A report by

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Report on the current status, impacts and potential of the European automotive component remanufacturing industry

Prepared for CLEPA by Oakdene Hollins on
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Report on the current status, impacts and potential of the European automotive component remanufacturing industry

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Value-driven consulting

Science-led research

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Glossary

AC	Alternating current
BEV	battery electric vehicle
CAGR	compound annual growth rate
CE	circular economy
DC	Direct current
EGR	exhaust gas recirculation
EoL	end of life
EoU	end of use
EU	European Union
EV	electric vehicle
GDP	gross domestic product
GHG	greenhouse gas
HDOR	heavy duty and off-road
ICE	internal combustion engine vehicle
ICI	industrial, commercial & institutional
IRP	International Resources Panel
LC	life cycle
M&A	mergers and acquisitions
NACE	pan-European classification system that groups organisations according to economic activity
OEM	original equipment manufacturer
RoHS	Restriction of the Use of Certain Hazardous Substances
SME	small and medium-sized enterprise

Units

Conventional SI units and prefixes used throughout.

kt, Mt	Thousands, millions of metric tonnes mass (1 tonne = 2205 lb)
g, kg	Grammes, kilogrammes mass (1 kg = 2.205 lb)

Definitions – related to end-of-life treatment

Core	A product assembled from durable components suitable for recovery and remanufacture. Paraphrased from (Patterson, Ijomah, & Windmill, 2017)
Remanufacturing	A standardised industrial process by which cores are returned to same-as-new, or better, condition and performance. This process is in line with specific technical specifications, including engineering, quality and testing standards. The process yields fully warranted products. (CLEPA, 2016)
Waste	Any substance or object which the holder discards or intends or is required to discard. (The European Parliament and the Council of the European Union, 2008)
OEMs	Vehicle manufacturers that may also undertake remanufacturing.
Tier 1	Component manufacturers that may also undertake remanufacturing.
Independent	Remanufacturers that are not involved in the manufacturing of new components.
Core brokers	Intermediate company that sources core for a remanufacturer.
Wholesaler	Company that sells both new and remanufactured components in bulk to workshops.
Ex supplier	The selling cost of components from the original supplier.
End consumer	The actual price that the end-user pays for the component.

Contents amendment record

This report has been amended and issued as follows:

Version	Date	Description	Author(s)	Editor
6	25/11/21	Final report	RW and AR	KB

1 Executive summary

This study examines the **current status, impact and potential** of the European (EU27 +UK) automotive component remanufacturing market for 2020 to 2030. Insights for this report were gathered through a programme of in-depth interviews with a broad range of remanufacturing actors in the aftermarket for both the passenger vehicle and the commercial vehicle space and supported by desk-based research.

Remanufacturing is a key component of the Circular Economy and is already a well-established activity within the automotive sector. However, if this activity is to continue to contribute towards generating economic value and avoiding CO_2 emissions, the ongoing transition towards electrification of the vehicle parc requires OEMs and EV component manufacturers to consider remanufacturing in their current and future decision-making.

This study values the 2020 passenger car remanufacturing market at between **€2.5 billion** and **€2.6 billion** (ex. supplier level) and is estimated to either remain stable or experience a slight decline over the decade with a value between **€2 billion** and **€2.6 billion** in 2030. This projection is underpinned by stakeholders' anticipation that the impact of the declining trend in ICE sales will start to be felt towards the end of the decade.

In contrast stakeholders have noted that the commercial vehicle sector will be relatively stable. At an ex. supplier level, the market for commercial vehicle component remanufacturing is estimated at **€2.1 billion** in 2020 and is expected to remain stable to 2030. Electrification is anticipated to have a delayed impact for commercial vehicles due to the challenges of electrifying these larger vehicles combined with their longer lifespans.

Electrification is expected to affect the type, volumes and values of components considered for remanufacturing. A battery electric vehicle has around seven times fewer parts than a traditional ICE and while stakeholders expect lower failure rates, the increased complexity and value of these components may favour centralised remanufacturing over distributed repair. An initial estimate of the remanufacturing opportunity for EV components indicates the market could be **€120 million** in 2030.

In this study, a sector-wide approach for quantifying the CO_2 impact was developed, and outlines a method focused on calculating emissions avoided from remanufacturing by considering the material retained during the remanufacturing process. The results revealed that annually, approximately **490 kt CO_{2eq}** is avoided by remanufacturing of passenger car components and approximately **317 kt CO_{2eq}** is avoided by remanufacturing of commercial vehicle components. This is equivalent to the annual emissions produced by **120,000 Europeans citizens**.

2 Context and background

In Europe, the automotive manufacturing sector is the greatest contributor to GDP and is the largest employer[1]. The largest contributors to this GDP are eight countries: Germany, Spain, Czech Republic, United Kingdom, Slovakia, Italy, Poland and Hungary[2]. Although GDP and employment are important factors to consider in relation to wellbeing and prosperity, the sector is a major consumer of material and energy (5.23 kg of raw materials and energy resources is required to produce 1 kg of vehicle[3]).

Today, the issue of resource constraints is particularly important considering the rapid increase of consumption of energy and materials, and the concomitant emissions of greenhouse gases. To satisfy both consumer needs and economic activity, resource-efficient methods such as remanufacturing are needed.

According to CLEPA[4], remanufacturing is defined as:

> *"A standardised industrial process by which cores are returned to same-as-new, or better, condition and performance. This process is in line with specific technical specifications, including engineering, quality and testing standards. The process yields fully warranted products."*

Remanufacturing keeps components and a large percentage of a product's embodied material in use for longer. This reduces the resources used to provide the function, performance and extends the lifetime of the component.

The size of remanufacturing markets and the support they are given from governments differ across countries and continents. The USA has the biggest remanufacturing market in the world[5]. Its federal law permits the use of remanufacturing labels on products and there are state laws to promote the sale of remanufactured products. Its neighbour, Canada, on the other hand, has reported a decline in remanufacturing activities. This is due to barriers around cheaper imports, difficulties in achieving economies of scale, high costs around core logistics and increased labour costs[6].

The second largest market is found in Europe. The passenger vehicle automotive remanufacturing market was valued at €3.6 billion (ex-supplier level and including tyre re-treading) in 2015 and was estimated to have the potential to reduce CO_2 emissions by

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1 European Remanufacturing Network, 'Remanufacturing Market Study' (Aylesbury, 2015), pp.61-65

2 International Organisation of Motor Vehicles, 'Car Production By Country 2021',World Population Review [28 July 2021]

3 F.E.K Sato & T Nakata, Energy Consumption Analysis of Vehicle Production through a Material Flow Approach (2020), Energies, 13 (2020), (1-18), <doi:10.3390/en13092396

4 CLEPA, 'Remanufacturing Associations Agree on International Industry Definition', CLEPA, 13 Sept 2016, [28 July 2021]

5 United States International Trade Commission, 'Remanufactured Goods: An Overview of the U.S. and Global Industries, Markets, and Trade', 4356 (Washington D.C. 2012)

6 Environment and Climate Change Canada, Socio-economic and environmental study of the Canadian remanufacturing sector and other value-retention processes in the context of a circular economy / prepared for Environment and Climate Change Canada by Oakdene Hollins and Dillon, 2021

400,000 tonnes[1]. The commercial vehicle market in that same year was valued at €2 billion (ex-supplier level)[1]. The remanufacturing markets in Germany and the UK are historically the most active in Europe[10]. From a national leadership perspective, France, the Netherlands, and the Scandinavian countries are leading the way with national policies to promote remanufacturing[7]. Policies in Europe that currently support remanufacturing are the End-of Life Vehicle (ELV) Directive and the Motor Vehicle Block Exemption Regulation (MVBER) No. 461/2010 and 330/2010, which are sector-specific guidelines that support the independent aftermarket[10]. On paper, the ELV Directive encourages reuse and recycling of automotive components. Although remanufacturing is considered an end-of-life (EoL) practice, it only makes up a small proportion of vehicle recovery in Europe[8]. The MVBER ensures the participation of the original equipment manufacturers (OEMs), which should foster healthy competition among OEMs and remanufacturers[10]. In 2012, 55% (at a volume level) of the automotive aftermarket was estimated to be made up of remanufactured components[9]. Since then no other in depth study has been done.

The Asian market differs from country to country. The current leader in Asia is China, where there are policies in place to promote remanufacturing through circular economy initiatives. South Korea's market is relatively small, but the country was the first nation to have guidelines for remanufacturing quality certification[10]. In Japan, remanufacturing is largely driven by the private sector[10].

In the first half of the 20th Century when automotive remanufacturing first began to emerge, operations traditionally began as small, family businesses driven by profitability and with little thought about sustainability[11]. However, over the course of the century, this activity evolved into an industry. While independent businesses (some still family-run) continue to play an active role in the sector, they have been joined by both OEMs, and Tier 1 suppliers, who have begun to see the importance of remanufacturing in terms of both its economic and environmental benefits.

One such benefit is related to the circular economy, which aims at promoting the reusability of a product by maximising its circulation[12]. Remanufacturing perfectly fits into this definition, as it transforms used and worn products (core) into functional products whose performance is the same as new products. This process conserves both energy and material making it an inherently sustainable option.

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[7] A.I. Totara, 'Remanufacturing is central to the circular economy', Green Biz, 2 July 2021 [28 July 2021]

[8] Remanufacturing and whole-life costing of lightweight components

[9] F.J. Weiland, European Automotive Remanufacturing: Technical Trends & Market Development, FJW Consulting (2012), p.156

[10] H.Y. Kang et al., Comparative Analysis on Cross-national System Enhance the Reliability of Remanufactured Products, Procedia CIRP. 40 (2016), 280-284 <doi: 10.1016/j.procir.2016.01.121> 280-282

[11] Stakeholder interviews

[12] Ellen Macarthur Foundation, 'Design and business model considerations for heavy machinery remanufacturing: Caterpillar', [28 July 2021] 'Design and business model considerations for heavy machinery remanufacturing: Caterpillar', [28 July 2021]

Remanufacturing plays a significant role in the automotive aftermarket, where spare parts are required for several years after serial vehicle production has ceased. Remanufactured parts offer an alternative to a newly manufactured part, to new 'copy' parts (often imported from the Far East), and to reused parts (see Figure 1).

Historically, remanufactured parts have offered a higher quality than 'copy' and reused parts, while being cheaper than new parts. However, remanufacturers have been experiencing a 'squeeze' due to high remanufacturing labour costs and, in some cases, an increase in the quality of the 'copy' parts[11].

As organisations begin to monitor their emissions for carbon calculating, finding approaches to reduce not only tailpipe emissions but also life cycle emissions will become a priority. These are the areas where remanufacturing capabilities can be built. In addition, material retention will become important for products such as batteries, magnets and electronics where critical raw materials or copper is needed, but supply may become constrained.

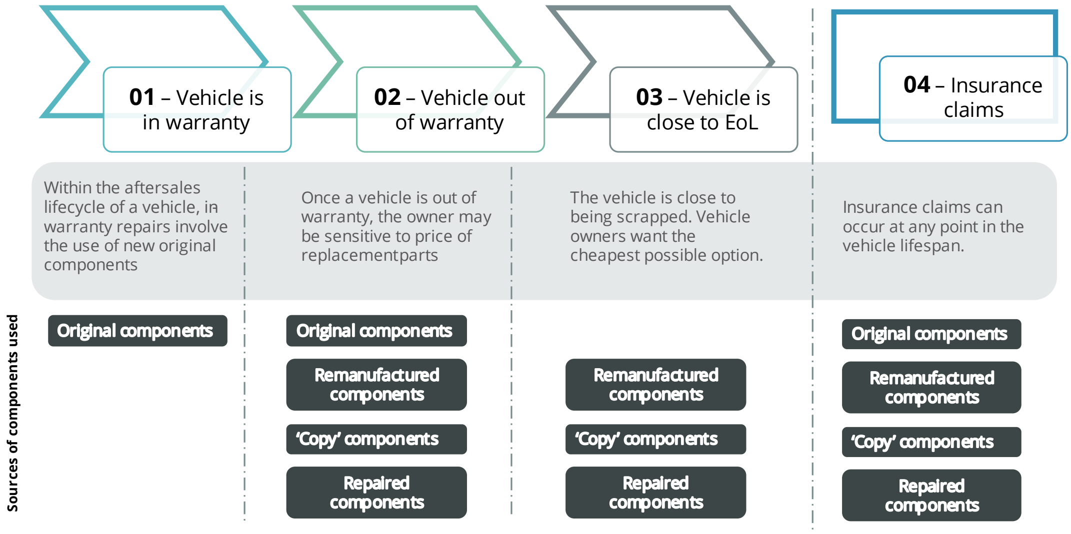


Figure 1: Sources of components at different stages of a passenger car's life

(Source: Stakeholder interviews)

Currently, these factors are important for bigger aftermarket players; however, as emissions become a priority for policy makers, more localised actors will need to find methods to monitor their emissions.

The automotive aftermarket can be categorised six types of actors:

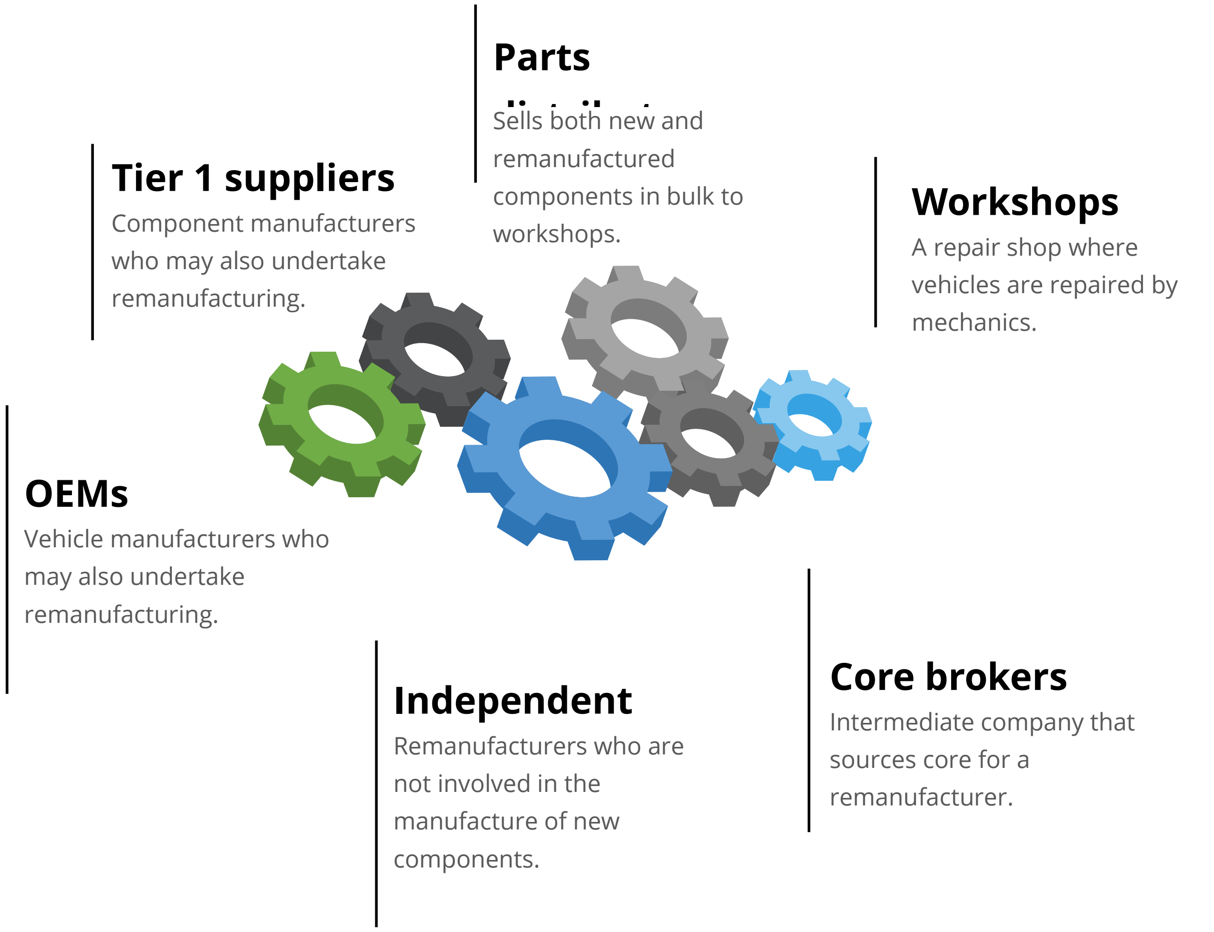


Figure 2: Description of the different remanufacturing actors

(Source: Stakeholder interviews, Oakdene Hollins analysis)

Within this remanufacturing aftermarket, there are actors that operate in the passenger car space, the commercial vehicle space, or both. The physical process of remanufacturing components is similar. The characteristic differences occur in the how these industries operate, the purpose of the vehicle and the life of the vehicle[13], as shown in the following table.

[13] Stakeholder interviews

Table 1: Characteristic differences between remanufacturing of passenger car and commercial vehicle components

		
Type of market	Mature market, with upcoming changes (electric vehicles)	Mature market
Typical type of work	After the vehicle is no longer in serial production	Remanufacturing is often based on contracts with fleets
Age of vehicle	10 to 15 years	20 to 30 years
Access to core	Differs between contract and independent work, multiple sources, e.g. core brokers	Low number of cores
Size of components	Smaller	Larger (higher profit margins)
Nature of components	High level of standardisation	Greater variability in components Different component portfolio
Designed with remanufacturing in mind	No (generally)	Yes
Justification for remanufacturing	Reducing cost and low emissions impact	Reducing total cost of ownership and minimising down-time
Key decision makers	Workshops, garages, individual customers, and an increase in fleet owners from increased electrification	Fleet owners, owner operators, logistic companies

(Source: Stakeholder interviews, Oakdene Hollins analysis)

Regardless of the nature of the remanufacturing operations or the type of actor, determining how remanufacturing can help save greenhouse gas emissions would provide valuable insight. This would help position the activity as a valuable contributor towards societal ambitions of net zero emissions and long-term sustainability in the automotive sector.

This paper looks at the outlook of remanufacturing, and how understanding the carbon savings can advance the remanufacturing agenda in Europe. This also involved creating a better understanding of current barriers and triggers for different actors in the remanufacturing sector.

3 Study scope

The focus of this study is on quantifying the current and potential economic and environmental impacts of remanufacturing automotive components in Europe (EU27+UK). The study distinguishes between components remanufacturing for the passenger car and commercial vehicle segments.

No systematic collection and reporting of economic or environmental data related to remanufacturing takes place at a European or Member State level, and there is no separate economic classification of remanufacturing in NACE codes (European classification system), or equivalents. Stakeholder interviews provided key insights into the status and future potential of the industry. The study involved interviews with a diverse spread of remanufacturing actors to develop a better understanding of market trends, barriers and triggers. Overall, 22 interviews were conducted across the different remanufacturing groups, with the largest participation coming from Tier 1 suppliers.

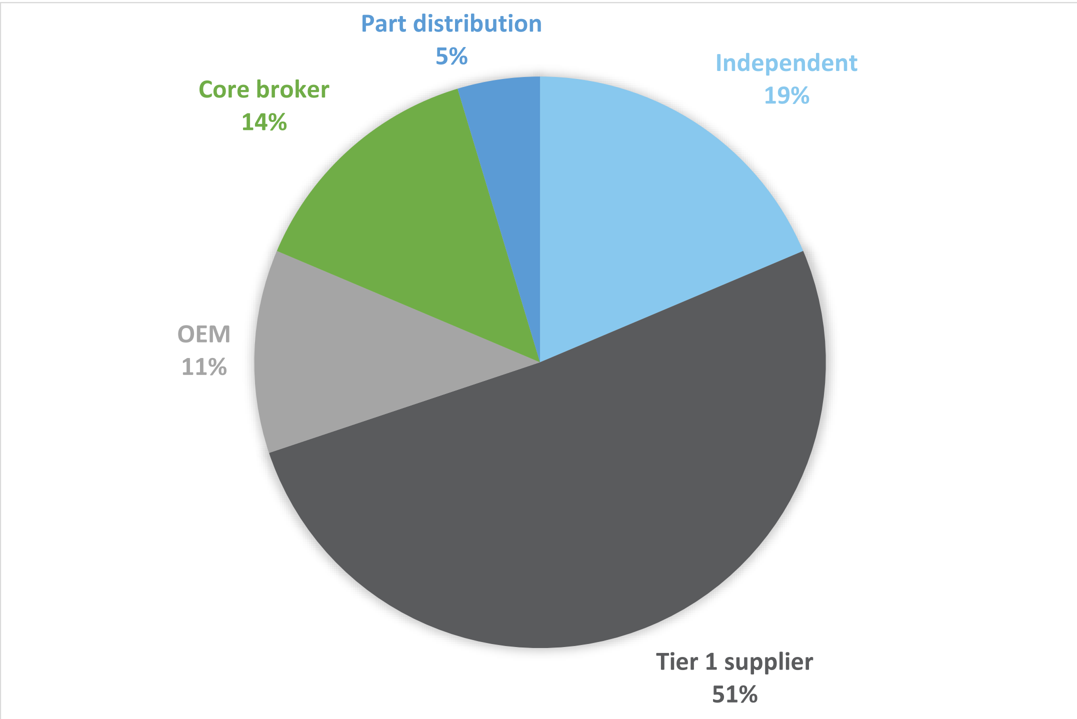


Figure 3: Interview participants by remanufacturing actor
(Source: Oakdene Hollins analysis)

Insights were gained on how the barriers and triggers affect different actors differently. A further literature study was performed, based on the stakeholder statements, to develop a deeper understanding of how technical, economic, social and political factors are limiting or promoting remanufacturing.

In particular, the themes discussed examined how the introduction of electric vehicles and sustainability-related policies will affect the different actors and different operations.

The economic analysis performed involved a bottom-up approach using component unit prices and the number of remanufactured unit components from the JCR SMART Report (2021) as a baseline. This was then scaled to determine the overall size of the market.

Quantifying the environmental impact of remanufacturing was a key ambition of this project as there is no sector-wide approach or analysis to date. To develop an overall understanding of this impact for Europe, a methodology involving material retention was used.

The time-scope of this study was to 2030, however, some stakeholders provided insights into trends that would affect the industry beyond this period.

4 Movement of different actors

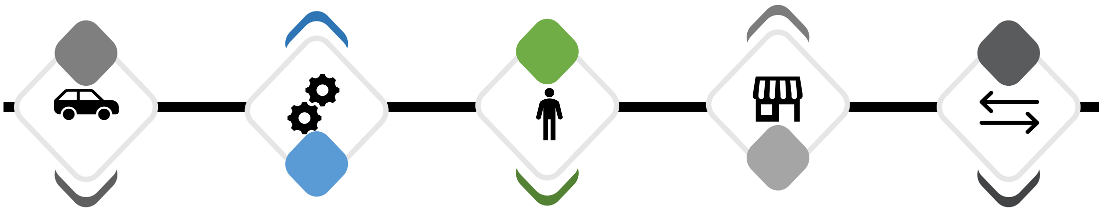
Currently, the remanufacturing industry is dominated by Tier 1 suppliers and independent remanufactures, but movement is anticipated over the next 10 years. These changes are primarily being driven by the barriers around increasing digitalisation and the high value and complexity of components in electric vehicles.[14]

Tier 1 suppliers

May **undertake more remanufacturing contract work** with OEMs, capitalising on their existing relationship with them and to gain access to the data and software needed to remanufacture increasingly complex and digitised products.

Wholesalers

Wholesalers are moving into the remanufacturing space as they **can easily access the number of cores needed** for remanufacture. The wholesale market is consolidating and OEMs are exploring ways to collaborate.



OEMs

Are **slowing moving into the remanufacturing space** for reasons of sustainability or to secure an aftermarket business for high value components.

Independent

Many increasingly struggle to reverse-engineer components with software, which OEMs may not want to share, or charge very high prices for it. **Smaller players are likely to be acquired** by bigger companies or disappear. Agile independents are likely to be attractive partners for OEMs and Tier 1s, including for EV components.

Core brokers

The number of brokers may decrease with an increase in OEM remanufacturing due to increased competition.

Figure 4: How the market will change for different remanufacturing actors

(Source: Stakeholder interviews)

[14] Stakeholder interviews

5 Growth trends and projected market (passenger cars – traditional product portfolio)

At ex supplier level, the current market value is around €2.5 billion while the expected value in 2030 is €2.3 billion. This is based on stakeholder insights, who see a declining trend in the sales of major remanufacturing components like diesel injectors, starters and alternators.

The market estimate was based on the expected number of units remanufactured for each traditional component category and the estimated price (see **Error! Reference source not found.** and Annex F); a detailed description of how this was calculated can also be found in **Error! Reference source not found.**).

To determine the annual growth trends for the number of remanufactured units on a component level, the predictions in the JCR SMART Report[15] were coupled with stakeholder opinions to develop growth trends till 2030. These trends were characterised as declining, stable and increasing. Within each of these trends an upper and lower bound percentage was determined, as shown in Table 1. The JCR SMART report covers the periods 2012 to 2018 and 2018 to 2023. To ensure a more accurate estimate, the same date ranges were used. Although some of these trends are based on historic periods, it is necessary to include these in calculations to get a better estimate for future trends. An additional period between 2023 and 2030 was added to the study, for which growth rates were estimated by the different interviewees.

Table 2: Growth profile ranges - passenger vehicles

	Lower bound	Upper bound
Declining	-10%	-3%
Stable	-2%	2%
Increasing	3%	15%

[15] Bobba S. et al., Sustainable use of Materials through Automotive Remanufacturing to boost resource efficiency in the road Transport system (SMART), European Commission: Joint Research Commission (2021), p.15

(Source: JCR SMART Report)

Estimated unit prices at ex supplier level were determined through extensive research and verified by stakeholders. The unit price for each component was multiplied by the number of units for each component.

Although the transition to electric vehicles (EVs) is expected to have a significant impact on the remanufacturing product mix, this impact is only expected after 2030. Combustion engine related components are predicted to have a marked decline over the next 10 years, but this is unlikely to have a significant impact on remanufacturing operations before 2030 (Figure 5).

As a rule of thumb, the number of units remanufactured in a year is generally based on the number of vehicles sold approximately 10 years before that year[16]. As traditional powertrains are still being sold today, none of these components will completely disappear from the remanufacturing portfolio in 2030. It is expected that by 2030, diesel injector components and starters and alternators will still be the dominant component group. However, on an individual component level, there is expected to be a decline in these three component groups.

This section covers the expected growth trends for each component and the market predictions for the next decade.

Overview of growth trends

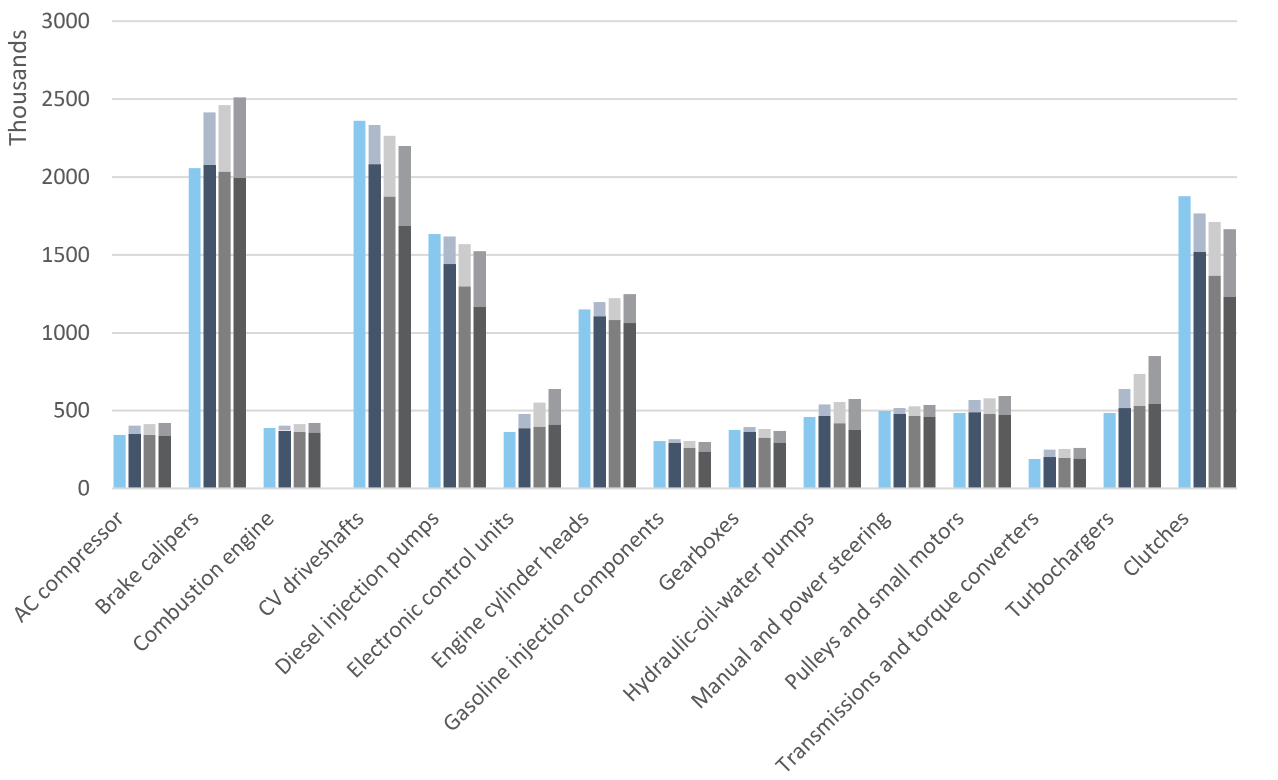
As policies push automotive sales in the direction of electric vehicles, stakeholders have predicted a long-term decline in the demand for traditional remanufactured components relating to the internal combustion engine (ICE). Over the next decade the decrease is likely to be predominantly in components for diesel vehicles, while other combustion engine components are likely to remain stable. These assumptions are based on the components present in hybrid vehicles and the current sales of petrol vehicles.

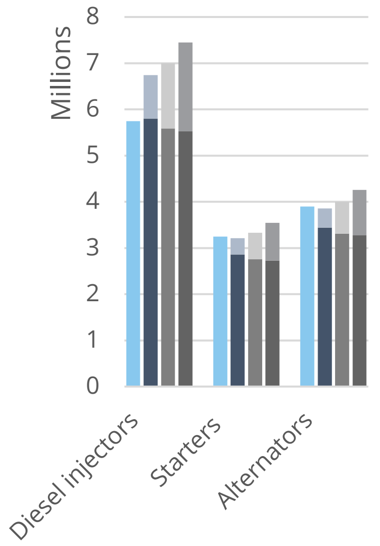
Components that will still be present in the future, in the remanufacturer's portfolio, are those that are deemed 'powertrain agnostic'; that is, are generally independent of the type of vehicle powertrain. These components may include, for example, brake components, air conditioning components and wiper motors, among others.

Figure 5 gives an overview of the predicted trends of the number of traditional remanufacturing components over a 15-year period at 5-year intervals. Each year represented shows a lower bound (minimum growth) estimation while the lighter

[16] Stakeholder interviews

part provides a higher bound (maximum growth) estimation. Stakeholders expect the trend to lie in between these two estimates.





There is an expected decline in the demand for the three largest remanufacturing groups, diesel injectors, starters, and alternators.

The only component expected to show growth over the next 10 years in all scenarios are electronic control units.

Figure 5: Projected evolution of demand for automotive passenger car component remanufacturing in Europe 2015-2030

(Source: Oakdene Hollins analysis)

Changes in market value

Using the estimated trends from 2012 to 2030, a market estimate at the ex supplier level can be determined at five-year intervals from 2015 to 2030.

In 2015, the estimated value of the remanufacturing market value at ex supplier level was € 2.4 billion, while in 2020 it was valued at between €2.5 billion and €2.6 billion. Using estimations and growth trends, the 2030 market is likely to be between €2.0 billion and €2.6 billion.

At an end consumer level, the automotive remanufacturing market for 2020 was estimated at €6 billion. This is much lower than other estimates but is in line with stakeholder views that the market has continually been overestimated.

Our bottom-up approach for calculating these values involved multiplying the component growth profiles by component prices. Historic inflation prices were used to determine the component prices for 2015 and 2020.

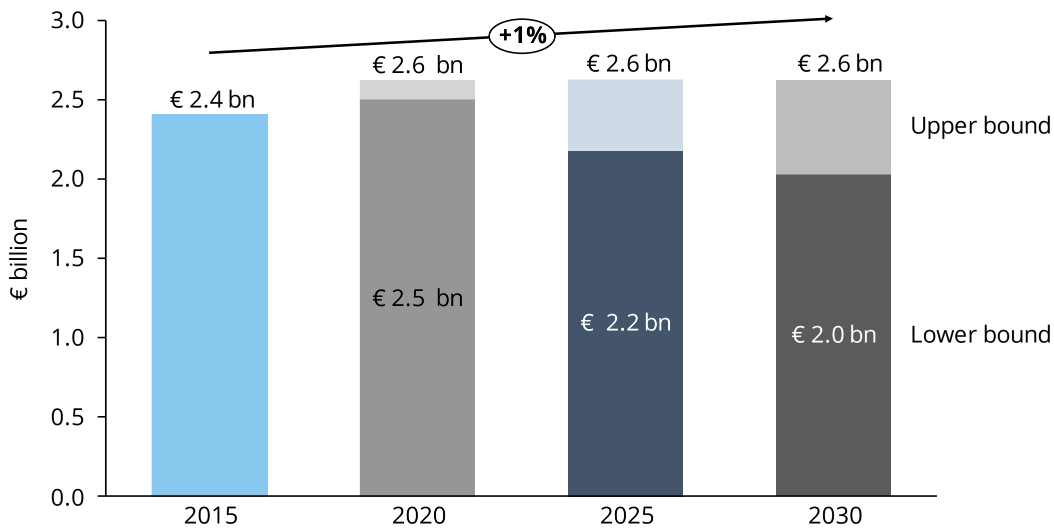


Figure 6: Estimates of the size of the remanufacturing market (ex supplier level)
(Source: Oakdene Hollins)

The expected growth rate for the next decade for the remanufacturing market is much lower than the expected growth rate for the entire aftermarket. This is because our approach assumed a business-as-usual case. Although some stakeholders believe that the remanufacturing growth rate should be greater than the general aftermarket after 2025, many disagree with this view as the decline in number of diesel powertrains has had a significant impact on the remanufacturing industry. Those who see a high potential in remanufacturing believe that biggest driving force behind the growth will be sustainability.

Table 3: Compound annual growth rate for the general and remanufacturing aftermarkets

	2020-2025	**2025-2030**
General aftermarket[17]	4% to 5%	1% to 2%
Remanufacturing aftermarket	-3% to 0%	-1% to 0%

(Source: Boston Consulting Group (2021), Oakdene Hollins analysis)

[17] Boston Consulting Group, At the Crossroads: The European Aftermarket in 2030 (2021), p.9

6 Growth trends and projected market (commercial vehicles)

Of the two markets under investigation, the commercial vehicle space is considered the more stable remanufacturing market as it is less affected by the transition to low carbon powertrains in the short term. The estimated market value at ex supplier level is relatively stable with a value of around €2 billion in 2020 and 2030.

The projected market value of the commercial vehicle (CV) space was calculated using a different methodology to the approach that was used for passenger vehicles. This is due to the lack of available information on individual component groups, prices and expected trends.

The information that is available divides the traditional remanufacturing portfolio into eight groups. The number of units for each of these groups were taken from Remanufacturing of Heavy Duty Vehicle Components (2014)[18]. The values shown are based on heavy duty figures as individual commercial vehicle component figures were not available. The growth rates used for these trends are shown below:

Table 4: Growth profile ranges - commercial vehicles

Trend	Compound annual growth rate
Growing	3.0%
Stable	1.0%
Declining	-1.0%

(Source: Oakdene Hollins analysis)

Overview of growth trends

The projected outlook for components in the commercial vehicle space is relatively stable. Commercial vehicles have a longer lifespan than passenger vehicles, and it is expected that diesel vehicles will remain dominant in this sector over the next 10 years.

[18] F.J. Weiland, Remanufacturing of Heavy Duty Components (2014), FJW Consulting, pp.29-33

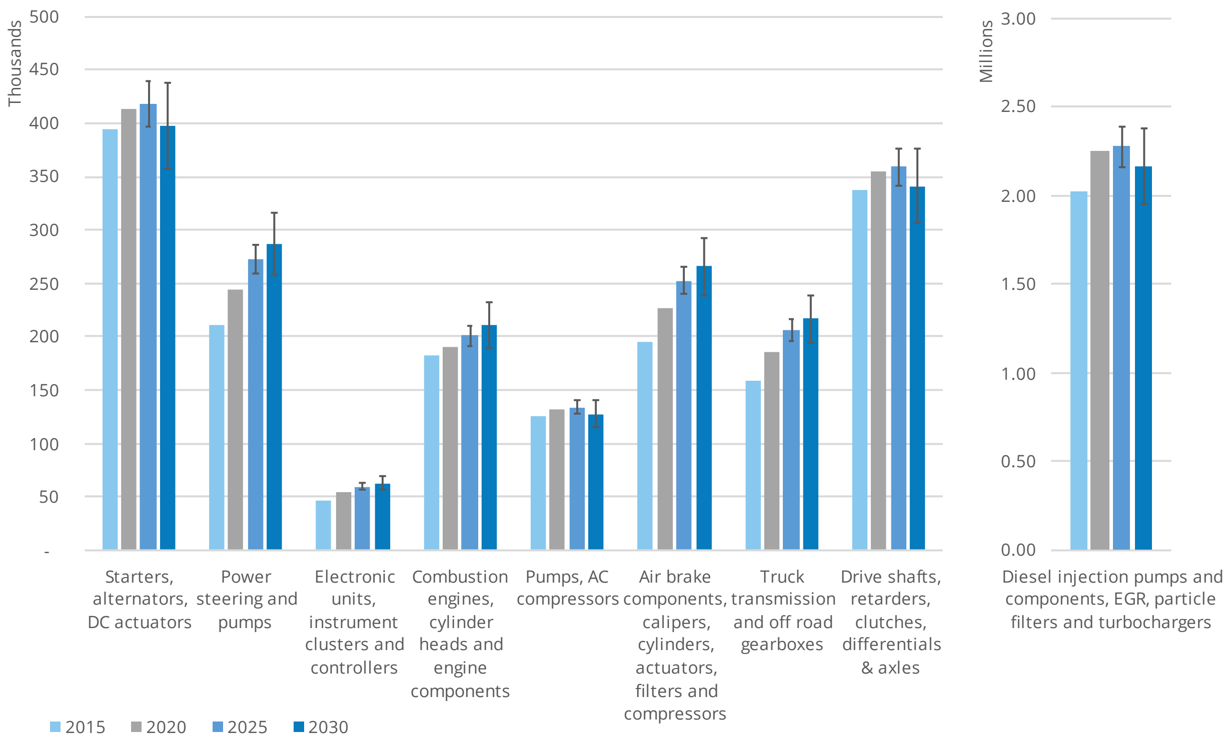


Figure 7: Projected evolution of demand for remanufacturing parts in Europe (2015-2020)

(Source: Oakdene Hollins analysis)

It is expected that the electrification of powertrains will have a delayed impact on the commercial vehicle space. This is because there are currently few viable electric options and commercial vehicles tend to have a longer lifespan[11].

Although electrification may not have a significant impact on the CV industry in the short- to medium-term, stakeholders have reported that the design of components have changed. CV components today are more durable than older components. The first life of these components would therefore be longer, resulting in a declining or stable trend in the second half of the next decade for some components.

Changes in market value

As for passenger vehicles, the market value (at ex supplier level) of CV remanufacturing was determined for five-year intervals from 2015 to 2030. Our estimates predict a slow decline over the next decade, with a CAGR of 1% over the 15-year period, as shown in Figure 8.

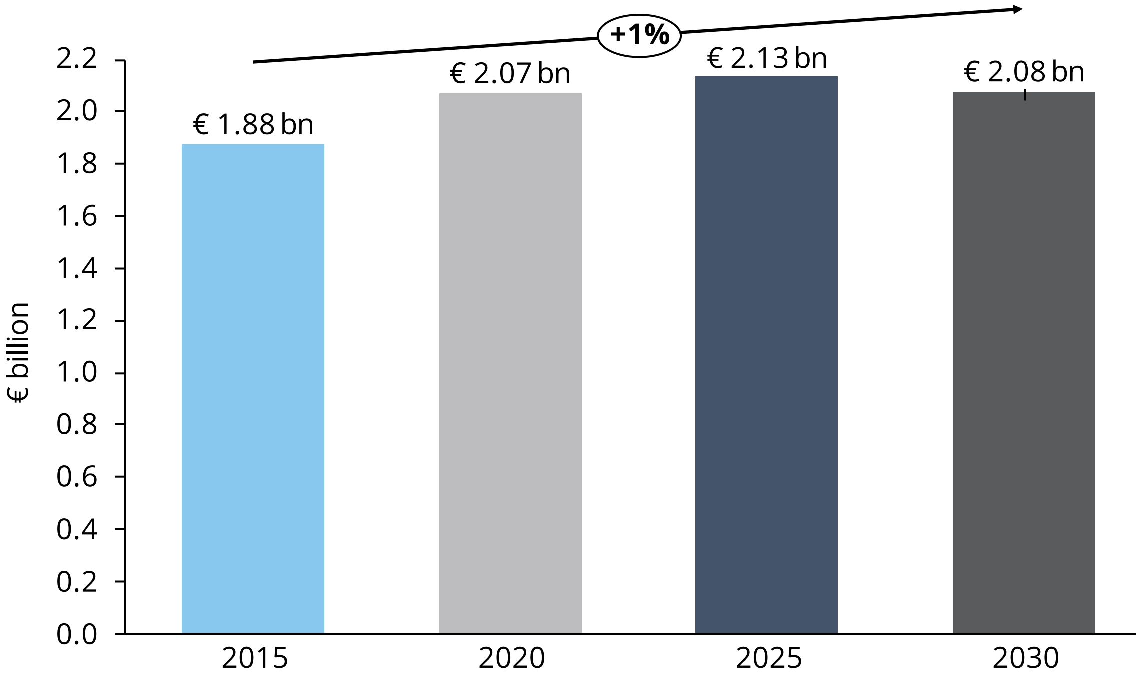


Figure 8: Estimates of the size of the CV remanufacturing market (2015-2030)
(Source: Oakdene Hollins analysis)

The expected slow declining trend in the second half of the next decade is similar to other predictions by Frost & Sullivan[19], who have reported a low vehicle-in-operation growth in 2020 and a slow recovery of sales in commercial vehicles during the COVID-19 pandemic. However, this trend has led to some new opportunites. There will be an increase in the number of older trucks on the road; fleet operators will therefore look for the cheapest possible aftersales options. This would provide opportunites for growth for remanufacturers operating in the commercial vehicle space.

[19] Frost & Sullivan, Benchmarking of OEM Strategies for the Commercial Vehicle Aftermarket in Europe, June 2021

7 Market trends

From the stakeholder interviews and literature review, five priority market trends have been identified and investigated. These trends are captured in Figure 9.

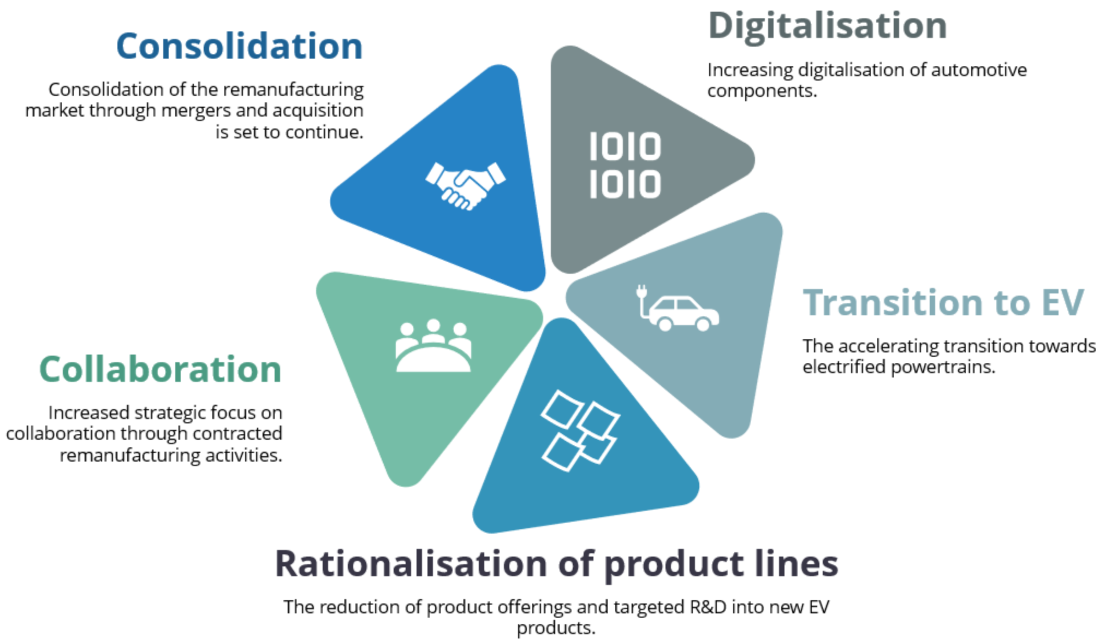


Figure 9: Priority market trends
(Source: Stakeholder Interviews)

These trends will influence the trajectory of the automotive component remanufacturing industry to different degrees between now and 2030. Industry consultation did not establish a consensus on the order of priority of these trends, which may affect both the operational and strategic objectives of remanufacturers to 2030 and beyond.

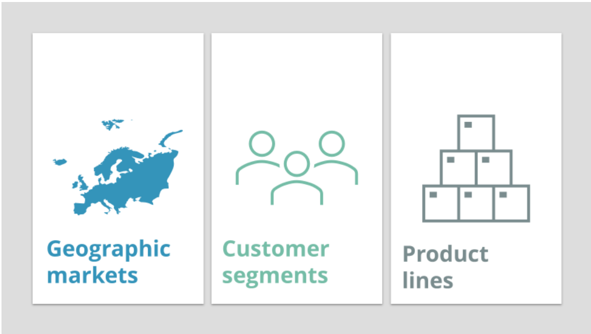
There is an element of interconnection between many of these trends; for example, the rationalisation of product lines is at least partly driven by the transition to EV. However, while rationalisation is already evident in the market, with some remanufacturers ceasing activities on specific traditional product lines, the transition to EV is anticipated to have a less immediate impact on remanufacturing in comparison to the impact of digitalisation.

Each market trend is explored in more detail in the rest of this section.

Consolidation of the market

Remanufacturing stakeholders confirmed during interviews that the market is becoming consolidated, most notably among independent remanufacturers who are active in acquiring other independent remanufacturers. There is also anecdotal evidence of weaker independents failing in the market. This consolidation activity is expected to continue in the short- to medium-term.

Motives for this consolidation can be broadly categorised around:



- *To gain access to new geographic markets* – the acquired company may have an established distribution network and sales presences in regions the acquiring company has not yet penetrated.
- *To access new customer segments* – the acquired company may have established relationships with customer segments to which the acquiring company is not as well connected.
- *To access new product lines* – the acquired company may have remanufacturing expertise, supply chains and distribution channels for products that the acquiring company do not.

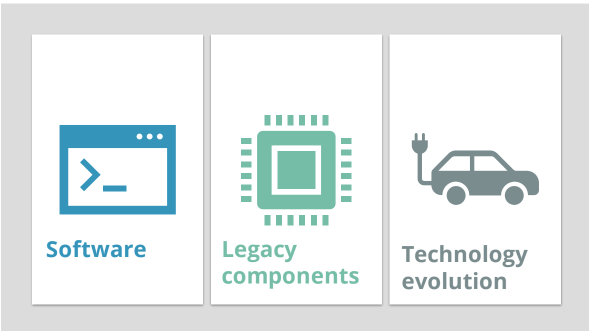
The more agile an independent remanufacturing company is, the more likely it is to seek to acquire others: acquisition allows a company to gain new markets, customer segments, and/or product lines more quickly than developing the capability internally.

Borg Automotive, the largest independent automotive parts remanufacturing company, concluded its acquisition of Danish brake component remanufacturing specialists Scandinavian Brake System (SBS) Automotive in May 2021. This follows on from its acquisition of Turbo Motor Inyección (TMI), a Spanish remanufacturer of turbochargers, in 2020. Jens Bjerg Sørensen, CEO of Schouw & Co (the Danish conglomerate of which Borg Automotive is a part), reports that:

"Borg Automotive's growth journey is far from over".

Increased focus on collaboration

Tier 1 and independent remanufacturers are increasingly looking to develop opportunities to undertake contracted remanufacturing activities for OEMs, and OEMs and Tier 1 suppliers, respectively. This is driven by the rising technical and economic challenges of remanufacturing highly digitalised components without OEM support to access software and legacy components. There was also an indication from stakeholder interviews that independent remanufacturers in particular are interested in further developing contracted activities in the commercial vehicles space to mitigate against the faster pace of technology evolution in the passenger car segment.



- *Software* – the increasing electrification of components coupled with the increasing complexity of the associated software creates challenges for remanufacturers operating independently from the original manufacturer. To develop the capability to remanufacture these components in-house requires an increasing investment in reverse engineering resources, including specialists in electrical engineering. Remanufacturers can also face challenges integrating their components into the overall vehicle software architecture, with remanufactured components not being recognised due to different part

> *"Access to OEM software is a huge problem."*
>
> (Stakeholder interview)

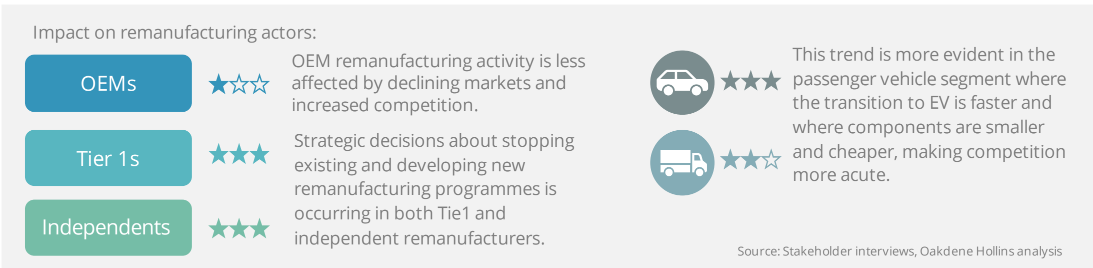
identifiers. There are also concerns around potential issues of intellectual property infringement associated with reverse engineering software elements. Collaboration, particularly through contractual activities, provides a clear route to by-pass these concerns and gain access to the original software.

- *Legacy components* – access to these, particularly electronics, can be a challenge for remanufacturers operating independently from the original manufacturer. Electronic components can have a short production cycle making it difficult, or even impossible, to procure replacement components. Prohibitively high minimum order quantities may also make components uneconomic to procure. Collaboration with original manufacturers can facilitate access to these components, either through ongoing serial production or stock of spare parts. Original manufacturers may also wield greater power when it comes to negotiating component runs.
- *Technology evolution* – the technology turnover in passenger cars was reported by stakeholders to be faster than in commercial vehicles. Along with the faster turnover in digitalisation associated with passenger cars, commercial vehicle component remanufacturing activities are attractive as technology stable, longer-term product lines. Rather than pursuing this as an independent activity, remanufacturers are looking to expand their contracted activities; for example, to access fleet management contracts.

Rationalisation of product lines

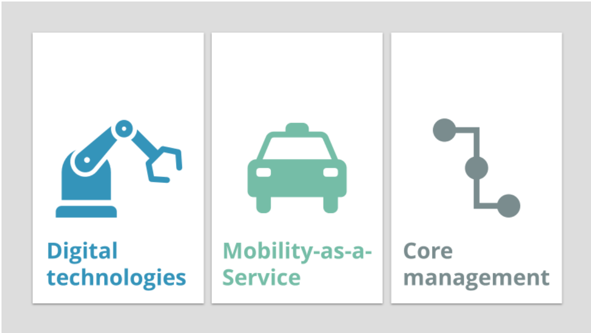
While the upcoming transition to electric powertrains will drive an evolution in the portfolio of remanufactured products, the traditional portfolio of products has also evolved historically. Successful remanufacturers will constantly be evaluating the prospects of their current offerings and monitoring the market for new opportunities. From the stakeholder interviews we heard how remanufacturers may choose to rationalise their product offers due to declining markets and increased competition, or to redirect effort to new opportunities.

- *Declining markets* – the analysis in the JRC SMART report of component outlooks for remanufacturing identifies components for which the remanufacturing market is already, or will shortly be, in decline. These components include: clutches (declining from 2012) and alternators, CV driveshafts, pumps and starters (declining from 2018-2023). Stakeholder interviews gave examples where decisions to stop remanufacturing particular product lines due to declining markets had been made or were expected in the near future. The most at-risk components are those that have been made obsolete by technological developments (e.g. the transition from manual to automatic transmissions) and those associated with fossil-fuel powertrains.
- *Increased competition* – remanufactured products compete on the market with both new original products and new 'copy' products both on price and quality. Stakeholder interviews indicated that decisions to stop some remanufacturing lines have been influenced by increased competition, where increasingly high labour costs in Europe and increased quality of imported 'copy' products have meant remanufactured products are less competitive.
- *New opportunities* – for remanufacturers that are primarily involved in remanufacturing components specific to fossil-fuel powertrains, there is a need to seek out new opportunities. Where resources are constrained, remanufacturers may need to move away from some product lines to free up resources to invest in building new capabilities in either technology-agnostic components (e.g. braking components) or EV components.



Increased digitalisation

Stakeholders confirmed that the trend for increasing digitalisation of components continues. Not only are more components moving from being mechanical to electro-mechanical, but the complexity of digitalisation is also increasing, with the number of electronic components within each component increasing. In addition to digitalisation of the vehicle, business models are increasingly incorporating digital aspects, which has implications for remanufacturing practitioners and prospects[20].



- *Digital technologies* – technologies encompassed by Industry 4.0 practices may prove to be of benefit to remanufacturers: the digitalisation of processes (including via automation and robotisation) and facilities in a 'smart factory' can help improve the quality and reduce the costs of remanufacturing.
- *Mobility-as-a-Service (MaaS)* – this emerging business model has been supported by a rise in the use and functionality of 'smart' devices such as smartphones. The rise of these business models will influence the shape of the future vehicle parc, car ownership and technology uptake – for example, many MaaS schemes use or are moving to EV fleets.
- *Core management* – digital technologies may support better management of core and improve the efficiency of reverse logistics, a key barrier in remanufacturing (see section 10). For example, digital technologies may enable better traceability of core, which may improve the speed of core deposit returns.

"Cars have become computers on wheels."

(Stakeholder interview)

[20] Bobba S. et al., Sustainable use of Materials through Automotive Remanufacturing to boost resource efficiency in the road Transport system (SMART), European Commission: Joint Research Commission (2021)

Transition to electric vehicles

Perhaps the biggest market trend facing European remanufacturers is the transition away from 100% fossil-fuel powertrains to alternatives, such as hybrids (including hybrid electric vehicles (HEVs), mild hybrid electric vehicles (MHEVs) and plug-in hybrids (PHEVs)), battery electric vehicles (BEV) and fuel-cell vehicles (FCV). For passenger cars and light commercial vehicles, electric vehicle penetration (HEV, MHEV, PHEV, BEV) is expected to increase from 1% in 2019 to 19% in 2030[21].

The trend towards electrified powertrains is more marked in passenger cars than commercial vehicles, where the uptake is anticipated to be slower and the technology options more divergent (e.g. electrification of buses and delivery vans, hydrogen for long haul)[22]. Current penetration of electrified powertrains in the commercial vehicle segment is 0.04% for trucks and 0.6% for buses in 2019[23].

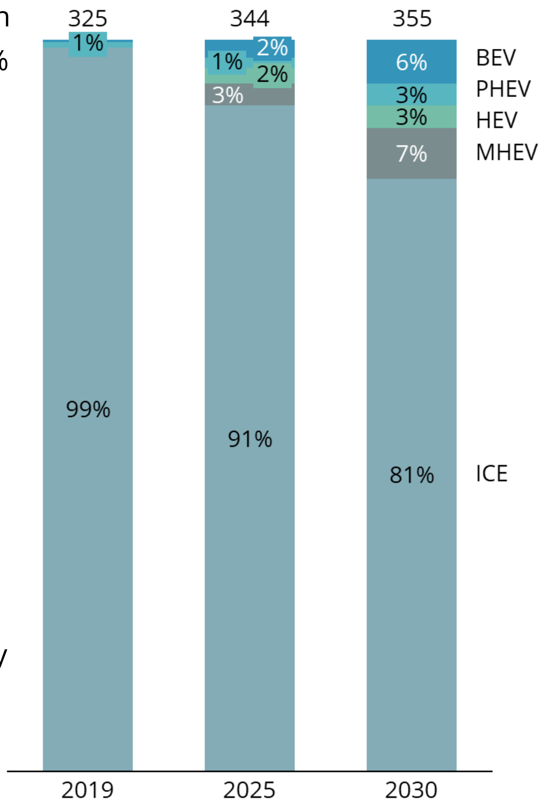


Figure 10: Electric vehicle penetration European passenger car and light commercial vehicle car parc
(Source: Boston Consulting Group (2021)[21])

The transition to EVs will result in a complete overhaul of the remanufacturing industry in the long term, but the consensus from stakeholder interviews was that the impacts of the transition are expected to be minimal before 2030 in terms of remanufacturing operations and sales. However, to facilitate the smooth transition to an EV portfolio in the medium- to long-term, investment and R&D into EV component remanufacturing will be necessary from today. Stakeholders indicated a range of activity on this front, with some already engaged in active R&D programmes, and others not yet active.

The impact of the transition to EVs can broadly be characterised across three product categories:

- *Traditional portfolio (powertrain specific)* – these components are specific to the vehicle powertrain (e.g. petrol or diesel) and are related to the function of the

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[21] Boston Consulting Group, At the Crossroads: The European Aftermarket in 2030 (2021), p.11
[22] Stakeholder interviews
[23] ACEA, Share of alternatively-powered vehicles in the EU fleet, per segment (2019) Link Accessed Oct 2021

combustion engine. Remanufacturing of these products will decline with the transition to EVs, and while petrol and diesel vehicles within the car parc will continue to require maintenance, these numbers will decrease as the sale of ICEVs is phased out. This transition will be propelled by the new 'Fit for 55' plan which will see the stop of the sales of ICEVs by 2035[24]. In the UK, sales of ICEVs will be banned from 2030, with hybrid sales banned by 2035[25]. In addition to these regulatory measures, consumers may be encouraged to transition to EVs earlier through scrappage schemes, tax breaks and increasing coverage of low- and ultra-low emissions zones.

- *Traditional portfolio (powertrain agnostic)* – these components, while used in ICEVs, are not connected with the combustion engine. Many of these components (e.g. brake components) will be present in EVs and so remanufacturing activities would be expected to continue. Stakeholder interviews indicated that even for these powertrain-agnostic components, there may be some impact from the transition to EV; for example, in the degree of wear of brake callipers, or the potential shift to brake drums.
- *EV portfolio* – these components are unique to EVs and represent a new opportunity for remanufacturers. Developing remanufacturing capabilities for these product lines will require significant investment in the coming years.

The impact of electrification on remanufacturing is explored in more detail in Section 8.

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[24] S.G. Carroll, Fit for 55: EU sets clock ticking on fossil and diesel engines, Euracitv (2021), 20 October 2021
[25] https://www.gov.uk/government/news/government-takes-historic-step-towards-net-zero-with-end-of-sale-of-new-petrol-and-diesel-cars-by-2030

8 The impact of electrification on remanufacturing

The transition to EVs will affect the type, volumes and value of components considered for remanufacturing. This section explores in greater detail the impact of - and opportunities arising from = electrification, for remanufacturing in Europe.

The large difference in the number and type of components in an ICE (~1,400) and a BEV (~200)[26] will have a major effect on future remanufacturing operations. This is illustrated in Figure 11 for drivetrain components.

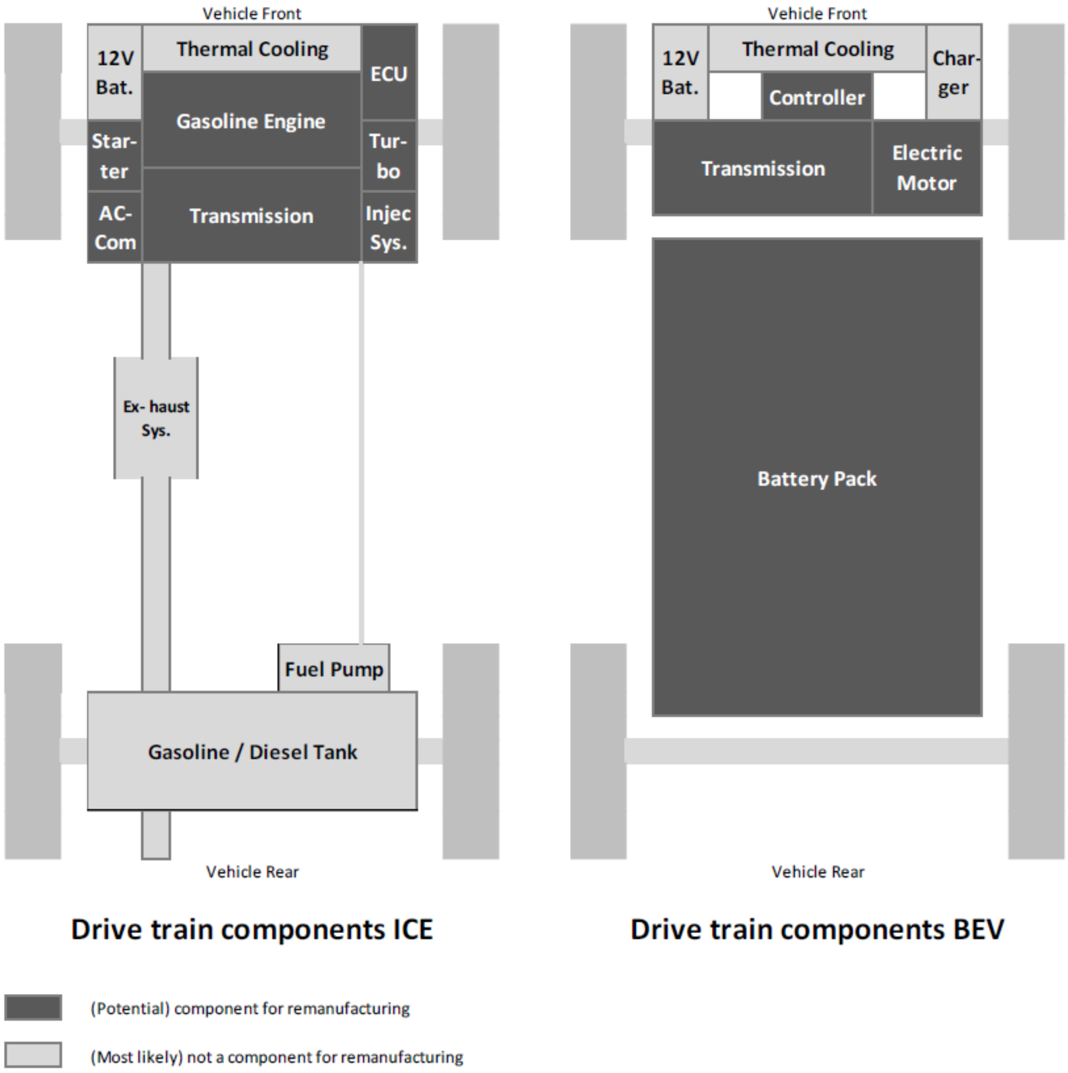

Figure 11: Differences in component suitability for remanufacturing ICE vs BEV drivetrains

(Source: Casper and Sundin, Challenges and Opportunities in the transition towards electric vehicle part remanufacturing (2019))

[26] Casper and Sundin, Challenges and Opportunities in the transition towards electric vehicle part remanufacturing (2019)

The impact on remanufacturers of the transition to BEVs includes:

Fewer (and different) car part suppliers

The transition to a new EV portfolio will require the identification and development of new supply chains. For Tier 1 remanufacturers, these new upstream supply chains will be developed as part of their serial production activities, but independent remanufacturers will need to identify new component suppliers to support EV remanufacturing activities. It is likely that at least some of these suppliers would be different to their existing suppliers for the traditional remanufacturing portfolio.

Main implications:
• New supplier relationships needed

Changes in drivetrain complexity

With respect to the number of components, drivetrain complexity will decrease in the transition to EV. As the number of components in a vehicle will decrease. However, this would also lead to an increase in the complexity of reverse engineering components, especially when there is no standardised technology being used. This may lead to increased competition for remanufacturing activities. With respect to the technical complexity of the components, stakeholder interviews suggest that complexity may increase, as EV components are emerging as highly integrated and with sophisticated electrical control systems and software. This may also support a move away from workshop-based repairs towards centralised remanufacturing activities. Workshops and garages will not likely have the skills and tools to carry out EV repair activities on site, reducing competition for remanufacturers.

While the complexity, and therefore cost, of remanufacturing is likely to increase requiring significant investment in establishing remanufacturing programmes, the value of these components will also increase, making the market an attractive opportunity for those that can successfully penetrate it.

Main implications:
• Increased competition (fewer units) • Reduced competition from workshops • R&D investment required • Increased component value

Fewer wear parts

With the transition to EV there is a reduction in the number of components with moving parts within the drivetrain (starter, alternator, turbocharger etc.) that may be subject to wear. While wear may be a significant reason for products in the traditional portfolio reaching their end of life, this is less likely for EV components, where failure is more likely to be associated with electrical faults. The remanufacturing processes used for remediating EV components are therefore likely to be rather different to those for traditional products.

There is also an indication that, with the use of regenerative braking technology, wear on brake components is reduced. This may result in lower remanufacturing volumes and therefore increased competition for these components as their life is extended.

Main implications:
• Increased competition • Re-skilling of remanufacturing workforce required

Less use of liquids such as oil and grease, fuel, and coolants

With the reduction in moving parts and the elimination of high temperature combustion, many of the liquids associated with ICEVs (lubricants, fuel and engine coolants) are no longer required. This will support a shift away from the image of remanufacturing as a 'dirty' industry towards a more high-tech, electronics-based activity. Practically, this will reduce the need for labour-intensive cleaning of components and the generation of hazardous liquid wastes during remanufacturing processes. However, liquid coolants are still required for battery packs.

Main implications:
• Reduction in hazardous waste

Up-skilling required for processing the EV portfolio

With the new EV portfolio of products comes the need for a new skill-set for remanufacturing practitioners. Firstly, to operate safely with high voltage parts, such as the battery pack, remanufacturers need to train their staff to handle and process these parts. There are stringent requirements for high voltage working and some remanufacturers have already begun investment in new facilities and staff training for developing capabilities in battery remanufacturing[27].

Secondly, the suite of EV parts for remanufacturing may represent a step-change in technology particularly for independent remanufacturers operating in the ICE-specific traditional portfolio. To remain viable, remanufacturers in this conventional ICE space will need to adapt significantly to take on the challenges of remanufacturing EV components and up-skill their workforce accordingly. For Tier 1 remanufacturers active in developing EV components for serial production, this transition will already be well underway.

Main implications:
• Investment in workforce up-skilling required

Divergence between component and vehicle lifecycles

While EV components are less likely to fail due to mechanical issues such as wear, stakeholder insight suggests that the lifetimes of these electrical components differ from the lifetime of the vehicle. Remanufacturing these high value components will likely be an attractive aftermarket option for supplying parts during the lifecycle of the electric vehicle.

Main implications:
• Increased opportunities for remanufacturing of EV components

Potential candidates for EV component remanufacturing

In addition to technology-agnostic components, such as brake components, the transition to EV presents opportunities for remanufacturing a new suite of products. This section explores the likely EV component candidates for remanufacturing.

Lithium batteries

Used to power the electric motors of a BEV or HEV, these batteries have a higher energy density than other batteries such as lead-acid or nickel-metal hydride

[27] See, for example, Autocraft Drivetrain Solutions, Link Accessed October 2021

batteries[28]. If the battery provides DC electric power and the motor operates using AC(alternating current) electric power, an inverter is required to convert between these two.

Developing capabilities for remanufacturing of battery components was identified during stakeholder interviews as an opportunity to move into other e-mobility markets such as batteries for trains, boats, electric bicycles and scooters.

Key challenges to EV battery remanufacturing include:

- *Lack of design for remanufacturing* - during interviews, stakeholders reported their concern that new EV components were not being designed for remanufacturing. For EV batteries, the use of irreversible joining techniques, such as glue and spot welds, makes disassembly more difficult and increases the risk of damaging core.
- *Complexity of understanding battery cell health* - key to determining the fates of individual battery cells is the ability to interrogate and understand battery cell state-of-health. Developing this understanding and capability is a steep learning curve for remanufacturers, relying on significant R&D investment. Some remanufacturers are already committed to developing capability in this area; for example, Autocraft EV Solutions Limited, part of the Autocraft Solutions Group, has developed its own technology for evaluating battery state-of-health, as showcased at ReMaTec 2019[29].
- *Evolving battery design and chemistries* - the technology underpinning EV batteries is continuing to evolve at a pace. The design of EV batteries varies between battery manufacturer, with different OEMs backing different battery solutions. Additionally, battery chemistries continue to change, driven by the significant research effort in developing lower cost, longer life, and greater energy storage. Efforts are currently focused on developing new lithium-ion cathode chemistries[30], with lower TRL (technology readiness levels) research developing batteries solution beyond lithium-ion, including solid-state, sodium-ion and lithium-sulphur batteries[31]. The challenges for remanufacturers operating with an evolving product such as this are the continual need for investment to keep up with the technology, a lack of standardisation across vehicles and the risk of product obsolescence.

Despite these challenges, remanufacturing of EV batteries remains an attractive opportunity due to the high unit price. Limited data is available on the price of battery packs, with low aftermarket demand driven by battery leasing schemes and extended warranty periods that keep battery packs within the dealerships.

[28]Nissan Motor Corporation, Electric vehicle lithium-ion battery (2019), 12 August 2021
[29] Autocraft Solutions Group, Making it Sustainable at Rematec (2019), 13 August 2021
[30] The Faraday Institute, Lithium Ion (2021), 13 August 2021
[31] The Faraday Institute, Beyond Lithium Ion (2021), 13 August 2021

However, they are estimated to be several thousands of euros and are of significantly higher value than any of the traditional remanufacturing portfolio. Contracted activities are currently the main route through which remanufacturers are establishing their position in this market.

Electrical motors

The main electric motor provides the power that rotates the wheels of a vehicle. The electrical motor is either an AC or DC motor[32] and acts as a generator to charge the battery when the vehicle is braking. The motor is an attractive component for remanufacturers, particularly those who are active in serial production and/or have remanufacturing experience with other (smaller) electrical motors.

In theory this component is relatively easy to remanufacture in comparison to combustion engines as the components are simpler; however, there is no existing process to replaced windings in stators or rotors[33].

Inverters

Inverters act as the intermediary between the battery and the motor/generator, converting the electric current from an AC current to a DC current, and vice versa[32].

48-volt systems

This system stores energy and supplies it to a hybrid system, particularly for providing auxiliary power to vehicle systems when the ICE is not operating as part of the start-stop system[34]. In some cases, this component contains a DC/DC converter for vehicles that still contain 12V systems. 48-volt systems are found in several transport applications in addition to EVs, including electric scooters and bicycles. Examples of remanufactured hybrid battery packs can be found on peer-to-peer online platforms, such as eBay, while BNA Battery[35] in the Netherlands offers refurbished hybrid batteries direct to customers.

E-axles

Also known as "electric axle drive", an e-axle is a compact drive solution that directly powers the vehicle's axle. It simplifies electrical drives by combining the electric motor, power electronics and transmission[36]. This is a component of interest to remanufacturers; for example, it has already been identified by independent remanufacturer ATC Drivetrain as one of the eMachine components it is already

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[32] EDF, How do electric cars work? (2021), 13 August 2021
[33] Weiland, F.J., Electric Vehicle Challenges & Opportunities for European Remanufacturers (2020), 8 October 2021
[34] Vetus, Vetus 48 volt solution; an introduction (2021), 13 August 2021
[35] BNA-Battery Link, October 2021
[36] Bosch, eAxles (2021), 13 August 2021

investing in, to develop remanufacturing capabilities[37]. However, the trend of increasingly close integration of the elements within this component is reported to lead to challenges in access for undertaking maintenance and repair[38]. Remanufacturers would likely encounter similar issues. This component is also a remanufacturing candidate for Tier 1 suppliers with serial production activities.

E-booster

This electric compressor assists the turbocharger by improving boost pressure and transient engine response at low engine speeds[39] and can support better performance for ICEVs and HEVs. No evidence of remanufacturing of e-boosters has been found to date, but the underlying compressor technology makes it a likely candidate, with its similarities to products that are currently remanufactured. Little indicative pricing information on new, used or remanufactured e-boosters has been found to date; however, the greater complexity of the e-booster, with its integrated electric motor, suggests it would operate at a higher price point than that of a turbocharger.

xEV transmission

For vehicles where electric drive axles are not being used, EV transmissions will be required and will be a candidate for remanufacturing. The xEV transmission technology is a natural development from the ICEV transmissions that form part of the traditional remanufacturing portfolio, with applications in both passenger car and commercial vehicle markets.

Outlook for remanufacturing actors

Tier 1 suppliers manufacturing EV components may have advantages in developing remanufacturing programmes through their experience of developing serial production capabilities and their ability to use infills to supplement core. By incorporating 'design for remanufacturing' principles in their EV product development, they can maximise the efficiency of their future remanufacturing operations. While some stakeholders confirmed during interviews that new components are designed with remanufacturing in mind, not all Tier 1s are yet considering remanufacturing at the design stage.

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[37] ATC, ATC has invested millions in developing remanufacturing capabilities to support the industry's migration to electrification (2021), 13 August 2021
[38] Emobility engineering, E-axle transmissions (2021), 13 August 2021
[39] Borg Warner, Electric Boosting Technologies (2021), 13 August 2021

Independent remanufacturers may have advantages in their ability to be agile in developing and deploying remanufacturing programmes across a broad range of products and markets (e.g. other e-mobility applications). There is evidence from both stakeholder interviews and corporate marketing that several of the largest independent remanufacturers are proactively engaged in building remanufacturing capabilities for EV components[40]. Operating independently, these remanufacturers could initially struggle to access enough core to operate in the independent market. This is because OEMs are likely to retain access to high value components such as batteries through leasing schemes[41] and extended warranty periods[42]. Remanufacturing through collaboration and contracting with OEMs will therefore be an important strategy for accessing the EV remanufacturing market to 2030.

Modelling the EV remanufacturing market

BEVs are expected to represent 6% and hybrid vehicles are expected to represent 13% of the European car parc in 2030[43]. The structural impact of this on the market is that the value of the aftermarket with respect to maintenance will decrease. As repair activities associated with the lower levels of wear and tear and maintenance for EVs decrease, the increasing technological complexity of EV components for spares will likely result in a relative shift in aftermarket activities away from repair and maintenance activities at garages towards remanufacturing.

A key element of analysing the potential size of EV component remanufacturing is modelling EV core arisings. Core arisings can be modelled by considering the failure rate of components. Stakeholders confirmed during interview that components from the traditional portfolio of remanufactured products typically have a failure rate of 2-3%. In contrast, stakeholders indicated that EV components may have a failure rate as low as 0.5%. The failure rate of new EV components will be an important factor in determining the viability and speed of deploying an EV remanufacturing programme. Literature supports the narrative that EV components have low failure rates[26], while interviews suggested a more mixed picture depending on application; for example, higher performance EVs were reported to experience greater failure rates.

The potential size of the market for remanufacturing of EV components to 2030 has been estimated by modelling EV core arising and using a proxy component value.

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[40] Companies include ATC Drivetrain, Autocraft Solutions Group,

[41] Groupe Renault, All you need to know about battery leasing for the Renault Zoe (2020), 31 May 2021

[42] Nissan, Plug into potential savings (2021), 31 May 2021

[43] Boston Consulting Group, At the Crossroads: The European Aftermarket in 2030 (2021), pp. 9

The potential candidates for EV component remanufacturing have been mapped to hybrid (including MHEV, HEV and PHEV) and battery EVs in the table below. Proxy unit prices from stakeholders have been used to model the potential value of the EV market at ex supplier level.

Table 5: Mapping out of new EV components (ex supplier level)

Components	**BEV**	**PHEV**	**HEV**	**MHEV**
Electrical motor	✓	✓	✓	-
Inverter	✓	✓	✓	✓
48-volt system	-	-	-	✓
e-axles	✓	-	-	-
e-booster	✓	✓	✓	-
xEV transmission	✓	✓	-	-

(Source: Stakeholder interviews)

The typical price of a remanufactured component is 60-80% of the unit prices shown in Table 5; this analysis utilises the mid-point of that range (70%) to estimate remanufactured prices.

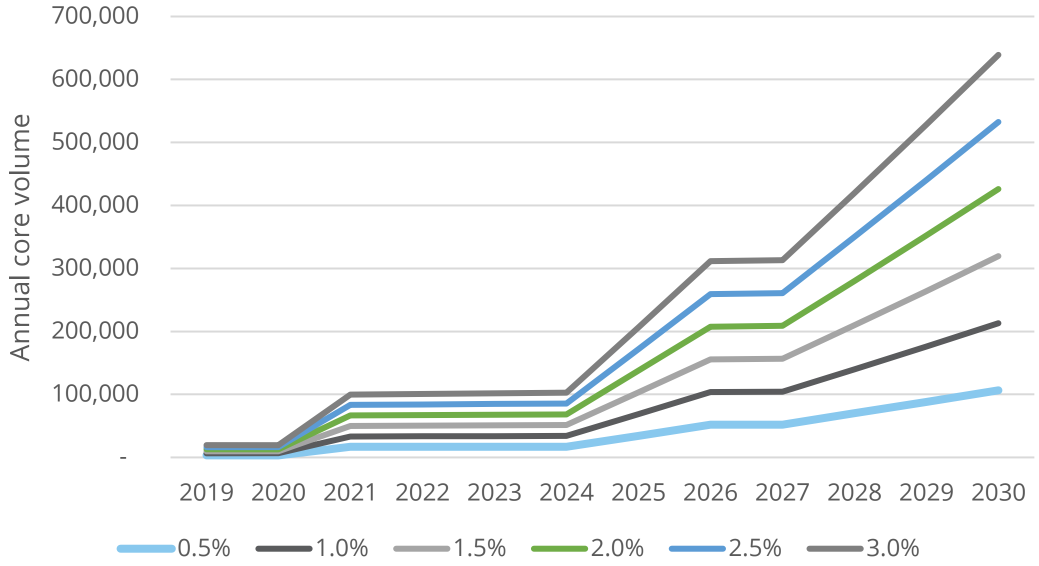

Figure 12: Impact of failure rate on core volumes (EV)
(Source: Boston Consulting Group (2021)[44], Oakdene Hollins analysis)

Using the conservative failure rate of 0.5%, the available core can be determined on a component level for both BEVs and HEVs. From this analysis, the greatest potential for available core lies in components that are present in both vehicles.

[44] Boston Consulting Group, At the Crossroads: The European Aftermarket in 2030 (2021), pp. 11

Even working with the assumption that only 50% of the core can be remanufactured, the continual increase in the sale of EVs means that the potential remanufacturing market in 2030 is not insignificant, as shown in Figure 13. The largest element of the market is expected to be electric motors due to their prevalence and high value in both BEVs and HEVs.

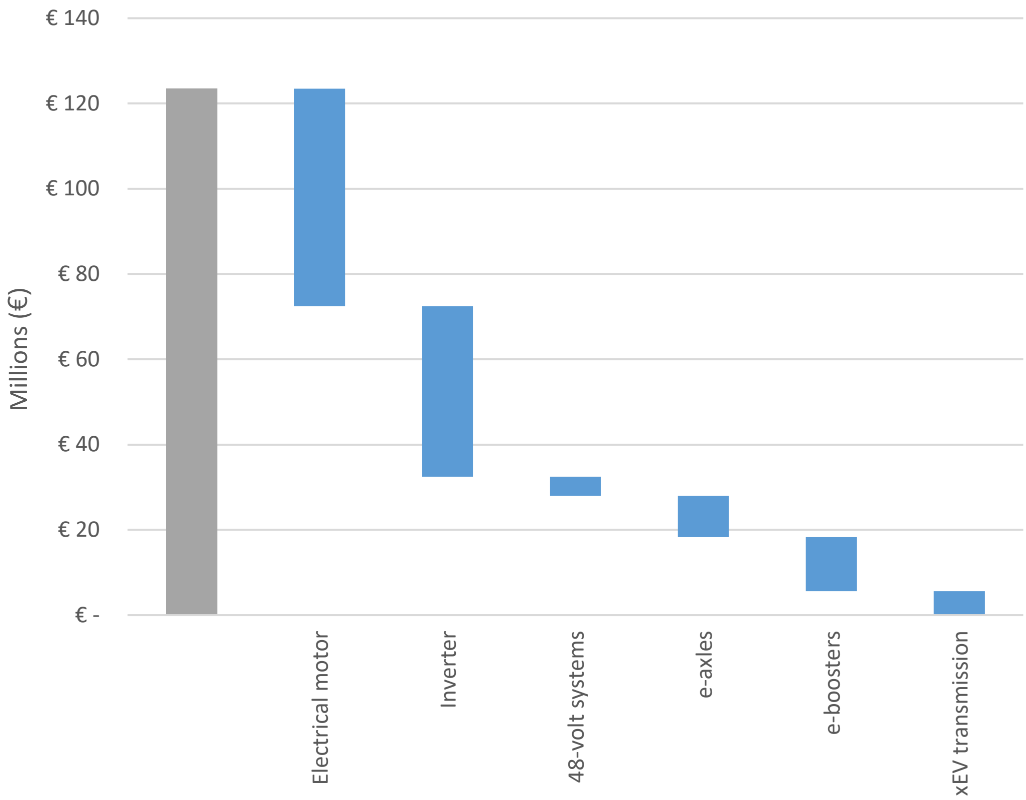

Figure 13: Breakdown of potential EV remanufacturing market in 2030 (ex supplier.)
(Source: Oakdene Hollins analysis)

The EV remanufacturing market opportunity could be as much as €120 million in 2030 (See Figure 14). While this value will make up around 5% of the overall remanufacturing market, there is significant uncertainty as to what degree this would be realised. The failure rate of EV components remains a significant uncertainty and validation of real-world failure rates would be a valuable aid to estimating future EV component remanufacturing activity. Furthermore, the continuing evolution of EV components - particularly battery technology - may render the oldest core obsolete and so reduce remanufacturing opportunities. Lastly, ongoing political activity may influence technology forecasts; for example, the recently published 'Fit for 55' legislative package will have a significant impact on the automotive market to 2030 and could dramatically alter vehicle sales forecasts.

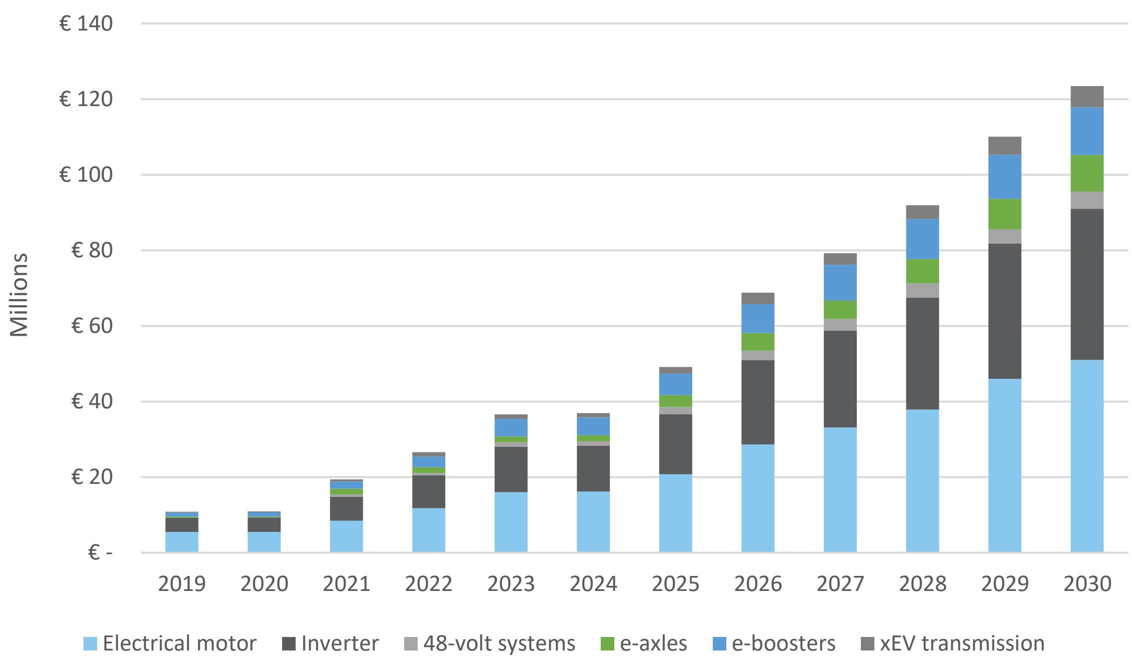

Figure 14: Potential future EV remanufacturing market

An additional consideration that may influence the uptake of EV component remanufacturing is the materials contained within these components. EV production typically requires 3-4 times more copper than traditional powertrain vehicles, and batteries in these vehicles contain cobalt, lithium, nickel, manganese, and graphite[45]. There is a mismatch between supply and demand of these materials, as there in an increasing demand with limited supply that is prone to disruptions such as from natural disasters and civil unrest. Additionally, the emissions associated with producing these critical raw materials can be high. For instance, a study comparing the emissions produced from manufacturing an ICE and a EV vehicle of the same model, noted that EV production produces 1.4 times more emissions than ICE production (see Figure 15[46]) . Remanufacturing operations could therefore play an important role in reducing both supply risk and production emissions by keep these materials in use for longer.

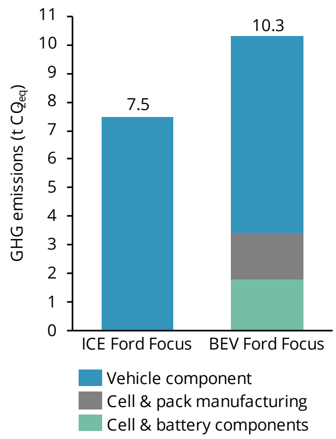

Figure 15: GHG emissions for an ICE and BEV Ford Focus[46]

[45] Jones, B., Elliot, R.J.R. and Nguyen-Tien, T., The EV Revolution: The road ahead for critical raw materials demand (2020), Applied Energy
[46] Kim, H.C., Wallington, T.J., Arsenault, R., Bae, C., Suckwon, A. and Lee, J, Cradle-to-Gate Emissions from a Commercial Electric Vehicle Li-Ion Battery: A Comparative Study (2016). Environmental Science and Technology, 50, 7715-7722. DOI: 10.1021/acs.est6b00830

9 Quantifying the CO_2 impact

Motives for quantifying CO_2 impacts of remanufacturing

The automotive sector has long been aware of the importance of quantifying and reducing their CO_2 impacts. The transport sector is responsible for almost a quarter of European greenhouse gas emissions[47], and the recent announcement of the 'Fit for 55' EU climate package is punctuated by targets to reduce greenhouse gas emissions by 55% of 1990 levels by 2030 and to reach climate neutrality by 2050[48].

However, reductions in greenhouse gas emissions from the transport sector have not shown the same level of progress as in other sectors, not least due to increasing mobility demands and, with road transport making up more than 70% of the transport sector's greenhouse gas emissions in 2014[47], the sector is under even greater pressure to decarbonise.

To achieve this requires a greater increase in the demand for electric vehicles, and the associated infrastructure is required in a shorter time. The 'Fit for 55' proposal would also ban the sale of hybrid vehicles by 2035. However, many have argued that all options need to be considered, including using efficient low-carbon ICEs, HEVs and hydrogen vehicles as well as reducing fleets that are currently on the street.

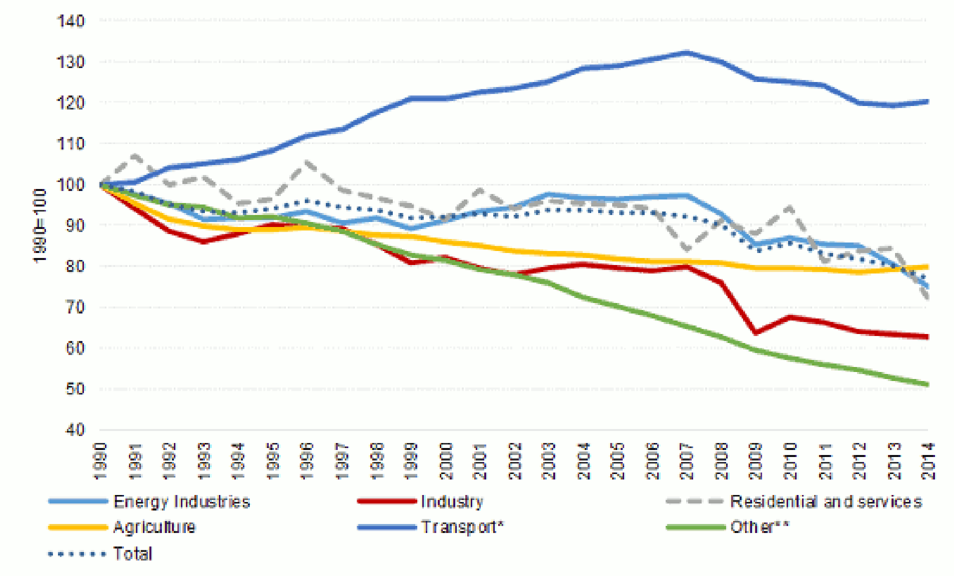

Figure 16: Evolution of sectoral greenhouse gas emissions, scaled to 1990 levels

(Source: EEA)

[47]European Commission, A European Strategy for low emission mobility (2021), 13 August 2021

[48] European Commission, 'Fit for 55' delivering the EU's 2030 Climate Target on the way to climate neutrality (2021), 15 October 2021

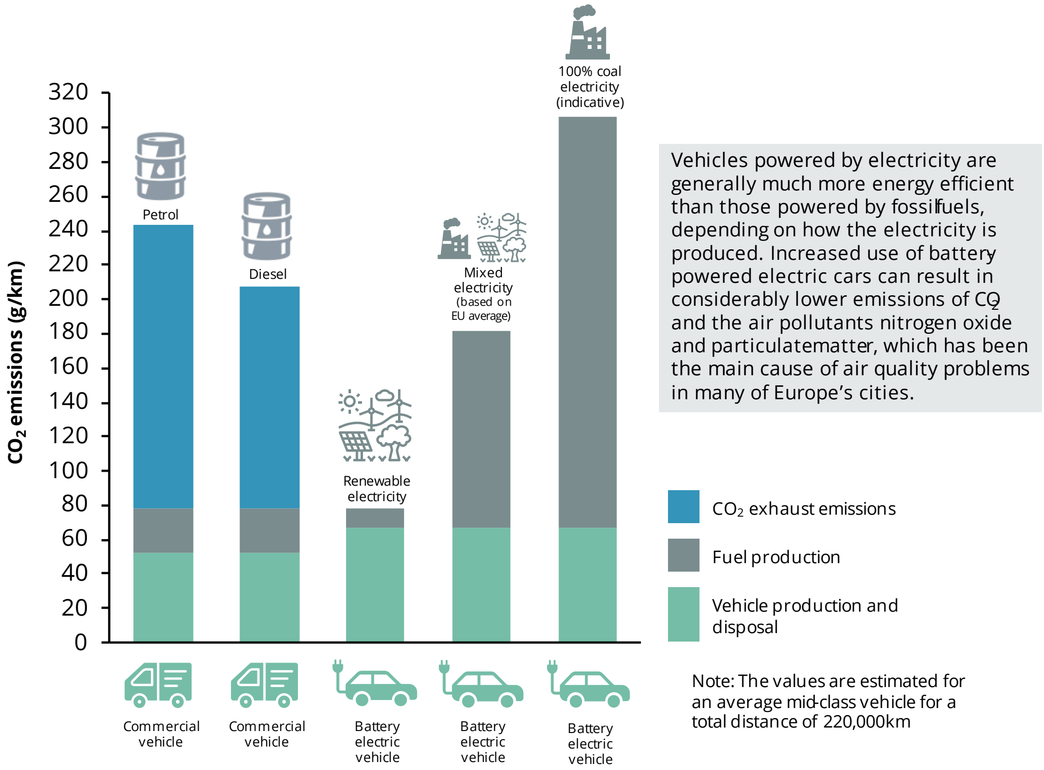

Figure 17: Range of life-cycle CO_2 emissions for different vehicle and fuel types

(Source: European Environmental Agency[50])

From a life cycle perspective, most of the greenhouse gas emissions for an ICE over its life are associated with the use-phase of the vehicle, from both fuel production and exhaust emissions[49,50]. For this reason, regulatory activity has focused on tailpipe emissions with a series of specific emissions targets, previously Regulation (EU) 2019/631 to achieve from 1 January 2020 EU fleet-wide targets of 35% of the current baseline of 95g CO_2/km and 31% of the current baseline of 147g CO_2/km for the average emissions of new passenger cars and light commercial vehicles, respectively, with periodic reductions in emissions targets to 2030.

The new 'Fit for 55' pushes this emissions target to 55% for passenger cars and 50% for light commercial vehicles by 2030. The proposal for heavy-duty vehicles will be released in 2022.

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[49] BloombergNEF, The Lifecycle Emissions of Electric Vehicles (2021), 13 August 2021

[50] European Environmental Agency, Range of life-cycle CO2 emissions for different vehicles and fuel types (2020), 13 August 2021

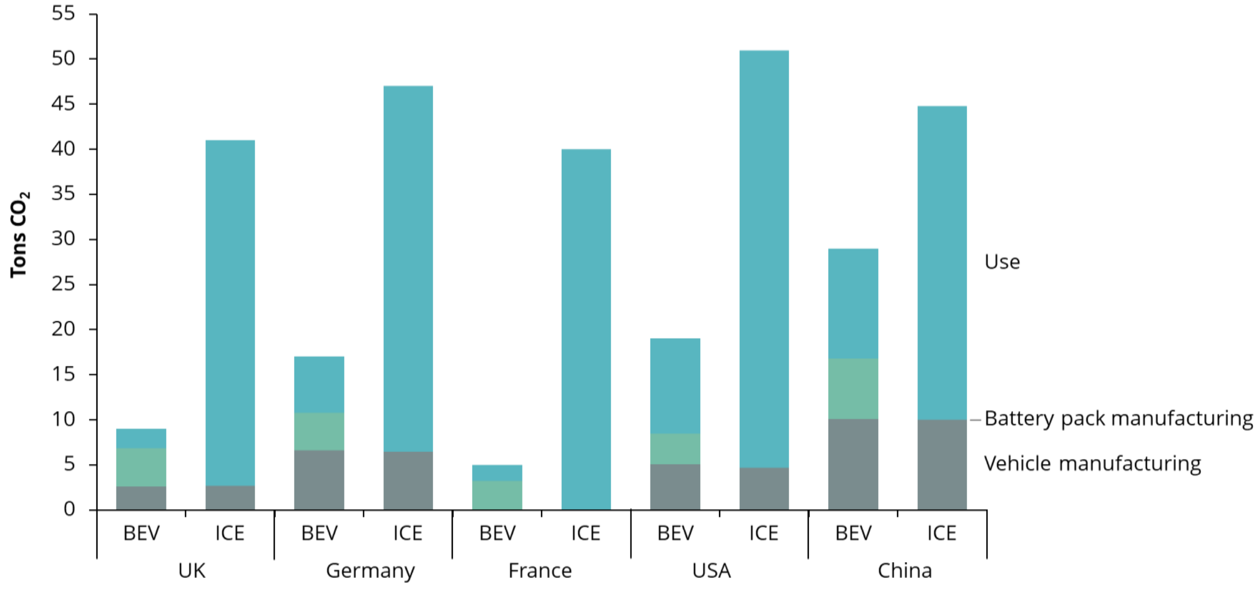


Figure 18: Total CO_2 emissions of medium segment ICEs and BEVs produced in 2020 and used for 250,000 km

(Source: BloombergNEF[49])

However, the emissions associated with the production and disposal (and maintenance) of vehicles is not insignificant and, with the transition to zero- and low-emission vehicles, this part of the vehicle life cycle will come under increasing pressure to reduce its greenhouse gas emissions.

It is against this backdrop of a sector under intense pressure to decarbonise whilst navigating a fundamental technology transition that the emissions benefits of remanufacturing is of increasing interest to the industry, policy makers and the public. The features of remanufacturing that make it economically attractive heavily suggest that there are also environmental benefits: the components and materials retained during the remanufacturing process both reduce costs and preserve the embodied greenhouse gas emissions. Where remanufacturing can be shown to have a significant environmental benefit, this provides the automotive sector with another demonstrable example of its efforts to reduce emissions to communicate to policy makers and the public. It is also a supplementary route to greenhouse gas (GHG) reductions in the existing ICE and emerging EV car parcs that could be further developed.

Therefore, developing a robust assessment of the emissions impact of remanufacturing of automotive components in Europe is an important aspiration of this study.

Approaches for quantifying CO_2 impacts

There is a range of approaches that could be taken for quantifying the CO_2 impacts of automotive component remanufacturing. These are outlined in the tables below:

Approach	**Life cycle assessment (LCA) study**
Description	From ISO 14040:2006[51], *"LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave)."* An LCA study involves defining the goal and scope of the study, including the system boundary under consideration and the functional unit against which the results will be compared. Life cycle inventory (LCI) data is collected, which quantifies the environmental impacts of each element within the lifecycle. Then a life cycle impact assessment (LCIA) provides supplementary information for consideration in the final interpretation phase, where the results are discussed to inform "conclusions, recommendations and decision-making".
Examples and results	Examples of individual product LCAs can be found in academic literature demonstrating significant differences in CO_2 impacts between new and remanufactured products. Some stakeholders are beginning to undertake LCAs for their products, but these are generally not publicly available.
Benefits and limitations	While LCAs represent a robust methodology for assessing the GHG impacts of the system being studied, they are extremely data-intensive, requiring data on every element of every life cycle phase. To apply an LCA approach to an assessment of the CO_2 impacts of all remanufacturing activity in Europe for automotive components would require a vast data gathering and generation exercise. Additionally, to be able to give an indication of the emissions "saved" or "avoided" from remanufacturing over new manufacturing, would require an additional data set associated with new manufacturing. This dataset would require assumptions, e.g. over theoretical manufacturing locations and activities. While this is relatively straightforward for comparing individual products, defining the theoretical system where all remanufacturing is displaced by new manufacturing is more challenging to robustly define.
Conclusions	For this study, LCA was considered to be inappropriate due to the scale of data gathering/generation required. LCA is considered to be more appropriate for individual products than for whole sectors.

[51] ISO:14040: 2006, Environmental Management-Life Cycle Assessment-Principles and Frameworks

Approach	Life cycle inventory (LCI) study
Description	From ISO 14040:2006[51], *"There are cases where the goal of an LCA can be satisfied by performing only an inventory analysis and an interpretation. This is usually referred to as an LCI study".*
Examples and results	The 2012 study by Ecofys used an LCI approach for estimating the difference in carbon footprint between new and remanufactured products by grouping components with similar material compositions together[52]. The UNEP IRP report[53] also uses an LCI approach when comparing the impacts of new manufacture, remanufacture, refurbishment and reuse.
Benefits and limitations	An LCI can be less data-intensive than a full LCA but is still subject to many of the same limitations of LCAs; namely significant data requirements and the need to define theoretical comparative systems.
Conclusions	For this study, LCI was also considered to be inappropriate due to the scale of data gathering/generation required. However, elements of LCI are considered important for quantifying emissions robustly.

Approach	Material retention analysis
Description	This analysis focuses on the material that is retained during the remanufacturing process. The CO_2 impact of this retention can then be interpreted in different ways: • Comparison with new production, e.g. if 1 kg of steel is retained during remanufacturing, the emissions impact is estimated to be equivalent to avoiding the manufacture of 1 kg of steel. • Comparison with alternative processing step. This approach distinguishes between materials that are conventionally recycled and those that are not, e.g. if 1 kg of steel is retained during remanufacturing, the emissions impact is estimated to be equivalent to avoiding the recycling of 1 kg of steel. For a material that is not recycled, the emissions impact is calculated as per comparing with new production.

[52] Ecofys, Carbon Impact of Remanufacturing in the EU-27, 2012

[53] Nabil Nasr, Jennifer Russell, Stefan Bringezu, Stefanie Hellweg, Brian Hilton, Cory Kreiss, and Nadia von Gries Re-defining Value – The Manufacturing Revolution. Remanufacturing, Refurbishment, Repair and Direct Reuse in the Circular Economy, IRP (2018), A Report of the International Resource Panel, United Nations Environment Programme, Nairobi, Kenya.

Examples and results	Several stakeholders indicated that they reported the emissions impact of their remanufacturing activities using a material retention approach. Generally, the comparison with new production was used to quantify impacts. A material retention approach was used to evaluate the emissions impact of value retention activities (including remanufacturing) for Canada. The analysis only considered the impact of retaining steel during remanufacturing but estimated that 111,000 tonnes of CO_2e were avoided through remanufacturing of automotive components in Canada in 2019.[54]
Benefits and limitations	One benefit of the material retention approach is the reduced data requirement compared to LCA/LCI studies. The data requirements are limited to the volumes and types of material retained during remanufacturing, and corresponding emissions factors for new manufacturing/recycling, depending on the analysis approach chosen. However, even with this simplified approach, robust evaluation of the impact of the whole sector requires the definition of proxy products with validated data on material retention rates. Limitations of this approach include the fact that it does not take into consideration any differences in the impacts associated with transport or remanufacturing processes
Conclusions	For this study, we considered a material retention analysis to be the most appropriate approach when considering the data requirements and the robustness of modelling assumptions. We consider that the comparison with alternative next step approach would be the most conservative quantification, although we recognise that several of the stakeholders interviewed had taken the approach of comparison with new. Emissions factors for recycled metal alloys were used in calculations to provide conservative estimates on emissions avoided.

Overview of modelling approach

The modelling approach for quantifying the CO_2 impacts of remanufacturing of automotive components in Europe uses the material retention approach as described in the previous section. The method is built on the premise that more emissions are released from extracting raw material and producing parts than from manufacturing and assembly, as demonstrated by a comparative LCA[55] comparing

[54] Environment and Climate Change Canada, Socio-economic and environmental study of the Canadian remanufacturing sector and other value-retention processes in the context of a circular economy / prepared for Environment and Climate Change Canada by Oakdene Hollins and Dillon, 2021

[55] V.M. Smith and G.A. Keoleian, The Value of Remanufactured Engines: Life-Cycle Environmental and Economic Perspective (2004) Journal of Industrial Ecology

the production of a new engine to three different remanufacturing scenarios (see Table 6 and Figure 19).

Table 6: Possible remanufacturing scenarios

Remanufacturing scenario	Percentage of material retained
Minimum part replacement	69%-90%
Total dependent part replacement	50%-69%
Maximum part replacement	26%-50%

(Source: The Value of Remanufactured Engines (2004))

From Figure 19 it is evident that, in most cases, material and parts production have the greatest environmental impact. Focusing on a material approach will therefore provide valuable insight into the sustainability agenda while still providing a conservative estimate of the potential impact of remanufacturing on the automotive sector.

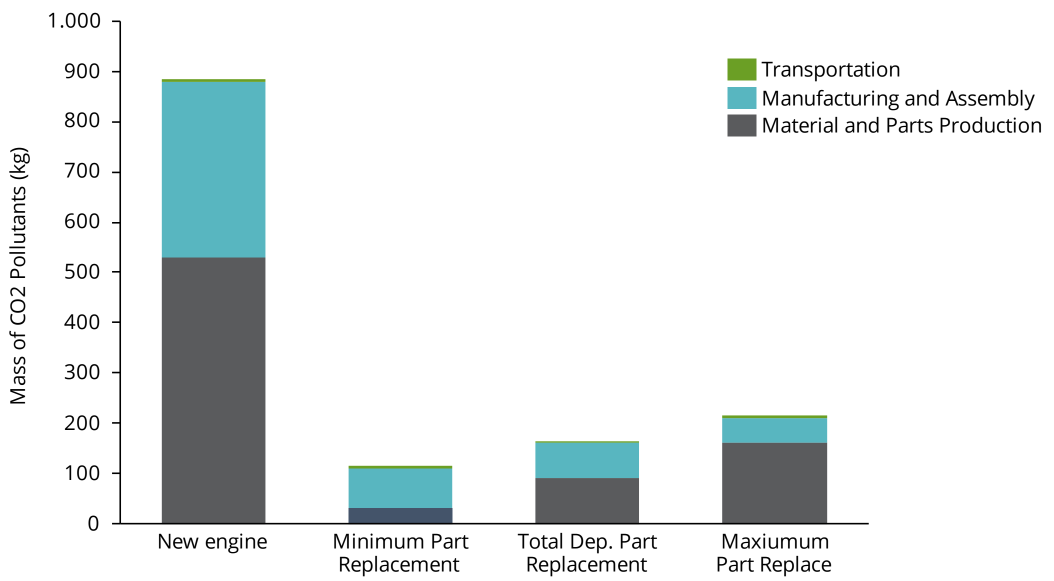


Figure 19: Total life cycle CO_2 emissions for new and remanufactured engines

(Source: The Value of Remanufactured Engines)

From a resource conservation perspective, this approach is also important in terms of understanding how to conserve resource internally (in terms of not needing to rely on exported material) to create more resilient and local supply chains.

The case for remanufacturing from a material perspective is that far less raw materials is extracted from nature in comparison to manufacturing a new component. Hence the difference in emissions impact is the difference between the green section and the blue section in Figure 20.

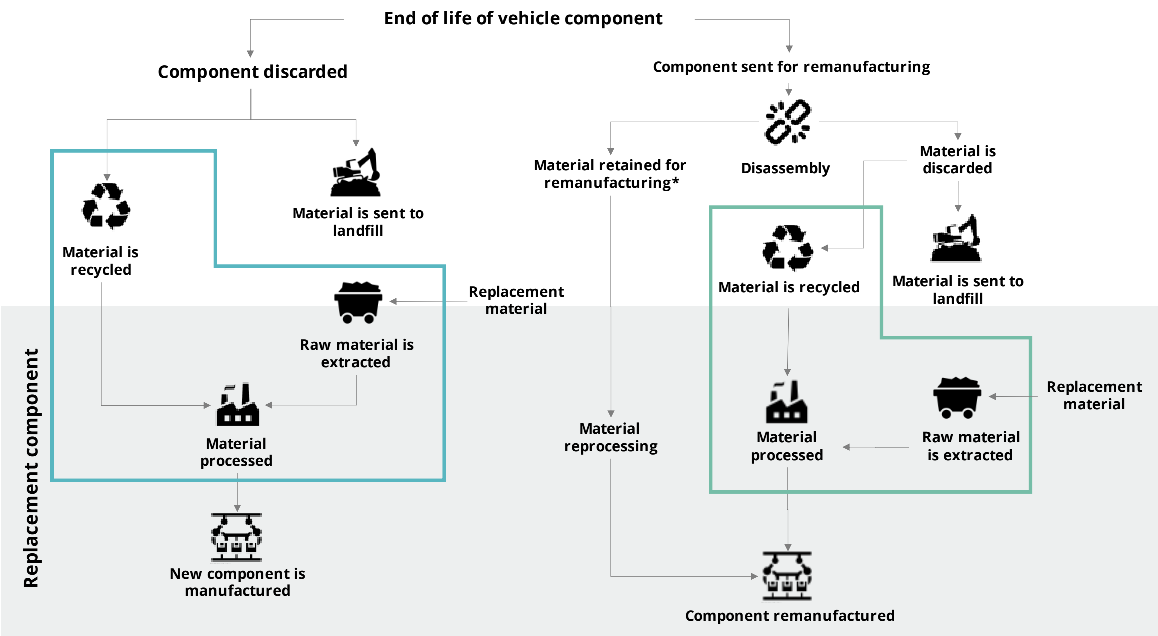


Figure 20: High level process flow of material consumption for new vs remanufactured
(Source: Oakdene Hollins Analysis)

There is a large environmental footprint associated with the extraction of raw materials. Focusing on this provides sufficient insight into the potential opportunities in using remanufacturing processes to reach Net Zero targets.

Passenger cars

For this analysis, we defined a collection of proxy (representative) products to align with the market analysis for passenger cars (see Table 7). Some of these components were further disaggregated than in the market value analysis to allow a more targeted estimation of material composition and retention rates. For some components, multiple proxies were defined to incorporate the difference in material composition between those with cast iron elements and those with cast aluminum elements.

Table 7: Proxy products for CO_2 impact analysis

AC compressor*	Diesel injection pump*	Gasoline injection component – EGR valve	Pumps – hydraulic power steering pump
Alternator	Diesel injector	Gearbox	Pumps – oil pump
Brake calliper*	Electronic control unit	Ignition distributor	Pumps – water pump
Brake component – ABS pump module	Engine component – connecting rod	Instrument cluster	Starters

Clutch	Engine cylinder head	Manual and power steering – steering rack	Torque converter
Combustion engine*	Gasoline injection component – air flow mass meter	Manual and power steering – steering column	Transmission (automatic)
CV driveshaft	Gasoline injection component – Electrical/electronic throttle body	Pulleys and small motors – wiper motor	Turbocharger

**Components where different material variants were included in the modelling*

(Source: Oakdene Hollins)

For the four components with multiple proxies based on different material profiles, we sought stakeholder verification for the approximate split of the market by material. The final market shares used in the modelling are summarised in the table below:

Table 8: Market share of cast iron and cast aluminium material profiles

Component	% share	
	Cast aluminium	*Cast iron*
AC compressor	50	50
Brake callipers	50	50
Combustion engine	50	50
Diesel injection pumps	99	1

(Source: stakeholder validation)

Some of the product categories as defined in the JRC SMART report (used as the initial basis for the market analysis) were not specific enough to define a proxy product material composition. For these components, one or more proxy products were defined to allow a material composition to be specified. In some cases, the proxy products chosen do not reflect the entire group but rather were chosen as material information was provided and could be validated by stakeholders. This mapping is shown in the following table:

Table 9: Proxy product mapping between this study and JRC SMART report categories

JRC SMART report component category	*Proxy products as defined in this study*
Brake components	ABS pump module
Engine components	Connecting rod
Gasoline injection components	Air flow mass meters
	Electrical/electronic throttle bodies
	EGR valves
Hydraulic-oil-water pumps	Hydraulic power steering pump
	Oil pump

	Water pump
Manual and power steering	Steering rack
	Steering column
Pulleys and small motors	Wiper motor

(Source: Oakdene Hollins analysis, JCR SMART Report)

Initial evaluations of material composition and retention rates were defined for each proxy product in Table 7 using a range of sources from literature and previous Oakdene Hollins analysis. For some components, no appropriate literature was identified, and composition was based on visual estimation. These values were shared with stakeholders for validation.

Commercial vehicles

Due to the lack of available information on individual components, a different method, also based on emissions avoided, was used. This involved taking figures from *Remanufacturing of Heavy Duty Components*[56] and was verified by stakeholders where possible. As with the market calculations for CVs, the results of the CO_2 analysis are presented in component groups.

Results of CO_2 impact analysis

The results of the CO_2 impact analysis indicate that, in 2020, 490,000 tonnes of CO_2e were avoided by remanufacturing passenger vehicles and 317,000 tonnes of CO_2e were avoided by remanufacturing commercial vehicles.

[56] Weiland HDOR reference

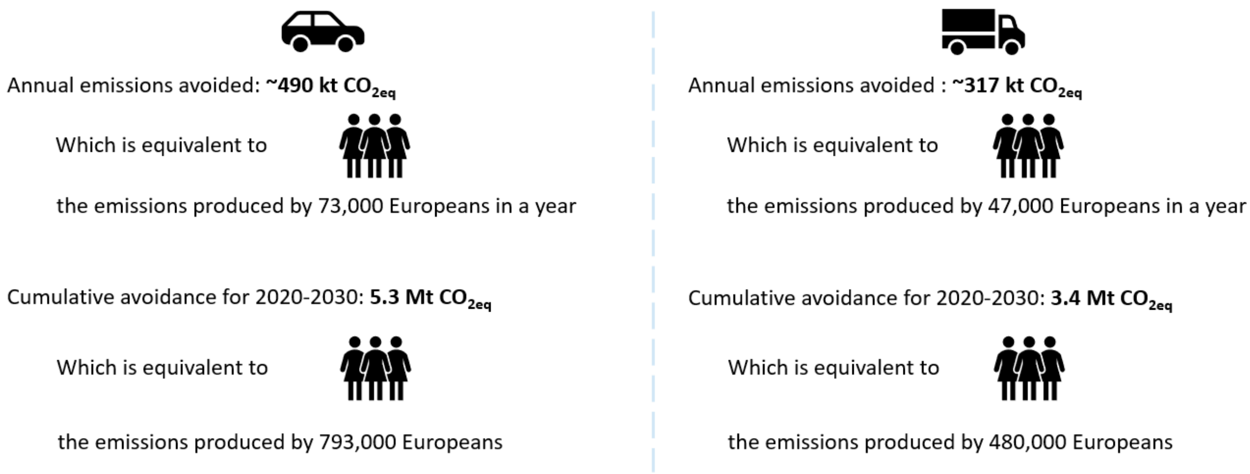


Figure 21: Estimated GHGs avoided in Europe in 2020 by remanufacturing automotive components

(Source: Oakdene Hollins analysis)

Passenger cars

In 2020, the estimated emissions avoided due to remanufacturing activities for passenger car components was 490,000 tonnes of CO_2e. Most of the emissions avoided are associated with remanufacturing of combustion engines and engine cylinder heads, with both components predicted to have a stable growth within the next decade. However, stakeholders have predicted that this market will start to decline after 2030.

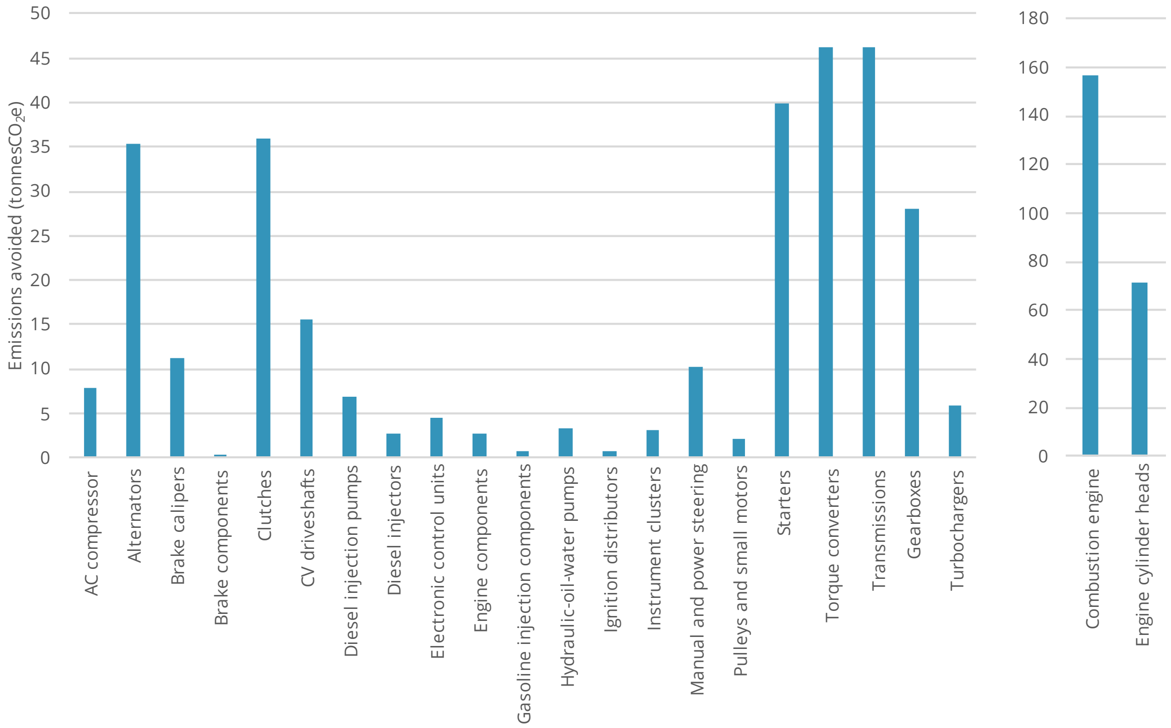


Figure 22: Emissions avoided in 2020, by passenger vehicle component
(Source: Oakdene Hollins analysis)

Over the next decade (2020-2030), assuming the level of remanufacturing activity projected in Section 5, the expected cumulative emissions avoided is 10 Mt CO_2e. This does not include any additional benefits from remanufacturing of EV components.

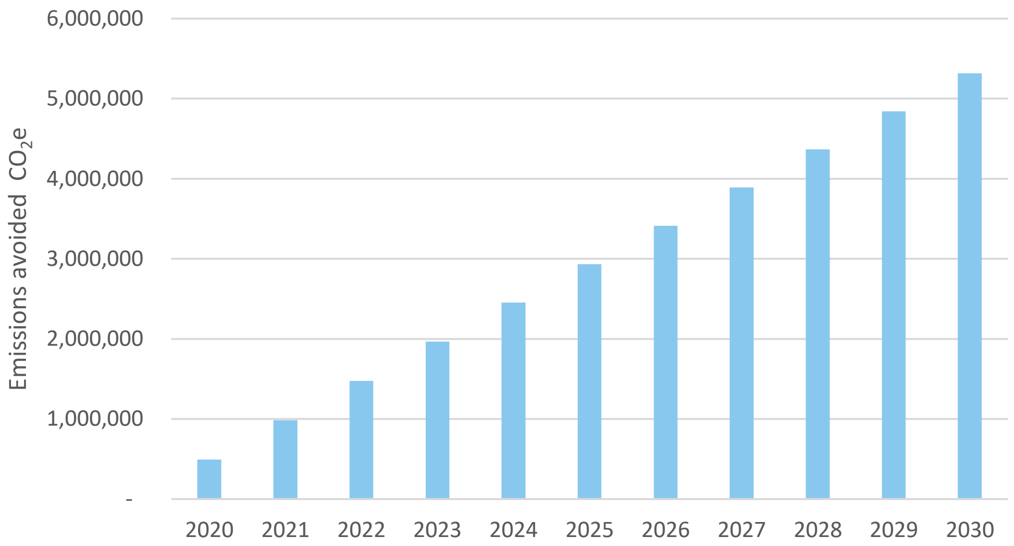


Figure 23: Cumulative GHG avoided through remanufacturing passenger car components in Europe, 2020-2030
(Source: Oakdene Hollins analysis)

These figures are comparable to figures found in the 2012 Ecofys study, which estimated the potential emissions avoided to be 382,000 tonnes of CO_2e per year[52].

Commercial vehicles

The emissions avoided for the commercial vehicle sub-sector is reckoned at 317,000 tonnes of CO_2e. The emissions avoided per component group were multiplied by the projected growth values presented in Section 6. A 10% error margin was included to reflect the uncertainty in the calculation, as there was limited stakeholder validation for the component composition and material retention analysis.

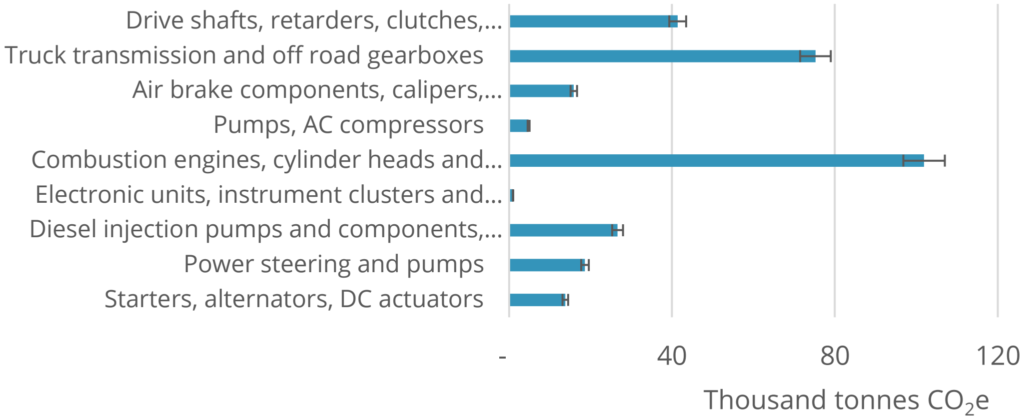


Figure 24: Estimated GHG emissions avoided, by component groups, for CVs

(Source: Oakdene Hollins analysis)

Over the next decade (2020-2030), assuming the level of remanufacturing activity projected in Section 6, the expected cumulative emissions avoided will be 12 Mt of CO_2e.

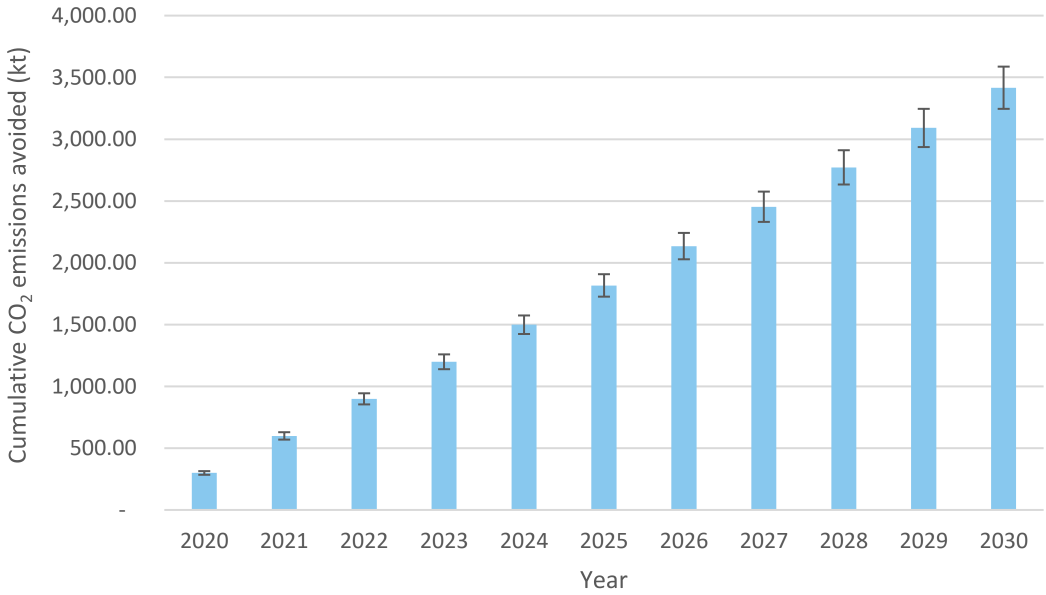


Figure 25: Cumulative GHG avoided through remanufacturing commercial vehicle components in Europe, 2020-2030

(Source: Oakdene Hollins analysis)

Overall emissions avoided

The study has estimated the GHG emissions avoided by having automotive components in Europe remanufactured, rather than being scrapped and the constituent materials recycled or disposed of, to be 807,000 tonnes of CO_2e in 2020.

To put this value into context, we can compare this value to other statistics related to the European automotive industry:

- The EEA reports that, in 2019, road transport emissions from the EU27+UK were 903 Mt CO_2e, of which 548 Mt CO_2e were from passenger cars, 237 Mt CO_2e were from heavy duty trucks and buses, and 107 Mt CO_2e were from light duty trucks[57]. Remanufacturing of passenger car components avoided the equivalent of 0.1% of road transport emissions from passenger cars. However, as the tailpipe emissions of vehicles reduce with the transition to low- and zero-carbon drivetrains, the relative impact of remanufacturing will rapidly increase.
- ACEA reports that, in 2019, European car makers emitted 8.7 Mt CO_2e, or 0.53 tonnes of CO_2 per car[58]. Remanufacturing of automotive components avoided the equivalent of 6% of European car makers' CO_2 emissions, or the emissions from making 920,000 cars.

Conclusions on and recommendations for CO_2 impact analysis

The very nature of remanufacturing, which enables as much material in the original component to be retained as possible, gives a strong indication of the potential environmental benefits of remanufacturing. Evaluating the emissions impact of remanufacturing at a sectoral level can demonstrate the scale of this intervention and validate the role that this circular business model plays in the automotive aftermarket. While the emissions-reducing activities of the automotive sector are normally associated with tailpipe emissions reductions, through low- and zero-carbon powertrains and lightweighting programmes, remanufacturing represents another valuable activity in the transition to Net Zero for the sector.

Using a material retention impact approach, this analysis has provided estimates of the CO_2 emissions avoided by favouring remanufacturing over alternatives fates, such as recycling and landfilling. While this analysis represents an important first step in quantifying this emissions benefit, further refinement of the underlying data through ongoing stakeholder validation would improve the robustness of the

[57] https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer
[58] https://www.acea.auto/figure/co2-emissions-from-car-production-in-eu/

findings. Additionally, increasing numbers of remanufacturing actors, including Tier 1 remanufacturers and wholesalers, are undertaking LCA studies of individual components to quantify the environmental impacts of remanufacturing compared to new manufacturing. A recommendation of this work would be to encourage the publication of these studies and for CLEPA to develop a mechanism for consolidating and reporting these results, from which sector-level life cycle impacts could be extrapolated.

10 Barriers

The remanufacturing market has been heavily affected by the changing world. Across the different actors interviewed, the barriers that affected all stakeholders were: access to appropriate core, software, and developing the appropriate operations to deal with future components.

	Technical	Economic	Social	Political & Legal
OEM	Developing remanufacturing operations		Increased labour costs	Obtaining core from non-EU countries
Tier 1	Lack of access to software, original specifications and tolerances	Economics and logistics of core recovery	Increased labour costs	Obtaining core from non-EU countries
	Limited component availability	Cheap 'copy' parts		Perception of core as a waste
Independent	Lack of access to software, original specifications and tolerances	Economics and logistics of core recovery	Skills needed to deal with electrical components	Obtaining core from non-EU countries
	Limited component availability	Cheap 'copy' parts		Perception of core as a waste
Core Brokers	Limited component availability			Obtaining core from non-EU countries
	Determining the quality of the core in real time			Perception of core as a waste
Triggers across different actors	**Accessing software and core**	**Managing projects and communications**	**Upskilling the workforce to deal with electric components**	**Designation of core value globally**
	Developing remanufacturing operations			

Figure 26: Barriers to remanufacturing, by actor and type of barrier

(Source: Stakeholder interviews)

Five priority barriers have been identified from stakeholder interviews:

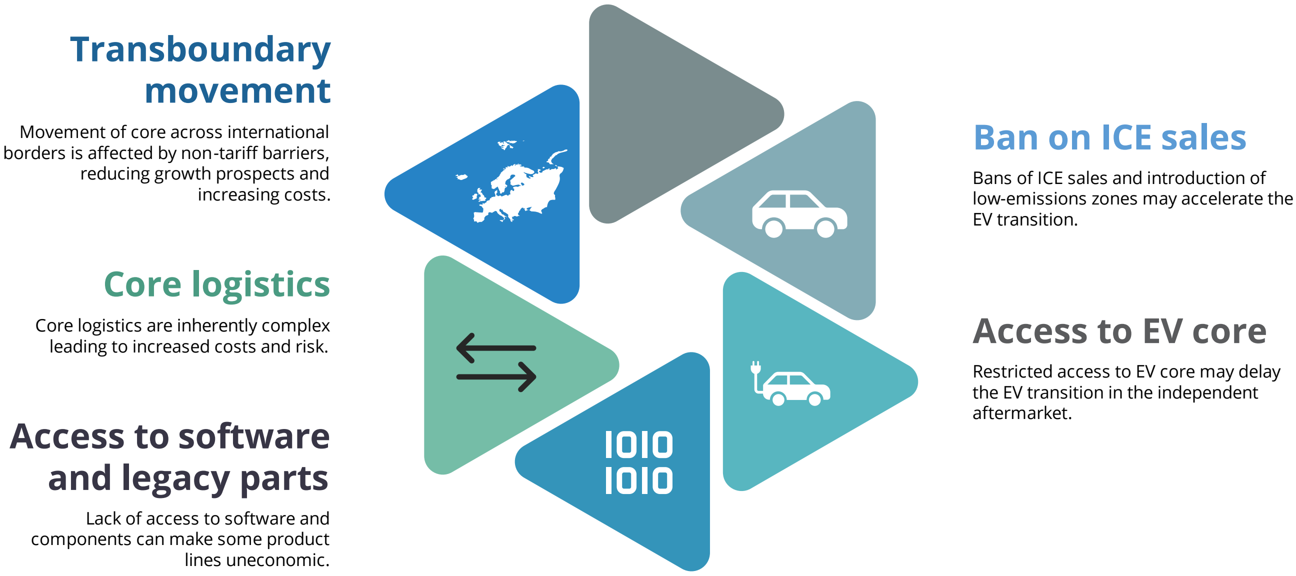


Figure 27: Key barriers to remanufacturing activities, reported in stakeholder interviews

Industry consultation did not establish a consensus on the relative importance of these barriers, with some barriers felt more accutely by different actors. These barriers are described in more detail in the following sections.

Transboundary movements

Stakeholders reported that barriers associated with the transboundary movement of core and remanufactured products create a lost opportunity for increasing remanufacturing activities and accessing new markets. These barriers can also result in increased costs for moving and storing core.

Three categories of transboundary restriction of core have been observed:

- *Intra-EU:* differences in core valuation protocols between Member States were reported to cause delays and create additional costs when moving core across Member State boundaries.
- *EU-UK:* post Brexit, there have been additional costs and delays for moving core, particularly into the UK, due to new customs protocols. UK remanufacturers and the UK trade body, SMMT, are currently in dialogue with UK Government to address these issues, which could be as part of the UK's upcoming post-Brexit tariff suspension scheme.
- *Extra-EU:* cores from outside of the EU, e.g. from North Africa and Asia, cannot currently be imported into the EU due to their classification as waste. This

restriction is at odds with the EU's promotion of the Circular Economy, as many of these parts would have originated in the EU before being exported within vehicles. Additionally, remanufactured products cannot currently be imported into some countries, including Turkey and Korea. This limits the opportunities for growth from the perspective of both the supply of core and access to markets. The lack of consistency regarding the definition of country of origin has also been reported by stakeholders to lead to delays: Stakeholders indicated that the country of origin should relate to where the part was removed from the vehicle. Bilateral agreements were recommended by some stakeholders as the most effective mechanism to address the inconsistency of core classification.

Recommendations for addressing barriers

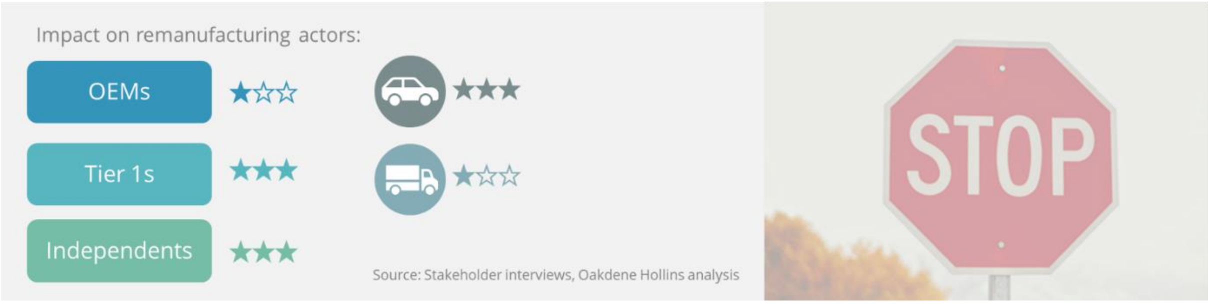
The most important recommendation for addressing the tariff and non-tariff barriers around transboundary movement of core and remanufactured products is to **lobby for supportive changes to legislation**. This would specifically be in relation to the Waste Shipment Regulation (WSR) and waste classifications. With the increasing electrification and digitalisation of automotive components, these products will be more likely to get caught up in the regulations originally intended to prevent the dumping of waste consumer electronics and may make it increasingly difficult to access core.

Policy makers need to better informed so that they recognise the significant role remanufacturing can play in diverting materials and components (including electronic components) from waste, and in facilitating their recirculation. A key challenge to this is to shape a regulatory framework that enables legitimate movement of core for remanufacturing, while preventing the misuse of this channel for dumping or unsafe recycling practices. A recent whitepaper on a circular vision for the revision of the WSR outlined recommendations for reframing the WSR to support circular economy business models. This included recommendations to simplify procedures for those facilities that are certified as operating at a suitably "high-performing, environmentally superior" level[59].

Connected to the issue of waste classification, there was a mixed reaction from stakeholders on the role **certification and labelling** could play in overcoming barriers around transboundary movement. Some stakeholders considered this to be a valuable mechanism for legitimising core movement, while others considered it to be an unhelpful administrative burden, particularly for independent remanufacturers. A concept that sparked some interest was around the potential

[59] Towards a circular vision for the revision of the Waste Shipment Regulation

use of a **designed-for-reman label**, which could visually distinguish core from waste, reducing the variability in interpretation at Customs.



Core logistics

In addition to the barriers around movement of core mentioned above, reverse logistics for accessing core can be extremely complex. This complexity has the undesirable impact of reducing competitiveness, particularly compared to new 'copy' parts.

> *"Availability of core is one of the biggest constraints… Reverse logistics are needlessly complex."*
>
> (Stakeholder interview)

The complexity around core logistics arises because core is generated in a dispersed manner, it is difficult to predict when and where it will arise, and it is of critical importance as the input material to the remanufacturing process. The formation of core brokers sought to improve the efficiency of reverse logistics through consolidation and pre-filtering for remanufacturing suitability; however, core may also be acquired by several different routes, including directly from workshops or OEMs.

The complexity around core logistics has three main implications:

- *Large core inventories:* remanufacturers may mitigate against the risk of missing core by holding large core inventories. This incurs cost for both core acquisition and storage, and risks accounting complexity (see below).
- *Surcharge/deposit schemes:* the use of surcharge/deposit schemes to encourage core return adds complexity and upfront cost, which may put off some customers. The sometimes-lengthy delay between payment and reimbursement for core surcharges/ deposits may make purchasing of a new 'copy' part more attractive. While remanufacturers may be able to negotiate more favourable terms for customers who reliably provide remanufacturing suitable core, surcharge and deposit schemes are crucial for accessing these parts. While Tier 1 remanufacturers may be able to use infills from serial production to supplement their remanufacturing activities, independent remanufacturers are

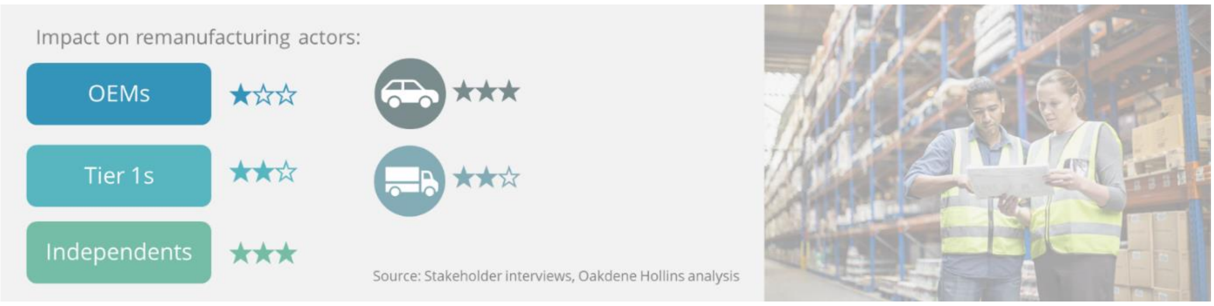
not able to do the same: without core, they cannot provide the customer with a product.

- *Investment hesitancy:* core inventories and surcharge/deposit schemes introduce accounting complexity and may appear less attractive when seeking external investment.

Recommendations for addressing barriers

With the rising profile of remanufacturing as an important component of the Circular Economy, there has been an increase in publicly-funded remanufacturing research. Among this has been projects exploring the development of **new business models**. The ReCiPSS project is exploring new business models for core return using "put-options", with an analogy to stock trading. The benefits of this approach could be the simplification of core movements and better visibility of the supply chain using centralised software platforms. This project builds upon the trends in the industry around developing and using software platforms to improve the efficiency of core logistics, such as those developed by CoreManNet and Encory. The wider technological trends of **Industrie 4.0, Internet of Things** and **blockchain**, for example, should also be monitored for opportunities to enhance reverse logistics practices.

We would also recommend **supporting the adoption of accounting standards for core valuation:** The ReValu-Parts report, the output from a network project with the Ellen MacArthur Foundation, and led by Circle Economy Solutions GmbH, proposes an approach for using the International Financial Reporting Standard for consistent valuation of core[60].



[60] ReValu-Parts report

Access to software and legacy parts

Remanufacturers operating in the independent aftermarket have reported that a lack of access to software, original specifications and components is prohibiting competitive remanufacturing.

The OEMs have the power when it comes to software access, and without support it may not be possible to develop a viable remanufacturing programme. Remanufacturers operating independently have to invest significantly in R&D to develop their own software solutions. Some remanufacturers also expressed concerns around the issues of potential intellectual property infringement that could arise from reverse engineering software.

> *"Access to software is a huge problem."*
>
> (Stakeholder interview)

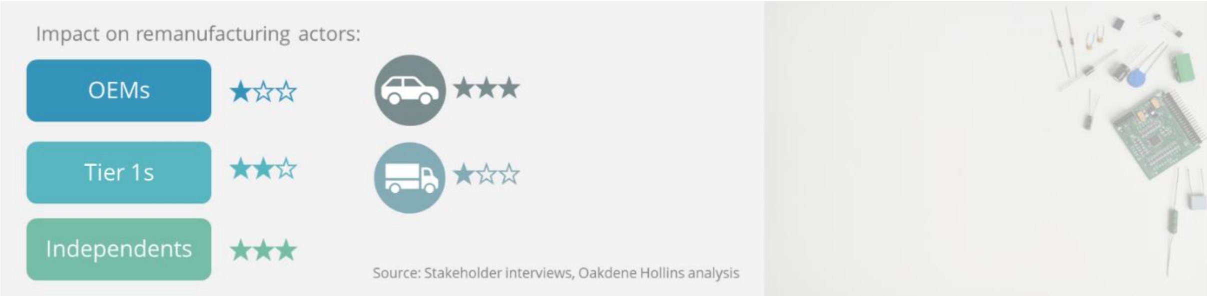
A key tenet of remanufacturing is that the remanufactured part meets the original specification of the part as new. Without access to the original software, it is difficult for an independent remanufacturer to provide that assurance.

Prohibitively large minimum order quantities for replacement components, or no spares available at all, can also derail otherwise suitable remanufacturing candidates. This is exacerbated for electronic components that can have extremely short product life cycles.

Recommendations for addressing barriers

Some stakeholders expressed support for action to **lobby for "Right-to-Repair" initiatives** as have recently been developed for electronics in the EU and the UK. An equivalent initiative for the aftermarket would place obligations on vehicle manufacturers to support legitimate remanufacturing activities through economic access to software and spare parts for a defined period after the end of production. There may, however, be conflict between right-to-repair initiatives and the most recent 'Fit for 55' regulations, which seek to accelerate the transition to low carbon transport systems. If right-to-repair initiatives are perceived to prolong the life of carbon-intensive vehicles, it may be challenging to advocate for them, unless their application is limited to EV-compatible components.

Another mechanism for maintaining access to legacy components could be through the targeted **development of additive manufacturing capabilities**. Additive manufacturing processes could help maintain supply of legacy components without the need to store large volumes of stock for long periods of time. This capability could also align well with any right-to-repair initiatives.



(VDA President Hildegard Müller)

Ban on ICE sales

The recent 'Fit for 55' package has been met by a range of responses in the automotive sector. OEMs such as Volvo, who have already indicated the intention to rapidly transition away from ICEs, have responded to the announcement positively. Others, including ACEA and CLEPA, have indicated that the target to reduce CO_2 emissions from new cars sold in the EU to zero by 2035 is an effective ban on ICE sales (including hybrids) that negates the role of renewable fuels and will stifle innovation[61].

In addition to the proposed bans on ICE sales, an increasing number of cities, towns and other regions are introducing low- and ultra-low-emissions zones, which may further accelerate the transition away from petrol and diesel vehicles.

While bans on ICE sales may support remanufacturing (as the aftermarket is no longer serviced by the authorised channel, and so reducing competition), low- and ultra-low-emissions zones may erode the value of petrol and diesel vehicles and their components. If the decline in these components occurs faster than the uptake in powertrain-independent and/or EV components, independent remanufacturers specialising in petrol and diesel components particularly, may be at risk.

Recommendations for addressing barriers

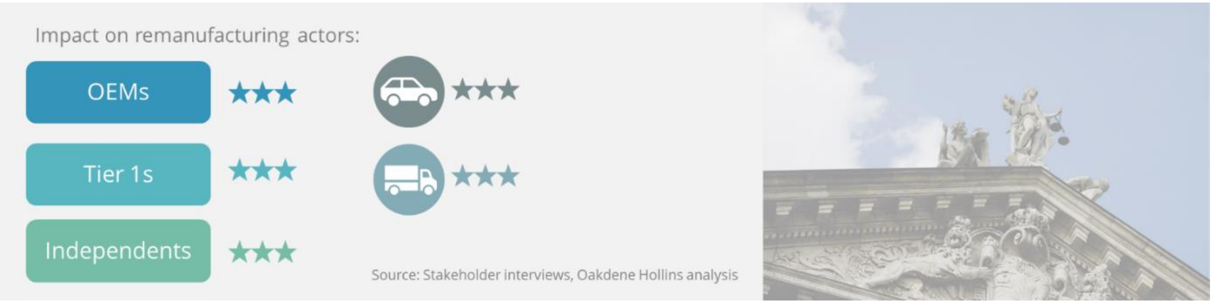
Remanufacturers should prioritise **investment in EV component research.** They should ensure they are proactive in preparing a roadmap for the transition away from petrol and diesel components. This will likely involve significant upskilling of staff and R&D, which will already be well underway for many Tier 1 suppliers active in the development and manufacture of EV components for serial production.

[61] Automotive News Europe 14 July 2021, Combustion engine ban proposal criticized by auto lobby groups

Independent remanufacturers will have to invest to make sure that they are not left behind.

The industry should continue to closely **monitor emissions regulations**. The ambition of the 'Fit for 55' regulation is an indication of how quickly the regulatory landscape can change. The industry should be aware of dates for ICEV sale bans and the introduction of low- and ultra-low-emission zones. These dates may change and are more likely to be brought forwards than delayed.

Remanufacturers should look to **diversify their portfolios to include powertrain-agnostic components**. These components will be unaffected (or less affected) by the transition to EV and may act as a buffer to an unexpected increase in the decline of petrol/diesel components.



Access to EV core

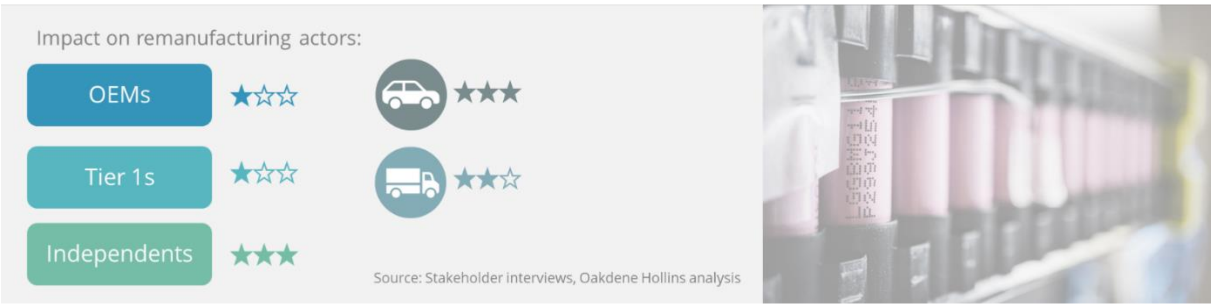
With the transition to electric vehicles, OEMs may pursue strategies to keep customers within dealerships; for example, through EV battery leasing schemes and lengthy warranty periods. This is in part to reassure customers during the transition towards EVs, but also to manage the transition away from ICEVs in relation to the OEM workforce and to retain the value of high price components such as batteries.

This may have the effect of restricting core access to the independent aftermarket and delay the ability of independent remanufacturers to launch an economic remanufacturing programme for these components as they cannot rely on infills, unlike Tier 1s. This may prove detrimental if the decline of ICE component remanufacturing occurs faster than EV component uptake.

Recommendations for addressing barriers

Remanufacturers should **prioritise collaboration with OEMs** to ensure sufficient access to EV core. Early collaboration with OEMs would allow access to core and support with establishing remanufacturing programmes. This strategy is already being pursued by several independent remanufacturers.

Along with access to core, remanufacturers will need to **develop effective EV logistics protocols**. The logistics for moving EV components may be more complex than ICEV components, e.g. risk of battery fires, greater risk from damage in transit, need for workshop training to avoid damage during removal. These elements of an EV remanufacturing programme should not be neglected to ensure that the most core can be safely recovered for remanufacturing operations.



Other barriers

In addition to the five main barriers described in the previous sections, several other barriers were mentioned by interview participants, some of which are only likely to have a significant impact on remanufacturing in the longer term. These barriers generally revolved around design, cheaper 'copy' parts, social mobility trends, failure rates and specific policy implications. These barriers are explored in greater detail below.

Technical barriers

EV components are not being designed for remanufacturing

Some stakeholders report that the suitability of EV components for remanufacturing may be limited by a lack of design for remanufacturing - particularly design for disassembly. Examples of this include the use of glue and spot welds over reversible fasteners in EV batteries. The trend towards designing increasingly complex and integrated components also makes disassembly more technically challenging and labour-intensive. The design of new EV components does present an opportunity to incorporate design principles that will facilitate

"OEMs would rather sell new parts than design components to be remanufacturable."

(Stakeholder interview)

remanufacturing, but the business case for design for remanufacturing has not yet been made, particularly for OEMs.

Failure rates of EV components are unknown

As explored in Section 8, the failure rate of EV components is a critical variable in quantifying the potential market size for EV component remanufacturing. If real-world failure rates are low, this would add pressure to the remanufacturing market as remanufacturers will be competing for lower core volumes.

Economic barriers

Online sales give an advantage to new 'copy' products

Customers using online sales platforms may not be aware of the differences between a new 'copy' part and a remanufactured component. Without a robust understanding of the difference in processing and performance, customers - particularly the general public - may prioritise price over performance, and may have reservations over purchasing what they may consider to be a "used" or "second-hand" part.

Designing for remanufacturing can be more expensive

Some stakeholders indicated that the process of designing for remanufacturing may result in more expensive components to manufacture. Therefore, it is important that the business case for justifying a design for remanufacturing approach will need to be made. This is perhaps more straightforward for components that an OEM is actively remanufacturing, either itself or via contracted activities. However, for components where the OEM does not have a vested interest in remanufacturing, there will likely be little economic incentive to design a more expensive product that is easier for an independent actor to remanufacture. In this case, some stakeholders felt the only motivator for a change in design approach would be via policy.

> *"Design changes to support remanufacturing will only be driven by policy. Cost is always a bigger driver."*
>
> (Stakeholder interviews)

Societal barriers

Social mobility trends leading to reduced car usage

Emerging from the Covid-19 pandemic, it is as yet unclear to what degree businesses and society will return to pre-pandemic practices. For example, the widespread adoption of home and flexible working practices may continue to some degree in the long term. Additionally, many towns and cities are introducing infrastructure to support alternative transport modes, such as e-scooter rental schemes and greater cycling infrastructure, as part of ambitions to reduce traffic and emissions and encourage more active lifestyles. These trends may lead to reduced passenger car ownership and usage, which would in turn lead to a reduced market for remanufactured components.

Political barriers

REACH regulations may prevent remanufacturing of older products

Currently, REACH regulations allow for remanufacturing under the "repair as produced" exemption, which allows for a repaired part to contain the same substances as when originally put on the market. However, with over 200 groups of substances identified as potential substances of very high concern and subcategories of these substances difficult to identify due to different naming conventions, the risk of accidental non-compliance is increasing. There is also concern that the repair as produced exemption may be revoked in the future.

"Fears over public exposure to substances of very high concern encourages a view that exemptions (such as Repair as Produced) should not continue. There is an on-going debate over where to draw the boundary between absolute protection from such risks as soon as possible and a more pragmatic approach that allows for the continued use of substances that present very low risk of public exposure. The circular economy adds some weight in support of remanufacture but ECHA is often at variance with circular economy objectives. As yet, the boundary has not been definitively set to the disadvantage of remanufacturers but the trend toward greater complexity can be regarded as unfavourable."

(David Fitzsimons, European Remanufacturing Council)

Obligations to report CO_2 emissions may incur significant additional costs

Some stakeholders felt that increasing obligations around emissions reporting would increase costs and put pressure on the competitiveness of remanufacturing. While CO_2 analysis can help to demonstrate the relative environmental benefits of using remanufactured parts compared to alternative options, it is a resource-intensive activity, particularly for non-OE remanufacturers who would have less visibility of the upstream processes and materials used in original manufacture.

11 Triggers

The sustainability agenda, consolidation of the market, and changes to ownership models will drive the growth of remanufacturing.

	Technical	Economic	Social	Political & Legal
OEM	Redesigning with remanufacturing in mind Increasing price of raw materials	Leasing of battery components	Increased funding and research into remanufacturing	Climate change and CO_2 reduction strategies
Tier 1	Redesigning with remanufacturing in mind Increasing price of raw materials	Consolidation of the market Transition to mobility as a service and changes in ownership models	Better marketing and promotion	Climate change and CO_2 reduction strategies Current and future legislations
Independent	The ability to be agile in comparison to OEMs and Tier 1 suppliers	Consolidation of the market Transition to mobility as a service and changes in ownership models	Better marketing and promotion	Obtaining core from non-EU countries Current and future legislations
Core Brokers		New business models for core surcharge		
Triggers across different actors	**Accessing software and core**	**Managing projects and communications**	**Marketing and research**	**Climate change and CO_2 reduction strategies**

Figure 28: Triggers to remanufacturing, by actor and type of barrier

(Source: Stakeholder interviews)

Five priority triggers have been identified from stakeholder interviews, as shown in the figure below.

Figure 29: Triggers for remanufacturing activities, reported in stakeholder interviews

Industry consultation did not establish a consensus on the relative importance of these potential triggers, with some more relevant to specific actors. These triggers are described in more detail in the following sections.

New opportunities

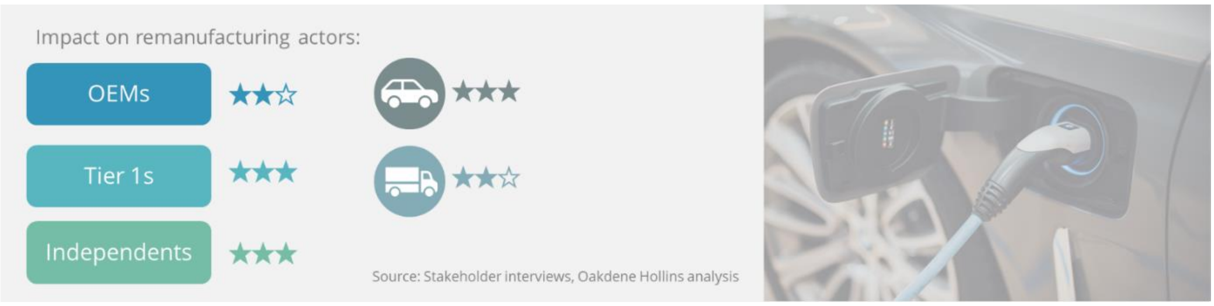
New components in electrified vehicles could present new opportunities for remanufacturing. This is explored in greater detail in Section 8. While these components may be more complex, their value will also be higher, increasing the incentive to remanufacture. Workshop-based repair will be less feasible with EV components, requiring specialist knowledge and training, again increasing the appeal of exchange-based remanufacturing programmes.

The skills and knowledge developed to process electrified automotive components may lead to additional opportunities in other transport market (e-bikes, e-scooters), as well as other sectors (e.g. marine, renewables, energy storage etc.).

Recommended actions

Invest in EV component research: Remanufacturers should ensure they are preparing a roadmap for the transition away from petrol and diesel components. This will likely involve significant up-skilling of staff and R&D.

Support workshop transition: Core availability will be even more critical with EV components while OEMs seek to retain customers through dealerships. Collaboration with workshops to support their transition to servicing EVs will help maximise core availability.



Sustainability agenda

The Green Deal, Circular Economy Action Plan, and other regulatory frameworks around the circular economy support remanufacturing, in theory. Some stakeholders indicated that, in their opinion, this theoretical support did not yet translate into practice.

"Policy supports on paper, but not in practice."

(Stakeholder interviews)

To better support remanufacturing, policy should be refined to comprehensively and coherently tackle non-tariff barriers and promote remanufacturing as a high-value circular economy activity.

This new framework could include:

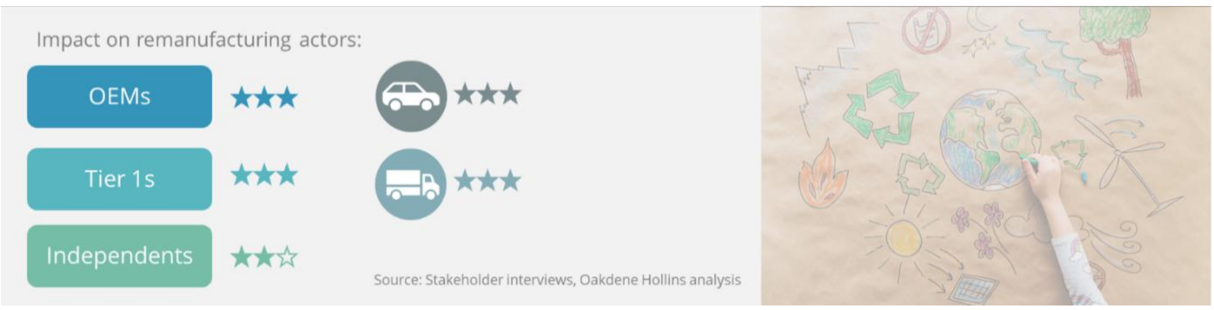
- Improving the competitiveness of remanufactured products. Increasing taxation on fossil fuel use, CO_2 border tax adjustments, and reduced taxation for remanufacturing would all be mechanisms by which remanufacturing could become more competitive.
- Tackling non-tariff barriers that limit the uptake and growth of remanufacturing related to movement of core and remanufactured products.

Recommended actions:

Lobby for fiscal initiatives that support remanufacturing: For example; tax reductions for remanufacturing (like the Swedish tax breaks on repair activities), and monitoring developments in discussions on CO_2 border tax adjustments such that they are explicitly supportive of remanufacturing.

Lobby for tackling of non-tariff barriers: These should focus on core movement and bilateral definitions of waste to facilitate remanufacturing growth.

Raise political awareness of remanufacturing: Some stakeholders felt that remanufacturing is not well understood at higher political levels. Identifying and educating political advocates for remanufacturing (for example, through a programme of site visits to advanced remanufacturing facilities) could help raise the profile of the industry and more effectively demonstrate the valuable contribution remanufacturing activities make to a circular economy.



Green investments

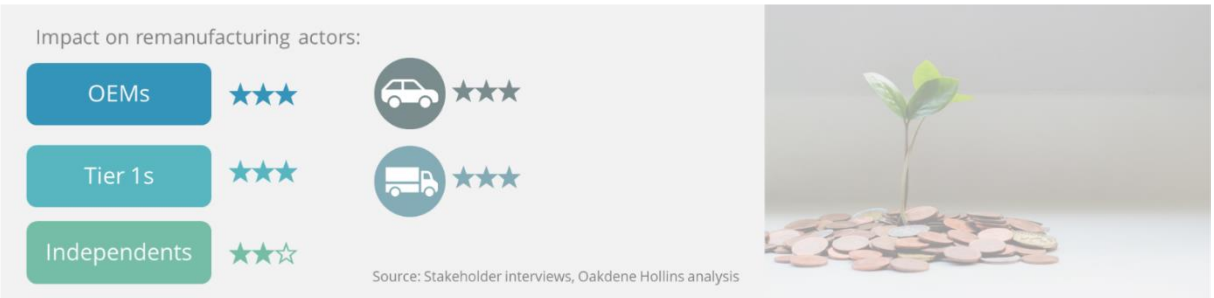
Investing practices are changing, with investors increasingly focused on investing only in companies that are aligned with the sustainability agenda. The benefits of remanufacturing in terms of conservation of natural resources and CO_2 emissions avoided should position remanufacturing as an attractive investment option.

Investors are increasingly asking companies to demonstrate and report on what they are doing in terms of sustainability[62]. Remanufacturers, and purchasers of remanufactured products, can practically demonstrate this. This is a trend that is likely to stay.

Recommended actions:

Develop industry-wide protocols for quantifying CO_2 benefits of remanufacturing: Encouraging consistent quantification of the benefits of remanufacturing and reporting industry-wide impacts would help demonstrate the environmental benefits of remanufacturing to both policy makers and the public. Quantifying industry-wide emission impacts on a full LCA-basis is unlikely to be feasible, both in terms of data availability and the resource required. However, there may be alternative approaches to quantify impacts; for example, a centralised database on LCA studies, or the refinement of the emissions analysis presented in Section 9, with more frequent and rigorous industry validation.

Report on sustainability initiatives: Annually reporting on what the business is doing from an emissions perspective can make a business more attractive to investors. As part of the proposed CO_2 impact quantification described above, accurate data on the volumes of remanufacturing activity taking place would increase the robustness of the subsequent emissions analysis. Again, this could be captured either through company sustainability reporting, or reported, anonymously, to a central industry-wide dataset, for example, managed by CLEPA.



[62] Environmental Reporting Guidelines: Including streamlined energy and carbon reporting guidance March 2019, available here

Design

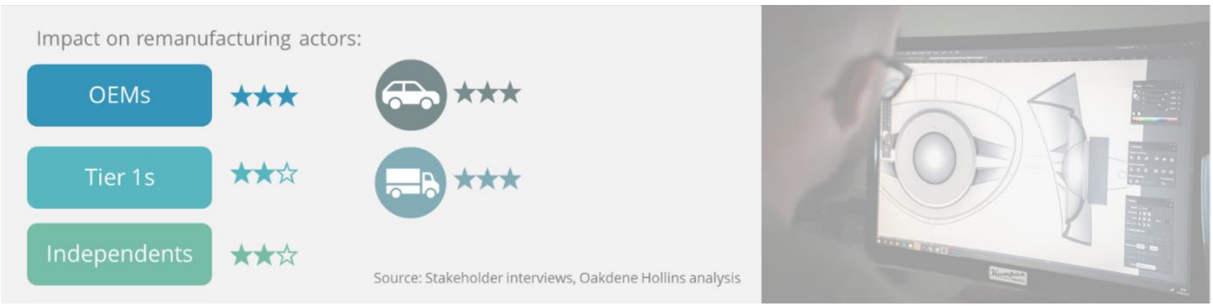
An intentional shift to 'design for remanufacturing' for automotive components would improve the competitiveness of remanufacturing through economies of scale: design for remanufacturing would support greater automation of remanufacturing processes, reducing processing time and labour, and would help maximise material retention. It could also open opportunities to remanufacture products that are currently not economic to remanufacture due to the unfavourable balance of labour costs/ remanufacturing efficiency to resale price.

Stakeholders reported that design for remanufacturing is already an embedded practice for some Tier 1 suppliers, but greater uptake, including from OEMs would elevate remanufacturing to a new level. This strategy may be aligned with design strategies for modularity.

Recommended actions:

Develop and promote industry guidance on design for remanufacturing: Sharing best practice and disseminating information about the business case for designing for remanufacturing would encourage take-up by suppliers. There are also opportunities for independent remanufacturers to feed back information to OEMs to share valuable information on failure modes and methods for improving remanufacturability.

Engage with OEMs to promote design for remanufacturing, particularly in EVs: The design of new EV components presents a unique opportunity to embed design for remanufacturing principles. OEMs with high-profile circular economy strategies, such as Renault and Volvo, may be priority organisations to engage with. With stakeholder experience pointing towards increasingly complex and integrated EV components appearing on the market, incorporating design for remanufacturing principles (which strongly align with design for repair and maintenance) is a crucial enabler for remanufacturers to retain the maximum value from EV components and prevent these high-value, and often difficult to recycle, components from facing preventable disposal.



Market consolidation

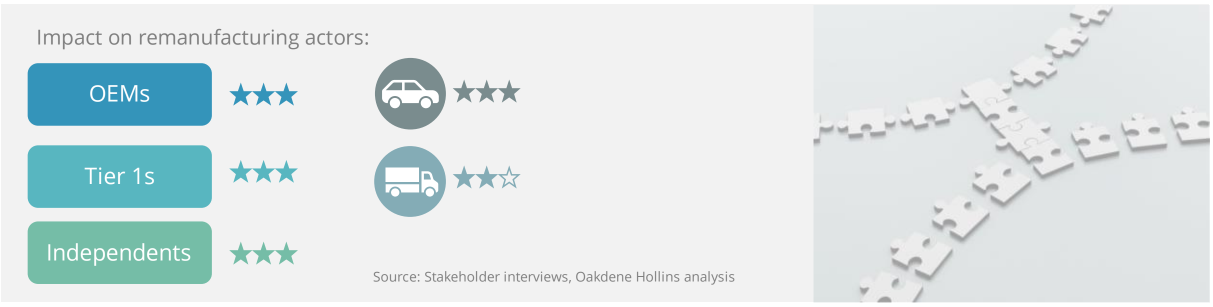
Ongoing consolidation of remanufacturing actors could drive uptake in remanufacturing over the next decade. Consolidation will support the simplification of core logistics and help achieve economies of scale that would improve remanufacturing profitability, with weaker players disappearing from the market, expedited by the operational challenges of the Covid-19 pandemic.

Consolidation is currently being driven by the strategic merger and acquisition activities of independent remanufacturers, wholesalers and Tier 1 suppliers, with consolidation of OEMs considered highly likely, as they adapt to the changes from the EV transition and seek to develop their aftermarket activities to compensate for losses from the traditional ICEV manufacturing route. The recent release of the 'Fit for 55' package has increased the urgency of this transition with the effective time horizon of 2035 to pivot away from ICEV (including hybrid) technology.

Recommended actions:

Monitor consolidation activities and opportunities: Actors should proactively monitor consolidation activities to identify potential opportunities and risks. This is particularly relevant to independent remanufacturers who are seeking to enter new markets.

Engage with OEMs to support consolidation aspirations: Consolidation activities may provide suppliers with opportunities to support OEMs as they develop their remanufacturing and aftermarket strategies. Collaboration could strengthen supplier relationships and provide mutual benefits in terms of access to core, components and software, and new markets.



Other triggers

In addition to the five main triggers described above, several others were mentioned by interview participants. These triggers are explored in greater detail below.

Technical triggers

Advances in additive manufacturing

The use of additive manufacturing techniques by remanufacturers could support the replacement of legacy components that are no longer (economically) available. The technology could also be used to help reduce R&D costs; for example, by allowing remanufacturers to manufacture prototype jigs and fixtures quickly and cheaply. While affordable additive manufacturing technologies are predominantly associated with polymers currently, there is increasing development of metal additive manufacturing technologies, which should become more accessible and economic for smaller remanufacturers over time.

Economic triggers

Supply risks associated with battery materials

"The materials for batteries are controlled by China."

(Stakeholder interview)

The transition to EVs is associated with a significant growth in the manufacture and supply of batteries. These batteries contain a mix of critical raw materials, many of which are only found and manufactured at scale outside of Europe. While battery recycling technologies are a keen area of research and development, remanufacturing of EV batteries would allow these critical raw materials to be retained within the Europe. If viable remanufacturing programmes for remanufacturing of EV batteries can be developed, this would provide an attractive processing route.

Societal triggers

Increasing car parc age

Data indicate that the average age of vehicles in the car parc is increasing[63]. This could be a positive trend for remanufacturing, due to longer access to the market with reduced competition from new parts, as they are no longer in serial production. With the upcoming ban of ICEVs, there may be a significant proportion of vehicle owners who would prefer to maintain and prolong the life

[63] ACEA reported the average age of a passenger car was 10.8 years in their 2019 Vehicles in Use report and 11.5 years in the 2021 report.

of their petrol or diesel vehicles (including hybrids) rather than transition to a battery electric vehicle.

Increased focus on resilient supply chains

The potential weaknesses of global supply chains operating with little stock has been exposed both by the Covid-19 pandemic and the recent Suez Canal blockage. These incidents, while possibly unique, have shown that manufacturing operations can be very exposed to disruption to international movement of materials and components. Stakeholders provided anecdotal evidence of where remanufacturing supply chains centered around local sources of core were more resilient, particularly during periods of lockdown in the Covid-19 pandemic. This resilience could support the business case for remanufacturing, as companies reassess their reliance on highly lean, global supply chains.

Political triggers

Taxation on use of raw materials or embodied carbon

Fiscal measures that penalise resource consumption would give remanufactured products an advantage over newly manufactured parts. Measures to tax carbon emissions on imported products would be another mechanism for improving the competitiveness of remanufacturing, particularly against the new 'copy' parts imported into the EU. The Carbon Border Adjustment Mechanism outlined in the 'Fit for 55' package is currently focused on targeting materials from the foundation industries (metals, ceramics, glass, chemicals, paper and cement), where carbon leakage is a concern. Longer term, this mechanism could be extended to manufactured products, at which point this translates into an economic advantage for remanufactured products.

Remanufacturing certification and labelling

The use of remanufacturing certification schemes could theoretically help separate high quality remanufacturers from those describing their activities as remanufacturing, while not adhering to the commonly accepted definition of remanufacturing presented in Section 2. These lower quality activities tarnish the reputation of remanufacturing and reduce consumer confidence. Certification and product labelling schemes could go some way to increase trust. There may also be a role for certification in conjunction with a re-framing of the Waste Shipment Regulation to support circular practices like remanufacturing that use 'waste' as an input material. However, there were mixed views from stakeholders as to how effective these schemes would be in practice, along with their potentially high cost.

12 Action plan roadmap/ Recommendations

Pursue opportunities for collaboration

Market forces and the sustainability agenda are opening the eyes of OEMs to aftermarket opportunities and independent actors are consolidating.

Engage with OEMs to identify opportunities to collaborate through contracted remanufacturing and design for reman, especially for EV components.

Negotiate access to software and core as priorities.

Harmonise approaches for core valuation and accounting practices across the industry to support investment.

Proactive EV positioning and roadmap

OEMs may pursue strategies to retain customers within the authorised repair channel. EV technology may evolve rapidly.

Monitor technical and regulatory developments and build agility into remanufacturing planning to respond to rapid change.

Investigate alternative markets for EV capabilities both within the mobility sector and beyond.

Prioritise upskilling of workforce and knowledge transfer along the whole supply chain, including workshops and distributors.

Lobby for harmonised, coherent and supportive policy

Inconsistent policy and unintended consequences have created non-tariff barriers to remanufacturing activity.

Cultivate remanufacturing champions within policy makers to advocate for remanufacturing.

Demonstrate the inconsistency of trans-boundary restrictions on core movement with Circular Economy principles.

Explore fiscal levers for practical support, e.g., tax break for remanufactured products.

Suggest "Right-to-Repair" activities for automotive components.

Build evidence base for sustainable business case

Evidence on the environmental benefits of remanufacturing is anecdotal and inconsistent. A more robust evidence base is needed to support promotion.

Develop guidance and mechanisms for reporting environmental impacts of remanufacturing at a sector level.

Emphasise the role remanufacturing can play in a resilient supply chain and the retention of critical raw materials.

Annex A *Interview method and approach*

Understanding market trends, barriers and triggers

A semi structured interview process was used to validate the growth in the market for different components and to develop our understanding of key market trends, barriers and triggers.

The questions used use to gain these insights are shown below:

Dear participant,

We are pleased to be working with CLEPA to better understand the European automotiveremanufacturing status and potential. In this study, we are looking at remanufacturing market trends, political barriers, and opportunities for development.

We are extremely grateful for your interest in conducting an interview via video call, at yourconvenience. We anticipate that this will take between 30-60 minutes. We will produce a summary of the interview, which will be sent to you to review.

All information is treated as confidential, and anonymity is ensured. We have attached a copy of our data privacy notice for your reference and would be happy to address any additional concerns you may have.

We attached here the question framework we will use as a basis for our discussion, although,we would of course be glad to extend the discussion to other areas you feel are relevant.

We look forward to speaking to you - please do not hesitate to get in touch if you have any questions about the project.

With all best wishes,

Rachel Waugh

Question 1: Interviewee details

Name: Organisation and role:

Summary of personal (remanufacturing) expertise:

Category of remanufacturing actor: What best describes your activity?

- OEM/OES remanufacturer (i.e. on your own products)
- Contract remanufacturer (i.e. on behalf of an OEM)
- Independent remanufacturer
- Core broker
- Part distributor
- Dealership/workshop

Market segment: Passenger vehicles/trucks/combination

Question 2: What role do you think remanufacturing should play in the automotive supplychain?

Is it different for in-warranty vs. out-of-warranty parts?

Competition against low-cost imports?

Could it have a role in assembly of new vehicles (i.e. not just aftermarket?)

Could it help reduce CO_2 impacts?

Could it secure the availability of spare parts? (esp. electronic parts)

Could these parts be used in insurance claims?

Are there any other roles that come to mind?

Question 3: What (if any) are the differences between remanufacturing components forpassenger vehicles and trucks?

Question 4: How would you describe the current state of the automotive remanufacturingindustry in Europe?

How would you describe the structure of the aftermarket sector for the components you work with? (Share of OEM/OES, contracted and independent, number and size ofplayers etc.)

Previous analysis suggests in 2018, the automotive component remanufacturing market was ~€8.2 bn (c.f. €123 bn automotive parts aftermarket in 2017) – what proportion of that would you estimate is made up of the components you work with?

Do you have requests from OEM to offer specific components as remanufactured parts?

Question 5: How is remanufacturing of automotive components likely to develop in Europeover the next 10 years?

What are the key drivers for these changes?

What are the key challenges to be faced?

Question 6: How might the shift to electric vehicles impact on remanufacturing uptake? Arethere any other technological advances that might influence remanufacturing activity?

How does remanufacturing components for EVs compare to ICE components?

Are the technology/logistics/skills available for EV component remanufacturing?

Are EV components being designed with remanufacturing in mind?

How is your business preparing for the shift to EV?

Will there be differences between the electrification of passenger vehicles and trucks?

Question 7: What policy interventions (at an EU level) do you anticipate in the short tomedium term that could impact remanufacturing uptake? What might be the scale ofpotential changes?

Will EU policy support or hinder remanufacturing activities in Europe? Examples: Circular Economy Action Plan, Eco-design policy, EPR schemes, ELV Directive, Green deal, CO_2 emissions performance standards, EU battery directive, EU plastics strategy, Clean vehicles directive, REACH, Right-to-repair initiatives, Bans of ICE sales.

Question 8: How might issues of climate change and the net zero agenda impact on remanufacturing uptake?

Do you evaluate the life cycle/CO_2 impacts of remanufactured vs. manufactured components?

If so, does this analysis show benefits to using remanufactured components over others? What magnitude of benefits?

Do you include scope 2 and scope 3 emissions in your analysis?

Question 9: What do you consider to be the most important barriers to increasing the uptakeof remanufacturing? Will these barriers likely change in time?

Question 10: Do you think there are natural limits to remanufacturing? (As a proportion ofmanufacturing.)

Limits to the peak level it could reach? E.g. as a percentage of manufacturing.

Limits to the rate of uptake?

When might these limits be reached?

Are these limits specific to particular components?

Question 11: How might the remanufacturing industry size and structure change betweennow and 2030, including in terms of the roles of and interactions between OEM remanufacturers, contracted remanufacturers, and independent remanufacturers?

What might trigger these changes?

Question 12: What factors might affect the profitability of remanufacturing between now and2030, and so make it more, or less, commercially attractive?

THESE QUESTIONS RELATE TO YOUR BUSINESS ACTIVITY (only relevant to **remanufacturing practitioners)**

Question 13: What influences your business to undertake remanufacturing?

Question 14: What is the current remanufacturing status and 2030 potential for differentcomponents?

What proportion of in-warranty part demand is met by remanufactured parts?

What proportion of off-out warrant part demand is met by remanufactured parts?

How does in-warranty reman volume compare with out-of-warranty reman volume?

What is the approximate proportion of remanufacturing to manufacturing, byvolume?

Is this component made obsolete by the move to electric

vehicles?Has it been experiencing growth/decline/stability?

What are its remanufacturing prospects in 2030?

Question 15: For any components that you currently manufacture but do not remanufacture,what are the reasons for this?

Would you consider remanufacturing these in the future? Why? Why not?What would need to change?

AND FINALLY…

Question 16: Do you have any other thoughts or comments you would like to share on the topic of automotive component remanufacturing in Europe?

Thank you again for your participation!

Annex B *Passenger cars market estimations*

Product growth trends

Product growth trends for the **traditional portfolio** for 2012 to 2018 and 2018 to 2023 were originally taken from the JRC SMART report (2021)[64] and updated based on responses from stakeholder interviews.

The actual figures from the JRC SMART report (2021), are the following:

Table 10: Number of remanufactured components (2012)

Component	**2021 units**	**Component**	**2021 units**
AC compressors	285,000	Gasoline injection components	250,000
Alternators	3,220,000	Gearboxes	312,000
Brake callipers	1,700,000	Hydraulic-oil-water pump	380,000
Brake components	200,000	Ignition distributors	150,000
Combustion engine	320,000	Instrument clusters	400,000
CV driveshaft	1,950,000	Manual and power steering	410,000
Diesel injection pumps	1,350,000	Pulleys and small motors	400,000
Diesel injectors	4,750,000	Starters	2,680,000
Electronic control units	300,000	Transmissions and torque converters	156,000
Engine components	200,000	Turbochargers	400,000
Engine cylinder heads	950,000		

(Source: JCR SMART Report (2021))

Growth trends for the period 2023 to 2030 were projected based on stakeholder interviews and Oakdene Hollins' analysis. Stakeholders were presented with the numbers in Table 10 and were asked to predict the historic trends from 2012 to 2018, the current trends from 2018 to 2023 and future trends for 2030. This was coupled with the estimates in the JRC SMART Report (2021); the individual component profiles provide justifications behind these trends and where there were differences in stakeholder opinions.

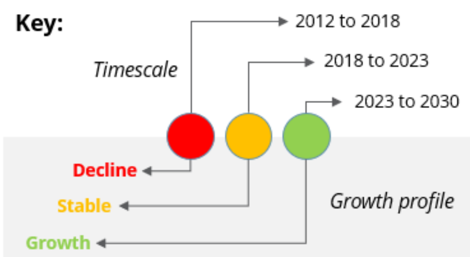
[64] Joint Resource Council, The Sustainable use of Materials through Automotive Remanufacturing to boost resource efficiency in the road Transport system (EU Science Hun, 2021), 15

Table 11: Summary of component growth trends

Product	Growth
AC compressor	Green, Yellow, Yellow
Alternator	Yellow, Red, Red
Brake calipers	Green, Yellow, Yellow
Brake components*	Yellow, Yellow, Yellow
Clutches	Red, Red, Red
Combustion engine	Yellow, Yellow, Yellow
CV driveshaft	Yellow, Red, Red
Diesel injection pump	Yellow, Red, Red
Diesel injectors	Green, Yellow, Red
Electronic control units (ECUs)	Green, Green, Green
Engine components**	Green, Green, Yellow
Engine cylinder heads	Yellow, Yellow, Yellow

*ABS and EBS modules, brake pumps etc.
** Connecting rods, valves etc.
*** Air flow mass meters, electrical/electronic throttle bodies, EGR valves
**** Steering racks, steering columns

Product	Growth
Gasoline injection components***	Yellow, Yellow, Red
Gearboxes	Yellow, Yellow, Red
Hydraulic-oil-water pumps	Green, Yellow, Red
Ignition distributors	Yellow, Yellow, Red
Instrument clusters	Green, Yellow, Yellow
Manual and power steering****	Yellow, Yellow, Yellow
Pulleys and small motors	Green, Yellow, Yellow
Starter	Yellow, Red, Red
Transmissions	Green, Green, Yellow
Torque converters	Green, Green, Yellow
Turbochargers	Green, Green, Green



(Source: Stakeholder interviews, JCR SMART Report (2021))

The upper and lower bound growth percentages were based on the same parameters mentioned in the JCR SMART report; these growth percentages were the following:

Table 12: Upper and lower bound growth percentages[64]

Growth trend	Lower bound	Upper bound
Growth	3%	15%
Stable	-2%	2%
Decline	-10%	-3%

(Source: JCR SMART Report (2021))

Validating the market

Current and future market sizes were calculated by estimating the projected number of units of different components and multiplying by the estimated component price at ex supplier level.

The component prices were validated by stakeholders and stakeholders provided multipliers for values at ex supplier and end consumer level.

The overall bottom-up approach can be found in Figure 30 below:

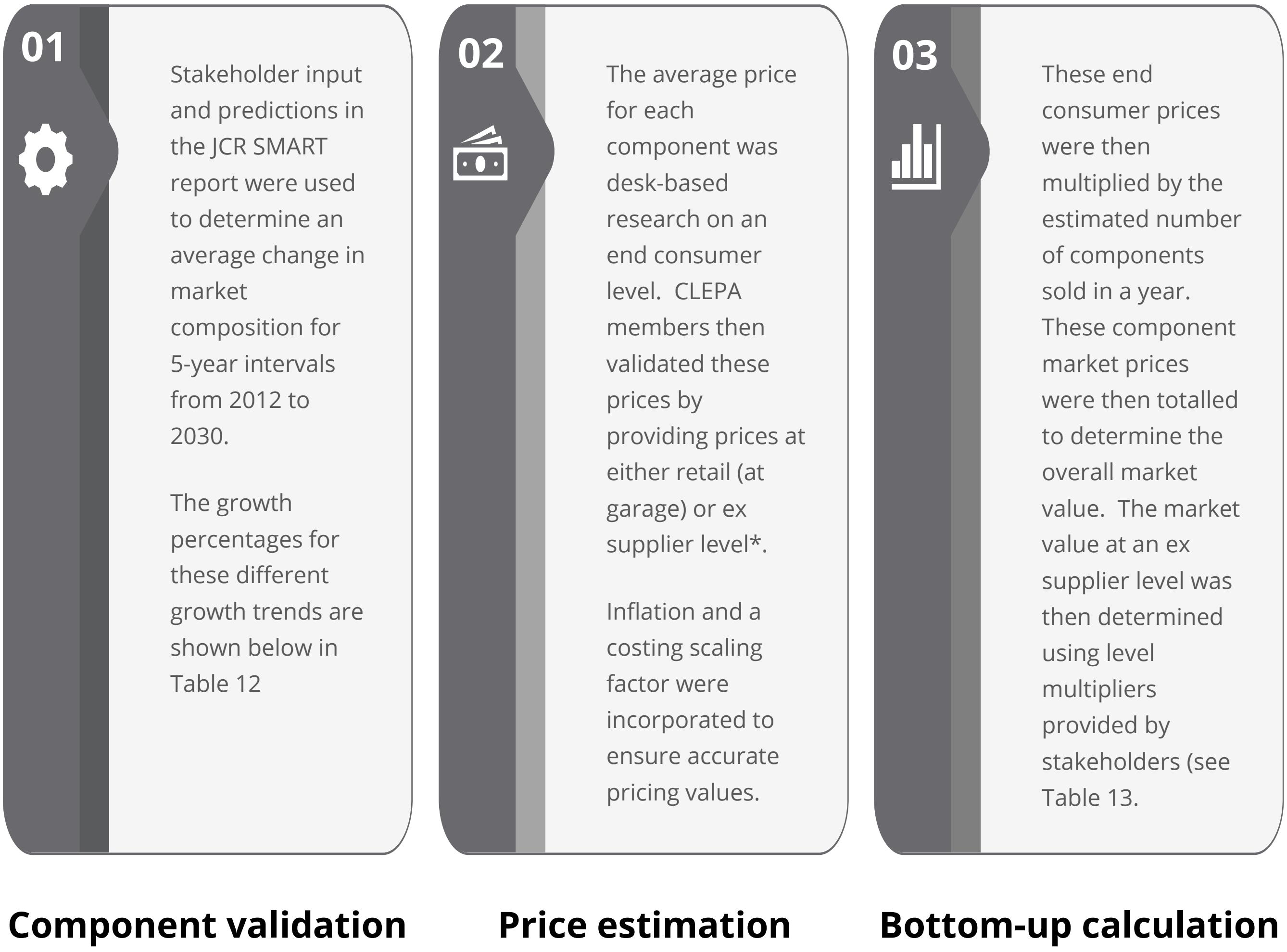


Figure 30: Market validation process

The market value multipliers provided by stakeholders were the following:

Table 13: Market multipliers

Market level	Multiplier
End consumer	1.15
Retail @ garage	1.4
Ex. Supplier	1

(Source: Stakeholder interviews)

Note: The value of the market is shown at an ex supplier level, unless stated otherwise.

Annex C *Commercial vehicle market estimations*

Product growth trends

The number of remanufactured units in this section was based on values given in Remanufacturing of Heavy Duty Vehicle Components (2014)[65]. This publication divided components into eight groups as shown in Table 14; insights into the potential growth of these component groups was also provided.

Table 14: Commercial vehicle component breakdown

Components	No. of units
Starters, alternators, DC actuators	390,000
Power steering and pumps	205,000
Diesel injection pumps and components, EGR, particle filters and turbochargers	1,965,000
Electronic units, instrument clusters and controllers	45,000
Combustion engines, cylinder heads and engine components	180,000
Pumps, AC compressors	125,000
Air brake components, callipers, cylinders, actuators, filters and compressors	190,000
Truck transmission and off-road gearboxes	155,000
Drive shafts, retarders, clutches, differentials & axles	335,000
Total	3,590,000

(Source: Remanufacturing of Heavy Duty Vehicle Components (2014))

To determine the growth trends for the components, stakeholders were asked to predict the trends for individual components. These insights were then remodeled to represent the eight component groups.

As the majority of the stakeholder interviewees worked in the passenger vehicle space, only a few components were covered by stakeholder insights.

[65] Weiland F.J., et al, Remanufacturing of Heavy Duty Vehicle Components (2014), FJW Consulting.

Table 15: Commercial vehicle growth trends

Stakeholder insights

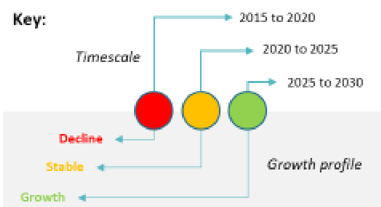
Product	Growth
AC compressor	Amber, Amber, Red
Actuators	Amber, Amber, Red
Alternators	Amber, Amber, Red
Brake calipers	Amber, Amber, Amber
Brake components - ABS	Green, Green, Amber
Brake components - EBS	Green, Green, Amber
Clutches	Red, Red, Red
Starters	Amber, Amber, Red
Turbochargers	Green, Amber, Red

Modelling assessment

Product	Growth
Starters, alternators, DC actuators	Amber, Amber, Red
Power steering and pumps	Green, Green, Red
Diesel injection pumps and components, EGR, particle filters and turbochargers	Green, Amber, Red
Electronic units, instrument clusters and controllers	Green, Green, Amber
Combustion engines, cylinder heads and engine components	Green, Green, Amber
Pumps, AC compressors	Amber, Amber, Red
Air brake components, calipers, cylinders, actuators, filters and compressors	Green, Green, Amber
Truck transmission and off-road gearboxes	Green, Green, Amber
Drive shafts, retarders, clutches, differentials & axles	Amber, Amber, Red

Qualitative assessments of the growth profile of some commercial vehicle components was available from stakeholder interviews, as summarised above. This was used along with literature review and Oakdene Hollins analysis to define the product growth trends to 2030 used in our modelling assessment, using the product categories defined by Weiland (2014) for analysis of heavy duty components.

The general view from stakeholders was that the outlook for the CV parts aftermarket was positive to 2030.



(Source: Stakeholder interviews, Remanufacturing of Heavy Duty Vehicle Components (2014))

Validating the market

Calculating the value of the commercial vehicle market involved two approaches to determine an upper and lower bound estimation. Both estimates were calculated at an end consumer level and then converted to an ex supplier level.

The Remanufacturing of Heavy Duty Vehicle Components (2014) estimated the end consumer market value at € 3.7 billion.

Stakeholder input provided insight into how trends will change. A baseline CAGR of 1.9% from a Frost & Sullivan mobility study was used.

Authors

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Rachel is a Senior Consultant and holds an Engineering PhD from the University of Cambridge in options for achieving a 50% reduction in steel industry CO_2 emissions by 2050. Since joining Oakdene Hollins in 2013, Rachel has been active in the analysis of remanufacturing and value retention markets ranging from geographical regions (e.g., the UK, Canada, Malaysia, and Scotland) to individual products (e.g., electric vehicle batteries, power distribution equipment, printer cartridges) and sectors (e.g., copper, automotive). She has experience in assessing the economic and environmental benefits of remanufacturing, developing policy and innovation recommendations, and modelling the impacts of future remanufacturing scenarios.

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