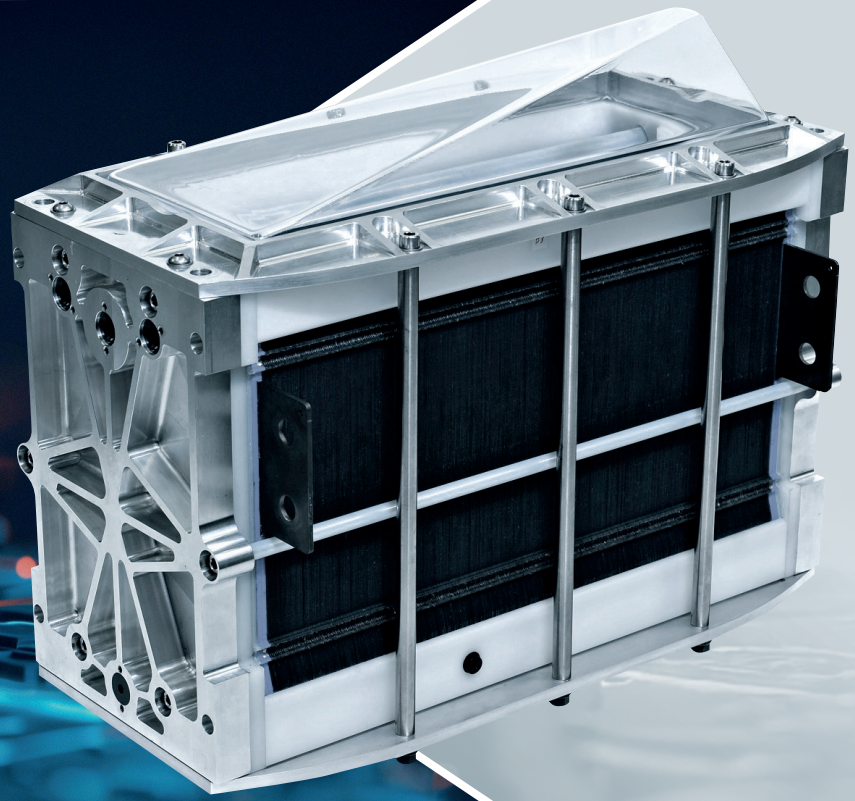
Hydrogen Fuel Cell System and Hydrogen Storage

Innovation Opportunities Report

2025



ADVANCED PROPULSION CENTRE UK

Information correct at time of publication

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1 Foreword

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The Innovation Opportunities report for hydrogen fuel cells and hydrogen storage provides a deep dive into all themes and sub-themes identified on the roadmap and tracks them against the European and UK supply chain capabilities within the context of automotive applications.

Hydrogen ICE is not in scope for this report, but will form a central component of the upcoming Internal Combustion Engines Innovation Opportunities report.

This analysis provides an overview of key focus areas and associated strengths and gaps to guide industry's direction of travel across the global landscape in the fuel cell and hydrogen storage industry. Covering a range of metrics to prioritise innovation opportunities, the report focuses on market value, market growth, ease of innovation, and then maps these against innovation significance and current UK industry capability.

The report is divided into a set of significant innovation areas:

- Fuel cell stack developments, including membranes and catalysts
- Fuel cell balance of plant developments, such as thermal management and fluid handling
- Hydrogen compressed gas storage and structural integration
- Thermal and pressure regulation for the onboard hydrogen storage.

This report provides an insight into building a resilient fuel cell and storage industry for the future of the UK automotive industry.

2 Introduction

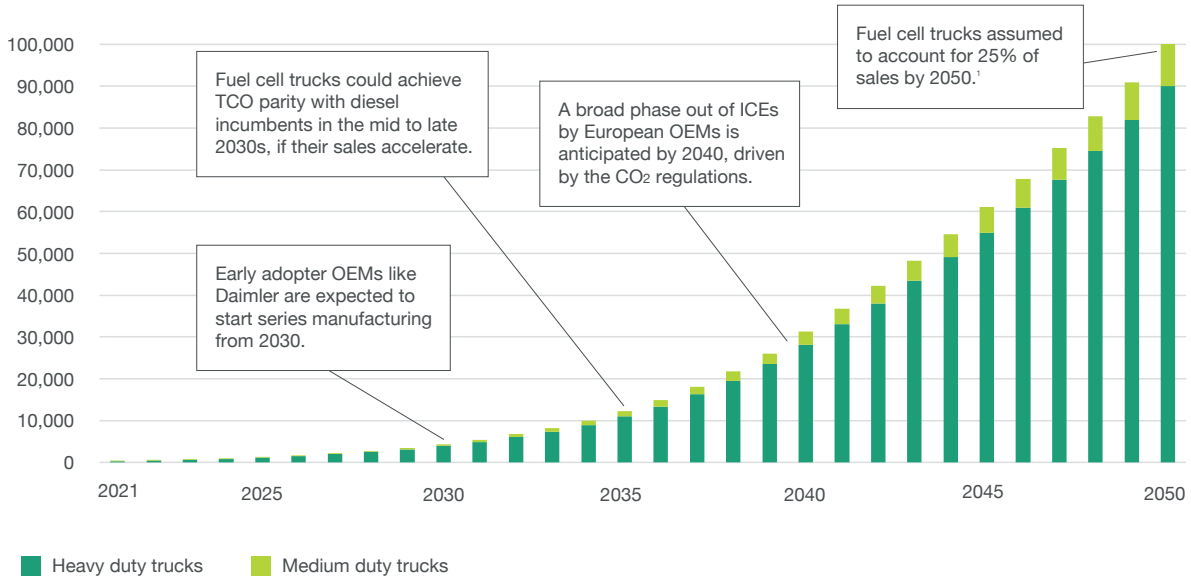
Heavy-duty vehicles (HDVs) are set to lead fuel cell and hydrogen storage market growth

The market landscape and future outlook for fuel cell truck sales also shows off-highway and non-road mobile machinery (NRMM) innovations focusing on lifetime, performance and total cost of ownership (TCO). While battery electric vehicles (BEVs) are effective in many segments, gaseous hydrogen offers improved range and fast-refuelling for high-demand, long distance and hard-to-decarbonise applications. The graph in figure 1 shows that by 2050, fuel cell trucks are estimated to account for 25% of all heavy-duty and medium-duty trucks combined, with TCO parity achieved by 2035 if sales continue to accelerate at current pace.

Fuel cells, especially polymer electrolyte membrane fuel cells (PEMFCs), are already proven in buses and show strong potential in trucks, with growing adoption in Europe. Though passenger cars are mostly BEVs or hybrids, around 40,000 fuel cell electric vehicles (FCEVs) are in use globally, mainly in Europe, the USA, China, South Korea, and Japan.

In non-road mobile machinery (NRMM), notably in construction and mining, hydrogen fuel cells and internal combustion engines (H2 ICEs) are better suited for high-power and long-duration tasks, especially where grid access is limited. BEVs meet some needs, but hydrogen powertrains are more viable for operations requiring hundreds of kW to several MW. Fuel cell NRMM is unlikely to be widely commercialised before the 2030s, though development is ongoing. BEVs will remain competitive, while H2 ICE adoption will depend on hydrogen costs and carbon pricing. Fuel cell forklifts, in use for over 15 years, offer quick refuelling and long operation, ideal for large fleets with dedicated H2 stations. While batteries still dominate, companies like Hyster and Toyota offer fuel cell models alongside Li-ion and lead-acid options to meet diverse customer requirements.

Figure 1: Projected annual fuel cell truck sales in Europe (ERM, 2025)



1 Based on total annual truck sales (all powertrains)

Fuel cells and hydrogen storage: main challenges

The increasing share of HDVs, off-highway and NRMM in the global fuel cell market is shaping innovation requirements.

Five overarching techno-economic and environmental challenges have been identified for fuel cells, and six for hydrogen storage, corresponding to the technology challenges listed as part of the APC's Fuel Cell Industry Challenges report.

Fuel cell stack and balance-of-plant
Reducing system cost
Increasing power density and system efficiency
Improving durability and lifetimes
Fuel cell and battery systems optimisation
Reduce life cycle impacts

Hydrogen storage and balance-of-plant
Reducing cost of storage
Standardisation and scale manufacturing
Increased safety
Improvements in storage capacity and loss reduction
Vehicle integration and assembly improvement
Higher recyclability

Table 1: Expected targets for heavy-duty trucks and NRMM

Use case	Date	System efficiency (%)	Durability (hours)	FC Power (kW)	Range/ autonomy	Stack price
Heavy-duty truck	Today	55-65[3]	22,000	150-300[1]	400-700 km[1]	$180/kW[3]
	Target (2030[2,6])	68	27,000	NA	750 km	$118/kW
	Target (2040-50[2,6])	70	32,000	NA	750 km	$40/kW
NRMM	Today	50-55[3]	10,000	800[4]	NA†	$180/kW[3]
	Target	-	50,000+[5]	800[4]	>20 hrs/ day	$60-80/kW[2]

† Range is of low importance for such applications, therefore not published. Figures above are a combination of the linked sources (right) and 2024 Automotive Council UK Hydrogen Fuel Cell and Hydrogen Storage roadmap[6].

1 Roland Berger, 2020. Various other vehicle specifications (Hyundai, Daimler, Volvo, Hyzon)
2 US Department of Energy, 2020. Prices assume > 100k units p.a.
3 US Department of Energy, 2023. Assumes > 50k units p.a.
4 Anglo-American, 2022.
5 Komatsu, 2022.
6 APC and Automotive Council UK 2024; Hydrogen Fuel Cell and Hydrogen Storage roadmap

3 Results

Fuel cell and hydrogen storage: significant areas of innovation

Three priority categories for fuel cell innovation to address multiple challenge areas are:

A Catalyst layers and power management,

B Membranes, gas diffusion layers, and bipolar plates,

C Balance-of-plant (BoP) systems.

Four priority categories for hydrogen storage innovation, which can address multiple challenge areas, are:

A Carbon fibre development, and improved thermal resilience,

B Recovered materials and balance of plant,

C Polymer and liner,

D Other storage forms.

X Denotes significant contribution to the innovation in the area for solving selected challenges.

Significant areas of innovation

Table 2: Fuel cells innovation significance map

		Techno-economic and environmental challenges				
Fuel cell		Cost	Durability / lifetime	Power density / efficiency	Life Cycle impact	System optimisation
Stack	Membrane	X	X	X	X	
	Ionomers				X	X
	Catalyst layers	X	X		X	
	Gas diffusion layers				X	
	Bipolar plates			X	X	
	Power management and manufacturing	X	X	X		X
BoP	Thermal management	X	X		X	X
	Air, H_2 and fluid handling	X	X			X
	Power and ancillary management	X	X	X		X
	Control system		X			X

Hydrogen storage		Cost	Scale manufacture	Safety	Capacity	Vehicle integration	Recycling
Stack	Compressed gas	X	X	X	X		X
	Other storage forms				X		
	Structural integration	X	X		X	X	
BoP	Thermal regulation/resilience	X		X	X		X
	Pressure regulation and manifolds	X	X	X		X	
Safety / life cycle	Safety technology and condition monitoring	X		X			
	Material recovery	X	X				X

Fuel cell: UK capability

There is significant potential to expand capabilities and encourage the UK industry to innovate in BoP systems and fuel cell membranes.

There is capability within the UK to address the significant innovation opportunities based on the number of active companies and their expertise, as well as those in related adjacent fields.

A Catalyst layers and power management

Numerous UK companies are at the forefront of catalyst development on a global scale, although expertise is concentrated amongst those developing whole stacks, which may limit cross-sector innovation and reduce agility. Innovation in stack power management holds significant potential and should be prioritised, particularly as it could unlock performance gains across the entire fuel cell system. However, advancing catalyst innovation remains a challenge due to high R&D costs and long development cycles. A collaborative approach would mitigate these risks and reduce duplication of effort, in turn, accelerating progress and positioning the UK as a global leader in next-generation fuel cell technologies.

B Membranes, gas diffusion layers, and bipolar plates

The UK has a strong industrial base in bipolar plates, but membrane development is largely confined to academia. This disconnect between research and commercialisation may hinder the translation of breakthroughs into market-ready solutions. Gas diffusion layer expertise, while strong, is fragmented. Given the high skill level but limited industrial presence in membranes, this area represents a strategic opportunity. Targeted investment and industry-academia partnerships could bridge the gap, fostering a pipeline of innovations that support domestic manufacturing and reduce reliance on imports.

C Balance of plant

Globally, few companies supply complete BoP systems, presenting a niche area where the UK could excel. Leveraging expertise from adjacent sectors like aerospace and advanced modelling could enable the UK to develop service-based BoP solutions, offering not just components, but integrated, optimised systems. This approach aligns with global trends toward digitalisation. The UK is well-positioned to lead in this space, but doing so will require coordinated efforts to align design, manufacturing, and digital capabilities.

Table 3: Fuel cells UK industry capability map

Fuel cell stack	Number of current UK entities	UK industry skill level
Catalyst layers	>5	Global leaders
Power management	2-4	Experienced and capable
Gas diffusion layers	2-4	Global leaders
Bipolar plates	>5	Experienced and capable
Membranes	<2	Global leaders

Balance-of-plant	Number of current UK entities	UK industry skill level
Thermal management	<2	Experienced and capable
Air, hydrogen and fluid handling	2-4	Experienced and capable
Power and ancillary management	2-4	Limited capacity
Control systems	<2	Limited capacity

Significant areas of innovation

Hydrogen storage: UK capability

The UK has strong capabilities in the development of carbon fibre and improving the thermal performance and recyclability of materials.

A Carbon fibre development and improved thermal resilience

Several UK companies produce carbon fibre products, though none have yet achieved scale. This presents a strategic opportunity where targeted support could enable these firms to lead in next-generation materials. Prioritising investment in scalable manufacturing and cross-sector collaboration (e.g., with aerospace) could accelerate breakthroughs in thermal resilience and cost reduction, which is critical for global competitiveness.

B Recovered materials and balance of plant

The UK's limited expertise in BoP systems is a bottleneck that could hinder the scaling of hydrogen technologies. Addressing the gap requires not just technical innovation but also workforce development and supply chain integration. Strategic investment in training and cross-disciplinary R&D could unlock synergies and accelerate deployment.

C Polymer and liner

While UK capabilities in polymers and liners are modest, there is untapped potential in leveraging adjacent sectors such as aerospace and motorsports. Facilitating knowledge transfer and incentivising cross-sector partnerships could boost innovation. A proactive approach here could position the UK as a leader in high-performance liner technologies.

D Other storage forms

The UK's strength in diverse hydrogen storage technologies, such as metal hydrides, liquid storage, and cryogenic methods, is a valuable asset. However, the lack of demand in mobility applications suggests a need to reassess strategic focus. Redirecting efforts toward industrial or grid-scale storage, where demand is growing, could yield greater impact and commercial returns.

Table 4: Hydrogen storage UK industry capability map

Hydrogen storage	Number of current UK entities	UK industry skill level
Carbon fibre	>5	Global leaders
Recovered and bio-based materials	<2	Experienced and capable
Polymer and liner	2-4	Experienced and capable

Balance-of-plant	Number of current UK entities	UK industry skill level
Balance of plant innovations	<2	Experienced and capable
Thermal regulation and resilience	2-4	Global leaders
Other storage forms	2-4	Global leaders

Significant areas of innovation

Fuel cell innovation priorities

Innovations in catalysts, power management, and balance of plant systems are important to improve performance and cost, representing a significant market opportunity.

1 Balance of plant systems (Thermal, power, ancillary, Air H_2 and fluid management)

BoP systems can have significant impact on the overall power density and efficiency of a fuel cell system, through reduced ancillary loads, improved control and management. Current UK capability is relatively small, but adjacent industry experience, like aerospace, and design capabilities are valuable. Balance of plant systems are perhaps an underestimated area for investment and innovation. They are critical to most major improvement challenges and represent a significant share of the fuel cell market. The UK industry has the expertise, but there are few organisations. It is comparatively easy to innovate with some systems, similar to internal combustion engines and battery electric vehicles. This represents a significant opportunity to increase UK capability.

2 Catalyst layers and fuel cell power management

Catalyst development is a largely global and competitive market in which producing 'step-change innovations', could be difficult to achieve. Catalyst layers represent major technical challenges The UK industry is well-placed to overcome them and should continue to innovate in this market. These are areas with strong technical capability from several companies in the UK, representing a sizable market opportunity, which could have a significant impact on the performance and cost reduction.

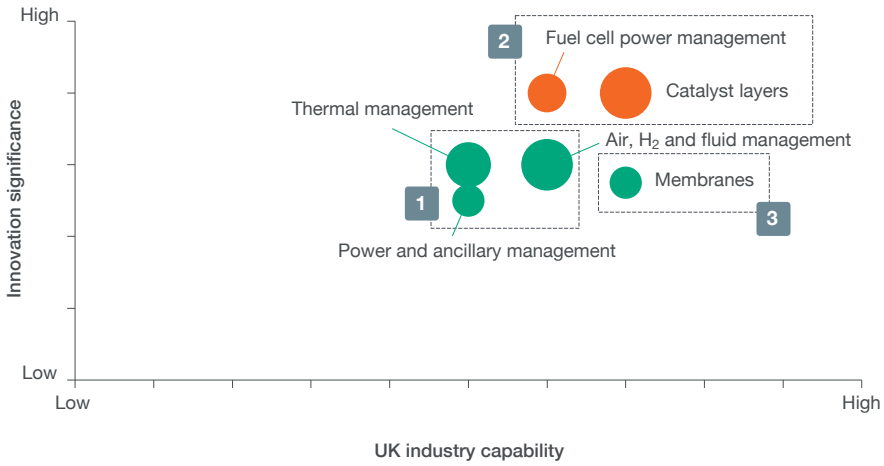
3 Membranes

These system components have a smaller performance and cost reduction impact. However, the UK has strong technical capabilities, with several industrial and academic organisations driving advancements. Their contributions, alongside expected innovations in membranes, strengthen the UK opportunity. These innovations include:

- advancements towards fatigue resistance for longevity and lifespan,
- reinforcement for flexibility in fluctuating conditions within the fuel cells, and
- the ability to withstand high temperatures (above 120°C).

The overarching goal in membrane development is to support high-temperature PEMFC operations, focusing on proton conductivity, thermal stability and water management. A key limiting factor for these innovations is the current use of fluoropolymers, however alternative non-fluorinated membranes are challenging to develop due to cost and complexity.

Figure 6: Prioritisation of innovation areas for the UK automotive fuel cell industry



Innovation significance
Expert assessment of the importance of technical innovation in the area, combined with an estimate of the system cost reduction potential.

UK industry capability
Estimation of the ability of industry to innovate, based on an analysis of the number of active companies in the sector and expert opinion on the average skills level in the UK.

Market opportunity
The size of the bubble represents the estimated market opportunity in terms of market value and growth potential.

Ease of innovation
The colour of the bubble represents an assessment of the ease of innovation and market entry in the area.

Challenging Easier

Hydrogen storage innovation priorities

The largest development opportunities lie in material recovery and bio-based precursors for storage tanks and improving their thermal resilience.

1 Carbon fibre and temperature regulation and resilience

The development of new materials will advance the prospects for hydrogen storage as well as reduce the risks of shorter lifetimes caused by thermal effects (i.e., rapid heating / cooling cycles). The UK capability in this area is strong, with several companies and sectors able to innovate to reduce costs, improve performance, and address other challenges. Improving thermal performance offers significant opportunities within onboard hydrogen storage and will lead to a lower risk of degradation in the storage system, providing longer lifetimes.

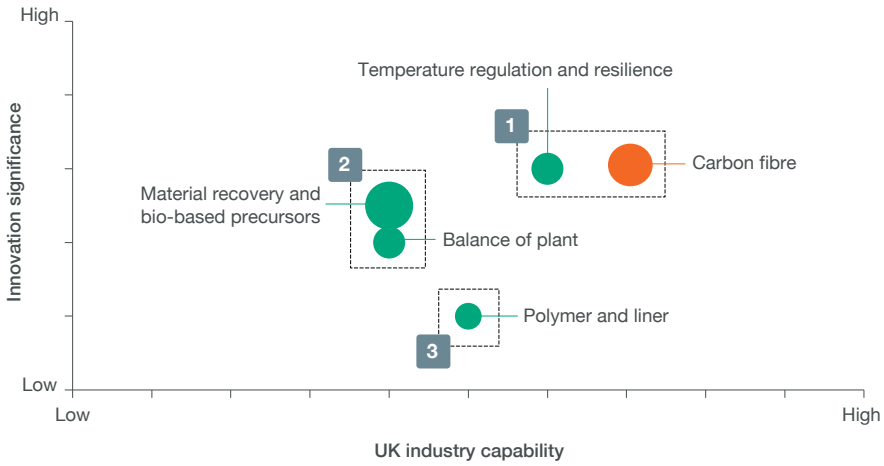
2 Material recovery, bio-based precursors and balance of plant

The UK has a fantastic opportunity to enhance its hydrogen storage development by leveraging expertise from other sectors, such as motorsports and aerospace. The development of innovations in materials, e.g., bio-sourced, is likely to precipitate and require manufacturing innovation. Focusing on the development in this area, such as solutions to integrate pressure regulation in tanks, would alleviate several challenges and support fuel cell system development, whilst increasing the UK's capability.

3 Polymer and liner

Innovation in these areas will also help to alleviate the challenges and reduce the cost of hydrogen storage. The general trend seen in hydrogen storage is moving from Type III tanks, with a metallic inner liner, to Type IV tanks, which have a non-metallic liner made with composite materials. This reduces the overall weight of the tanks significantly; however, it comes at an increased upfront cost for the required materials. Type V tanks also are a possibility since they contain no liner and fully manufactured from polymer composites. Type V-tank development is not a priority for the automotive industry, but is for weight-reliant applications, such as in aerospace. There also is the concern about recycling hydrogen tanks, and Type V tanks could alleviate some of these concerns being less complex to disassemble.

Figure 7: Prioritisation of innovation areas for the UK automotive hydrogen storage industry



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Challenging Easier

4 Conclusions

Hydrogen supply, infrastructure and cost

- **Challenges and constraints:** High cost and limited availability of hydrogen remains a substantial barrier to scaling up fuel cell technologies, as well as the underdeveloped refuelling infrastructure. Essentially, the infrastructure and vehicle market are locked in a self-reinforcing cycle where each inhibits the growth of the other.
- **Innovation development needs:** Fuel cell performance in terms of energy density and power output is currently sufficient, but advancements in cost reduction, durability, and life cycle impacts are essential for broader implementation. Hydrogen storage technologies are well-established through incremental innovations (e.g., material enhancements, increased standardisation, and improved thermal resilience), and are necessary to address economic and safety concerns.
- **Market outlook and future considerations:** Present market demand does not necessitate significant modifications to existing hydrogen storage solutions. However, increased adoption will require optimisation in storage design, manufacturing scalability, and integration strategies, particularly for heavy-duty applications such as long-haul trucks and non-road machinery, where durability and life cycle performance are critical factors.

Recommendations for priority areas in hydrogen fuel cells

- **Balance of plant systems** is a key area for investment and innovation. It is critical to most major improvement challenges and represents a significant share of the fuel cell market. The UK industry has the expertise and can capitalise on this opportunity. It is comparatively easy to innovate with systems similar to internal combustion engines and battery electric vehicles. This represents a significant opportunity to increase the UK capability.
- **Power management systems** the UK has strong existing capabilities, but the market offers further opportunities. This makes it an attractive area for innovation and growth. Similarly, there is currently limited capability and expertise in the UK for thermal management, offering a further opportunity for development and leadership. Thermal management is particularly important in heavy-duty and off-highway applications. UK industry should target support for sectors such as commercial vehicles, buses, freight, and construction machinery.
- **System level efficiency** is critical, as reducing component size, weight, and complexity can increase overall power density. Although catalyst layers have a high innovation significance, there is less opportunity, and ease of innovation, with marginal gains when compared to system level focuses. However, UK industry is still well-positioned to overcome these barriers.

Recommendations for priority areas in hydrogen storage

- **Improving thermal performance** offers significant opportunities within onboard hydrogen storage. Improving this leads to a lower risk of degradation in the storage system, providing longer lifetimes. There are several UK companies involved in the sector with good technical capabilities in thermal design, which can be strengthened.
- **Balance of plant systems** is relatively simple to innovate for hydrogen storage, but the capability in the UK is an area that could see improvement. Focusing on solutions to integrate pressure regulation in tanks, would alleviate several challenges and support fuel cell system development, whilst increasing the UK's capability.
- **End of life and material recovery** is crucial for the UK industry, offering significant opportunities for innovation in recycling hydrogen storage tanks. The UK has existing expertise in material recovery that can be exploited to develop more efficient processes to recover and repurpose valuable materials, such as carbon fibre, tank liners, and polymer composites (particularly in Type V tanks).

Glossary

BEV	Battery electric vehicle
CAGR	Compound annual growth rate
DoE	Department of Energy
EoL	End of life
FC	Fuel cell
FCEV	Fuel cell electric vehicle
GDL	Gas diffusion layer
HDV	Heavy-duty vehicle
HGV	Heavy-goods vehicle
HT-PEM	High temperature polymer electrolyte membrane
ICE	Internal combustion engine
LCA	Life cycle analysis
LH_2	Liquid hydrogen
MW	Megawatt
NRMM	Non-road mobile machinery
OEM	Original equipment manufacturer
PEM (FC)	Polymer electrolyte membrane / proton exchange membrane (fuel cell)
PFAS	Per- and polyfluoroalkyl substances
PGM	Platinum group metals
SOFC	Solid oxide fuel cells
TCO	Total cost of ownership

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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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