



Appendix

Appendix A – Fuel cells techno-economic and environmental challenges

Challenges	Key innovation requirements noted in stakeholder discussions
Reducing system cost	<ul style="list-style-type: none"> • Catalyst layers remain the most expensive part of the system; however, development of hydrocarbon membranes are another potential to reduce cost. • Balance of Plant development could also lead to significant cost savings in operation and component costs.
Increasing power density and system efficiency	<ul style="list-style-type: none"> • Enhancing efficiency is key to lowering hydrogen consumption and addressing high costs. Efficiency should be considered across the entire system, not just the stack, with improvements in power management and component selection crucial for maximizing gains. • While higher power density can aid packaging, thinning the membrane risks greater degradation, impacting durability and operating costs. • Reducing the weight of other components may have a more significant effect on power density than focusing solely on the stack. Innovations from sectors like aerospace could further drive advancements in power density.
Improving durability and lifetimes	<ul style="list-style-type: none"> • HDVs and NRMM demand enhanced durability and operational lifetime requirements, heat removal and increased efficiency will be more critical for these heavier applications where incremental improvements will provide more benefit. • Development of catalyst layers and hydrocarbon membranes for longer term operation are key innovation areas.
Fuel cell and battery systems optimisation	<ul style="list-style-type: none"> • Thermal management was ranked as a high priority for many stakeholders, with respect to the development of HT-PEM systems. Removing heat is more important for heavy applications compared to lighter applications due to the longer operating times, higher loads and often stationary application. • Smarter design and integration of materials is important to ensure solutions are designed to manage heat flows. • Optimisation reduces the risk of systems operating outside of design envelopes resulting in improved performance and longer lifetimes.
Reduce life cycle impacts	<ul style="list-style-type: none"> • PFAS removal may be important in coatings and sealants, as well as potential of operating at lower temperatures for automotive applications (< 120°C). Utilising hydrocarbon membranes could reduce PFAS use in PEM fuel cells, although the amount of PFAS in a fuel cell is relatively small. • Removing PGM from the fuel cell stack is relatively simple for recycling purposes using chemical processes, although some stakeholders were keen on reducing the precious metal content in cathodes and anodes. • Using recycled materials in components such as recycled carbon fibres in GDLs could be considered, although traceability, standardisation and legislative requirements are needed. Some OEMs are researching recycling composites as reinforcement produced favourable lifecycle analysis results compared to metallic components.



Appendix B – Hydrogen storage techno-economic and environmental challenges

Challenges	Key innovation requirements noted in stakeholder discussions
Improvements in storage capacity and loss reduction	<ul style="list-style-type: none">OEMs highlight hydrogen storage as a major challenge, utilising conformable tanks and reducing balance of plant complexity could improve vehicle range whilst minimising complexity.
Reduced costs of storage	<ul style="list-style-type: none">Hydrogen storage cost remains a key concern, primarily due to small scale manufacturing.Savings could come from using lower-cost materials, optimizing production processes, and increasing scale for greater efficiencies.
Vehicle integration and assembly improvement	<ul style="list-style-type: none">Optimising vehicle integration with conformable tanks would simplify development for OEMs.Additionally integrating storage regulators would reduce complexity and cost.
Standardisation and scale manufacturing, reduced cycle time	<ul style="list-style-type: none">Current hydrogen storage manufacturing relies on bespoke systems. Scaling production requires either standardization or higher volume for conformable designs. Streamlining manufacturing and design can reduce cycle time, accelerating deployment.
Increased safety	<ul style="list-style-type: none">Public perception often regards safety as a key consideration in hydrogen usage. While stakeholders acknowledge this concern, they do not identify it as a direct technical challenge.The primary issue was identified to lie in the complexity of standards and technical norms for hydrogen systems, but absence of standards for automotive-based hydrogen applications.
Better temperature control	<ul style="list-style-type: none">Effective heat management and resilience are essential developments required for hydrogen storage. Designing systems to prevent hydrogen cooling during refuelling could significantly streamline operations and reduce costs.Enhanced temperature regulation and durability facilitate faster refuelling and improve the recyclability of tank materials.
Higher recyclability	<ul style="list-style-type: none">OEMs are under increasing pressure to minimize their environmental impact, making material recycling a priority. Using recycled or partially recycled materials is essential, though reusing carbon fibres remains complex. Early-stage studies show potential for integrating recycled storage fibres into fuel cells, but further validation is needed.



Appendix C – Innovation priorities – methodology for multi criteria analysis

Key areas of innovation across fuel cell and gaseous hydrogen components can be ranked across multiple factors to determine the market opportunity

The first two phases of the study focused on analysing the areas of innovation that are important in meeting market needs and the capacity of UK businesses to carry out the associated technological developments.

In the final phase, we assess the market opportunities related to different innovation areas and propose a prioritisation of opportunities by assessing at four dimensions: innovation significance, UK industry capability, market opportunity, including ease of innovation.

The market opportunity was qualitatively assessed for each innovation area (rating from 1-5), qualitatively based on 3 sub-dimensions:

I - Market value: Assessment of the share of each component in the total market value of fuel cells and compressed hydrogen storage, based on ERM analysis¹, validation by external shareholders and the share of each component in the total cost breakdown of the system².

II – Market growth: Compound annual growth rate (CAGR) estimated from ERM's market outlook and Roland Berger study. The growth in compressed hydrogen storage is higher than for PEM fuel cells, as innovations will also benefit stationary applications.

III – Ease of innovation: Expert assessment of the ease of innovation and market entry, considering existing market barriers, for the selected innovation area.

The market opportunity is the average of:

- I - Market value
- II - Market growth and
- III - Ease of innovation

Table 5: Hydrogen fuel cell and hydrogen storage market assessment

Innovation areas	Market opportunity	Market value	Market growth	Ease of innovation
Fuel cell components				
Membrane	2.5	2	3	2
Catalyst layers	4	5	3	3.5
Gas diffusion layers	2	1	3	3
Bipolar plates	2.5	2	3	4
Power management	3	3	3	3
Thermal management	3.5	4	3	2
Air, H ₂ & fluid handling	4	5	3	2
Power & ancillary management	2.5	2	3	2
Control systems	2	1	3	3
Gaseous hydrogen components				
Carbon fibre	4.5	5	4	2
Recovered/bio-based materials	4.5	5	4	3
Polymer and liner	2.5	1	4	3
H2 tank manufacturing	3	2	4	2
BALANCE OF PLANT	3	2	4	3
Temperature regulation/resilience	3	2	4	3
Other storage forms	2	3	1	3

Legend	1 (low)	2	3	4	5 (high)
Market value (share of total FC and compressed hydrogen storage market value)	0-5%	5-10%	10-20%	20-30%	>30%
Market growth (CAGR)	0-10%	10-20%	20-30%	30-40%	40-50%
Ease to innovate in the component area and to enter the market (e.g., competition)	Very high to absolute barriers to entry	High barriers to entry	Medium barriers to entry	Low barriers to entry	Very limited barriers to entry



Appendix D – Innovation priorities – methodology for multi criteria analysis

Areas of innovation have been prioritised in a matrix structured around the importance of innovations and the ability of UK industry to lead their development

Each fuel cell and hydrogen storage sub-system was assessed in terms of the market opportunity and the ability of UK industry (primarily the automotive sector, but also adjacent industries, e.g., aerospace) to innovate in these areas.

Each key innovation area was evaluated to prioritise innovations based on their significance across sectors, not limited to just automotive, as well as UK industry capability. Market opportunity was assessed by:

- Component market value relative to the total fuel cell and hydrogen storage market
- Estimated market growth, with hydrogen storage typically growing faster due to broader applications

Experts also assessed ease of implementation and market entry, considering potential barriers. This analysis informs the required actions for each innovation area (see figure 9), with scoring details in Appendix C.

Innovation significance

Market barriers addressed	0-20%	20-40%	40-60%	60-80%	80-100%
Cost reduction potential	0-2.5%	2.5-5%	5-10%	10-15%	>15%

UK Capability

No. of companies identified	0	1 to 2	2 to 5	5 to 10	>10
R&D capability	No capability identified	Limited capability	Experienced companies / R&D centres	Globally recognised	Global leaders

Innovation significance	Strengthen the presence of UK actors in these areas and develop the skills needed to innovate and lead technology development	Secure the presence of UK organisations able to innovate in these areas with the highest market potential
		Leverage the presence of the UK organisations to integrate and strengthen the value chain
	UK industry capability	

Figure 9: An explanation on the innovation areas prioritisation

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