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DEMAND-LED INNOVATION FOR THE AUTOMOTIVE SECTOR: MATERIALS REQUIREMENTS IN 2030 AND BEYOND

Final Report

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Glossary

Term	Definition
AHSS	Advanced High Strength Steel
ASR	Automotive Shredder Residue
BEV	Battery Electric Vehicle
BF	Blast Furnace
BF-BOF	Steel production process using BF and BOF
BIW	Body in White
BOF	Basic Oxygen Furnace
CBAM	EU Carbon Border Adjustment Mechanism
CCUS	Carbon Capture, Utilisation and Storage
CF	Carbon Fibre
CFRP	Carbon Fibre Reinforced Polymers
CO2	Carbon dioxide
CO2e	Carbon dioxide equivalent
DESNZ	Department for Energy Security and Net Zero
DR	Direct Reduction
DRI	Direct Reduced Iron
DRI-EAF	Steel production process using DRI and EAF
EAF	Electric Arc Furnace
EC	European Commission
ELV	End-of-Life Vehicle
EoL	End of Life
ETC	Energy Transitions Commission
EV	Electric Vehicle
GFRP	Glass Fibre Reinforced Polymers
GHG	Greenhouse Gas
GJ	Gigajoule
GJ/t	Gigajoule per tonne
Gt	Gigatonne
GWP	Global Warming Potential
H2GS	H2 Green Steel
HDV	Heavy Duty Vehicle
HEV	Hybrid Electric Vehicle
HSS	High Strength Steel
IAI	International Aluminium Institute
ICE	Internal Combustion Engine
ICEV	Internal Combustion Engine Vehicle
IEA	International Energy Agency
JLR	Jaguar Land Rover
kg	kilogram
LCA	Life cycle assessment
LDV	Low Duty Vehicle
MCDA	Multi-criteria Decision Analysis
MDPI	Multidisciplinary Digital Publishing Institute
MJ	Megajoule
NFRP	Natural Fiber Reinforced Plastic composites
OEM	Original Equipment Manufacturer

ONS	Office for National Statistics
PHEV	Plug-in Hybrid Electric Vehicle
SMMT	Society of Motor Manufacturers and Traders
t	tonne
UKRI	UK Research and Innovation
VOC	Volatile Organic Compound
ZEV	Zero Emission Vehicle

EXECUTIVE SUMMARY

UKRI's Transforming Foundation Industries Challenge, delivered by Innovate UK, Engineering and Physical Sciences Research Council (EPSRC) and the Economic and Social Research Council (ESRC), aims to reduce energy and resource use within the foundation industries (metals, glass, chemicals, ceramics, cement and paper). The purpose of this study is to support these industries to understand the anticipated demand for materials in 2050 by their downstream customers in the automotive sector.

Demand-led innovation is innovation incentivised by a visible gap in the market for a product or a service that consumers or buyers want access to and for which they would be willing to pay. Clear demand signals from downstream companies assure manufacturers that they can generate financial returns by designing a new product or service and bringing it to the market. Certainty over demand reduces the risk of investment in research and development (R&D) of new products and services, improving the economic feasibility of innovation and commercialisation of new products and production processes. Actions by the UK Government can support demand-led innovation in UK industry in such a way as to accelerate climate action and decarbonisation (Cambridge Institute for Sustainability Leadership, 2023).

The goal of this "Demand-led Innovation Study" is to support the foundation industries to understand the market opportunities and challenges, potential impact of disruptive products or business models, and the relevant research and development efforts required to meet the automotive sector's future needs.

Through an extensive literature review, evidence was gathered of existing and future demand for foundation industry materials. Innovation challenges stemming from automotive material requirements were also identified. The literature provided a policy context for automotive manufacturing in the UK, its key export markets, and a quantitative assessment of material demand in UK automotive production. A shortlisting process was undertaken to identify key materials with the following considerations:

- High share of vehicle weight.
- Significant UK material production rates.
- The UK's influence on the material's supply chain.
- Innovation potential.
- Material sustainability.

Note that the scope of this study excluded battery-specific materials considered in other work. The resulting shortlist contained six groups of materials: **cast iron & steel, aluminium, plastics, polymers & composites, copper,** and **glass.**

The shortlisted materials were then subjected to a deep dive to understand their current method of production, innovations in production methods, the estimated current and future demand for these materials, and their sustainability performance. The research findings were used to shape engagement with automotive manufacturers (OEMs) through interviews, which explored their company-level perspectives on material challenges in the context of reducing the environmental impacts and advancing electrification of their vehicles. To broaden the context and understand the industry-wide trends, and to consider potential support mechanisms and their urgency, a roundtable workshop was held with automotive OEMs, Tier 1 suppliers, and material suppliers.

The key material innovation challenges facing the automotive industry as identified from literature, stakeholder interviews and roundtable are:

1. A need to replace materials with alternatives to reduce vehicle mass to reduce greenhouse gas (GHG) emissions or increase range (**lightweighting**). This may mean replacing traditional cast iron & steel with lightweight alternatives like high-strength steels, aluminium, and non-metal composites.
2. A need for **lower carbon material** options to replace conventional materials to reduce embedded GHG impacts. This means lower-carbon material production methods (e.g., with increased use of renewable energy) or using alternative materials with a lower carbon footprint.
3. A need to **increase circularity** through improving the availability and suitability of **recycled material** options to replace conventional materials while ensuring **high recyclability** of the vehicle at end-of-life. This may require closed-loop supply chains and designing vehicles for ease of recycling.

The automotive industry therefore needs **innovative materials** that enable lightweight vehicles, have a lower carbon footprint, and increase recycled material content in the vehicle and its recyclability at the end of life, compared to established materials. Vehicle OEMs are driven by the end-users (vehicle buyers) and so also need to maintain the safety, quality, durability, and performance standards and competitiveness of their products, which results in more general cross-cutting challenges for material demand:

A. A need to identify solutions to improve the **cost-effectiveness/affordability** of innovative materials.
B. A need to identify solutions to improve and validate the **sustainability** of materials.
C. A need for a **dependable supply** of innovative materials of **suitable performance** (grade).
D. A need for **capacity building and upskilling** within the sector to adapt to **new processes** associated with the use of innovative materials.

To address these material innovation challenges, a range of potential interventions were identified from the roundtable workshop and through Ricardo's analysis. These are:

Funding for research and demonstration projects: Research funding can be targeted where further development of materials or production methods is needed, cross-sector challenge, or where a lack of confidence in or experience with new materials and associated vehicle design changes acts as a barrier to their adoption. Research funding that links recycling and material recovery to automotive manufacturing and enables demonstrator projects could build experience with, and set precedents for, more integrated supply chains. These include:

- Material separation technologies that address challenges related to the purity and quality of recycled materials better suited to automotive applications, such as appropriate grades of aluminium, steel, and polymers, increasing recycled content as well as recyclability.
- Using vehicle design that facilitates disassembly for more effective recycling, including the material recovery challenges of copper in control units and painted plastics, and considering how new technologies such as lightweight materials and hybrid structures may complicate material separation.
- Showcasing the feasibility and potential benefits of adopting lightweight and/or high recycled content materials along with effective design and manufacturing processes, particularly considering challenging applications such as for HGV structures.
- Cross-sector closed-loop innovation demonstrations that bring together the vehicle end-of-life and recycling industry with automotive manufacturing to showcase sustainable material utilisation.
- Support for material innovations to develop materials with a reduced environmental impact over their lifecycle, with high recycled content and recyclability, provide the performance and quality standards required by automotive applications, and explore ways to apply the new materials.

Capacity building to meet the pace of change needed in material adoption means equipping the industry with the necessary skills and knowledge to produce and utilise lightweight and/or low-carbon materials rather than traditional materials. This includes training and upskilling within the steel industry to develop low-carbon steel products and supply chains suited to the demands of the automotive sector, and training for the new forming and assembly processes in lightweight materials to provide increased flexibility and resiliency in the workforce to changing material demands and needs.

Commercialisation support for innovative materials to address the challenge of them reaching sufficient scale and reducing costs to be competitive with traditional materials. Low-cost loans or other ongoing financial support targeted at scaling up the production of key innovative materials such as carbon fibre-reinforced plastic could facilitate investment in larger, smarter, and more efficient facilities, and help to attract private investment.

The establishment of a stakeholder community was recognised by stakeholders as a valuable step to enabling greater collaboration and dialogue among and between stakeholders in the foundation and automotive industries, that would help to overcome the cross-sector challenges for innovative material adoption. An outcome of this study is a commitment from several organisations to participate in a stakeholder community led by the Transforming the Foundation Industries Challenge, which could help ensure that any proposed intervention is suitable to overcome the innovation challenges faced by their industry.

Several other potential interventions and policy developments were also identified in supporting materials innovation in the automotive sector. These include:

- The introduction of standards to certify the performance properties of recycled materials.

- Standards to compare the environmental impacts of materials through life cycle analysis.
- Improving and enhancing the End-of-Life Vehicle (ELV) directive in the UK to increase targets for the recycled content in and recyclability of vehicles, among other policies to improve circularity.
- Support for new material recycling facilities within the UK by minimising the export of waste material.
- Expediating the approval processes for developing brownfield sites to speed up the development of facilities for recycling and manufacturing with recycled materials.
- Support for localised cost-effective renewable electricity production or procurement.
- Investing in the hydrogen economy enabling its use both by industry and hydrogen vehicles.

1 INTRODUCTION

1.1 STUDY AIMS AND OBJECTIVES

The Transforming Foundation Industries Challenge, delivered by Innovate UK, EPSRC and ESRC aims to reduce energy and resource use within the foundation industries. This study focuses on the automotive sector, a key consumer of foundation industry materials and a stakeholder with significant influence over the foundation industry materials supply chain. This work will gather evidence to quantify existing and future demand for foundation industry materials and generate a list of innovation challenges stemming from material requirements from the automotive sector. This will be used to inform demand-led innovation programmes and supply chain collaboration initiatives. This work intends to enable foundation industry companies to gain more certainty on where to focus future research efforts and investments in a proactive manner. A list of key project outputs is given below.

Key project outputs:

- An engaged community of automotive sector stakeholders committed to involvement in a demand-led innovation programme (Task 1).
- Literature analysis of current and future material requirements from the automotive sector; including trends and innovation areas (Task 2).
- Lists of innovation challenges from the automotive sector on a company and industry level (Task 3).
- Suggestions on further areas of activity to support demand-led innovation in the automotive sector (Task 4).

1.2 STUDY WORKFLOW AND DELIVERABLES

The overall study was carried out in 4 key tasks that align with the main project objectives in **Section 1.1**.

Task 1 of the study sought to identify key stakeholders in the automotive sector (**D1**) and gauge the level of interest in pursuing a demand-led innovation programme. The stakeholders were invited to take part in the one-to-one interviews and the roundtable event within Task 3, and to express interest in the stakeholder community described in Section 6.3.

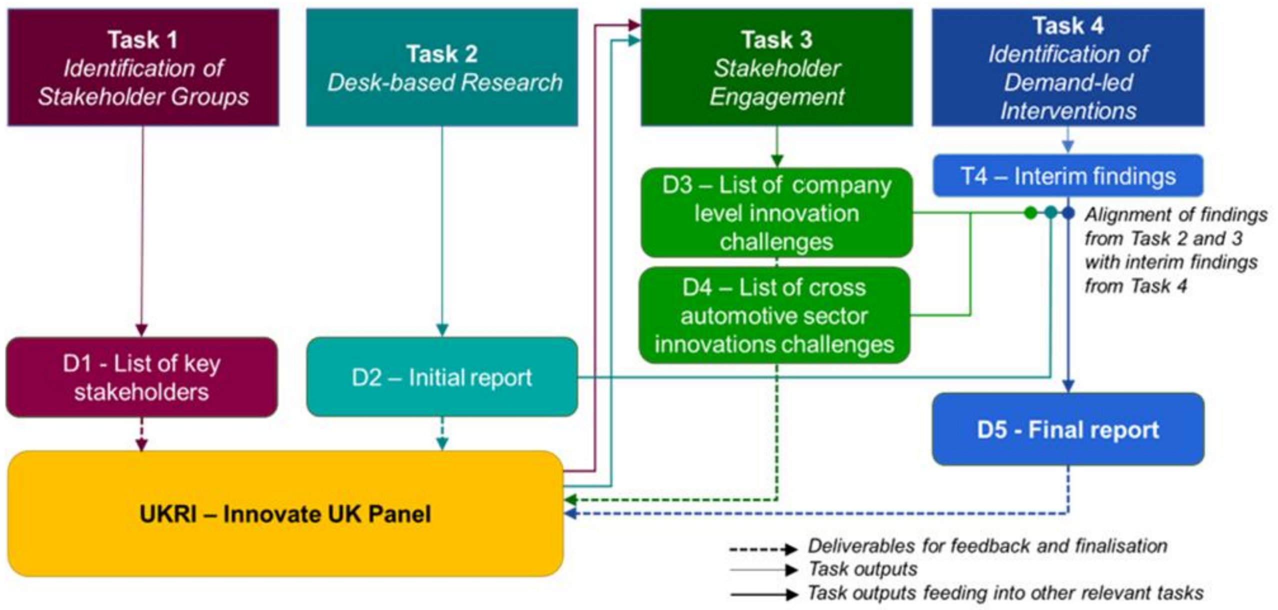
Task 2 comprised a comprehensive literature assessment exploring the current and predicted future material trends. It also assessed and quantified foundation material requirements to 2030 and beyond. The full literature assessment report (deliverable **D2**) has been published and is available on Ricardo's website, and a summary is provided in Section 2 of this report.

Task 3 built on the evidence gathered from the literature review to inform stakeholder engagement through the medium of one-on-one interviews and an industry roundtable. Throughout this engagement, Ricardo aimed to draw out industry insight into specific material innovation challenges. The findings from the stakeholder interviews are detailed in Section 3 and the outputs of the roundtable workshop are in Section 4 of this report.

Task 4 concluded the study by pulling together all gathered information from literature to industry input. Key material innovation challenges were identified on a company and cross-automotive sector basis and potential intervention mechanisms that could help overcome any barriers to material innovation extracted from the roundtable discussions expanded with potential interventions identified in literature and interviews. Ricardo then applied its own expertise to consolidate and add to the potential intervention mechanisms followed by a qualitative shortlisting exercise in Section 5, to present a range of potential interventions that could support foundation industries in meeting the challenges of developing innovative materials solutions for the automotive industry in Section 6.

The overall workplan and deliverables of the study are displayed in Figure 1-1. This report constitutes deliverable **D5**. The list of company-level innovation challenges (**D3**) derived from interviews can be found in Section 3.4 and the list of cross-automotive sector innovation challenges (**D4**) identified from the roundtable workshop can be found in Section 4.4. In Section 4.5 these challenges were ranked in terms of their urgency: short (by 2030) medium (2030-2035), and longer-term (beyond 2035); and their likely level of complexity to address based on the feedback from the workshop.

Figure 1-1: Project workplan



1.3 RECAP ON FOUNDATION INDUSTRY MATERIALS

An in-depth analysis of foundation industry materials has already been elaborated in our separately published literature review. By means of a summary, to set the context for this report, this section contains an overview of what are the foundation industry materials and what are their relevance and importance to the automotive sector.

The foundation industry materials include metals, chemicals, cement, glass, ceramics, and paper. Many of these are in high demand from the automotive sector. The UK has historic capabilities in both automotive manufacture and foundation industry material supply, therefore there is an intrinsic link between the two sectors. Both sectors are major economic contributors and employers within the UK with the automotive sector being the main driver for material innovation, manufacturing and product design.

Current innovation trends across the foundation industries centre around the need to become more sustainable, including drives for increased circularity, improved recyclability, increased efficiency of production and emission reduction across the manufacturing process. We are now only one investment cycle away from 2050 by which time foundation industries should reduce their emissions by 90%. Further advancements in material science also drive innovation with improvements in material strength, high performance and production from a wider range of feedstock materials. External pressure from consumers, the political landscape and competition from non-foundation industries materials are creating challenges, therefore opportunities, for the foundation industries to address.

2 DESK-BASED RESEARCH

2.1 SUMMARY OF APPROACH

Desk-based research was carried out to inform a literature analysis of the current and future foundation industry material requirements of the automotive sector. Owing to the complex composition of materials in a vehicle's construction, including a multitude of alloyed components, a deep dive into all materials could prove to be time-consuming. As a result, this study was initiated with the identification of a longlist of materials, following which the most promising and highly relevant shortlist of materials were identified and subjected to further desk-based research.

A long list of seven foundation materials used in glider construction[1] of vehicles was compiled using previous LCA work performed by Ricardo for the European Commission (Ricardo, 2020). The longlisted materials were then shortlisted to the key foundation materials most relevant to the automotive sector using a multi-criteria decision analysis (MCDA), where materials were assessed based on selection criteria such as projected automotive material demand, extent of UK production and influence on the supply chain, and current and future sustainability characteristics. Subsequently, five material groups (Iron and steel; Aluminium; Glass; Plastics, Polymers and composites; and Copper) were shortlisted.

Informed by an in-depth review of relevant literature, the current sustainability and future innovation potential for each shortlisted material was assessed. Also, the current and future demand in 2030 and beyond for each shortlisted material was quantitatively determined to illustrate higher-level material trends, using Ricardo's proprietary vehicle LCA model based on our previous analysis (Ricardo, 2020), (Ricardo, 2022) with industry projections on vehicle production in the UK (SMMT, 2023a) (SMMT, 2023b).

More details on the methodology used for material shortlisting and material demand trends, and justification for each shortlisted material's assessment against the selection criteria, are provided in the appendices to the initial findings report covering the desk-based research stage of this project, published separately on the Ricardo website here.

2.2 SUMMARY OF DESK-BASED FINDINGS

A summary of the main conclusions from the desk-based research phase - covering material-specific findings, cross-cutting trends, and identified innovation challenges for the automotive industry - are provided below. The full findings and conclusions from the desk-based research phase of this project, along with the full methodology and justification of material shortlisting, were recorded in the initial findings report "Demand-led Innovation for the Automotive Sector: Material Requirements for 2030 and Beyond" published separately, which can be found on the Ricardo website here.

2.2.1 Material findings

A summary of material-specific findings from the desk-based research phase for each of the shortlisted material groups (Iron and steel; Aluminium; Glass; Plastics, Polymers and composites; and Copper) is provided below, covering the relevance to and projected demand from the automotive sector, sustainability characteristics, and key challenges, limitations, and potential innovation areas.

2.2.1.1 Iron and Steel

Due to its desirable physical properties, durability and relatively low cost, steel remains an important material for structural and bodywork components across all vehicle types in the automotive sector. Demand for steel in a typical passenger car[2] is projected to be over 500kg in 2025, representing 45% of total typical car weight, with similar steel vehicle content shares for other light-duty vehicle (LDV) and heavy-duty vehicle (HDV) categories. In addition, cast iron, although less desirable than steel due to greater brittleness and lower malleability, is used in engine and brake components, accounting for 9% of total car weight in 2025. However,

[1] Note that although this study focussed on the sustainability and innovation challenges of foundation materials found in the vehicle glider, battery-related materials pose significant environmental impact and are expected to increase in demand due to vehicle electrification.

[2] Note that the quantification of future material demand required the assumption of specific vehicle segments for each vehicle type considered. In the case of passenger cars, it was assumed that the lower medium vehicle segment provides an indicative material content for the whole UK passenger car fleet. However, variations between vehicle types will produce differences in material content volume and shares, i.e., for the "SUV" vehicle category in the passenger vehicle type which requires more material for production. For more details, see Section A1.3 below.

with vehicle manufacturers increasingly pursuing lightweighting to reduce vehicle lifecycle emissions from the use phase (see Section 2.2.2.1), both steel and cast iron content is projected to decline between 2025 and 2050 for all vehicle types. The main alternatives for conventional steel in structural components are advanced- or ultra-high-strength steel (HSS) or lightweight alloys, such as aluminium and (more rarely) magnesium. As the projected removal of conventional steel outweighs the addition of HSS, steel content is projected to reduce by around 45% in a typical passenger car by 2050, and by around 75% in a representative articulated lorry. Therefore, whilst steel remains an important material for innovation in the near to medium term, the projected shift to a wider range of materials in vehicle gliders by 2050 will require a diverse approach towards material innovation challenges facing the automotive sector and the foundation material industry.

Pure iron is the main feedstock for both cast iron and steel, with 90% of mined iron ore currently reduced into pure iron in the blast furnace (BF) using coke. Current production of steel for the automotive sector is dominated by the integrated “primary” blast furnace-basic oxygen furnace (BF-BOF) production route, with a carbon intensity of around 2.0 tCO_2e per tonne of steel[3]. The largest sources of emissions are from the use of coke and limestone in the BF to reduce the mined iron ore and the release of CO_2e process emissions in the BOF.

Emerging processes to lower the carbon intensity of pure iron include the use of hydrogen injected into the BF (21.4% emission reduction potential) and, most promisingly, the direct reduction of iron ore using hydrogen (HDR) (near 100% emission reduction potential) (Turek. et al, 2017). The main alternative steel-making technologies which offer the largest sustainability improvements on the primary BF-BOF route are the “secondary” electric arc furnace (EAF) production route, where scrap steel content is recycled in an EAF; and the primary hydrogen direct reduction-EAF (HDR-EAF) pathway, which uses hydrogen from renewable sources to directly reduce iron ore into pure iron before processing into steel in an EAF. Both these routes can deliver over 90% emission reductions compared to the primary BF-BOF route when using 100% renewable energy (ETC, 2021), (IEA, 2020).

The secondary EAF pathway is an established steel production technology, representing a large share of total steel production in Europe (43% in 2023) and future UK production (with recent announcements for conversion of existing BF-BOF sites at Scunthorpe and Port Talbot to EAFs by 2025) (EUROFER, 2023). Scrap steel from end-of-life vehicles has a high recoverability of around 97% material weight. However, only 15% of an average vehicle’s steel content is currently comprised of recycled steel from the secondary EAF pathway (Watari, T., et. al., 2023). The low share of recycled steel content found in the automotive sector is primarily due to the lack of sorting and recycling processes which separate out lower steel grades to prevent the introduction of impurities that exceed the level required by performance-critical components in a vehicle. Therefore, secondary EAF production holds large innovation potential to decarbonise automotive steel in the UK through the implementation of improved scrap processing and recycling capacity and capabilities, and greater integration between automotive OEMs, the steel foundation industry and scrap processing centres.

The main low-carbon alternative to the primary BF-BOF pathway is the HDR-EAF pathway, where green hydrogen (produced in an electrolyser using renewable electricity) is used to produce pure iron through direct reduction of mined iron ore before the pure iron is converted to steel in the EAF. Whilst several full-scale green hydrogen DRI-EAF plants are currently under construction in Europe and set to begin production in 2026 (H2GS, 2023a) (SSAB, 2023b), the UK lacks both green hydrogen production facilities and integrated DRI-EAF steelmaking infrastructure to enable low-carbon primary steel production. Therefore, a key area for innovation is the support of cost-competitive low-carbon primary steel production in the UK, in particular through the development of affordable, reliable green hydrogen production and storage infrastructure linked to green steel hubs and the wider supply chain.

2.2.1.2 Aluminium

Aluminium has versatile physical properties, such as high formability and strength-to-weight ratio, which make it desirable as a lightweight alternative in vehicle bodies in white (BIW) applications over traditional materials such as conventional steel, HSS and cast iron. As such, driven by a greater policy focus on the energy efficiency of vehicles, passenger cars and commercial vehicles are increasingly leaning towards lightweighting options involving aluminium. Currently, aluminium content accounts for 150kg in a typical car by 2025 (12% of vehicle weight), with similar shares in vans (10%), rigid lorries (11%) and articulated lorries (14%). However,

[3] A carbon dioxide equivalent or CO_2 equivalent, abbreviated as CO_2e in this report, is a metric measure used to compare the emissions from various greenhouse gases on the basis of their global-warming potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential (Eurostat, 2021).

this share is expected to grow substantially between 2025-2050, with average vehicle aluminium content projected to reach 18% of BIW content by 2040 (Giampieri. et al, 2020). Total aluminium demand by the automotive sector is projected to double in the medium term, before falling by 2040 due to an overall decline in vehicle sales and effects of greater vehicle lightweighting towards 2050.

The key challenge to the wider deployment of aluminium in the automotive sector is addressing the energy intensity of the current production process, and subsequent high emission intensity and cost, relative to steel – with 53.8GJ of energy consumed per tonne of aluminium for the electrolysis process alone (MPP, 2023) compared to 15.8GJ per tonne of BF-BOF steel (MDPI, 2019).

The consumption of electricity, primarily in the electrolyser, accounts for more than 60% of the total aluminium sector emissions (Cooper. et al, 2017) (Environdec, 2013). As such, the total carbon intensity of primary aluminium is highly dependent on the regional grid energy mix, and electricity decarbonisation through securing renewable energy sources for aluminium production will be key to lowering the production and subsequent overall lifecycle emissions. Limited support from carbon capture and storage (CCUS) deployment where low-carbon energy sources are not readily available is also a secondary option. Furthermore, direct emissions, from using thermal energy from fossil fuels and process emissions from carbon anodes consumed during electrolysis, account for over 30% of total aluminium emissions (IAI, 2021). Technological and process innovations (such as inert anodes and mechanical vapour recompression) that seek to reduce direct production emissions are in the later stages of development and trials and will require further support to ensure deployment on a commercial scale.

Aluminium is a highly recyclable material, with infinite recycling potential, lower energy requirements compared to primary production (5% of primary aluminium production) and a carbon intensity of 0.5 tCO_2e per tonne of recycled aluminium (representing a 97% reduction relative to primary production emissions) (MPP, 2023). Currently, 90% of aluminium scrap from vehicles is recycled (Auto Recycling World, 2021), with different aluminium alloys typically combined in the recycling process to produce a single, mixed grade of recycled aluminium. Although this mixed grade can be used for some automotive components such as the engine block of internal combustion engine (ICE) vehicles, the downgrading of the alloys constrains their wider use in vehicles. Whilst the UK has limited primary aluminium production or refinement capacity, the availability and suitability of recycled aluminium from end-of-life (EoL) vehicle scrap and other sources within the UK provides a key opportunity to establish a strong domestic secondary aluminium supply chain. As such, closing the loop on automotive aluminium through improved scrap collection, sorting and processing would provide a rapid and low-cost route to rapidly reducing production emissions. Key to this is establishing a closed-loop supply chain between scrap processing and recycling centres, automotive OEMs and the foundation industry.

2.2.1.3 Plastics, polymers, and composites

Plastics, polymers and composites[4] currently make up a number of components in a vehicle including airbags, seats, fenders (wings), dashboards, handles, engine covers and interior wall panels. Currently, around 200kg of a typical car is estimated to be made of plastics, representing 13% of car material mass in 2025, and similar proportions for vans (10%), rigid lorries (5%), articulated lorries (5%), and buses (14%). Fibre-reinforced polymer (FRP) demand, such as carbon FRP (CFRP) and glass FRP (GFRP), is projected to increase significantly between 2025-2050 due to their lightweighting potential and falling costs as the market develops. As such, overall automotive demand in the plastics, polymers and composites category is projected to increase by between three to five times above 2025 levels by 2050.

Plastics are conventionally produced from petrochemicals which, in turn, are sourced from fossil-derived crude oil and natural gas – as such, plastic bulk products are resource-intensive and lock in dependency on fossil resources. Production of one kilogramme of virgin plastics can require anywhere between 75-90MJ of energy depending on the type of plastic produced, higher than both steel and aluminium.

One of the main pathways to reduce embodied emissions of plastic, polymers, and composites from the production stage, as well as reducing non-biodegradable waste from automotive scrap, is to improve the recovery and integration of recycled plastics into vehicle content. Post-consumer scrap plastic is not widely deployed in automotive applications due to undesirable performance characteristics and a lack of recycling methods which efficiently recover and sort plastic waste. Currently, most ELV plastic is shredded as part of

[4] Plastics are a type of polymer produced from petrochemicals, with other naturally occurring polymers including cellulose, starch, rubber and natural fibres. Composite materials are made from two or more constituent materials, with a common example in the automotive sector being fibre-reinforced plastics (FRP) made from a polymer matric reinforced with fibres such as carbon (for carbon FRP) and glass (for glass FRP).

the ELV management process, where ferrous and non-ferrous metals are separated from the plastic and composite residues, with this automotive shredder residue (ASR) then typically landfilled or incinerated due to the potential presence of hazardous contaminants (Santini, 2012), (Macini, 2020). Whilst other polymer composite material recycling processes exist, such as thermal (pyrolysis) or chemical (solvolysis) recycling, these processes have high energy requirements of 50MJ and 26MJ/kg of recycled product respectively (Composites UK, 2016b). However, mechanical recycling, where disassembly and sorting of components before shredding takes place, is an emerging low-carbon CFRP recycling process, requiring only 0.2MJ/kg of recycled CFRP, with initial large-scale deployment beginning in 2023 (JEC, 2022), (FAIRMAT, 2023). However, mechanical recycling is still under development, has low efficiency and is yet to be commercialised for mass production. A key innovation action for automotive OEMs is to collaborate with scrap and recycling companies and the foundation material industry to ensure future vehicle designs allow semi- or fully-automated disassembly and separation of recyclable materials.

FRPs, such as CFRP and GFRP, can deliver better performance and CO_2e emission savings during the vehicle's use phase compared to metal components, due to their significantly lighter weight, comparable durability and consistent mechanical properties. Moreover, recent research has shown that CFRP can provide more cost-effective emissions savings when compared to AHSS in ICEVs (Shanmugam, et al., 2019), although AHSS performed better in BEVs (which can have low or near-zero use phase emissions). Moreover, the cost of producing CFRP at a small scale in the US has been demonstrated to fall by 25% in a five-year period, with greater demand and investment for large-scale production expected to accelerate the affordability of FRPs.

However, production of FRPs rely on even more energy intensive processes, with the GWP of CFRP over 20 times higher than a comparable steel part and 10 times higher than aluminium. As such, a key challenge to the further deployment of FRP components in vehicles is the current lack of commercial-scale sustainable production processes for FRPs, with emerging innovative processes requiring support to commercialise and deliver cost-competitive and mass-produced components. One emerging alternative to conventional plastic is natural fibre composites, which replace petrochemicals with natural materials (e.g., flax and hemp) in interior panelling and even bodywork in high-end LDVs, reportedly reducing CO_2e emissions by between 60-85% (Automotive World, 2022). Natural FRPs (NFRPs) are also expected to partially replace traditional petrochemical-based plastics and composites in the medium- to long-term due to their higher sustainability, lighter weight, and good performance properties. However, deployment of bio-based plastics and natural fibre composite has currently been limited to small-scale trials and high-end vehicles and remain more expensive than conventional plastics.

Therefore, support is needed to commercialise both low-carbon alternatives to conventional plastic, polymers and composites (such as NFRPs), alongside reducing production emissions and virgin material demand through recycling and innovative low-carbon production processes for key lightweighting materials such as CFRP and GFRP.

2.2.1.4 Copper

Copper is widely used in vehicles' electrical wiring, motors, and batteries due to its high conductivity, ductility, and durability. Roughly 20-30kg of copper is estimated to be found in ICEVs (cars, in particular, mainly in electrical wiring), while much higher contents are used in EVs (40 kg in PHEVs and 80 kg in BEVs) (Copper Alliance, 2017). Driven by the transition from ICEV to BEV powertrains, total automotive copper demand is expected to peak in 2040 at around 2.5 times above demand in 2025, before plateauing as more efficient innovations in BEV design such as thinner wires and smaller, higher energy density batteries reduce the need for copper within vehicles.

Virgin production of copper uses conventional metallurgical extraction, which produces large quantities of by-products (such as iron and nickel) as waste and relies on fossil fuels to generate thermal energy and electricity for extraction and refinement. In order to decarbonise conventional copper production, increasing the share of recycled copper whilst tackling emissions from primary production through electrification of equipment, and using alternative fuels and clean electricity is vital (International Copper Association, 2023).

Copper is 100% recyclable without any loss to its performance, and is typically sourced from either EoL vehicle scrap or semi-finished and finished manufacturing waste. Secondary copper production is significantly less energy and CO_2e intensive, with the highest purities of copper achieving an 85% CO_2e emissions reduction compared to primary production. Copper from secondary sources already accounts for 55% of European production and is projected to increase to 66% by 2050 (Eurometaux, 2022). As such, this is one of the major, currently practiced activities which can boost process material efficiency. Implementing sound EoL management strategies that enable the collection, segregation by scrap quality and 100% circularisation of copper is a key action for the automotive and foundation material industries to reduce copper production impacts and ensure a secure supply of this material as the EV transition, and copper demand, accelerates.

Furthermore, to decarbonise conventional (virgin) copper production, increasing the share of recycled copper whilst tackling emissions from primary production through the electrification of equipment, and using alternative fuels and clean electricity is vital (International Copper Association, 2023). Reducing copper content in a vehicle through technological innovations (e.g., battery and electric motor, nanoparticles) is also currently being explored to reduce the reliance on copper and resulting embodied emissions. This reduction in copper demand from EVs is forecast through shifting to more compact batteries for weight and cost savings, meaning that cells don't require copper wiring to modules; using thinner copper foil in battery cells; shifting to higher voltage systems that require less wiring throughout the EV.

2.2.1.5 Glass

Glass is primarily used in vehicle windscreens, side and rear windows, and some internal applications such as dashboards. Most commercial vehicles have little glass content as a share of total vehicle weight, ranging from 0.3-0.6%, with a slightly higher share estimated in cars (2.5%) and buses (4.6%). No significant change is expected in the future, although there is limited potential for replacement in some cases by polymer composites to reduce mass.

Glass is conventionally produced through energy-intensive melting and forming of key components such as silica, soda ash, lime, and dolomite with recycled glass cullet (mainly production scrap, and less than 1% post-consumer scrap). Glass, as a material carries a GWP of 1.4 kgCO_2e/kg. Although historically energy-intensive, consuming between 13-30MJ of energy per kg glass, the glass foundation industry in the UK has improved its energy efficiency significantly since 2010 through glass furnace optimisations and investment in waste heat recovery. This has reduced the overall energy intensity to 5.3MJ/ kg of material (British Glass, 2021).

As windscreens and windows are typically made up of plastic and glass components, recycling requires specialist management of the EoL route where crushed windshields are sieved to separate glass fraction from plastics. Whilst glass can be recycled to form a new vehicle component, any residual contamination of the glass cullet renders the product cullet unusable as automotive grade glass and therefore reused in other product systems. This has prevented post-consumer scrap glass from being fed back into primary glass production. Therefore, future systems for closed-loop recycling of automotive glass must ensure the separation of potential contaminants at the recovery and sorting stages of recycling to ensure quality is maintained.

Furthermore, the glass sector has strived to reduce its environmental impact significantly, almost halving the overall energy consumed to produce glass, since 2010 (Griffin, et al., 2021). In the short term, some of the most effective ways of reducing the overall production-related impacts are switching to renewable energy and using recycled glass cullet in primary glass production (Griffin, et al., 2021) (SEKISUI Chemical Co. , 2023). Longer term, switching from the current gas-fired furnaces to furnaces using electricity, both electricity and gas or hydrogen furnaces promises significant decarbonisation potential and cost-competitiveness with current production, with large-scale plans for replacing natural gas with hydrogen in the UK (British Glass, 2021).

For the vehicle use phase, technological innovations are being explored by automotive OEMs to reduce the energy demand from heating and cooling the vehicle's internal temperature by instead managing the temperature of glass. In cold and warm climates where heating and air conditioning contribute a significant amount of vehicle energy demand, these innovations have the potential to reduce use-phase and overall lifecycle emissions significantly. Similarly, alternative materials for glass have been explored, i.e., plastic windshields, however, these alternatives typically lack long-term durability and repair options after minor damage, resulting in early replacement/scrapping which impacts their overall sustainability.

2.2.2 Cross-cutting themes

From the evaluation of collected literature used to determine material-specific innovation challenges, three cross-cutting themes emerged which are expected to influence automotive material demand in the medium to long term. These are:

- Impact of vehicle lightweighting on foundation material demand trends.
- Impact of renewable electricity on the sustainability profiles of foundation materials.
- Need for supply chain circularisation as a means of introducing supply chain resilience, in addition to improving the sustainability profile of the foundation materials.

2.2.2.1 *Vehicle lightweighting*

A key automotive material trend to reduce vehicle emissions during the use phase is to lower fuel requirements through the pursuit of lighter weight designs, both by replacing denser materials (typically iron and steel) with less dense materials, alongside minimising material use through a component redesign. This is particularly relevant for ICE vehicles, where most of their lifecycle emissions are created through the combustion of fuel during the use phase (Ricardo, 2020). Materials which enable weight savings whilst maintaining tensile strength and durability include high-strength steels, light alloys (aluminium, magnesium, titanium) in varying compositions, and an array of composites (glass-, carbon-, and natural fibre-reinforced polymers) (Taub, et al., 2019) (Zhang and Xu, 2022), with each material better suited for use in different areas of a vehicle given their individual properties.

However, a challenge facing the automotive sector in pursuing lightweighting, particularly in BEV powertrains where the main source of lifecycle emissions comes from the embedded material production emissions, is to balance the potential for use phase emission reductions with the typically higher embodied emissions from the production of lightweight materials relative to conventional materials (Monteiro, et al., 2022)**.** Therefore, continued growth in the deployment of lightweight alternatives in the medium to long term will require the commercialisation of lower energy intensity, more sustainable and cost-competitive production processes to ensure that emissions and energy consumption are not shifted from the vehicle use phase to material production.

2.2.2.2 *Supply chain circularisation*

Throughout the collected literature, the need to build and improve material efficiency is emerging as a key cross-cutting theme when considering material innovation, both in terms of composition, design and end-use. One of the overarching sustainability requirements for both conventional and lightweight alternative (see Section 2.2.2.1 above) materials is the need to reduce the overall virgin material demand by the automotive sector, either through improved material production and component forming (i.e., cutting-edge casting/ moulding technologies) or through material recovery strategies (recover, reuse and recycle).

Most foundation materials were found to be 100% recyclable, excluding plastics, polymers and composites (see Section 2.2.1.3), with significantly lower energy consumption and emission intensity associated with recycled materials compared to virgin production. Moreover, the establishment of a domestic circular supply chain between scrap ELVs, sorting and recycling centres, the foundation industry and automotive OEMs provides potential for improved supply chain resilience, particularly in the UK where there is limited virgin material production but sufficient domestic supply of automotive scrap material.

However, the current technical (recycling methods) and demand-driven (loss of desired functionality while recycling) limitations associated with recycled materials lead to restrictions in their closed-loop utilisation. Challenges persist for the automotive sector and key partners in the circular economy supply chain to increase the recycled content used in vehicles and reduce virgin material demand. From the desk-based research phase, some of the key challenges to circularity were identified to include the following:

- From a supply chain perspective, there is a lack of guidance or dedicated business models for setting up reliable supply chains for secondary materials.
- The material supply chain, from foundation material production to ELV scrap processing, are currently isolated from each other as opposed to combining research and development efforts needed to realise material circularity.
- There is a lack of policy-driven pressure or subsidies incentivising secondary material integration and bolstering closed-loop material recovery targets specifically aimed at ELVs, as opposed to current generic recovery targets.
- There is a current lack of consideration given to material functionality from a life cycle perspective, particularly for emerging material alloy compositions which need to be designed for dismantling, high-quality segregation, and material recovery through EoL routes.
- Current lack of dedicated extended producer responsibility (EPRs) that accounts for establishing specialist EoL management infrastructure for ELVs, such as scrap segregation and processing, prior to recycling.

2.2.2.3 Use of renewable electricity and energy in the supply chain

Mining, refinement, and downstream production of foundation materials into vehicle components used in the automotive sector requires large energy inputs, either thermal energy (conventionally from fossil fuels) or electricity. Therefore, integral to reducing the lifecycle emissions from foundation materials is addressing the direct emissions from the on-site combustion of fossil fuels and indirect emissions from the energy sources used to generate imported electricity. Increasing the use of renewable energy in material production has large potential to reduce the total lifecycle emissions of automotive components, creating a more sustainable automotive material supply chain without the need for vehicle re-design or development of new innovative materials.

Green hydrogen, generated through electrolysis, has emerged as a key element for future low-carbon production of foundation materials for the automotive sector, including steel (see Section 2.2.1.1), aluminium (see Section 2.2.1.2), and copper (see Section 2.2.1.4). However, the environmental impact of green hydrogen is heavily dependent on the energy sources used to generate the electricity powering the electrolysis process. Therefore, sufficient renewable electricity will need to be secured and certified to ensure the production of "green" hydrogen for use in the foundation material industry. Furthermore, direct electrification of production and transportation stages can deliver deep emission reductions in the supply chain by replacing fossil fuel sources with renewable energy. However, this will typically require shifts to alternative production processes by the foundation material industry, requiring investment in new infrastructure, training and logistics. As such, shifts towards low-carbon material production will require strong demand indicators from the automotive sector, as well as the availability of reliable clean energy infrastructure and supply.

2.2.3 Key innovation trends within the automotive sector

Some key trends within the automotive sector have emerged from the review of published literature. These findings helped to inform a series of potential questions that were posed to stakeholders in the UK automotive industry (see Section 3).

Key finding 1: manufacturers continue to explore mass reduction in vehicles (although a trend to larger passenger cars is driving an increase in average mass for this vehicle category), and therefore lighter materials, in order to deliver use-phase emissions savings.

There is an incentive to reduce mass from ICEVs, and for BEVs to comply with CO_2 regulations to reduce energy usage during the use phase (reducing CO_2 for ICEVs and allowing for smaller batteries for BEVs). The literature findings suggest that the UK has historically been effective at early-stage funding for developing new materials but struggles with commercialisation. Viable candidate materials have already been developed from a functional perspective (aluminium, fibre-reinforced composites) and are being implemented in new vehicles. Achieving scale is critical to reaching a material cost which creates incentives for manufacturers to consider integration into mass-produced vehicles. It is therefore concluded, that support is required for the sustainable production of lightweight materials that UK OEMs consider fit for purpose, including steel, aluminium, glass, and alternatives to conventional plastics such as carbon fibre and natural composites.

Key finding 2: manufacturers are actively seeking closed-loop supply chains to reduce the sustainability impacts of automotive materials and preserve scarce resources.

Although recovering and recycling of foundation materials from EoL vehicles has clear sustainability benefits, current technologies, performance barriers of the outputs and the overall economic feasibility limit the deployment of recycled materials in the automotive sector. Efforts to increase the circularity of automotive materials, particularly aluminium and steel, are being pursued by several OEMs in the UK and Europe, including JLR and Volvo for aluminium (see Section 2.2.1.2). Cost- and energy-efficient carbon fibre recycling, which is also a high-impact material, may be crucial due to the anticipated increase in demand for further lightweighting of vehicles in the long term. Therefore, efforts are required to build and strengthen the UK as a 'circularity hub', by encouraging policy development, setting targets, incentives and support for OEMs and partners to close the loop for automotive scrap may be crucial. This support could start with materials with high realised recyclable potential but low recycled content in the UK, such as steel, glass and copper.

Key finding 3: manufacturers are increasingly favouring materials from suppliers using low or zero-carbon energy.

As BEV sales begin to outweigh ICEV sales, also reducing production emissions will become more important for the overall sustainability of vehicles. The production of foundation materials is energy intensive and requires a stable energy supply that can cater to competing demands from other sectors and the growing UK fleet of EVs in the medium and long term. Ensuring the production of foundation materials has access to sufficiently diversified and scalable renewable energy sources, supplemented by appropriate energy storage solutions should, therefore, be a priority. This is particularly relevant with the roll-out of a carbon border adjustment mechanism (CBAM) in the EU and consultation on a UK equivalent for introduction by 2027, which will increasingly penalise the import of high-carbon foundation materials (e.g., steel and aluminium) (DESNZ, 2023). It is therefore, recommended that further support is provided for production facilities to gain access to fully renewable energy and accelerate decarbonisation beyond grid-level improvements over a longer time horizon. This could be achieved through supporting domestic energy production facilities or a secure supply chain for green hydrogen, which is emerging as a critical alternative to fossil fuels for the low-carbon production of almost all foundation materials.

Key finding 4: manufacturers are ultimately concerned about the end user (customers) expectations and may not adopt material innovations beyond a certain degree without incentives.

Whilst policy and market trends have a large impact on material demand in vehicles, a thread running through all the above findings is that OEMs are primarily concerned with comparable profitability and customers' perception of their vehicle's market price. Regulatory policies seldom keep pace with innovation in material design or vehicle design in the automotive sector and this leads to emerging technologies being reserved for when relevant policies are proposed or enter into force. Demand-led innovation needs to be affordable from the OEMs' perspective, and by extension, any costs passed on to consumers cannot exceed any additional tangible benefits like running costs, engine performance, durability, reliability or comfort. Consumer considerations and relative profitability remain key knowledge gaps that are not explored extensively in the literature, being protected as commercially sensitive by OEMs. As such, the availability of cost-competitive solutions is a major innovation challenge, with potential for collaboration between automotive manufacturers and the foundation materials industry.

3 STAKEHOLDER INTERVIEWS

3.1 OVERVIEW OF INTERVIEW PROCESS

One-to-one interviews were carried out with various automotive OEMs. The aim of the interviews was to gain insight into the current and future material usage for automotive OEMs and understand where innovation challenges of using and sourcing materials occurs.

Two LDV OEMs and two HDV OEMs participated in this part of the consultation. All OEMs interviewed have significant UK-based operations.

A detailed account of the consultation methodology is included in appendix section A2.1.

3.2 TOPICS DISCUSSED DURING THE INTERVIEWS

The first set of interview questions posed to the stakeholders was informed by the outcomes of the desk-based research. The shortlisted materials identified (steel, aluminium, iron, plastics & polymers, glass and copper) in served as key discussion points in the contexts of both internal combustion engines and low/zero emission vehicles. Stakeholders were asked to comment on the importance of each material within their production. They were also asked to share the production processes (either traditional or innovative) of each material as well as where they are currently produced.

The second set of interview questions focused on expectations around future material use and innovation challenges. They were asked to share key barriers or challenges that their organisation is facing in adopting innovative materials, how they balance innovation and cost of the product, and how the foundation materials sector could support them in addressing any challenges.

The below shortlist of material innovation challenges highlights the key needs and concerns raised by stakeholders during the interviews.

3.3 MATERIALS OF CONCERN

During the interviews, the stakeholders discussed a range of materials, both from the shortlist and others, which they deemed important in current and future vehicle design and sustainability. Some key conclusions drawn from the discussions are listed below.

Key finding 1: Steel remains an important material but domestic supply of primary and secondary steel could be challenging.

All OEMs interviewed highlighted that steel remains important for vehicle design. However, they acknowledged a shift was needed from conventional steel products to higher and more durable high-strength steel (HSS) products. LDV manufacturers, in particular, highlighted the transition away from steel in favour of lighter material alternatives in the future. These insights from the interviews align with findings from prior desk-based research which estimated that the demand for steel across all vehicles being produced in the UK will fall between now and 2050, see Section 2.2.1.1.

However, HDV manufacturers were less convinced about an overall shift away from steel. These stakeholders, from a HDV perspective, expect steel to remain significant in trucks due to the lack of lightweight alternatives with the durability and strength that is required for long-distance and heavy payload use cases.

An LDV OEM raised concerns over the future of domestic steel supply to the automotive sector, with the UK's remaining virgin steel capacity shutting down. This aligns with findings from the desk-based research which alluded to uncertainty over the UK's future capacity to produce primary steel for the automotive sector. Findings from this research highlighted the proposals from British Steel and Tata Steel to convert current BF plants to secondary steel plants, producing steel from the scrap-Electric Arc Furnace (EAF) route instead. The LDV OEM highlighted during the interview that the supply of secondary steel alloys from recycled scrap is at insufficient grades for most automotive uses due to "downcycling"[5] during the recycling process.

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5 Downcycling is where the recycled steel is of lower grade (quality and performance) than the original/virgin material due to contamination from lower-grade alloys containing higher levels of impurities and other metals during the collection and recycling process. In the automotive sector, a high purity of steel in many Body-in-White components is required to ensure performance, durability and safety standards are met.

Another automotive OEM interviewed was more concerned about the cost of secondary steel than the quality. They highlighted that secondary steel processed in an EAF is a sustainable and viable alternative to virgin steel, however, they stressed it will need to reach cost competitiveness with the primary Blast Furnace-Basic Oxygen Furnace (BF-BOF) route to replace virgin steel supply to the automotive sector. The main factor driving secondary steel affordability is the cost of renewable electricity supply as the main energy feedstock to EAFs.

Key finding 2: Aluminium is seen as a lightweight alternative to replace steel for some components, especially for LDVs, but innovation in vehicle design is required for HDVs.

Aluminium was highlighted as the key lightweight alternative to steel components for LDVs by relevant manufacturers, with improvements in performance from lightweighting outweighing the higher production cost compared to steel. This aligns with key findings from the earlier desk-based research which found that aluminium is at the centre of significant design innovation with its potential to achieve lightweighting and material-efficient vehicle construction, see Section 2.2.1.2.

LDV OEMs indicated that the transition to heavier powertrains, particularly in association with BEVs, is driving additional replacement of steel components with lighter aluminium alternatives for LDVs. However, the HDV OEM perspective expressed in the interviews was that steel would continue to comprise a significant portion of HDV material content, due to high load-bearing strength requirements preventing direct replacement of steel with lightweight alloys. As such, whilst aluminium is expected to increase slightly in battery electric HDVs in non-structural use, innovations in vehicle design will be required to address the difference in material properties when replacing steel with aluminium alloys.

Key finding 3: Other materials (including plastic and polymer composites) could deliver important lightweight benefits but supply chain issues, costs and GHG impacts can be significant.

High-strength plastic and polymer composites were identified by an LDV OEM as another lightweight replacement to aluminium (and steel) for small-volume, high-performance vehicles. However, the long-term plant contracts; embedded infrastructure and existing technician skillsets, and embedded emissions from oil as a main feedstock are preventing another LDV OEM from relying heavily on composite or carbon fibre components in their mass-production vehicles. Several automotive OEMs also cited the inadequacy of mechanical recycling for carbon fibre and complex polymers, and the lack of chemical recycling facilities and supply chains, as impacting their use of plastics and polymers. This stakeholder view aligns with the desk-based research findings which identified these same barriers to increasing recycled plastic content in vehicles (namely, the lack of economically viable methods for dismantling and segregation of plastics from ELVs and the limited infrastructure to recycle plastic, see Section 2.2.1.3).

For HDVs, OEMs highlighted plastics and polymers as potential material replacements for heavy metals, with greater lightweighting requirements for BEVs expected to drive alternative HDV designs in the future.

Key finding 4: Additional key materials of interest identified by stakeholders – associated with battery production and tyres.

The stakeholders highlighted the importance of lithium and nickel for the batteries used in BEVs, with a HDV OEM citing new European legislation on the recovery and reuse of battery materials[6] as helping to deliver sufficient supply in the future. An LDV OEM estimated that around 40% of embedded CO_2e emissions from materials used in their light-duty BEVs comes from the battery critical raw materials and suggested that future sustainability regulations would be required to limit production emissions as demand for battery foundation materials. An LDV OEM expects the electrification of the vehicle powertrains is expected to increase the total demand for copper by more than 25%, due to high content in electric motors and high-voltage wiring. This is supported by the findings in the desk-based research which found that EV copper demand is expected to grow significantly, see Section 2.2.1.4. However, findings also highlighted that designs that reduce the demand for copper are being explored which are forecasted to reduce the demand.

3.4 LIST OF COMPANY-SPECIFIC INNOVATION CHALLENGES

Given the considerations summarised above regarding key materials for the automotive sector, the stakeholders interviewed also described where they see a need for innovation. Overall, the company-specific material innovation challenges identified reflect three key needs:

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[6] Council adopts new regulation on batteries and waste batteries - Consilium (europa.eu)

1. **Need to replace conventional materials with alternatives to achieve lightweight benefits and GHG reductions.**
2. **Need for lower carbon options for conventional materials to reduce embedded GHG impacts.**
3. **Need to increase the availability of recycled materials.**

Underlying these needs and beyond technical innovation challenges, stakeholders also pointed to more general challenges including:

A. **Need to identify solutions to improve the affordability of innovative materials.**
B. **Need to identify solutions to improve and validate the sustainability of materials.**

These are described in more detail below, where the specific needs and challenges are identified.

Company-Level Innovation Challenge 1: Need to replace materials with alternatives to achieve lightweight benefits and GHG reductions.

As outlined in Section 2.2.2.1, lightweighting is a key trend in the automotive sector to reduce the mass of vehicles through the reduction or replacement of materials used in vehicle components, and subsequently to improve energy efficiency and reduce GHG emissions during the vehicle's operational lifetime. In the interviews, stakeholders identified the need for sustainable lightweight alternatives which are cost-competitive and maintain overall performance compared to traditional materials.

Companies highlighted specific challenges with adopting alternative materials to reduce weight and use-phase emissions:

- Two LDV manufacturers identified the need for **high-strength polymers that can further displace lightweight alloys in LDVs**, with one identifying the specific need for **polymers to replace magnesium in cross-car beams and other structural components** due to the relative improvements in weight-to-strength, accessibility and affordability, and embedded emissions. This is supported by findings from the desk-based research which found that lightweight polymers can deliver comparable or even better weight-savings compared to light alloys, but the adoption is limited due to low availability on the market, see Section 2.2.1.3.
- One LDV OEM highlighted the need for investment into skills training and new manufacturing plant infrastructure in order to **replace conventional materials with alternative lightweight materials that require different forming and assembly processes**, such as carbon fibre.
- One HDV manufacturer identified the need for **redesigning of truck cabs to allow the replacement of steel content with plastic and polymer materials**, with the potential for significant overall weight savings freeing space for additional cargo and larger batteries, reduction in the payback time for initial investment in machine tooling equipment, and more flexibility and adaptability in the number of truck cab designs able to be manufactured.
- HDV manufacturers highlighted the need to balance weight savings and improvements in efficiency with a reduction in the overall durability and load-bearing capability of the vehicle, with plastic not robust enough for use in the chassis and steel not able to be directly replaced with aluminium due to differences in strain. To overcome this challenge, collaboration between automotive suppliers and manufacturers to **develop innovative lightweight solutions which account for the heavier durability and load requirements of HDVs, whilst incorporating changes to conventional truck design to allow weight savings**, is required.

Company-Level Innovation Challenge 2: Need for lower carbon options for conventional materials to reduce embedded GHG impacts.

As highlighted in Section 2.2.3, there is a need for lower-carbon options to substitute "conventional" materials in vehicle production. The availability of these materials is needed to improve the overall sustainability of vehicles.

In the interviews, companies highlighted the following specific challenges related to lower-carbon material options:

- Several OEMs identified the need for a **shift in steel production technologies to low-carbon primary steel production** (i.e., through the hydrogen DRI-EAF route) or **improved recycling of scrap steel to produce secondary steel from the EAF**, see Section 2.2.1.1.
- In addition, some OEMs commented on the need for renewable energy to support the development of these low-carbon materials:
    - An LDV manufacturer highlighted the need for a **national "renewable energy strategy"** which addresses future demand for low-carbon energy from industrial sources – this aligns with findings from the desk-based research which found that decarbonisation of the grid will be important to **improving the affordability of low-carbon primary and secondary steel,** see Section 2.2.2.3.
    - Several OEMs highlighted the need for a **domestic green hydrogen supply chain** to allow low-carbon primary steel production through the hydrogen DRI-EAF route in the future, as an alternative to conventional BF-BOF primary steel production. Findings from the desk-based research also highlighted the importance of green hydrogen in the production of green steel. While there are several full-scale green hydrogen DRI-EAF plants under construction in Europe, there are no current plans to establish low-carbon steel plants in the UK, see Section 2.2.1.1.
- They also mentioned the need to implement **low-carbon aluminium technologies** to address production emissions, namely using 100% renewable energy in the smelting process and reducing process emissions by replacing carbon anodes with inert anodes.
- Several manufacturers have expressed the need to **develop routes separating natural fibre composites** into their individual materials, to allow material recovery and recycling.

Company-Level Innovation Challenge 3: Need to increase the availability of recycled materials.

The shift from ICEV to BEV powertrains is driving a parallel shift in the scrutiny of vehicle emissions from the tailpipe to lifecycle perspective, leading to a greater focus on the production and EoL phases of a vehicle. As such, increased use of recycled content in vehicles represents a key trend to reduce the sustainability impact of automotive materials whilst improving supply chain resilience and conserving natural resources. The key foundation materials in the automotive sector currently lack closed-loop supply chain options, leading to logistical and economic barriers to securing recycled materials.

Companies highlighted specific challenges with increasing the availability of recycled materials:

- Several OEMs expressed the need for an **established closed-loop supply chain connecting scrap processing centres, foundation material industry and automotive OEMs**, with one manufacturer highlighting this as a key way in which the foundation industry could support automotive innovation challenges to deliver significant reduction in emissions at low cost.
- An LDV OEM highlighted the need for **recycled steel supply at the high grade required by performance-critical components** in the automotive sector, as well as at cost-competitiveness prices with current BF-BOF steel supply, through an established supply chain and affordable renewable energy (see Section 2.2.2).
- Several automotive OEMs highlighted the need for **recycled content targets for steel and aluminium** in new vehicles. This aligns with findings from Section 2.2.2.2, which identified a lack of policy-driven pressure or subsidies incentivising secondary material integration and bolstering closed-loop material recovery targets from ELVs.
- There is a need for **chemical recycling of polymer composites**. As outlined in Section 2.2.1.3, such recycling processes are challenging however, carbon fibre composite waste recycling is becoming more common in the UK to reduce virgin polymer demand.
- Automotive manufacturers expressed the need for further **design improvements to copper wire harnesses and control units** to improve the ease of recovery of these materials at vehicle EoL, and hence increase the recovery rate and material value.
- Several automotive OEMs highlighted the need to **eliminate hybrid vehicle structures** where steel, aluminium and other alloys are combined in order to make separation and subsequent recycling easier at the vehicle EoL.
- An OEM expressed that recycled content is perceived as of inferior quality to virgin material even where it shows equal performance and safety specifications coupled with emission savings and

potential for greater affordability. Therefore, several manufacturers highlighted the **need for an industry-wide certification of recycled materials** and/or the **establishment of an industry association** to provide confidence that recycled content is of equal quality, alongside recycled content targets to support their uptake.

- Several automotive OEMs highlighted the need for **alternatives to conventional paint on bumpers and other plastic vehicle components**, as the paint coatings are difficult to remove at the recycling stage and prevent greater plastic recycling rates.

Company-Level Innovation Challenge 4: A need to identify solutions to improve the cost-effectiveness/affordability of innovative materials.

Stakeholders agreed that the cost of materials is a primary factor in the design and material composition of vehicles and limits the level of innovation that can take place. According to a heavy-duty manufacturer, in a market where cost margins are so slim, the drive to reduce costs is greater than the drive to improve the sustainability of operations. Furthermore, the degree to which automotive OEMs are willing to replace conventional materials with more expensive alternatives is determined by end consumer's willingness to pay for more sustainable vehicles, with consumers of LDVs typically expressing more willingness to a pay a premium compared to HDVs.

Companies highlighted specific challenges balancing innovation and affordability of alternative materials:

- OEMs highlighted the overarching need for **technological readiness and cost-competitiveness of new innovative materials to replace legacy materials**, such as lightweight alloys for conventional steel, or natural fibre composites for CF and polymers.
- Several stakeholders expressed the need for **more affordable alternatives to conventional steel for HDVs** to enable lifecycle (production and use-phase) emission reductions, with the current premium for green steel highlighted as a challenge to adopting low-carbon alternatives.
- One HDV manufacturer highlighted the need for **cost-competitive lightweight alternatives to conventional materials**, as the amount of 'exotic' materials used in trucks is limited by small truck margins. For them, it is all about using low-cost materials in an efficient way rather than using exotic materials.
- Multiple OEMs highlighted the need to **translate plastics and polymers from expensive, high-performance vehicles into more cost-effective solutions** to replace steel components with more weight-optimised solutions.
- An LDV OEM noted a need for **innovations in magnesium production,** and greater supply chain options, that improve the affordability, with magnesium prices multiple times higher than aluminium currently. Both **machining process** and **time** are higher, with additional treatment needed due to magnesium corroding more easily.
- A HDV manufacturer highlighted that OEM margins are relatively slim and that this leaves little room for innovation or research into potential sustainable materials, with the need **for emphasis placed on Tier 1 suppliers** with more expertise in material innovation to propose alternatives to conventional vehicle components.
- A HDV manufacturer highlighted the need to **demonstrate the potential performance and durability gains** from the use of innovative materials to justify the higher upfront cost, preferably also demonstrating a clear payback on investment.

Company-Level Innovation Challenge 5: A need to identify solutions to improve and validate the sustainability of materials.

Although most stakeholders expressed an interest in improving the sustainability of the materials used in their vehicles, supply chain and availability concerns were raised as major barriers to the adoption of innovative materials with enhanced sustainability.

Companies highlighted specific challenges facing automotive OEMs in improving the sustainability of their vehicle designs:

- OEMs expressed a need for more action from **material suppliers to consider material sustainability and sustainable targets with higher importance**, driven by the greater influence of automotive manufacturers' scrutiny of their supply chains and sustainability targets for vehicle content.

- The need for materials sourced from **reliable and transparent supply chains**, where the origin of foundation materials and sustainability of production processes can be scrutinised and used to determine the environmental and social impact of the end (material) product consumed by the automotive industry.
- The need for **greater personnel and technical capacity of automotive OEMs and suppliers to understand and implement changes to comply with new Life Cycle Analysis regulations**.
- The need for a **shift in mindset** was highlighted by one heavy-duty vehicle manufacturer, with the automotive industry typically conservative regarding innovation and priority given to simply delivering a functioning product.
- Need for **more collaboration across key automotive OEMs and suppliers** to identify shared challenges to innovation and sustainability improvements and develop solutions to overcome these, such as through the establishment of an automotive stakeholder community.
- A HDV OEM highlighted the need to develop **changes in the vehicle design in parallel to innovative material solutions** from material suppliers, such as the redesign of HDVs required when replacing steel with lighter aluminium components due to differences in the material properties (i.e., lower stress limits for aluminium).
- **Need to align development cycles** for automotive consumers and material suppliers so that proof-of-concept for new innovative materials is available when vehicle design is taking place.
- **Need for a robust supply chain with secure supply**, otherwise price fluctuations will cause innovative materials to be replaced with cheaper, conventional materials.

4 STAKEHOLDER ROUNDTABLE

4.1 OVERVIEW OF ROUNDTABLE PLANNING

A roundtable event was held with stakeholders from across the automotive industry including OEMs, Tier 1 suppliers, and material suppliers. While the one-to-one interviews focused on company-specific innovation challenges, the focus of the roundtable was to broaden the context and understand the industry-wide trends. The aim of the roundtable was therefore to identify industry-wide innovation challenges and discuss potential support mechanisms that could address the challenges in the short, medium, and long term.

All industry contacts who were invited to participate in the one-to-one interview stage (see Section 1A1.1.1), were also invited to the roundtable, i.e. contacts from automotive OEMs and Tier 1 suppliers. In line with the aim of the roundtable, representatives from materials suppliers were also invited to participate in this second consultation activity.

The roundtable took place on Thursday 22nd February 2024. It was hosted as a hybrid event in which some stakeholders participated online while others participated in person at the Ricardo London office.

Table 4-1 outlines the number of attendees at the roundtable according to stakeholder type.

Table 4-1 Overview of roundtable attendees according to stakeholder type

Stakeholder type	No. of attendees
Automotive OEMs	4
Tier 1 suppliers	2
Material suppliers	4
Total	**10**

The gender breakdown of the roundtable participants is included in Appendix Section A1.2.1.

4.2 TOPICS DISCUSSED DURING THE ROUNDTABLES

Two key sets of questions were developed in advance for use during the roundtable:

i) those designed to understand industry-wide material innovation challenges and

ii) those designed to identify priority challenges and potential support mechanisms.

The two sets of questions are outlined below.

4.2.1 Understanding industry-wide material innovation challenges

The questions designed to understand the industry-wide material innovation challenges were informed by findings from the desk-based research (see Section 2.2) and the challenges previously identified in the one-to-one interviews (see Section 3.4). Most pronounced innovation challenges identified during the one-to-one interviews were grouped into those related to vehicle lightweighting, low-carbon materials, and recycled materials. Therefore, these key areas were used as the framework when preparing the roundtable materials, as these were expected to be the key areas of concern across the industry. Table 4-2 below outlines the questions that were prepared and used during the roundtable to collect industry-wide material innovation challenges.

Table 4-2 Topics and questions used to facilitate discussions on industry-wide material innovation challenges

Topic	Questions
Current and/or expected material innovation challenges related to achieving **vehicle lightweighting**	• How can the industry work toward replacing steel with lightweight alternatives? • What are the sustainability, cost, and function trade-offs between conventional materials and new/innovative lightweighting materials?

Topic	Questions
	• What may be preventing the replacement of aluminium with magnesium? • What lightweighting alternatives need greater collective demand and/or support to drive through to commercialisation?
Current and/or expected material innovation challenges related to the uptake of **low-carbon materials**	• What low-carbon materials need to be prioritised for research efforts? • How would you describe the current level of technological readiness of low-carbon materials? • What low-carbon alternatives need greater collective demand and/or support to drive through to commercialisation?
Current and/or expected material innovation challenges related to **recycled materials**	• What materials are considered to be of inferior quality when recycled? • What are the economic and technical barriers to recycling materials? • What materials need to be prioritised for research efforts related to recycling? • What are the efforts needed to improve or increase the use of recycled materials?

Stakeholder views and challenges collected during this section of the roundtable are outlined in Section 4.4.

4.2.2 Understanding priority challenges and identifying support mechanisms

The following topics were discussed to provide context on the challenges regarding level of complexity and urgency, and how they can be addressed:

1. Ranking of innovation challenges on scales from most challenging to least, and most time-sensitive (to be addressed by 2030) to least (to be addressed beyond 2035).
2. Support needed to address the challenges in the short-medium term (up to 2035) and the long term (beyond 2035).

Stakeholder responses from this section of the roundtable are outlined in Section 4.5.

4.3 METHODOLOGY

While the roundtable was primarily hosted as an in-person event, an option to join virtually was also offered to stakeholders who were unable to travel. Therefore, arrangements were made to ensure that the most value and input possible could be captured from both the online and in-person discussions, using different approaches for each context.

A brief presentation was delivered by Ricardo and Innovate UK to all participants at the beginning of the roundtable. This presentation included an overview of the study, the aims, and the innovation challenges identified thus far from both desk-based research and one-to-one interviews. At this point, two groups were formed: the in-person discussion group, and the online discussion group. Sections 4.3.1 and 4.3.2 below outline the approaches taken in each group to ensure maximum input and contribution from the attendees, while covering all key topics.

Stakeholder input from both the in-person and online discussion groups was collated and used to inform the key findings from the roundtable table, as presented in the following sections.

4.3.1 In-person discussion group

Five stakeholders attended the roundtable event in person. Physical whiteboards were used to facilitate the discussion among the in-person roundtable participants with one physical whiteboard used to present each topic, as outlined in Section 3.2. Attendees were provided with sticky notes on which they wrote down their insights and views on the topics presented. “Sticky notes”, outlining the innovation challenges identified, were then added to whiteboards along scales from most urgent to least urgent, and most challenging to least challenging.

Two Ricardo team members facilitated the discussions, with one leading and presenting the topics and questions, and the other taking notes on the key points raised. Following the roundtable, the notes outlining innovation challenges and potential support mechanisms were converted to a digital format and analysed together with the online discussion group findings.

4.3.2 Online discussion group

Five stakeholders attended the roundtable via the online, dial-in option. The online group used pre-prepared interactive virtual whiteboards to support the discussion. Each topic, outlined in Section 3.2, was presented to the participants as a single whiteboard, whereby the participants could add "sticky notes" to provide their insights on the given subject. As with the in-person discussion group, with the online interactive whiteboard, participants were able to move their sticky notes around. This allowed them to determine the level of complexity and urgency of each challenge identified by plotting the notes on a graph. The set of whiteboard slides used during the virtual roundtable discussion is included in appendix Section A1.2.2.

4.4 LIST OF INDUSTRY-WIDE INNOVATION CHALLENGES

Section 3.4 highlights the company-specific innovation challenges that were identified during the interview process. The same overarching themes and needs were also identified during the roundtable event. The industry-wide material innovation challenges will therefore be grouped as follows:

1. **Need to replace materials with alternatives to achieve lightweight benefits and GHG reductions.**
2. **Need for lower carbon options for "conventional" materials to reduce embedded GHG impacts.**
3. **Need to increase availability of recycled materials.**

The specific needs and challenges identified during the roundtable event are outlined below:

Industry-wide Innovation Challenge 1: Need to replace materials with alternatives to achieve lightweight benefits and GHG reductions.

As in the one-to-one interviews, roundtable participants highlighted lightweighting as a key trend in the sector to both improve energy efficiency and reduce GHG emissions over the vehicle's lifetime. Stakeholders highlighted the current lack of means of producing low-cost lightweight materials and ensuring their stable supply. They were also concerned about the ability of current lightweight material options to meet the functionality and specific needs of automotive components; as a result, the urgency of adopting lightweighting materials differs according to vehicle type.

Stakeholders in the roundtable highlighted the following challenges and needs related to lightweighting efforts:

- The need for training and upskilling of OEMs to be able to **replace conventional materials with alternative lightweight materials that require different forming and assembly processes.** This challenge was previously raised during the one-to-one interviews (see here).
- The need for **recycled content targets** which target key materials identified as strategic to delivering weight reductions and production emissions reductions, such as aluminium, and plastics, polymers and composites, see Section 2.2.1.2 and 2.2.1.3.
- The need for more **stable critical raw material supply chains** was highlighted. It was noted that critical raw materials, including magnesium, are often obtained from geo-politically unstable sources.
- The need for **high strength polymers that can displace lightweight alloys** in LDVs.
- The need for clarity on the potential **effect of innovations in aluminium giga-casting[7] techniques**. Stakeholders commented on the cost benefits of giga-casting, but highlighted challenges associated in the context of lightweighting. There were also concerns about the impact and potential for material repair.
- The need to **drive down lightweight material costs**. In particular, wider use of magnesium and carbon fibre were highlighted as (currently) unviable replacements for steel or aluminium due to a lack of cost competitive options, despite offering significant lightweighting and performance benefits.
- The need for **crashworthy lightweight materials**. Stakeholders commented on the potential impact on vehicle security and crash safety when replacing steel with lightweight materials. This potential

[7] Giga-castings are very large die-cast components that can be used for example to form large sections of a vehicle's structure.

impact was also identified from desk-research. It was found that certain lightweighting materials, including aluminium, may raise technical concerns related to crashworthiness and maintenance.

- **Servicing and repair considerations** were discussed related to the use of more lightweight materials. A concern was raised that costs associated with servicing and repair may become prohibitive, especially for composite components.
- The need to **fully assess the relevance of lightweighting materials based on their individual properties and production processes**. It was highlighted that the use of plastics for exterior vehicle panels would impact vehicle security as it provides less of a physical barrier than conventional metal panels. Also, the lower temperature thresholds which plastic components can withstand compared to metal counterparts would require changes to the final finishing processes, such as applying paint and adhesives.
- **Moving from copper wiring to lighter-weight aluminium** would help to reduce overall vehicle weight but presents technical challenges, with the different electrical properties (resistivity) of the two materials requiring a redesign to accommodate thicker wires in the vehicle architecture.
- The need for **sustainable lightweight material options that are fit for purpose**. There was some debate over the most sustainable lightweight materials for use in ICE vehicles. Stakeholders highlighted that often there are trade-offs and contradictions between lightweighting efforts and carbon reduction and/or recycling efforts. A discussion took place regarding efforts to reduce vehicle weight in a time when overall weight is increasing (due to preferences for larger cars, and the growth in BEV battery weight). Stakeholders discussed concerns around the use of magnesium for lightweighting purposes; they highlighted that magnesium produced through the Pidgeon process[8] generates significant CO_2e emissions, possibly negating the overall GHG reduction generated from its lighter weight. Using such examples, the roundtable participants stressed that implementing lightweighting strategies through use of alternative materials is not made up of a series of binary choices, i.e., switching one material for another, as there are many trade-offs to consider.
- Stakeholders discussed the high relevance of composites for lightweighting strategies and material efficiency. However, they stressed the limitations of current lightweight materials in terms of sustainability and recovery. Therefore, they highlighted the need for **innovative composite materials that support overall ease of disassembly, sorting and recovery**.
- The need for **combined focus of university research** to produce pathways for the commercialisation of new innovative materials that are financially and practically viable for use in the automotive sector.

Industry-wide Innovation Challenge 2: Need for lower carbon options for "conventional" materials to reduce embedded GHG impacts.

The main barrier identified preventing more significant uptake of low-carbon materials was cost. There is an unwillingness from OEMs to take on additional cost, associated with material premiums and updating of vehicle designs, production techniques and worker training, when there are a lack of clear (demand) indications that customers value these efforts. Stakeholders discussed the need for decarbonisation of both the electricity grid and material production processes to enable overall vehicle lifetime emissions reductions.

Specific challenges discussed in the roundtable related to the use of low-carbon materials are outlined below:

- Stakeholders highlighted the need for a **common set of definitions for low-carbon materials**, including a specific definition of low-carbon aluminium. The discussion demonstrated a shared sense of uncertainty around the linkages or differences between recycled materials and low-carbon materials. Aligning with this need for clarity, stakeholders also discussed the need for **clear guidelines and legislation regarding low-carbon material use** in the sector.
- The need for a **consistent and dependable supply of low-carbon materials**, at scale, to meet the demand in the automotive sector. Stakeholders highlighted that there is insufficient supply of bio-based products to meet the demand from the automotive sector, the need for more **research and innovations in bio-based plastic production**, and the need to ensure that these materials are sourced sustainably.
- The need for **low-carbon materials with better durability and strength** for use in the automotive sector. Steel is a significant material in vehicle composition, given its technical advantages regarding

[8] The Pidgeon process is a method of smelting magnesium but has a high energy demand.

tensile strength. Low-carbon materials must meet the strength specification required for each vehicle component. Preferably, the low-carbon material alternatives will have a high strength-to-weight ratio in order to balance both carbon reduction and lightweighting strategies.

- Stakeholders discussed the linkages between lightweighting efforts and carbon emission reduction efforts. They highlighted that current lightweighting material options have significant embedded carbon, e.g., magnesium, titanium, and aluminium alloys. Therefore, to achieve overall carbon reduction, they highlighted the need **for lightweight material options without high embedded carbon**.
- The need to **commercialise low-carbon material options whilst ensuring cost-competitiveness**. Stakeholders highlighted that the technology readiness level (TRL) of existing low-carbon material alternatives is already high (greater than TRL level 8) and was not considered to be a significant barrier to adoption. However, stakeholders also identified that the lack of large-scale manufacturing readiness (commercialisation) of these low-carbon materials was a barrier to their use in the automotive sector. Stakeholders outlined that the high production costs of such materials are limiting their use, exacerbated by the barriers faced by OEMs in changing legacy production processes. High-cost pressure was identified as a particular limiting factor in commercial vehicles.
- Stakeholders discussed the need to **increase the use of renewable electricity in the supply chain**. To reduce the lifecycle emissions from materials, it is important to consider the indirect emissions from the energy sources used to generate the electricity required in their production. This was highlighted as particularly important regarding the production of steel. A similar challenge was discussed during the one-to-one interviews when an LDV manufacturer stressed the need for a national renewable energy strategy (see here).
- As well as electricity grid decarbonisation, **decarbonisation of the production stages** was identified as a key priority. This challenge was also discussed during the one-to-one interviews, when several OEMs discussed the need for a shift in steel production technologies (see here). The use of the EAF in both the DRI-EAF primary production process for steel and in the secondary scrap-EAF route would allow for significant electrification of steel production. Given this expected transition in production, stakeholders identified the need for **upskilling of the steel industry workforce** to adapt from the conventional to more sustainable processes.
- The need for a **common LCA standard** was discussed during the roundtable. Stakeholders highlighted the need for a common understanding and assessment of sustainability across the lifecycle, incorporating aspects already discussed such as emissions associated with electricity generation and material production processes.
- Stakeholders discussed the current lack of chemical recycling options for polymer composites and the limitations this generates regarding the uptake of low-carbon materials. They highlighted the need to **develop routes for the separation and sorting of polymers and natural fibre composites** into their individual materials. Resolving this issue will allow for greater material recovery and recycling. Several automotive manufacturers expressed this concern during the one-to-one interviews, stressing the need for more efficient separating and recycling processes.
- The need to prioritise research efforts to achieve successful production and commercialisation of the following materials:
    - low-carbon battery materials, especially nickel and graphite,
    - low-carbon polymer materials without secondary land use impacts,
    - lightweight materials which don't have higher embedded carbon.
- The need for more **customer demand for low-carbon materials**. Currently, customers do not value efforts made by OEMs to use low-carbon materials. This is preventing greater organisational commitments to adopting low-carbon materials or low-carbon material targets. They highlighted that greater customer demand could be achieved through measures that help to add commercial value to CO_2 reduction efforts.
- Whilst alternative production techniques, such as joining vehicle components through bonding rather than welding, may offer small lightweighting gains and material reductions, it was highlighted that **OEMs typically prefer conventional techniques** due to existing plant setups and the downtime required to implement new processes.

- Due to the long production cycles and product lifetimes of vehicles, ICEV designs within Europe are already being finalised prior to the phase out of non-BEV powertrains by 2035. As such, stakeholders highlighted the need for low-carbon materials and other material innovations, such as lightweighting, to be **concentrated on BEV powertrains** as these will be the focus of automotive OEM designs over the coming decade.

Industry-wide Innovation Challenge 3: Need to increase availability of recycled materials.

As revealed in the one-to-one interviews and earlier desk-based research, there is a growing trend and focus on the production and EoL phases of the vehicle lifecycle. As a result, efforts to increase the use of recycled content are becoming more significant. These efforts aim to improve the overall sustainability of the sector while improving supply chain resilience and conserving natural resources. During the roundtable, stakeholders discussed the barriers preventing more significant use of recycled materials. These barriers are largely related to a lack of suitable and affordable material options, a lack (or perceived lack) of the required material quality, and a lack of common standards and definitions to unite the sector in these efforts.

Stakeholders highlighted the following specific challenges and needs related to the increased use of recycled materials:

- Several stakeholders discussed the need for **recycled content targets for steel and aluminium at the vehicle production stage**. The lack of policy-driven pressure or targets has been identified as a challenge throughout the consultation, raised both in the desk-based research (see Section 2.2.2.2), one-to-one interviews (see here) and the industry roundtable.
- Stakeholders highlighted the need to **shift the focus of automotive recycling targets** away from the current weight-based system to individual material content or component recycling targets at the EoL stage. This would help to incentivise recycling of materials with high value and embedded carbon emissions but fragmented use, such as carbon fibre and composite materials. Currently, these materials are found in small amounts (relative to total vehicle weight) and are not well-captured by EoL sorting due to current recycling targets designed for capturing the most prevalent materials in vehicles (i.e., steel). However, with plastic, polymer and composite content expected to increase in the near to medium term, it is increasingly important that these materials, and their high embedded emissions and value, are captured at the EoL stage.
- Stakeholders discussed the **need for standards for recycled composite materials.** Uniform material standards were highlighted as key to addressing the lack of consistency of material performance for use in vehicle production and to give confidence to OEMs in materials with high-recycled content. This was also raised in the one-to-one interviews when several OEMs highlighted that an industry-wide certification of recycled materials and/or establishment of industry association would be beneficial to reinforce the message that recycled content is of equal quality alongside recycled content targets to support their uptake (see here).
- Elaborating on the above point, stakeholders highlighted the need to establish **sustainability credentials of recycled materials**. Stakeholders discussed the need for recycling facilities to be scaled up significantly in the UK to be able to meet the automotive sector's needs. However, they stressed that these processes including collecting, transporting and recycling, need to be assessed to understand their environmental impact regarding GHG emission production. Concerns were raised that these processes may produce significant lifetime GHG emissions which may negate the overall environmental benefits of using recycled content for automotive components. They highlighted the **need to prioritise overall GHG emission reduction** over recycled material use.
- Stakeholders identified a lack of **recycled material traceability** as limiting the verification of the sustainability of the sources and production of foundation materials, with frameworks such as "digital materials passports" suggested to ensure that recycled materials do not lead to greater emission or sustainability impacts. One stakeholder highlighted the need for recycled material traceability to prevent companies from fraudulently increasing the value of materials by replacing different qualities of recycled content, such as post-industrial recycled content with post-consumer recycled content which typically has a lower value.
- A concern raised was that scrap material may not have the appropriate and necessary quality and performance to be used in the automotive sector. Another stakeholder highlighted that recycled feedstocks can be heavily contaminated with impurities, rendering them defective and inadequate for automotive sector component applications. Therefore, there is a need for **recovery and recycling processes which produce high-grade materials required for vehicle components**. This is

consistent with views shared during the one-to-one interviews, in which an LDV OEM voiced the concern related to quality of recycled content (see here).

- The need to **improve affordability and cost-competitiveness** of recycled materials. Stakeholders stressed the significant investment needed to ensure vehicles are designed with EoL and recycling considerations taken into account. The additional cost of extracting materials from vehicles at the EoL stage was also highlighted as a key concern. Recycling of key materials, such as steel and aluminium can be done domestically, but is currently too expensive due to higher energy costs and initial infrastructure costs, with a lot of waste material being shipped abroad to be recycled. Therefore, whilst there is sufficient domestic supply of end-of-life waste for key materials, stakeholders highlighted the need for recycling strategies and development of vertically integrated recycling hubs to realise domestic scrap material potential.
- There is a need to **design vehicles considering the EoL processes,** such as dismantling, to minimise downgrading of material quality in recycling and ensure greater material recovery rates. This will require collaboration between automotive OEMs and ELV processing and recycling companies to ensure uniform standards and methods are used. A stakeholder highlighted that this will be particularly challenging for legacy vehicle components, such as heat exchangers made from cast aluminium, which have established "uncircular" designs that do not easily allow separation of individual materials after shredding. For components with paints and adhesives, a stakeholder identified the need to preprocess (clean) before recycling or identify new recycling techniques to avoid the release of volatile organic compounds (VOCs) which would significantly impact the sustainability of the recycled material.
- Stakeholders identified the need for **efficient, automated ELV recycling processes.** They specified the need for mechanical separation of different material grades (i.e., steel grades to avoid contamination of copper impurities), as well as less prevalent materials with high value and embedded carbon emissions (i.e., carbon fibre and composites). They highlighted that such processes are key to ensuring cost competitiveness and conservation of material quality from recycled processes. It was highlighted that bonded joints are an issue for recycling due to their strength exceeding material substrates themselves, with the need for a reversible adhesive that allows automated disassembly.
- The need to **remove investment barriers to extracting high-quality scrap materials**, with a current disconnect between the potential of recycled ELV content for automotive OEMs and investment into recycling companies and processes by the foundation material industry.
- The need for **chemical recycling of polymer composites** was highlighted by the roundtable participants. This is consistent with findings from the one-to-one interviews (see here) in which stakeholders stressed that mechanical recycling alone cannot separate and sort fibres and polymers.
- There is a need for the **material validation processes to be simplified, more affordable and accessible to new entries**. Stakeholders discussed the long timelines and associated high costs of material validation processes. They highlighted that these challenges would exclude small and medium-sized recycling companies from entering the market and producing recycled materials that meet the needs of the automotive sector.
- The need for **greater availability and sustainable sourcing of recycled materials** at the scale required by the automotive sector. Stakeholders highlighted that there is currently a very limited supply of recycled materials and that they are in competition with other sectors (e.g., the construction industry) in their efforts to secure more recycled content. They therefore highlighted the need to restrict waste material export and for **more recycling companies to enter the market**. Stakeholders identified polymers and elastomers as a priority regarding increasing material supply to meet demand. They highlighted the need to **drive commercialisation of polymers and elastomers** to create a greater supply and choice of these materials for the automotive sector. This was also reflected more generally in the one-to-one interviews, where an LDV OEM highlighted that they struggled to source suppliers for innovative alternative materials due to few suppliers and high production costs leading to a lack of cost-competitive options.

4.5 PERCEIVED COMPLEXITY AND URGENCY OF THE IDENTIFIED INNOVATION CHALLENGES

Following the identification of material innovation challenges, stakeholders discussed the level of urgency and complexity associated with each. Participants were asked to rank and prioritise the challenges identified by placing their "sticky notes", outlining the challenges, on a graph with the following axis:

- **Perceived level of urgency**

  Stakeholders were asked to consider the timeline by which each challenge should be addressed. Challenges (via “sticky notes”) were placed along an axis to indicate the level of urgency with which each should be addressed. Those identified as most urgent were those that stakeholders believed need to be addressed as soon as possible, i.e., by 2030. Challenges that were placed in the middle, fell into a “medium urgency” category. These were challenges which stakeholders believed needed to be addressed by 2035. Finally, challenges identified as least urgent were those that stakeholders believed could be addressed in the longer-term, i.e., beyond 2035.
- **Perceived level of complexity**

  Stakeholders were also asked to consider the level of complexity of each challenge identified. The second axis along the graph served as a scale from least to most challenging. Those considered most challenging are those considered to require most support to address or overcome.

The following section outlines the findings from this activity.

4.5.1 Identification of priority challenges related to lightweight materials

Aligning with findings from the one-to-one interviews (see here), outputs from the roundtable suggest that a lack of awareness and experience with new materials among OEMs is a significant barrier preventing greater uptake of lightweight materials in the sector. Stakeholders suggested that this is not only a highly challenging issue but also one which needs to be addressed and resolved quickly. Stakeholders also identified priority challenges such as the need to reduce the cost of servicing and repair related to the use of lightweight materials, and the need to create more stable critical raw material supply chains. Discussions around trade-offs between lightweighting strategies and recycling targets continued in this segment of the roundtable. Stakeholders suggested that the lack of commercially available innovative composite materials that can be efficiently recycled and recovered was a key, time-sensitive issue that should be addressed with urgency.

A key factor discussed when determining the urgency of challenges related to lightweighting materials was vehicle type. Several stakeholders highlighted that the level of urgency or complexity associated with lightweighting challenges varies significantly according to the application, for example between a passenger car and a commercial vehicle. They also stressed that cost barriers vary in significance across the different vehicle types.

Challenges related to lightweighting strategies were listed initially in Industry-wide Innovation Challenge 1. Their ranking, according to their perceived level of urgency and complexity, is outlined in Table 4-3 below. In some cases, stakeholders selected and ranked only the challenges that they most resonated with, therefore, not all challenges that were initially identified related to lightweight materials were discussed in this exercise.

Table 4-3 Rating of urgency and complexity of innovation challenges related to lightweight materials

Challenge	Most Urgent	<< >>	Least Urgent
The need for training and upskilling of OEMs to be able to replace conventional materials with alternative lightweight materials.	High complexity		
The need to reduce costs associated with servicing and repair of lightweight materials.	High complexity		
The need for more stable critical raw material supply chains.	Low complexity		
The need for innovative composite materials that support overall ease of disassembly, sorting and recovery.	Low complexity		
The need for high strength polymers that can displace lightweight alloys in LDVs.		Medium complexity	
The need to drive down lightweight material costs.		Medium complexity	
The need for crashworthy lightweight materials.		Medium complexity	

Challenge	Most Urgent	<<	>>	Least Urgent
The need for clarity on the potential effect of innovations in aluminium giga-casting techniques.				Low complexity

4.5.2 Identification of priority challenges related to low-carbon materials

Stakeholders highlighted affordability and availability of low-carbon materials as key priorities that need to be addressed in the short term. Stakeholders stressed that, without demand from customers for vehicles made up of increased low-carbon components, there is little incentive for OEMs to assume the additional high cost of such materials. Other key priorities discussed regarding the uptake of low-carbon materials included the decarbonisation of the material production stages and the need for a common LCA standard.

Challenges related to low-carbon material use were listed initially in Industry-wide Innovation Challenge 2. Their ranking, according to their perceived level of urgency and complexity, is outlined in Table 4-4 below. Not all challenges that were initially identified related to low-carbon materials were discussed during the ranking exercise.

Table 4-4 Rating of urgency and complexity of innovation challenges related to low-carbon materials

Challenge	Most Urgent	<<	>>	Least Urgent
The need to increase affordability and cost-competitiveness of low-carbon material options.	High complexity			
The need to decarbonise the material production stages.	High complexity			
The need for a common LCA standard.	High complexity			
The need for more customer demand for low-carbon materials.	High complexity			
The need for a consistent and dependable supply of low-carbon materials.	Low complexity			
The need for low-carbon materials with better durability and strength for use in the automotive sector.	Low complexity			
The need for lightweight material options without high embedded carbon.				Medium complexity
The need to research and produce lightweight materials without embedded carbon increases (e.g., magnesium, titanium, and aluminium alloys).				Medium complexity
The need for more research and innovations in bio-based plastic production.				High complexity
The need to develop routes for the separation and sorting of polymers and natural fibre composites into their individual materials, i.e., the need for chemical recycling options.				High complexity
The need to add commercial value to CO_2 reduction efforts.				High complexity

4.5.3 Identification of priority challenges related to recycled materials

Challenges related to the use of recycled materials were listed initially in Industry-wide Innovation Challenge 3. Some of these challenges were then discussed and ranked according to their perceived level of urgency and complexity. In this category, cost considerations were among the key priorities identified when discussing the most urgent and complex challenges related to the use of recycled materials. Other than cost, stakeholders discussed the challenge associated with a lack of availability of recycled materials and highlighted the need for more recycling companies to enter the market. Stakeholders also discussed the need for efficient recycling processes such as mechanical recycling of polymer composites. This challenge was discussed as one which is both complex and time-sensitive. The challenge classed as least urgent, but with significant complexity, was the need to design vehicles with end-of-life processes in mind.

Their ranking, according to their perceived level of urgency and complexity, is outlined in Table 4-5. Not all challenges that were initially identified related to recycled materials were discussed during the ranking exercise.

Table 4-5 Rating of urgency and complexity of innovation challenges related to recycled materials

Challenge	Most Urgent	<< >>	Least Urgent
The need for chemical recycling of polymer composites.	High complexity		
The need to improve affordability and cost-competitiveness of recycled materials.	High complexity		
The need for recycled content targets for steel and aluminium.	Medium complexity		
The need for more recycling companies to enter the market.	Low complexity		
The need for standards for recycled composite materials that address issues such as lack of consistency of material performance for use in production.		Medium complexity	
The need for the material validation processes to be simplified and made more affordable.		Medium complexity	
The need for greater availability and sustainable source of recycled materials at the scale required for the sector.		Medium complexity	
The need to design vehicles considering the end-of-life processes to ensure limited downgrading of material quality.			High complexity

4.5.4 Summary of common innovation challenges across the automotive sector

Through the roundtable discussions, stakeholders highlighted key challenges related to the uptake of innovative materials which reflected those raised at a company level (in Section 3.4):

i) the challenge to reduce overall vehicle weight (**vehicle lightweighting**),

ii) the challenge to reduce the carbon footprint of materials (increasing the use of **low-carbon materials**) and

iii) the challenge to improve material circularity (increasing the use of **recycled materials**).

In their efforts to address and overcome these challenges, stakeholders discussed encountering similar barriers and challenges. The challenges, related to increasing the use of all innovative materials, can therefore be summarised and grouped according to the following more general and cross-cutting themes:

A. A need to identify solutions to improve the cost-effectiveness/affordability of innovative materials.

B. A need to identify solutions to improve and validate the sustainability of materials.

C. A need for a dependable supply of innovative materials of suitable performance (grade).

D. A need for capacity building and upskilling within the sector to adapt to new processes associated with the use of innovative materials.

4.6 IDENTIFICATION OF SUPPORT MECHANISMS NEEDED

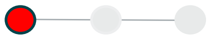
Following the identification and ranking of material innovation challenges, stakeholders discussed potential support mechanisms that would provide the most value and impact in addressing the needs of the sector. The participants were asked to provide examples of different support mechanisms that could be introduced. Each support mechanism was categorised according to when it should be introduced. They therefore grouped the measures into those which would be most valuable to introduce in the short term (up to 2030), the medium term (2030-2035), and the long term (beyond 2035).

The support mechanisms, including their associated timelines, discussed during the roundtable are outlined in Table 4-6.

Table 4-6 Support mechanisms identified during the roundtable to address material innovation challenges

Support type	Measure	Timeline
Commercialisation support for innovative materials and production methods	**Low-cost loans for innovative material commercialisation** To boost investment and uptake in innovative materials, stakeholders highlighted that financial support is needed. Stakeholders stressed that cost considerations are often a barrier to adoption or innovation when it comes to low-carbon, lightweight, or recycled materials. Offering low-cost loans specifically for commercialising such innovative materials can reduce the financial barriers and allow for quicker adoption. Stakeholders suggested that low-cost loans would support the uptake of such innovative materials in the short-medium term.	
Funding for research and demonstration projects	**Issue grants or fund demonstrators to enable optimal material separation** Stakeholders highlighted that investment and funding was needed into research and demonstration projects aiming to improve recycling processes. As discussed, there is a need for more innovative solutions in recycling processes to address challenges related to the purity and quality of the recycled materials. Stakeholders highlighted that only mixed-grade aluminium can currently be recovered in the UK from the shredding process, where high-grade aluminium is needed for direct use in automotive parts. Similar challenges are felt in the secondary steel industry, while polymers face comparable challenges in mechanical and chemical recycling processes.	
	Funded research / demonstrators for the use of lightweight materials in HDVs Stakeholders identified performance challenges related to the use of lightweight materials, causing uncertainty about their perceived value and suitability for use in vehicles, especially in HDVs. Some key performance concerns included load bearing capacity, safety in crash testing, and comparable maintenance costs given lower durability (particularly mentioned in the context of aluminium gigacasting). Stakeholders suggested that funding research and demonstrators for the use of such materials in HDVs could provide their potential benefits and feasibility in the sector.	

Support type	Measure	Timeline
Funding for research and demonstration projects (cont.)	**Issue grants or fund demonstrators to support changes in material** Stakeholders highlighted that significant changes in materials are needed to facilitate the adoption of recycled and low-carbon materials within the sector. They highlighted that material innovations are needed to develop suitable alternatives for currently used materials while meeting the specific requirements of vehicle components. Support, in the form of grants or demonstrators, is therefore needed to facilitate the robust research and development efforts required to produce materials that not only maintain the performance and quality standards of conventional counterparts but also exhibit reduced environmental impact throughout their lifecycle. This suggestion highlighted that investment in such material changes, for example the use of natural fibre reinforced polymers produced from diverse waste sources (like hemp) and in ever-lighter metal and metal composites, is needed in the long term, i.e., ongoing and beyond 2035.	<2030 >2035 
Policy and standards development	**Introduction of an End-of-life vehicles regulation** Stakeholders suggested that the introduction of an end-of-life vehicles regulation, that copies the EU model regarding material circularity requirements, would be beneficial. This would include the obligations for vehicle manufacturers to provide dismantling and recycling information and develop a circularity vehicle passport.	<2030 >2035 
	Increase recycled content targets for new vehicles As part of the end-of-life vehicles regulation, stakeholders suggested that specific recycled content targets are introduced for new vehicles, that align with the EU model. The EU proposal proposes to set targets for recycled plastics content of 25% by 2030, of which 25% is from closed loop ELV treatment. They also indicated the need for specific recycled content targets for steel and aluminium. It was recommended that this support measure is introduced as soon as possible, before 2030.	<2030 >2035 
	Introduce minimum standards for material performance Stakeholders highlighted the need for standards for certain materials to certify suitability for use in vehicles. Establishing minimum standards for attributes such as strength can ensure the performance and safety of vehicles manufactured using recycled materials without the need for additional checks by purchasers and address concerns about material durability and reliability.	<2030 >2035 
	Enable faster approvals for brownfield site development Stakeholders suggested that streamlining the approval processes for brownfield sites could help expedite the development of facilities for recycling and manufacturing recycled materials.	<2030 >2035 
	Restrict waste material export Stakeholders suggested that one way to provide reassurances to new material recycling facilities within the UK would be to minimise the export of waste materials outside of the UK, which could be prohibited via a Government strategy. Unsorted plastics and scrap metal were mentioned in particular as materials to focus on. Stakeholders recommended this strategy is put in place in the medium term, by 2035. This was to ensure sufficient time in the short term to establish more material recycling facilities in the UK.	<2030 >2035 

Support type	Measure	Timeline
Policy and standards development (cont.)	**Regulate the use of hybrid structures** Stakeholders suggested that hybrid structures could be restricted, because such hybrid materials are difficult to separate, recycle and recover, therefore reducing overall circularity. If restrictions were to be placed on the use of hybrid structures, the sector could improve the total recoverable potential of the UK fleet. However, in practice it is difficult to restrict how vehicles are designed, and an alternative demand-led innovation would be to increase recycled content targets as stated above to incentivise manufacturers to design with material separation in mind.	<2030 >2035 
	Introduce a globally recognised LCA standard Stakeholders suggested that there is not a common consensus on what defines a 'low-carbon' material. Adoption of globally recognised LCA assessment methodologies can provide automotive manufacturers with standardised tools for evaluating the environmental impact of their products, in turn allowing them to make informed decisions on balancing carbon impacts with non-carbon impacts.	<2030 >2035 
Capacity building	**Invest to retain and upskill the steel industry workforce** Stakeholders highlighted that they require support to implement a skills transition in the steel industry. This challenge was also discussed during bi-lateral interviews regarding the impacts of decarbonising steel production. They stressed that the steel industry will require significant upskilling in order to move away from the conventional production methods towards the more sustainable EAF and HDR-EAF routes. Stakeholders highlighted that this support mechanism should be introduced in the short term, by 2030.	<2030 >2035 
	Invest in training for new forming and assembly processes in lightweight materials Equipping industry professionals with the necessary skills and knowledge to produce lightweight rather than traditional materials can overcome barriers related to process complexity and unfamiliarity.	<2030 >2035 
Information campaign	**Introduce awareness and/or labelling campaigns for innovative materials** Stakeholders suggested that support mechanisms aimed at generating customer demand for recycled materials would be beneficial. Earlier discussions collected stakeholder views that customers do not sufficiently value the use of recycled or low-carbon materials in vehicle production. Support mechanisms could include awareness campaigns, incentives, or labelling initiatives to highlight environmental advantages, potential economic savings, and quality assurances of the materials. This support mechanism was expected to have most value if implemented in the medium term, by 2035.	<2030 >2035 

Support type	Measure	Timeline
Establishment of a stakeholder community	**Increase engagement with Local Enterprise Partnerships (LEP)** It was raised during the roundtable that, LEPs, with their regional focus and collaborative approach, can serve as catalysts for driving innovation and commercialisation of innovative materials in the automotive sector. By fostering partnerships between local businesses, academic institutions, and government bodies, LEPs can facilitate knowledge exchange and access to funding opportunities regarding material innovation. LEPs can also play a pivotal role in advocating for policy measures that promote sustainable practices and provide guidance on navigating regulatory frameworks. Stakeholders suggested that LEP engagement would be most valuable in the medium term, from 2030 to 2035.	<2030 >2035 
	Establish a stakeholder community Stakeholders discussed how in some cases, greater collaboration and dialogue among stakeholders in the automotive industry would help to overcome barriers to innovative material adoption. For example, regarding material circularity processes they discussed the need for collaboration between automotive OEMs and ELV processing and recycling companies to ensure uniform standards and methods are used.	<2030 >2035 

5 IDENTIFICATION OF DEMAND-LED INTERVENTIONS

While Section 4.6 outlines that various support mechanisms that were identified by stakeholders, it was necessary to sense check the viability of the suggested support mechanisms to see if these would be suitable in practice in addressing the challenges.

Good practice at national or policy level determines that interventions should address the root cause of a problem or challenge, rather than the symptoms of that challenge. To illustrate, if low uptake of a certain material was the example challenge, then subsidies to increase its uptake could be a potential intervention. However, this intervention would be ineffective if the material was not sufficiently strong to be a direct replacement for the legacy material. The root cause would therefore be insufficient material strength, which an alternative solution would be better placed to address. It was therefore necessary to create a database of challenges arising from the desk-based research (Section 2), the one-to-one interviews (Section 3), and the roundtables (Section 4), and identify the root causes of the problems faced by industry – we refer to these as 'challenge drivers'.

Once challenge drivers had been identified, a matching exercise was then performed with support mechanisms identified during the industry roundtable (see Section 4.6) to demonstrate their viability. Existing support mechanisms were then supplemented by suggestions made by Ricardo based on previous policy advisory experience. Together, the support mechanisms from industry and the Ricardo suggestions form the intervention longlist. This process is summarised in the diagram below.

Figure 5-1: Process followed to identify demand-led interventions.

A high-level graphical summary of the longlist is shown in Figure 5-2 below, demonstrating how each identified intervention aims to address a challenge driver. These are grouped by the three core themes that have materialised during the research and consultation phases of this study, and a cross-cutting theme.

- **Lightweighting** – addressing the need to replace materials with alternatives to achieve lightweight benefits and GHG reductions.
- **Lower carbon** – addressing the need for lower carbon options for conventional materials to reduce embedded GHG impacts.
- **Recycling** – addressing the need to increase availability of recycled materials.
- **Cross-cutting** – related to all three themes identified above.

Interventions were grouped according to the support types listed in Table 4-6, namely: capacity building; commercial support; funding research and demonstration projects; policy and standards development; information campaigns; and establishment of a stakeholder community. Each intervention group, and the arrows connecting each challenge driver to an intervention group, are uniquely coloured. The connections between challenge drivers and interventions identified during the course of this project are marked by solid arrows, whereas interventions suggested by Ricardo from previous policy experience are marked by dashed arrows.

Figure 5-2: Visual representation of how interventions were identified from relevant challenges

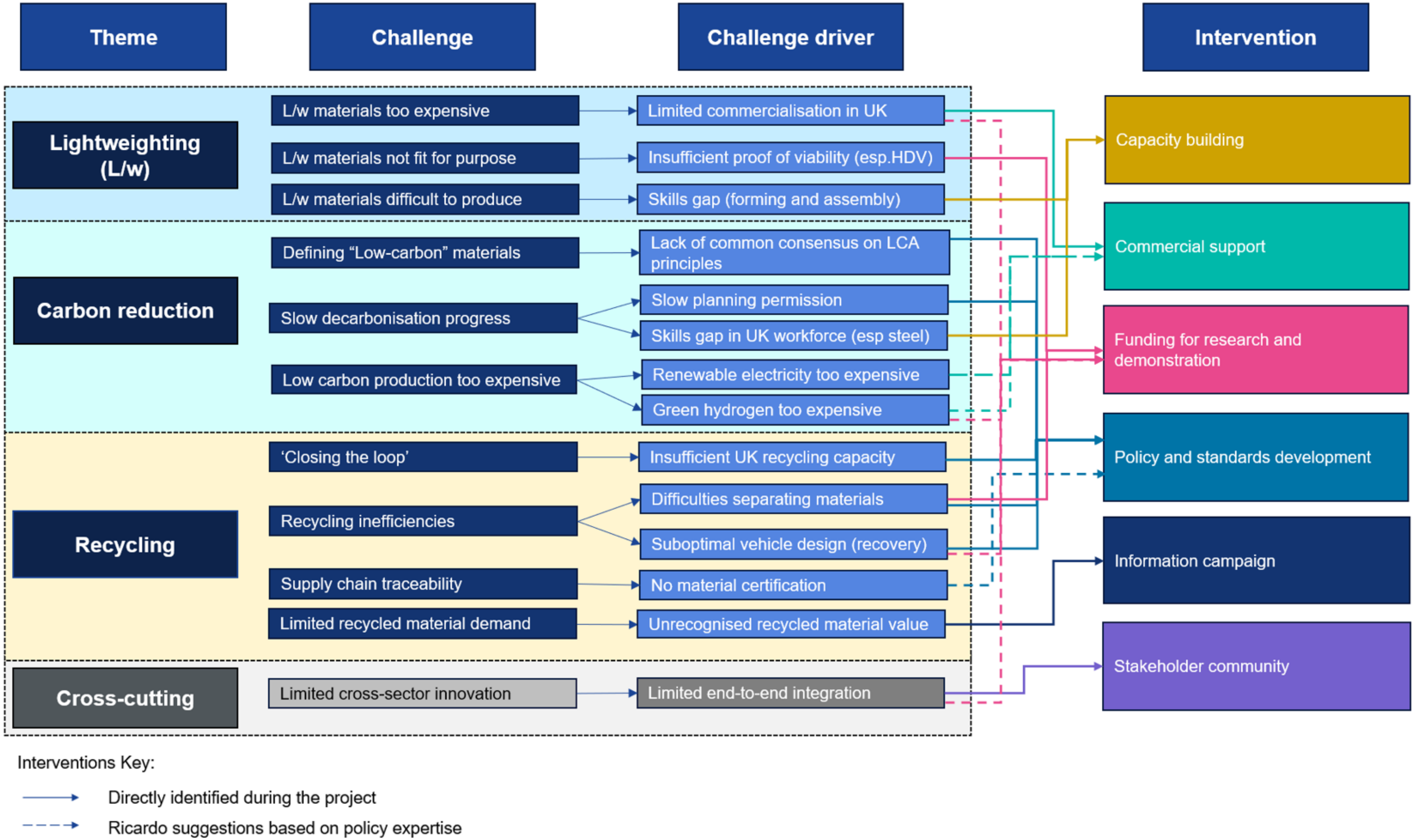


Table 5-1: Shortlist of demand-led interventions

Intervention style	Intervention
Commercial support	Low-cost loans for innovative material commercialisation
Policy and standards development	Introduce an End-of-life vehicles regulation
Funding for research and demonstration projects	Issue grants or fund demonstrators to enable optimal material separation
Funding for research and demonstration projects	Issue grants to achieve scaling in lightweight material production
Funding for research and demonstration projects	Funded research / demonstrators for the use of lightweight materials in HDVs
Commercial support	Issue grants to reduce the costs of local hydrogen production and/or storage
Capacity building	Invest to retain and upskill the steel industry workforce
Policy and standards development	Introduce minimum standards for material performance
Stakeholder community	Establish a stakeholder community
Funding for research and demonstration projects	Issue grants or fund demonstrators to support changes in material
Funding for research and demonstration projects	Fund demonstrators for cross-sector, closed loop innovations
Policy and standards development	Increase recycled content targets for new vehicles
Capacity building	Invest in training for new forming and assembly processes in lightweight materials

6 SUPPORTING DEMAND-LED INNOVATION IN FOUNDATION MATERIALS FOR THE AUTOMOTIVE SECTOR

From the identification of the challenges driving demand-led innovation in materials for the automotive sector and the review of potential interventions against those challenges, several interventions have been shortlisted as described in Section 5 that offer opportunities to support the development, production, and use of innovative materials. These are materials which enable lightweighting of vehicles, have a lower carbon footprint, and/or increase the circularity (recycling content and recyclability) of vehicles, and include alternative design and production methods for using established materials as well as new material technologies.

6.1 DEMAND-LED INTERVENTIONS THAT COULD BE IMPLEMENTED TO SUPPORT MATERIAL INNOVATION IN THE AUTOMOTIVE SECTOR

6.1.1 Funding for research and demonstration projects

In exploring the challenges linking the foundation industries and the automotive sector, several areas were identified where further development was needed, challenges crossed industry boundaries, or there is a barrier due to a lack of confidence in or experience with new materials and their associated vehicle design changes. These cases could be addressed with research funding that flows across sector boundaries to link recycling and material recovery to automotive manufacturing, and using demonstrator projects, build experience with and set precedents for more integrated supply chains.

i. The challenge of effectively separating materials of different types and grades is a barrier to increasing the recyclability of vehicles and increasing the recycled content within them. Funding research and demonstration projects for **material separation technologies** in the short term (pre-2030) could address challenges related to the purity and quality of recycled materials, making them more viable for use in automotive manufacturing, while improving the efficiency and effectiveness of recycling processes. In particular, stakeholders highlighted that only mixed-grade aluminium can currently be recovered in the UK from the shredding process, where high-grade aluminium is needed for direct use in automotive parts. Similar challenges are felt in the secondary steel industry, while polymers also face comparable challenges in mechanical and chemical recycling processes.

ii. Materials separation challenges at the vehicle EoL stage can be mitigated through **vehicle design that facilitates disassembly**. Stakeholders highlighted issues in material recovery from copper-based control units and painted plastic components, but these issues affect the vehicle as a whole. Research could explore where the greatest challenges lie, how to address material separation complications of new technologies such as lightweight materials and hybrid structures, and the opportunities for using vehicle design to improve disassembly and recycling processes. Solutions could then be illustrated through demonstration projects to inform industry. This research could start in the near term (by 2030) but would target longer-term benefits (from 2035).

iii. The **adoption of lightweight and high recycled content materials** in automotive applications is limited by concerns regarding their performance in load bearing and crash testing, the need for alternative forming and assembly processes, and competitive maintenance costs. Research and demonstration projects that showcase the feasibility and potential benefits of lightweight and/or high recycled content materials along with effective design and manufacturing processes in the short term (2030) could drive adoption in the medium-long term (2035 and beyond). The load bearing **demands of HGV structures** was identified as a particularly challenging area and could form the focus of a demonstration. Stakeholders highlighted aluminium giga-casting as a promising technology that could lead to commercialisation and more widespread use in vehicles, but currently faces concerns on durability in the use-phase.

iv. Stakeholders suggested that **closed loop innovation** would be effective at addressing the challenges of increasing the suitability of recycled materials for use in automotive applications, the recycled content of vehicles and their recyclability. Funding for cross-sector demonstrations that bring together the vehicle EoL and recycling industry with automotive manufacturing would be an investment in innovative solutions and scalable technology integration, and would showcase sustainable practices and material utilisation for wider adoption in the medium term (2030-2035).

v. Stakeholders felt that **material innovations** are needed to develop suitable alternatives for currently used materials while meeting the specific requirements of vehicle components. Innovations can develop materials with a reduced environmental impact over their lifecycle, high recycled content and recyclability, and the performance and quality standards required, and can explore ways to apply the new materials. Such research is likely to take time and so support as grant funding that provides sustained confidence to researchers and investors is needed, but commencing by 2030.

6.1.2 Capacity building

A common theme identified during this research was the pace of change needed in material adoption in the automotive sector. One of the key associated challenges is the upskilling of the UK workforce to adapt traditional manufacturing practices to those that produce lower embodied carbon materials. Equipping industry professionals with the necessary skills and knowledge to produce lightweight and/or low-carbon rather than traditional materials suitable for the automotive industry can overcome barriers related to process complexity and unfamiliarity.

vi. The strength, versatility, and recyclability of steel means it will remain a critical material for the automotive sector going forwards. It is recognised that the UK steel industry faces its own challenges in meeting the transition to lower carbon methods of steel production that are beyond the scope of this study. However, stakeholders felt there would be a need for **training and upskilling within the steel industry** to develop low-carbon steel products and supply chains (for example utilising the hydrogen-based primary production or secondary production of steel) suited to the demands of the automotive sector in the medium term (2030) and beyond.

vii. Another focus would be to invest in training for the **new forming and assembly processes in lightweight materials** as compared to traditional materials like iron and steel. This training would provide increased flexibility and resiliency in the workforce to changing material demands and needs.

6.1.3 Commercialisation support for innovative materials and production methods

Even where there is progress at the research stage for innovative materials that offer lightweight, high recycled content, and/or low-carbon intensity, stakeholders reported a challenge in their manufacturing reaching sufficient scale and reducing costs to be competitive with traditional materials. This seems to have been the experience of titanium research in recent years for example. Support targeted at enabling the production of innovative materials could include:

viii. **Low-cost loans** or other ongoing financial support for innovative material commercialisation, facilitating investment in larger, smarter, and more efficient facilities, and helping to attract private investment. Stakeholders expressed that this could be targeted at materials like CFRP, given their proven potential but lack of commercial applications in the UK automotive industry, although this material still faces other challenges as addressed in previous sections (e.g., chemical recycling at vehicle end-of-life, or secondary availability).

6.1.4 Establishment of a stakeholder community

Stakeholders recognised that many of the challenges crossed sector boundaries and felt there was potential for greater harmonisation of cross-sector dialogues aimed at material innovation.

ix. Stakeholders agreed that **greater collaboration and dialogue** among and between stakeholders in the foundation and automotive industries would help to overcome barriers to innovative material adoption in the medium term (2030-2035) (see Section 6.3).

6.2 WIDER MEASURES THAT COULD SUPPORT MATERIALS INNOVATION IN THE AUTOMOTIVE SECTOR

Some of the shortlisted interventions were prioritised due to the importance and urgency attributed to them by industry stakeholders and the value placed on them by relevant literature. Some of these require cross-governmental collaboration.

6.2.1 Policy and standards development

The study and engagement with stakeholders identified areas where changes in the automotive manufacturing and supply chains and the foundation industry would need policy development.

A key enabler that stakeholders identified for increasing the use of recycled materials in automotive applications would be the introduction of **standards to certify the performance properties** of the materials. The structural and quality requirements of automotive use demand specific material grades, and the risk of material degradation through recycling or "downcycling" limits the use of recycled material unless it can be demonstrated (certified) to meet the necessary grade.

Innovative materials with alternative production pathways promise lower embedded carbon emissions, but there is no clear and comparable measure by which manufacturers can evaluate this benefit. Standards to establish comparable environmental impacts of materials through **globally recognised life cycle analysis** methods would enable manufacturers to make informed decisions on the use of recycled, lightweight, and low-carbon materials in place of traditional materials.

The ELV Directive in the UK, first introduced in 2003, matches that of Europe, and both directives are currently being reviewed. The EU proposals place increased focus on circularity with **targets for the recycled content** of critical materials used including plastic, and for the **recyclability** of the vehicle. These also extend the producer's responsibility with a "**digital passport**" concept defining how the vehicle can be disassembled and recycled. Stakeholders suggested similar measures would increase demand for and value of recycled materials and improve vehicle design for increased recyclability. Improving and enhancing the UK ELV to strengthen the obligations on vehicle manufacturers to increase circularity would develop the market demand for innovative materials.

Currently, there is insufficient recycling capacity in the UK to be able to process the quantity of waste materials produced domestically, and so much of this is exported for processing abroad. Stakeholders suggested that one way to support new material recycling facilities within the UK would be to **minimise exported waste material**, which could be limited via a Government strategy. This would provide reassurances on the supply of these materials into the future and generate incentives to accelerate the development of new recycling facilities so that the waste can be dealt with. Unsorted plastics and scrap metal were mentioned as materials to focus on.

Another factor delaying the development of existing or new primary and secondary material production facilities is in **approval processes for developing brownfield sites**. It was expressed that any support to expedite this approval process would be welcome to speed up the development of facilities for recycling and manufacturing with recycled materials.

6.2.2 Support to development of renewable energy and green hydrogen to produce low-carbon materials

The automotive industry and its supply chain including the foundation industry do not exist in isolation, and stakeholders identified challenges that affect many industries including the need for cost-effective and reliable renewable power and an established green hydrogen supply.

Support for localised renewable electricity production, or support to procure or reduce the cost of clean power purchase agreements (PPAs), could reduce the effective cost of renewable electricity incentivising the production of lower carbon materials.

Similarly, **investing in the hydrogen economy** through localised grant funding can support hydrogen production and storage infrastructure, enabling both its use by industry and wider adoption of hydrogen vehicles in the medium-long term (2030 onwards), and in turn their use of lightweight materials.

6.3 STAKEHOLDER COMMUNITY

One of the outcomes expected from this study was not only to research the innovation challenges faced by automotive OEMs but also to create a dialogue with industry stakeholders from across the automotive and foundation industry sectors and to form the basis of a community with an active interest in pursuing a demand-led innovation initiative. As established in the previous section, stakeholders agreed that greater collaboration and dialogue among and between actors in the foundation and automotive industries is an intervention that in itself can lead to the greater adoption of innovative materials.

Having engaged with numerous stakeholders via email, interviews and a roundtable, commitment has been secured from several organisations who wish to stay informed and help develop a demand-led innovation intervention for the automotive sector in the future. Under the leadership of the Transforming the Foundation Industries Challenge this stakeholder community will serve as an industry-led steering group to help ensure that any proposed intervention meets the needs of the industry and is a suitable measure to overcome the innovation challenges highlighted by this study and other studies and working groups exploring similar topics.

It was noted by Ricardo during our engagement with industry that similar groups have explored automotive material challenges previously, as detailed in Table 6-1, however, none are focused solely on the foundation industry materials and their integration into the automotive sector.

Table 6-1: Other automotive material initiatives

Lead organisation	Group	Objective
SMMT	Environmental Policy Committee	Formulate policy on all environmental matters that impact vehicle and component manufacture, vehicle usage during its life and proper disposal and recovery on reaching the end of its life
	Manufacturing Environment WG	Provides advice and guidance on the environmental issues directly related to automobile manufacturing.
Automotive Council	Net zero material working group	Identify key future materials. Identify areas for carbon reduction for materials and via material substitution. Identify barriers to market development of such materials. Propose government actions to overcome challenges.
Broadway Initiative	Sector Plans (Manufacturing)	Create sector-specific plans on how to achieve net zero by 2050.
Materials Processing Institute	Circular economy, advanced materials and industrial decarbonisation groups	Although not focused solely on the automotive sector ongoing work is in place to improve the sustainability, performance and carbon intensity of foundation industry materials.
UK Metals Council	n/a	The UK Metals Council brings together industry leaders, trade associations, and government bodies to address challenges and opportunities within the metals sector. It focuses on promoting innovation, sustainability, and competitiveness across various metal-related industries, including steel, aluminium, and other foundation materials.
British Glass	Decarbonisation & energy efficiency and Recycling	British Glass is the trade association for the UK glass industry. It supports research and innovation in glass materials, manufacturing techniques, and recycling technologies to drive sustainability and competitiveness within the sector.
British Plastics Federation	Sustainability Committee	The leading trade association for the UK plastics industry. While plastics are not traditionally considered foundation materials, they play a significant role in various industries, including automotive. The BPF promotes innovation and sustainability in plastic materials, processes, and applications.

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id&utm_term=keyword&utm_content=adgroupid&gclid=Cj0KCQiA7OqrBhD9ARIsAK3UXh36qa-zu4akT
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APPENDICES

A1.1 METHODOLOGY OF ONE-TO-ONE INTERVIEWS

Planning and conducting the one-to-one interviews was carried out via the following key tasks and activities:

i) Task 1: Identification of the stakeholder group

Through this initial task, the long list of potential UK automotive OEM and Tier 1 suppliers was created. These stakeholders would make up the list of target companies to be involved in the one-to-one interviews.

ii) Task 2: Desk-based research

The key findings and trends identified through the desk-based research were used to inform the development of the interview checklists.

iii) Task 3: Stakeholder engagement

This task involved reaching out to the long list of potential interview participants and conducting the one-to-one interviews.

More detail on the methodology of the interviews, via each of the above tasks, is outlined below.

A1.1.1 Task 1: Identification of stakeholder group

A long list of potential OEM and Tier 1 suppliers was developed from a combination of information sources including Ricardo contacts from past projects, Innovate UK contacts and publicly available information. Shortly after the project initiation, the team contacted identified stakeholders on the long list. A key priority was to ensure the list provided appropriate representation across light and heavy-duty vehicle manufacturers, and Tier 1 suppliers. The initial email sent to the identified stakeholders included a brief introduction to the study and a request to participate in either the one-to-one interviews or the industry roundtable.

An overview of the long list of stakeholders contacted, as part of this task, is outlined in the table below.

Table A-4: Long list of stakeholders contacted as part of Task 1

Stakeholder type	No. of stakeholders contacted
Vehicle manufacturer/supplier association	3
Light-duty vehicle manufacturers	10
Heavy-duty vehicle manufacturers	7
Tier 1 suppliers	5

A1.1.2 Task 2: Desk-based research

The desk-based research activities allowed for a deeper understanding of the material trends for the automotive sector. Trends identified included key materials of concern, changing requirements and product design, and advances in material manufacturing. These key findings were used to inform the development of the checklist which guided the one-to-one stakeholder interviews.

A shortlist of materials was produced based on the desk-based research findings. These materials were considered to be the most relevant and promising foundation materials for the automotive industry, using a Multi-criteria Decision Analysis (MCDA) based on the following criteria:

- Current material production rates in the UK
- Contribution to the automotive industry, in the medium (2030) and long term (beyond 2030)
- Potential influence of stakeholders on the material supply chain
- Expectations for future evolution (innovation potential)
- Material sustainability credentials (current and future)

The materials shortlisted, as a result of the analysis, included i) steel, ii) aluminium, iii) iron, iv) plastics and polymers, v) glass, and vi) copper.

The interview checklist aimed to understand the trends, challenges and changing requirements for each of the above listed materials. The questions were structured as per the following overarching themes:

- Overview of current material usage
- Understanding drivers for change in material use
- Planned (or anticipated future) material change
- Innovation challenges
- Ongoing innovation projects
- Further engagement and involvement

A1.1.3 Task 3: Stakeholder engagement

This task included the key engagement activities, i.e. reaching out to stakeholders, explaining the nature of the study and its objectives, gaining stakeholder interest and support, and arranging and conducting the one-to-one interviews.

As outlined in Section A1.1.2, the aim of the interviews was to gain insight into current and future material usage at automotive OEMs and to understand where innovation challenges of using and sourcing materials occurs.

Given the dispersion of automotive OEMs across the UK, and the busy schedule of the senior stakeholders we plan to engage with, it was decided that conducting the interviews via MS Teams (rather than in-person) was the most feasible option.

Interviews were facilitated by two members of the project team. One team member present was an automotive sector expert and given the lead facilitator role. A second team member also joined these interviews, acting as a general facilitator and note-taker.

Following each interview, the notes were sent to the participant for approval. The team asked the participant if the notes reflected their views accurately. They also offered the opportunity to add more detail, case studies, or resources to their responses.

The D3 report on company level innovation challenges was produced based on the stakeholder input from the approved interview notes. A summary of this report is included in Section 3.

Click the icon below to review the final interview checklist, used in the one-to-one interviews:

Demand-led innovation_Interview

A1.2 ROUNDTABLE

A1.2.1 Gender breakdown of roundtable participants

In-person discussion group	
Male	Female
4	1

Online discussion group	
Male	Female
4	1

A1.2.2 Interactive whiteboards including stakeholder input from the online discussion group

The figures below are copies of the interactive whiteboards used during the roundtable's online discussing group. The input collected through the whiteboards has been included in Sections 4.4 and 4.5. Some "sticky notes" may not be visible in the figures however, all input has been collected and analysed, and included in the report, where relevant.

Figure 7-1 Outputs from online discussion on innovation challenges related to recycled materials

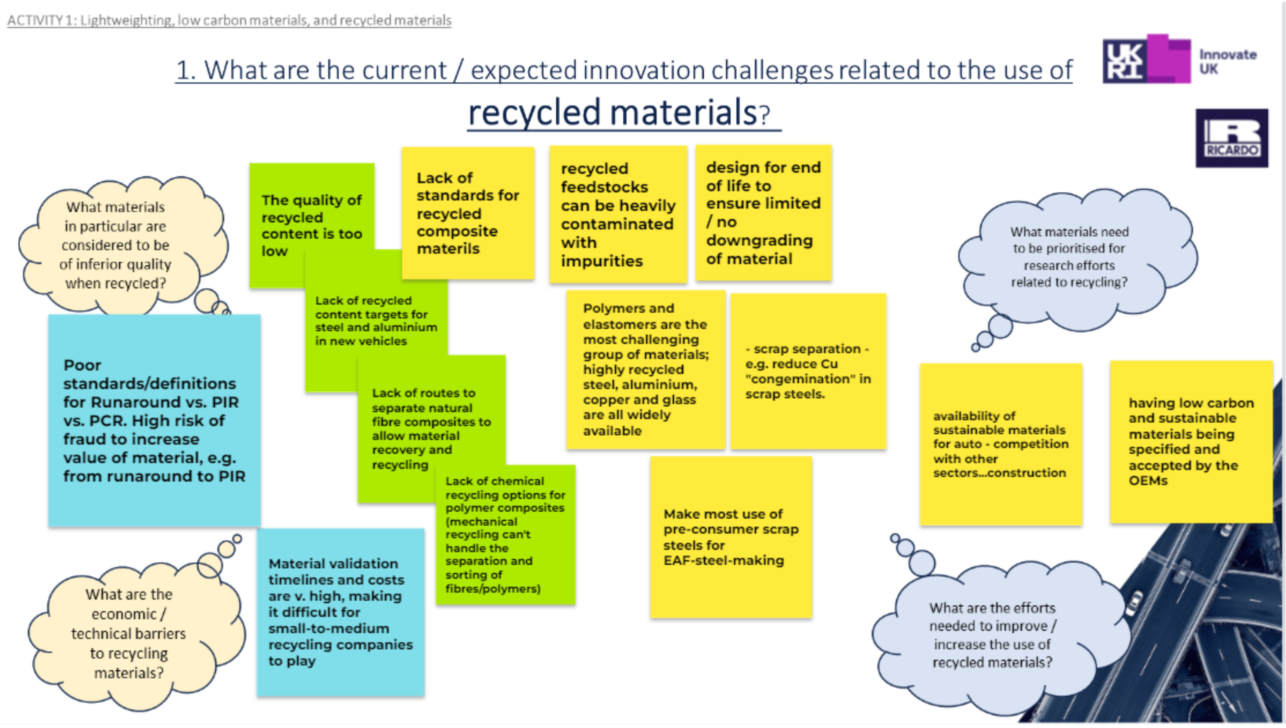


Figure 7-2 Outputs from online discussion on innovation challenges related to low-carbon materials

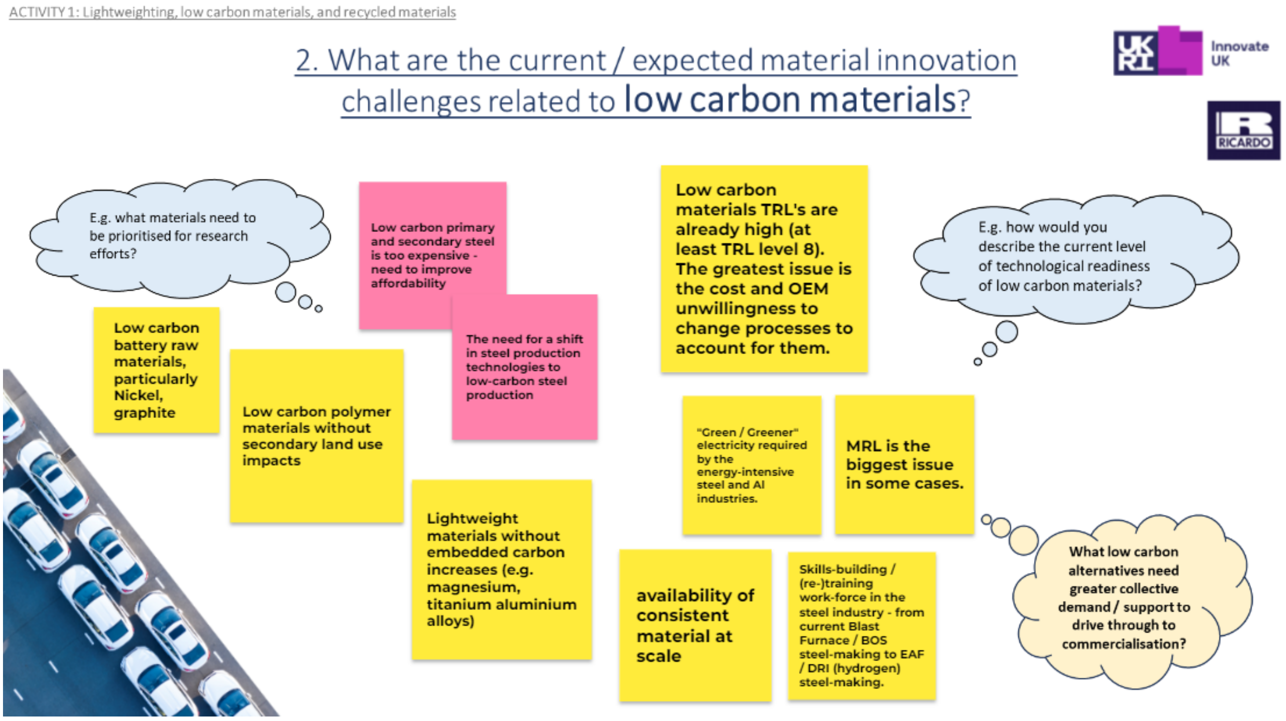


Figure 7-3 Outputs from online discussion on innovation challenges related to lightweighting

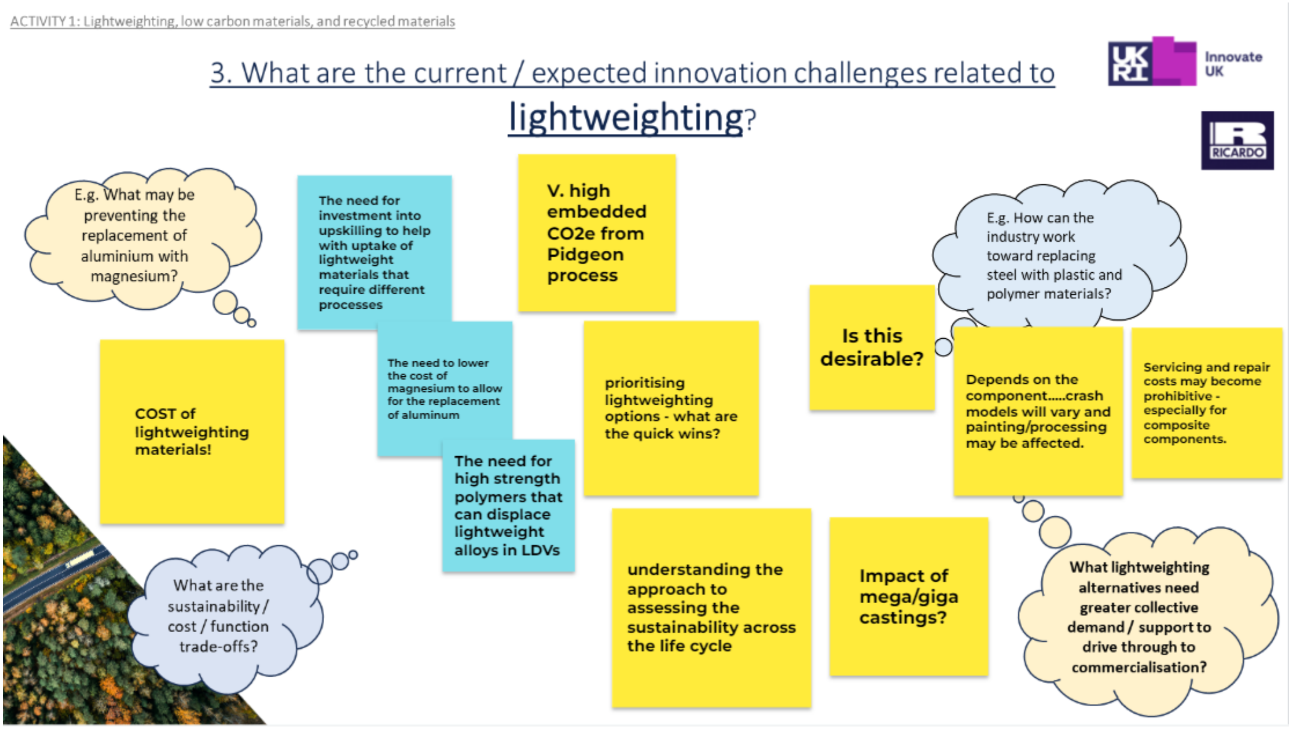


Figure 7-4: Outputs from online discussion on the ranking of innovation challenges

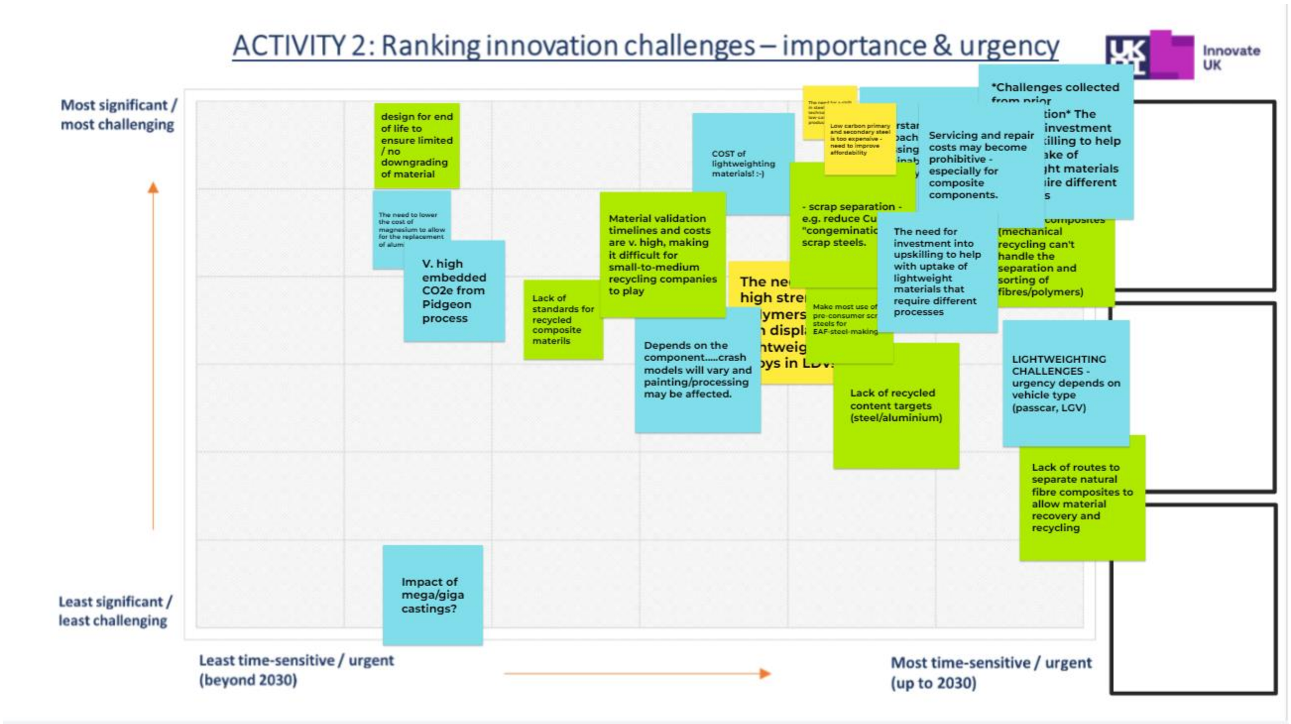
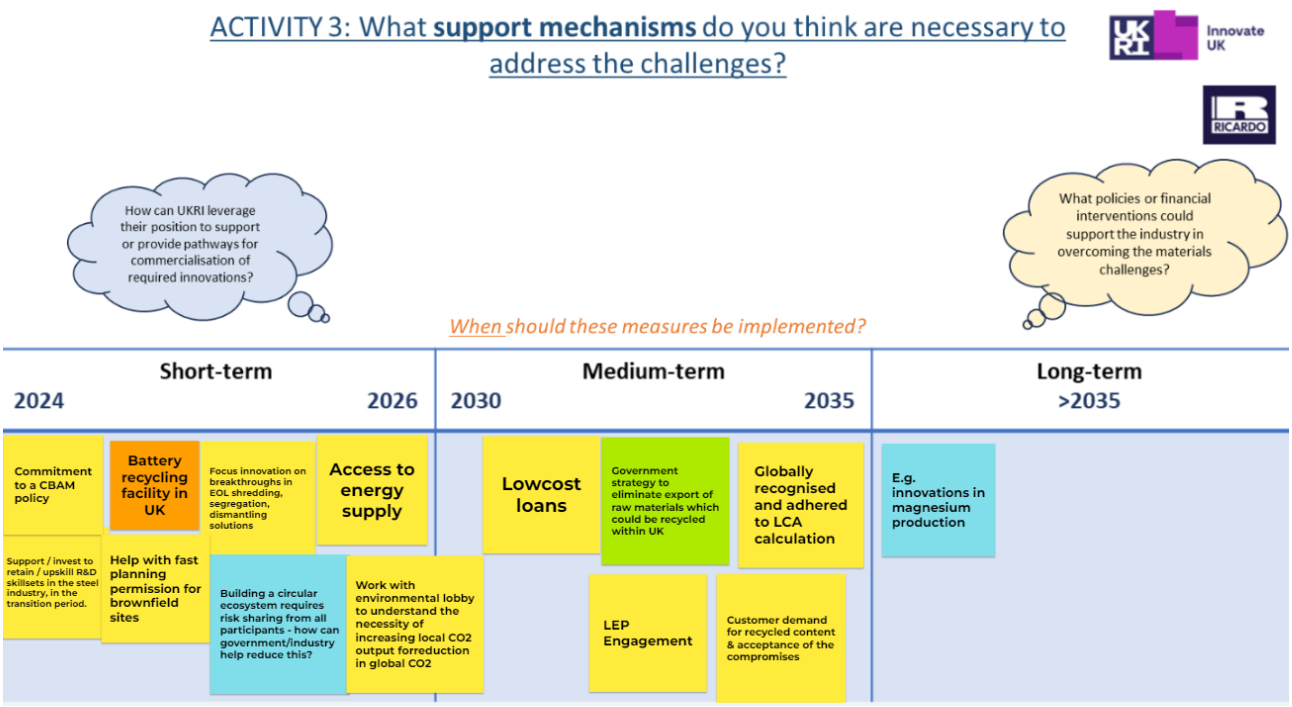


Figure 7-5: Outputs from online discussion on support mechanisms needed to address the challenges



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