Xing, B. and Gao, W. (2014): Computational Intelligence in Remanufacturing. Information science Reference (an imprint of IGI Global) Hershey, USA, 2014.

Yang, S. S.; Ong, S. K. and Nee, A.Y.C. (2016): A Decision Support Tool for Product Design for Remanufacturing. In: Procedia CIRP 40 (2016), 13th Global Conference on Sustainable Manufacturing - Decoupling Growth from Resource Use. Elsevier, pp. 144–149.

ZVEI/BITKOM (2015): Stellungnahme von ZVEI und BITKOM zum Gesetzentwurf der Bundesregierung zur Neuordnung des Gesetzes über das Inverkehrbringen, die Rücknahme und die umweltverträgliche Entsorgung von Elektro- und Elektronikgeräten (Elektro- und Elektronikgerätegesetz – ElektroG) [online]. On German Bundestag homepage, 12 June 2015, [retrieved on: 06 December 2016], available at: https://www.bundestag.de/blob/378300/5c7f12c1e4abb4185ba3ff6efa62f4c9/18-16-227-b_anhoerung_elektro_elektronikgeraete_stellungnahme_zvei_bitkom-data.pdf.

APPENDIX

Table 11: Elements for product design on a technical level mentioned in the literature

Source	Mentioned elements (design for …)	Class
Nasr and Thurston (2006): "Remanufacturing: A Key Enabler to Sustainable Product Systems" p. 17	• Design for disassembly (ease of disassembly)	Construction
	• Design for product reliability	Material
	• Design for product durability	Material
	• Design for restoration	Technology
	• Design for cleaning	Construction
	• Modular design	Construction
Yang et al. (2016): "A Decision Support Tool for Product Design for Remanufacturing", p. 146	• Used material	Material
	• Material joining method	Construction
	• Structure Design	Construction
	• Functional and decorative Surface Coating	Material
	• Durability	Material
	• Disassemblability and assemblability	Construction
	• Cleanability	Construction
	• Restorability/Upgradeability	Technology
	• Reduced Complexity	Construction
Prendeville and Bocken (2016): "Design for Remanufacturing and Circular Business Models", p. 5	• Design for Technology Integration	Technology
	• Detailed Design & Materials Selection	Construction & Material
	• Design for Standardisation & Reducing Complexity	Construction
Gray and Charter (2006): "Remanufacturing and Product Design", p. 25 sqq.	• Design for Disassembly	Construction
	• Design for Cleaning	Construction
	• Design for Product reliability	Material
	• Design for Product durability	Material
	• Design for Remediation	Technology
	• Design for Upgrade	Technology
	• Modular Design	Construction
Prendeville et al. (2016): "Map of Remanufacturing Product Design Landscape", p. 40	• Ease of Disassembly	Construction
	• Material selection	Material
	• Durable materials /parts; reliability	Material
	• Upgradeability/adaptability	Technology
	• Modular Design	Construction
	• Easy serviceability	Construction
	• Design for rapid repair	Construction
	• Design for milling and machining	Construction
	• Standardisation	Construction
	• Easy access to vulnerable/valuable parts	Construction
	• Small number of parts/designing layouts that segregate recyclable and remanufacturable Components	Construction

Table 12: Number of head offices for remanufacturing companies by country[166]

Country	Number of head offices	Country	Number of head offices
Germany	61	Finland	3
UK	37	Austria	2
The Netherlands	24	Denmark	2
France	12	Czech Republic	1
Greece	7	Hungary	1
Poland	7	Latvia	1
Sweden	7	Luxembourg	1
Italy	5	Romania	1
Spain	5	Other EU countries	1
Belgium	4	North America	4
Ireland	4	Asia-Pacific	1
Switzerland	4	Others	2

Table 13: Industry share of total turnover

Total industry turnover	Europe	Germany
Turnover in aerospace, automotive, heavy-duty and commercial vehicles, EEE, mechanical engineering and medical equipment industries	29.09 billion euros	8.60 billion euros
Total turnover (above-mentioned industries plus rail, furniture and marine)	29.83 billion euros	8.74 billion euros
Share of total turnover	97.5 %	98.4 %

Table 14: Distribution of responses regarding collection routes (44 responses from 30 survey participants)[167]

Collection type	Share of all responses for collection routes
Collection via purchase of used parts	34 %
Voluntary return	14 %
Ownership-based collection	14 %
Collection based on a service agreement	11 %
1:1-Collection	11 %
Collection by customer order	9 %
Collection via discount on refabricated products	7 %

[166] Following Parker et al. (2015), p. 28.
[167] Following Parker et al. (2015), p. 18 sq.

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