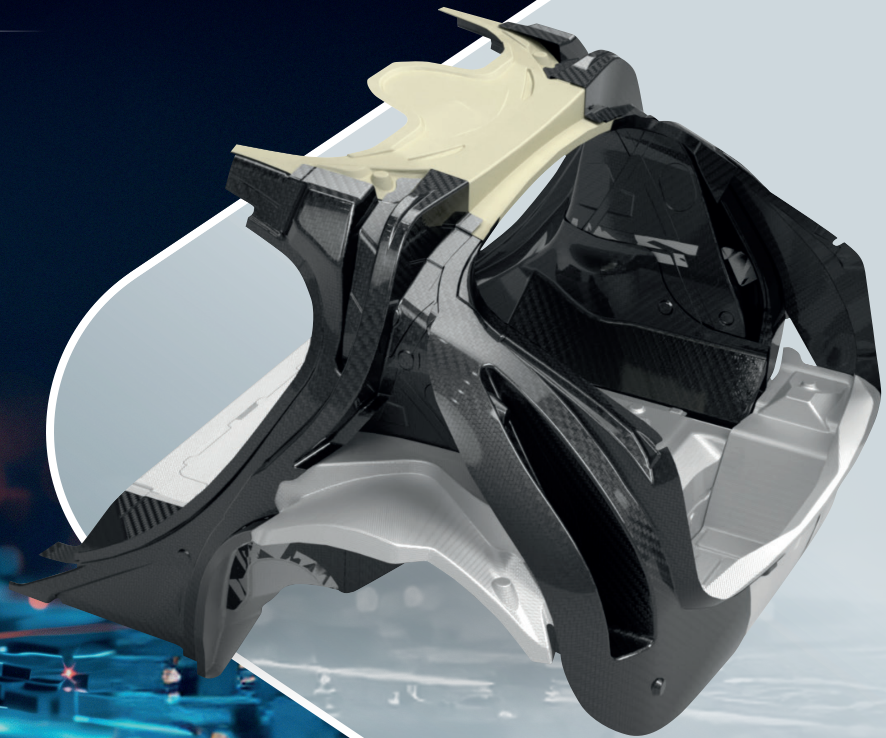
# Vehicle Efficiency, Circularity and Sustainability

# Innovation Opportunities Report

2025



ADVANCED PROPULSION CENTRE UK

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# 1 | Foreword

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Global demand for clean mobility is growing. To support the UK's competitiveness, secure jobs, and achieve the transition to zero-emission vehicles and towards a net-zero automotive industry, innovation will be key. Yet, taking innovative technologies to rapid commercialisation is an issue for the automotive industry. Even then, possibilities are limited by our supply chain's capabilities, strengths, and gaps.

Building on the Automotive Council UK's Technology Roadmaps, this series of Innovation Opportunities reports examine key technology priorities and associated supply chain opportunities for the UK automotive industry.

We highlight areas where collaboration between industry, government, and research institutions can accelerate commercialisation and encourage investment. These can future proof the UK automotive industry.

The reports map trends and drivers up until 2050 which might be at different levels of maturity or market readiness.

We do this across different regions, showing how even if a technology is at the point of implementation, the underpinning supply chain might not be geared up for change at scale and pace.

# 2 | Executive Summary

**The 'Vehicle Efficiency, Circularity and Sustainability' Innovation Opportunities report provides a deep dive into all themes and sub-themes identified on the roadmaps and maps them against the European and UK supply chain capabilities within the context of automotive applications.**

This analysis offers an overview of key focus areas and associated strengths, and gaps to guide industry's direction of travel across the global landscape of a sustainable automotive industry.

The report covers a range of metrics to identify innovation opportunities, focussing on benefit and capability, both relative to the UK. As a result, the report highlights four key innovation groups (see Figure 1) for research and development (R&D) as well as scale-up and commercialisation endeavours.

**Four key innovation groups:**

- Vehicle structural and optimisation weight,
- Design for circularity,
- Material recovery and closed loop,
- Sustainable material sourcing.

By clarifying associated R&D opportunities in technologies related to vehicle efficiency, circularity and sustainability, this report gives an insight into building a resilient value chain for the future of the UK automotive industry.

### Recommendations for strategic planning and decision-making in the UK

| Common definitions and metrics | Cross-industry closed-loop supply chains | Pre-competitive general development funding | Applying artificial intelligence (AI) and digital tools | Data sharing |
|---|---|---|---|---|
| Driving standardisation and building in the requirement for measurement and reporting of sustainability and circularity into project funding criteria. | Participating in collaborative efforts to drive secondary material supply and establishing material-specific working groups. Hence, enabling bringing together key players to drive supply chain growth and UK closed-loop material security. | Offering direct funding towards solving common cross-industry challenges. | Bringing together automotive, AI research and industry players from aerospace and manufacturing to share knowledge and develop AI and digital solutions for the automotive sector. | Sharing harmonised material data cards across the automotive sector, adjacent industries and research centres. Also, updating data regularly to reflect changes to production and material grades. |

# 3 Methodology

This study defines and assesses the four innovation groups highlighted in the green boxes in Figure 1. A five-step process (Figure 2) also identifies key innovation opportunities across the four innovation groups.

Figure 1: The four innovation groups across the lifetime of a vehicle, in relation to vehicle efficiency, circularity and sustainability

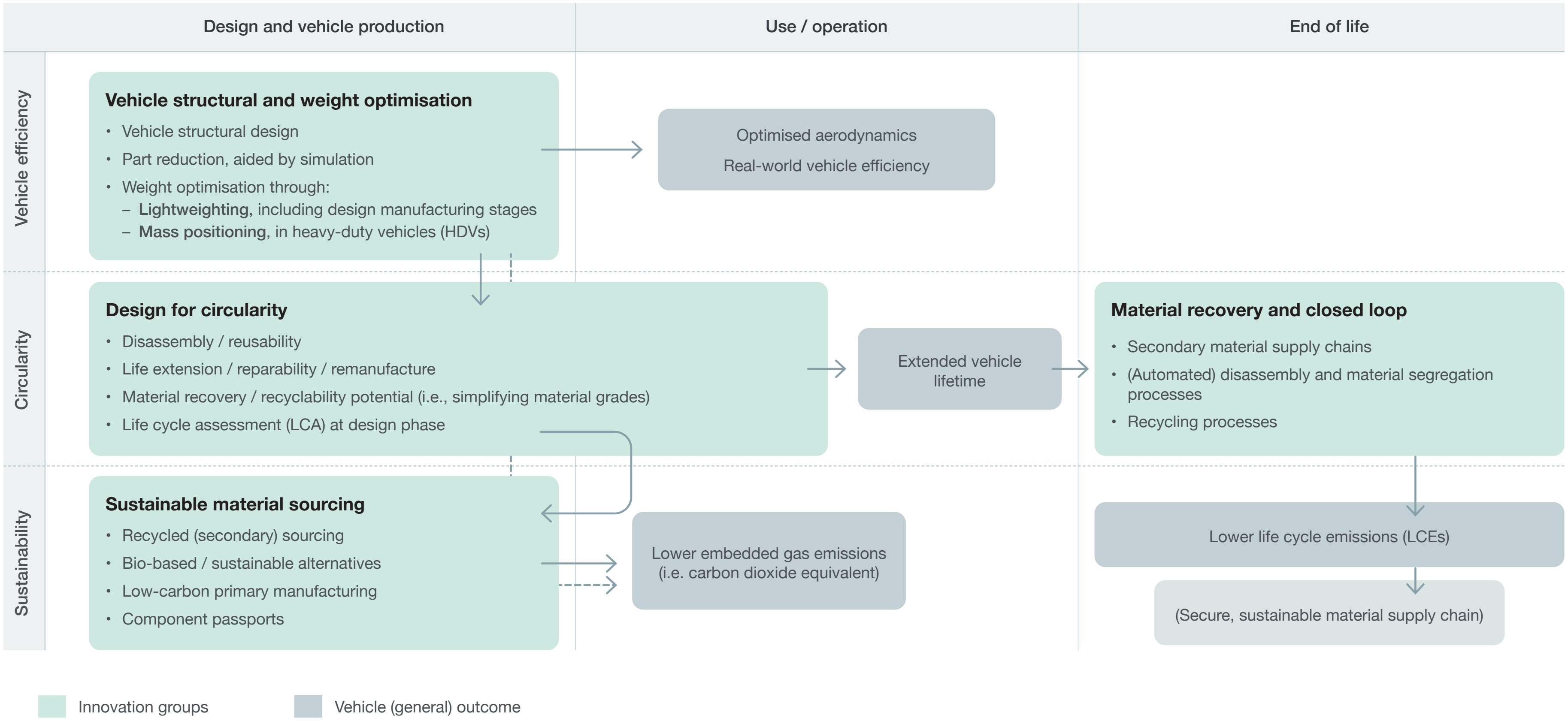

**Figure 2: Five-step process to identify key innovation opportunities within each innovation group**

**1**
Innovations from roadmaps categorised in one of the four innovation groups

- Identify key challenges for each innovation group
- Undertake desk research, including reviewing the technology roadmaps to identify innovation clusters for each innovation group

**2**
Filter innovations

- Filter innovations by qualitatively assessing 'benefit to UK industry' and 'relative UK capability'

**3**
1-2-1 consultations

Interviews with key industry stakeholders to

- Understand and identify industry opportunities
- Identify key UK strengths

**4**
Industry workshop

Workshop with additional industry stakeholders to

- Review industry opportunities
- Review innovations
- Develop recommendations

**5**
Innovation opportunities and recommendations

Final outcomes

- Key innovation opportunities
- Recommendations

**Deliverables for each step**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Base hypothesis of innovations | Prioritisation of innovations | Stakeholder insight | Stakeholder engagement | Final report and recommendations |

# 4 | Results

This report section covers the key innovation opportunities, which were identified as a result of the five-step process described in Figure 2.

## Vehicle structural and weight optimisation

The key innovation clusters for 'vehicle structural and weight optimisation' innovation group include AI-driven tools, modular structures, lightweight materials and novel joining techniques.

There is potential for conflict between vehicle structural and mass optimisation versus sustainability and circularity goals. Hence, trade-offs need to be modelled to be understood. The design process is extremely important and should leverage AI using real-world data. A portfolio of materials approaches is needed to meet the requirements of different sectors.

### Review of innovations: AI-driven tools

**Key innovation opportunities**

- Physics-based models using machine learning (ML) and AI to design and optimise structures, considering manufacturing processes (leveraging real-world data, including LCA)
- Digital tools and real-world databases for choice and validation of materials and designs
- Simulation of structures using deep neural network surrogate models

**Description**

- A change in design approach is required to incorporate sustainability and circularity aspects into current design and simulation for vehicle structural and mass optimisation. Hence, enabling avoiding unintended consequences later in the life cycle study
- Generative design methods and tools including engineering, manufacturing and performance validation allowing time and cost-efficient modelling of key design parameters, and adjustment for optimal performance, sustainability and circularity considerations

**Rationale**

- Design process tools can address the key challenge of understanding trade-offs between vehicle structural and mass optimisation, sustainability and circularity
- Applicable across all vehicle segments
- Leverage UK strength in AI and ML from research and product development at UK universities and domestic startups, i.e., DeepMind and Wayve

### Review of innovations: Modular structures

**Key innovation opportunities**

- Modularisation of components by combining functions, design optimisation to give fewer components
- Modular, scalable and flexible multi-product platform
- Giga- and tera-casting to mass-produce large structural parts used in modular structures

**Description**

- Multi-drivetrain platforms using fewer and monolithic parts to allow switch to BEV / fuel cell electric vehicle (FCEV) by reducing parts, cost and weight. These may include skateboard platforms to decrease part numbers and weight, with increasing integration of battery into vehicle structure
- Fewer joining techniques required for larger modular components

**Rationale**

- Reducing number of individual components can decrease manufacturing complexity and assembly time, hence lower embedded $CO_2$
- UK has strong motorsports heritage with experience in structural component integration

## Review of innovations: Lightweight materials

**Key innovation opportunities**

- High-strength steel grades
- Development of multi-material structures (e.g. aluminium and polymer composites) to replace steel components
- Automation of composite production process for rapid process time (enabling scale-up), quality control and repeatability

**Description**

- The industry needs innovative materials and manufacturing processes permitting lightweight vehicles with a lower carbon footprint
- New materials must balance increased recycled content use and end-of-life (EOL) recyclability compared to conventional materials, whilst maintaining quality, durability and performance standards

**Rationale**

- Innovation in materials and process is key to enable weight reduction and improve sustainability across automotive sectors
- The UK has a good base in fundamental science and research
- UK has strength in design and engineering knowledge for composites and low-volume manufacture
- Technology development brings mainly higher skilled jobs

## Review of innovations: Novel joining techniques

**Key innovation opportunities**

- Development and licensing of bonding / debonding solutions for multi-material components

**Description**

- The ability to be able to reverse / debond materials for remanufacture or EOL recycling is crucial for the application of multi-material structures in vehicles
- Requirement for solutions to reduce the contamination possibility when recycling (e.g., self-piercing rivets introduce steel contamination into aluminium)

**Rationale**

- Effective solutions for reversible adhesives and debonding structures exist at the UK academic research level
- Technology development brings mainly higher skilled jobs

## Sustainable material sourcing

The key innovation clusters for 'sustainable material sourcing' innovation group include transparent supply chains, sustainable alternatives and recycling processes.

Security of access to critical raw materials (CRMs), provenance of recycled parts and materials, and capital intensity of innovation scale-up are key challenges. Obtaining reliable and transparent supply of CRMs is critical for long-term viability of the UK automotive sector. However, there are no common definitions or key performance indicators (KPIs) to support adoption.

### Review of innovations: Transparent supply chains (primary and secondary materials)

**Key innovation opportunities**

- Mechanism to record sustainability of vehicle materials (i.e., component passport)
- Standardisation and simplification of material grades to facilitate recycling and secondary material demand

**Description**

- Innovations enabling better understanding of provenance and supporting confidence in using recycled materials to increase the demand in the automotive sector
- Component tracking crucial for second-life reuse as replacement parts to accurately assess vehicle sustainability

**Rationale**

- Providing confidence for original equipment manufacturers (OEMs) to adopt recycled materials and supporting secondary market and closed-loop supply chain, allowing value to be retained within the UK
- The UK is proactive and innovative when it comes to traceable systems (e.g., carbon accounting leadership and resource efficiency practices). This would lead the UK implementing material passport for tracking sustainability
- Other initiatives underway include Office for National Statistics (ONS) National Materials Data hub project, and organisation-led systems (e.g., from Far-UK, NCC, JLR and Alipro)

### Review of innovations: Recycling processes

**Key innovation opportunities**

- Cost-effective aluminium and steel recycling processes to reduce contaminants and improve energy efficiency
- Cost-effective processes for polymers and composite material recycling and for re-use using low-energy intensity
- Cost-effective commercialisation and improved sustainability of battery recycling technologies

**Description**

- Build out capabilities and plants to recycle key materials in the UK securing future supply, reducing reliance on overseas primary material supply locations and retaining material value

**Rationale**

- Supports increasing regulatory requirements to reduce the sustainability impacts of automotive materials and preserve scarce materials
- Material supply underpins UK manufacturing industry
- Retaining material value in the UK from EOL vehicles and other material sources

**Review of innovations: Sustainable alternatives**

**Key innovation opportunities**

- Sustainable battery chemistry design (ref. Electrical Energy Storage Innovation Opportunities 2025 report[1])
- Commercialisation of recycled fibres for polymer composite manufacture

**Description**

- Development of next-generation battery chemistries for energy efficient and environmentally friendly solutions
- Materials (partly or fully) derived from biomass feedstock, such as corn, sugarcane, or wood, with the renewable feedstock able to easily replace that of fossil fuel

**Rationale**

- Market for new battery chemistries is open, with novel recycled materials likely to be driven by legislation in the future (i.e., minimum LCA requirements)
- UK has a good base in fundamental material science and research, with strong potential for growth
- Opportunity for high-value employment in battery and advanced-material production

1 Electrical Energy Storage Innovation, APC report, 2025

# Circularity: design for circularity

The key innovation clusters for 'design for circularity' innovation group include design for repairability and disassembly, design for longevity and remanufacture, and tools and standards for circularity.

80% of UK-manufactured vehicles are exported. Hence, there is a challenge around vehicle EOL. The lack of defined metrics for assessing sustainability and circularity of a design and understanding provenance of parts / materials and changing mindsets are key barriers. Higher proportion of HDVs and off-highway vehicles are already sent for remanufacturing compared to passenger cars. The priority should be to design vehicle subsystems with repairability / second-use in mind.

## Review of innovations: Design for repairability and disassembly

**Key innovation opportunities**

- Modular designs to facilitate replacement of parts / systems for life extension (upgrade) / repairability
- Designing vehicle structures and subsystems (especially batteries, power electronics and electric motors) for ease of replacement and / or disassembly at EOL

**Description**

- Supporting ability to extend vehicle life through replacement part / upgrades
- Supporting ability to recover key materials at EOL
- Incorporate standardisation of components to allow remanufacturing and switching out of components at EOL

**Rationale**

- Supporting disassembly processes and enabling access for the UK to a reliable supply of key materials, which will reduce reliance on imports and help secure future domestic supply chain
- Retaining material value in the UK from EOL components especially for imported vehicles
- Leveraging UK strengths in vehicle and subsystem design, and development from UK-based OEM and motorsports industry

## Review of innovations: Design for longevity and remanufacture

**Key innovation opportunities**

- Use of virtual reality (VR) / AI / digital twins with real-world data to inspect and understand state-of-health as well as improve / optimise design to increase component life expectancy
- Non-destructive testing (NDT) methods to assess vehicle health / structural integrity after a crash without damaging the vehicle
- Designing for second-life and alternative applications into vehicle subsystems at the start

**Description**

- NDT is a cost- and time-efficient way to check vehicle component health, especially when combined with generative AI to review and identify faults
- Feedback of state-of-health data to the design process allows improvements to part longevity
- Battery, electric motors and other vehicle subsystems have applications in other sectors, including stationary energy storage, maritime sector and energy generation. Remanufacture requires designing for disassembly at component or vehicle EOL

**Rationale**

- Leveraging UK strengths in ML and AI, driving higher value employment, with digital techniques (AI / ML) for NDT already used (e.g., in aerospace)
- Second-life remanufacturing retaining value in the UK and supporting growth of existing remanufacturing industry base

| Review of innovations: Tools and standards for circularity |
|---|
| **Key innovation opportunities**<br>• LCA tools to model and optimise at design using well-defined and cross-industry technology specifications<br>• Monitoring in-use parts to feedback into LCA design process with real-world data<br>• Uniform measurement process and standards to compare technologies and materials (i.e., life cycle kilograms of carbon dioxide equivalent (kg$CO_2$eq))<br>• Standardise material grades across industries, such as between automotive and aerospace ones |
| **Description**<br>• LCA design tools considering sustainability and circularity factors, alongside traditional performance, and cost factors are critical for automotive companies to optimise across all parameters<br>• Emissions from operations across Scopes 1, 2 and 3 must be considered to fully assess vehicle impact |
| **Rationale**<br>• UK's strength in sustainability, circularity thinking and LCA consulting, with potential for marketable tools<br>• Expected implication in global standards and / or applying them providing opportunity to take global lead and shape future dialogue<br>• Need for solutions will continue to grow with increasing regulation / legislation over the horizon |

# Circularity: material recovery and closed-loop processing

The key innovation clusters for 'material recovery and closed-loop processing' innovation group include disassembly processes, closed-loop supply chains, and high-volume recycling.

Material recovery capability, cost-competitive processes and the lack of cross-industry collaboration are key barriers to material recovery and closed-loop processing. Material value from EOL sources are being exported from the UK, influenced by high-cost energy and low-volume production. Hence, cross-industry collaboration is needed to enable material recovery.

## Review of innovations: Disassembly processes

**Key innovation opportunities**

- Cost-effective, automated disassembly techniques for multi-material structures
- Cost-effective techniques for recovering advanced materials from end-of-life vehicle (ELV) systems including rare earth elements (REEs) from drive units, copper and composites

**Description**

- Cost-effective disassembly and material recovery processes are key enablers for recycling companies and automotive manufacturers to capture EOL value within UK supply chains, particularly for scarce and high-environmental impact materials, such as CRMs and REEs
- High-volume recycling processes will rely on automation and AI to correctly identify and separate material grades efficiently
- High-value and high-demand materials are a focus

**Rationale**

- Cost-effective disassembly processes will provide competitive access to REEs and other materials for the UK automotive sector, securing resilient supply chains
- The UK has research capacity in AI and autonomous technologies, with automated systems already deployed in adjacent sectors. A strategic alignment between existing UK capability and applying it to vehicle disassembly in the automotive sector needs to be made

## Review of innovations: Closed-loop supply chains

**Key innovation opportunities**

- Establishing a network of stakeholders at each stage of the recycling process
- Reduced material wastage and increased production yield, particularly for battery cells

**Description**

- Cooperative and transparent network of stakeholders is needed at each stage of the recycling process to establish a closed-loop system. This would enable efficiently recovering and redeploying secondary material within the automotive sector
- Communication of requirements between automotive companies (of design needs) and recycling companies (of disassembly and EOL management capacity)
- High-quality production waste should be captured and fed back into component manufacturing

**Rationale**

- Enabling retention of material value and supporting access for the UK to key materials. Hence, reducing reliance on imports and securing a reliable material and component supply chain for future growth

| Review of innovations: High-volume recycling |
| --- |
| **Key innovation opportunities**<br>• Scaling-up and commercialising existing recycling processes to promote circularity within subsystems that contain high-value and resource-scarce materials, including power electronics, hydrogen fuel cells, electric motors and batteries |
| **Description**<br>• Recovery and recycling of CRMs and REEs from BEV and FCEV powertrains supports the circularity, reliability and captured value within UK material supply chains relevant to the automotive sector and the electric vehicle (EV) transition |
| **Rationale**<br>• Providing competitive access to REEs and other materials for the UK automotive sector, which are valuable and resource-strained materials for future vehicle-segment electrification<br>• Retaining material value in the UK and securing resilient supply chains for strategic automotive industry expansion<br>• Several programmes developing UK capability in CRM and REE recovery from electric motors, batteries and fuel cells, including RECOVER, RaRE and other UK Research and Innovation (UKRI)-funded programmes |

# Special mentions

Several other innovation opportunities (some out-of-scope) were identified by external stakeholders in relation to vehicle efficiency, circularity and sustainability and are worth special mentions:

**Aerodynamics**

Aerodynamics of a vehicle can have significant impact on the in-use efficiency, particularly for HDVs with large frontal areas and long interurban trips. However, manufacturers have already undertaken significant work (i.e., computational fluid dynamics (CFD) simulations) to optimise vehicle design for lower drag, with some but limited improvement on existing designs expected in the short- to medium-term.

**Software-defined vehicles (SDVs)**

SDVs are an emerging trend[2] where vehicle operation focuses on software rather than hardware traditionally used to enable functionality and development.

- Use of software to offer enhanced performance and efficiency to conventional hardware-based architectures. This would enable constantly monitoring engine parameters, improving fuel or battery pack efficiency, and optimising driving dynamics.
- New features can be unlocked through over-the-air (OTA) updates, whilst vehicle health monitoring allows predictive maintenance to resolve potential issues before they escalate.

**Trained operators (and / or autonomous features)**

Trained operators (and / or autonomous features), particularly in construction equipment, for intelligent machine use, skilled teamwork and effective management improve efficiency and hence reduce energy consumption.

**Connected Automated Mobility (CAM)**

Using CAM technologies optimise route planning including fuel or toll costs.

- CAM vehicles remove human input from driving and connect with nearby vehicles and traffic systems to communicate and coordinate activity.

**Low-impact charging cycles**

Low-impact charging cycles (i.e., planned alternating current (AC) instead of rapid direct current (DC) charging) can be used to extend battery longevity and limit battery life-cycle impact

- This requires a comprehensive charging network across both residential and public (workplace / leisure) locations.

2 Advanced automotive software and control systems, APC report, March 2025

# 5 | Conclusions

## Summary

The key innovation clusters are summarised by innovation group and a timeframe has been determined for each.

**Summary of the key innovation clusters by innovation group with associated timeframe**

| Innovation group | Key innovation clusters | Market readiness timeframes |
|---|---|---|
| **Vehicle structural and weight optimisation** | • AI-driven tools<br>• Modular structures<br>• Lightweight materials and processes<br>• Novel joining techniques | • Short-Medium term<br>• Short-Medium term<br>• Medium-Long term<br>• Short-Medium term |
| **Sustainable material sourcing** | • Recycling processes<br>• Transparent supply chains<br>• Sustainable alternatives | • Medium-Long term<br>• Medium-Long term<br>• Short-Medium term |
| **Circularity: design for circularity** | • Design for repairability and disassembly<br>• Design for longevity and remanufacture<br>• Tools and standards for circularity | • Medium-Long term<br>• Medium-Long term<br>• Short-Medium term |
| **Circularity: material recovery and closed-loop processing** | • Disassembly processes<br>• Closed-loop supply chains<br>• High-volume recycling | • Medium-Long term<br>• Medium-Long term<br>• Medium-Long term |

**Key points to add to the report rationale**

- Whilst there are several innovation clusters with short- / medium-term timeframes for mass-market adoption, innovations within the circularity and sustainable material sourcing groups are longer term. They play to build supply chain resilience and growth for the future of the UK automotive industry.
- Many innovation clusters require collaboration across multiple sectors and industries to deliver. Hence, they cannot be effectively achieved by the automotive industry in isolation.

# Key insights

A few key insights can be taken away from this study in the UK context:

**Co-ordinated cross-industry, sector and value chain cooperation is required**

**Multi-disciplinary approach is needed**
to balance vehicle design and material considerations, optimising for cost and performance, with sustainability and circularity goals

**Economics must work for UK to be competitive**

**Scale-up and capital investment is key**

**Digital tool chain and leveraging AI / ML / real-world data are extremely important**

**Engineering targets and sustainability / circularity factors / considerations need to be linked**

**UK workforce needs to be ready to adopt innovations and a circularity 'mindset'**
training and upskilling required to design and handle new materials and processes

**Common definitions and metrics (e.g., KPIs) for measuring sustainability and circularity are needed**

# 6 Recommendations

Actionable high-level recommendations for strategic planning and decision-making in the UK in relation to 'Vehicle Efficiency, Circularity and Sustainability' are described in Figure 3. The need for cross-industry collaboration is the common thread across all the recommendation.

**Common definitions and metrics**

- Take a lead for the UK in driving standardisation of common terminology, metrics and LCA methods to measure and incorporate sustainability and circularity. This should be applied throughout vehicle design and life cycle management
- Build in the requirement for measuring and reporting of sustainability and circularity into project funding criteria

**Cross-industry close-loop supply chains**

- Facilitate and / or participate in collaborative efforts to drive secondary material supply (processing / production capacity) and automotive demand (grade alignment and quality assurance) between material suppliers, OEMs and recyclers
- Establish material-specific working groups to bring together key players to drive supply chain growth and UK closed-loop material security (join up and align existing strategies for similar challenges across industries)

**Pre-competitive general development funding**

- Offer direct funding towards solving common cross-industry challenges agreed upon by bringing automakers and the material industry together in a non-competitive environment (e.g., EOL to de-risk investment)

**Applying AI and digital tools**

- Bring together AI research and industry players from aerospace and automotive to share knowledge and develop AI and digital solutions. This will allow optimising for efficiency, circularity and sustainability at each stage of the vehicle life cycle

**Data sharing**

- Share harmonised material data cards, avoiding competitive sensitivities, across the automotive sector, adjacent industries and research centres to transparently assess the merits of material and design choices
- Update data regularly to reflect changes to production and material grades, and provide forecasting of future sustainability and circularity impacts to allow strategic investment decisions by companies

Figure 3: High-level recommendations for strategic planning and decision-making in the UK

## Glossary

| | |
|---|---|
| AC | Alternative Current |
| AI | Artificial Intelligence |
| APC | Advanced Propulsion Centre |
| BEV | Battery Electric Vehicle |
| LCEs | Lower Life Cycle Emissions |
| CFD | Computational Fluid Dynamics |
| $kgCO_2eq$ | Kilograms of carbon dioxide equivalent |
| CRMs | Critical Raw Materials |
| CV | Commercial Vehicle |
| DC | Direct Current |
| ELV | End-of-Life Vehicle |
| EOL | End of Life |
| EV | Electric Vehicle |
| FCEV | Fuel Cell Electric Vehicle |
| HDV | Heavy-Duty Vehicle |
| ICE | Internal Combustion Engine |
| KPI | Key Performance Indicator |
| LCA | Life Cycle Analysis / Assessment |
| ML | Machine Learning |
| NDT | Non-Destructive Testing |
| OEM | Original Equipment Manufacturer |
| REEs | Rare Earth Elements |
| R&D | Research and Development |
| TCO | Total Cost of Ownership |
| UK | United Kingdom |
| UKRI | UK Research and Innovation |
| VR | Virtual Reality |

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**Further information**

If you have any questions or would like more detail on any of the graphs or data, email info@apcuk.co.uk

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Mobility of People

Mobility of Goods

## Technology Roadmaps

Electric Machines

Power Electronics

Electrical Energy Storage

Lightweight Vehicle and Powertrain Structures

Internal Combustion Engines

Hydrogen Fuel Cell System and Storage

Find all the roadmaps at

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Established in 2013 and jointly funded by the Department for Business and Trade (DBT and the automotive industry, the APC accelerates the technologies that support the transition to zero-emission vehicle manufacturing and towards a net-zero automotive supply chain in the UK.

With a proven track record, the APC has facilitated funding for 354 low-carbon and zero-emission projects involving 614 partners. Working with companies of all sizes, this funding since 2013 is estimated to have helped create or safeguard over 59,000 jobs in the UK. The technologies and products are projected to save over 425 million tonnes of $CO_2$.

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