Insight report

The hydrogen landscape for automotive

ADVANCED PROPULSION CENTRE UK

Contents

Department for Business & Trade

The Advanced Propulsion Centre UK (APC) operational costs are funded by the UK Government's Department for Business and Trade (DBT) and industry contributions. DBT is the ministerial department for economic growth, supporting businesses to invest, grow, and export, creating jobs and opportunities across the country. Our combined mission is to accelerate the development of advanced propulsion technologies to reduce greenhouse gas emissions, minimise embedded carbon, and improve air quality.

Executive summary

The hydrogen landscape insight has been produced to build on existing Advanced Propulsion Centre UK (APC) and partner insights that focused on the potential for hydrogen in pursuit of the automotive industry's 2050 decarbonisation goals.

This document presents the way hydrogen can be used as a solution to mass decarbonisation, the benefits, opportunities and current challenges that hydrogen fuel cells and hydrogen internal combustion engines (ICE) represent, and the global policy landscape for these technologies.

In the global effort to decarbonise the automotive industry, hydrogen offers a promising solution, particularly for heavier duty applications. As a versatile and clean energy carrier, hydrogen has the potential to significantly reduce greenhouse gas emissions.

A supporting document has been produced alongside this report to provide an overview of hydrogen fuel cells and hydrogen ICE technologies.

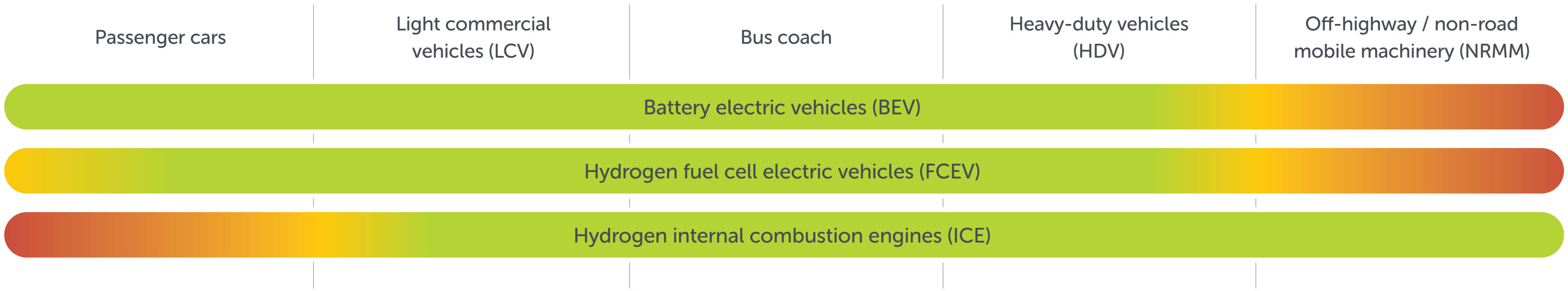
Hydrogen opportunities to accelerate decarbonisation

Hydrogen can be seen as a complimentary fuel vector to battery electric propulsion, providing a more viable alternative to battery electric vehicles (BEV) for certain applications such as medium to heavy-duty fleet operations and off-highway. These segments can benefit from the reduced transitional impact that hydrogen fuel cell electric vehicles (FCEVs) and hydrogen ICE vehicles offer over BEV, such as similar driving profiles, longer range and much shorter refuelling times.

Figure 1 illustrates the suitability of BEV, FCEV, and ICE technologies for applications across various automotive segments. The green on the spectrum signifies that the application is well-suited to the propulsion type, and that it is ready to be, or has already been implemented in that area. Red does not exclude the propulsion type for that segment but shows where it is less suitable due to cost, technology or customer preference.

In the Automotive Council's Mobility of People[1] and Mobility of Goods[2] Roadmaps, which were authored by the APC, hydrogen is noted as being suitable for the decarbonisation of medium-, heavy-duty, and off-highway vehicles, while BEVs will be the primary propulsion for private and shared mobility, and ultra-light goods vehicles.

Figure 1: Technology suitability map (BEV, FCEV, and ICE)



1 2024 Automotive Council Mobility of People roadmap
2 2024 Automotive Council Mobility of Goods roadmap

Hydrogen fuel cell electric vehicles (FCEV)

Multiple technologies are needed to support the decarbonisation of the automotive sector. BEV technology alone is not sufficient and hydrogen fuel cells serve as a complementary technology, addressing the needs of operators and applications where BEV adoption is challenging. Fuel cells generate their electricity through an electrochemical process, combining hydrogen and oxygen, with the only byproducts being water and heat.

The benefits of FCEV over BEV for fleet operators include; faster refuelling, longer range and similar driving characteristics to their existing fossil-fuel powered fleet. Pre-planned routes and return-to-base schedules mean fleets are well-suited for a dedicated hydrogen refuelling infrastructure, minimising downtime.

However, there are currently logistical complexities supplying a depot with hydrogen. Key complexities include, the method of site storage, the delivery of the hydrogen to the site (pipeline or road-freight), production of hydrogen and the safety and regulatory compliance, all of which have additional associated costs and technical challenges.

Hydrogen ICE

Hydrogen ICE is another viable decarbonisation propulsion technology. It delivers near-zero carbon emissions, with just a trace of NOx emitted due to the hydrocarbon lubricants used to improve operating efficiency. An industry-led report[3] focusing on non-road mobile machinery (NRMM) was released from the Department of Energy Security and Net Zero's (DESNZ) Hydrogen Delivery Council, quantifying the emitted NOx from various hydrogen engines, comparing both Stage V NRMM regulations and upcoming Euro 7 on-highway regulations. Figure 2 illustrates that the NOx emitted is significantly below the regulation limits. Hydrogen engines often operate with a higher air-fuel ratio than gasoline engines to ensure complete hydrogen combustion, even leaner usually than the stoichiometric air-fuel ratio of 34:1. Due to this, there is often a reduced power output when compared to similar sized gasoline engines. To achieve the same power output, hydrogen ICE engines are usually equipped with larger than traditional forced air induction systems, such as turbochargers or superchargers. This can lead to additional concerns, such as packaging and more complex on-board systems.

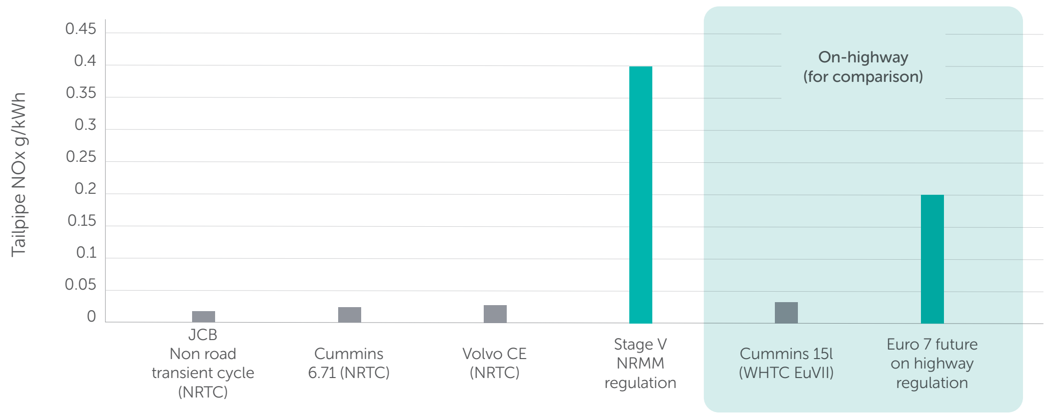
Hydrogen ICE is capable of addressing usability concerns and performance envelope issues associated with BEVs and FCEVs, but it can raise specific issues such as air-fuel ratio management. However, if these concerns are resolved, hydrogen ICE could enhance the overall efficiency and practicality of heavy-duty and off-highway vehicles. This technology is suitable for both on-highway and off-highway uses, but its adoption and success will be influenced by policy and regulatory support, particularly for on-road use.

Hydrogen ICE closely resembles existing heavy-duty diesel engines, but maintains a near-zero carbon emission output making it suited for off-highway applications where the operating environment is harsh and prone to contamination.

Hydrogen ICE engines also offer the benefit of retrofit as the same cooling and drivetrain of the incumbent diesel engines can be used, lowering cost of implementation. The UK already boasts a robust ICE supply chain and deep-routed engine expertise, which not only supports the transition toward decarbonisation, but also helps safeguard existing jobs in the ICE sector, while unlocking significant export opportunities in emerging hydrogen markets.

In contrast, fuel-cell trucks, despite their efficiency, would require significantly enhanced cooling and filtration to handle high-operating temperatures and air impurities, such as dust. These add cost and weight, hindering adoption of FCEVs in the off-highway space.

Figure 2: Stakeholder NOx emission data, tailpipe



Source: DESNZ Hydrogen Delivery Council

3 DESNZ Hydrogen Delivery Council: Hydrogen Internal Combustion Engine Sub-Group

Hydrogen infrastructure

A key challenge is the lack of a robust, nationwide refuelling infrastructure that extends beyond the depot. This could lead to bottleneck scenarios for cross-border operations for hydrogen-powered vehicles travelling between countries that have differing hydrogen infrastructure and policies. In this scenario, we could see these hydrogen-powered vehicles unable to continue journeys or have their payload off-loaded to a BEV alternative. This could potentially lead to a payload imbalance, requiring the payload to be split, to avoid breaching gross vehicle weight limits. This is due to the size and weight of the batteries in a BEV truck, leading to a reduced payload when compared to an FCEV or Hydrogen ICE truck.

Hydrogen storage

Hydrogen storage plays a pivotal role in the hydrogen economy across multiple industries and the UK is developing a comprehensive regulatory framework to address the unique challenges, focusing on safety, environmental sustainability, and operational efficiency. The new regulations will enable the safe operation of hydrogen across multiple sectors, legislating for current challenges which include:

- Hydrogen is less combustible with a lower radiant heat metric than fossil fuel, and this means a lower risk of secondary fires. It does however have a greater flammability range in air (4-75%), and can potentially ignite at a wider range of concentrations than gasoline.
- Hydrogen can cause embrittlement in certain materials by permeating solid metals, altering the metallic structure.
- Hydrogen is a small molecule that can leak and disperse quickly, which can cause accumulation and confinement.
- Hydrogen flames are invisible to the human eye and hydrogen is colourless and odourless making it difficult to detect.

The 2024 Automotive Council Hydrogen Fuel Cell System and Hydrogen Storage Roadmap[4] details plans to improve safety measures and standards. This includes work being undertaken by the Health and Safety Executive (HSE) and the British Standards Institute (BSI) in developing protocols to prevent accidental release and mitigate risks, ensuring hydrogen facilities operate safely. One example is the recent publication of BSI Flex 2073[5], which forms part of the BSI Zero Emission HGVs and Infrastructure Standards Programme and focuses on the safe design and implementation of hydrogen refuelling sites.

4 APC Hydrogen Fuel Cell System and Hydrogen Storage roadmap
5 BSI Flex 2073

Regulatory drivers for hydrogen

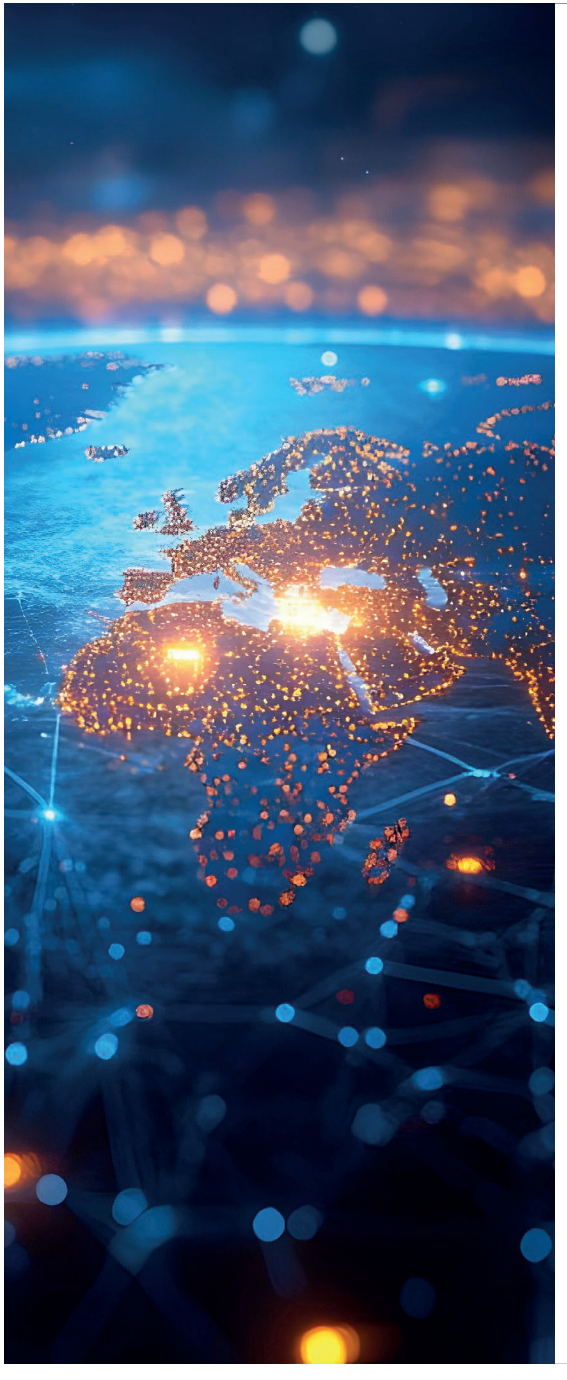
In 2021, transport was the UK's largest emitting sector of greenhouse gases, accounting for 26% of total emissions, 91% of which were from road vehicles[6]. Despite its trace NOx emissions, the use of hydrogen ICE, with relevant after treatments, could reduce CO_2 emissions by 99.95%, as well as reducing the global warming potential of all greenhouse gases by 99.9%, compared with current Stage V diesel engines[7].

The European Union (EU) has set out aims for Europe to be 'climate-neutral' by 2050[8], adopting holistic vehicle emissions standards, through Euro 7, that includes, not just tailpipe emissions, but those generated from tyres, brakes, and total CO_2 output. This legislation would enable the introduction of low-emission ICE or ICE using renewable fuels.

The DESNZ Hydrogen Delivery Council report demonstrates that, with efficiency measures and aftertreatments, such as injection methods and selective catalytic reduction (SCR), greenhouse gas CO_2-equivalent emissions for a zero-emission heavy-duty truck would be below EU requirements. EU Stage V and Environmental Protection Agency (EPA) Tier 4 standards address challenges for off-highway and NRMM vehicles, focusing on particulate matter (PM) and particulate numbers (PN), similar to the EU Euro 7 legislation. However, Stage V emissions for off-highway look exclusively at exhaust emissions and are tested in laboratory-based environments rather than real-world emission testing (RDE).

Globally, we are seeing a shift in forthcoming legislation to include a focus on emissions from an entire vehicle rather than just its engine. This offers a more comprehensive focus on emissions to include factors such as aerodynamics, tyre emissions, fuel efficiency, and advanced, smarter control systems.

6 Department for Transport: Transport and environment statistics 2023
7 DESNZ Hydrogen Delivery Council: Hydrogen Internal Combustion Engine Sub-Group
8 EU Commission: Emissions in the automotive sector



Global policy landscape

In the UK there are two key policies and frameworks that have been driving the UK's investment into hydrogen; the UK Hydrogen Strategy[9] and the UK Energy Act 2023[10]. These policies outline the Government's vision, expectations, and direction for the industry, focusing on scaling-up production, supporting innovation and investment, highlighting economic benefits, and establishing regulatory frameworks for hydrogen capacity and energy security.

To deliver this report, the APC has analysed the hydrogen strategy and policies from countries including the USA, the UK, Germany, France, Japan, South Korea, and China[11]. Some of the key themes uncovered[12] are:

Importance of blue and green hydrogen

Globally, there is a strong focus on generating clean hydrogen, either in the form of blue hydrogen (through carbon capture) or green hydrogen (generated from off-shore wind turbines or solar power). In France, pink hydrogen is utilised, leveraging their expertise in nuclear power. In the UK, HAR (Hydrogen Allocation Rounds) have helped facilitate the production of hydrogen through low-carbon mechanisms. Generating clean hydrogen is important to support net-zero targets and it is expected that affordable green hydrogen will be available by 2035 in some regions. Currently, the cost is four times that of grey hydrogen[13]. However, affordable green hydrogen is anticipated to be available in some markets by 2035.

Incentives to boost hydrogen production and uptake

Governments worldwide have invested hundreds of millions of euros in funding and incentives to scale hydrogen production and strengthen the supply chain, particularly in Germany, France, South Korea, and Japan. For example, in the EU 23 projects amounting to €4.6 billion were allocated to the development of a hydrogen value chain.

Emission targets

Producing hydrogen in an environmentally friendly, low-carbon process is challenging. EU, South Korea, and Japan, amongst others, have developed detailed pathways and set specific emissions targets which must be met for hydrogen to be officially certified as low-carbon or environmentally-friendly. These targets are defined in terms of the amount of carbon dioxide equivalent emitted per kg of hydrogen produced (CO_2 eq / kg H_2).

OEM engagement

Countries like Japan and South Korea have seen initiatives from major original equipment manufacturers (OEMs) like Toyota and Hyundai to drive adoption of hydrogen fuelled vehicles. One example is Hyundai's proposal to build a new fuel-cell plant in Ulsan, South Korea, as part of its plans to expand it's hydrogen vehicle business[14].

9 UK Hydrogen Strategy
10 UK Energy Act 2023
11 https://cms.law/en/int/expert-guides/cms-expert-guide-to-hydrogen/united-kingdom
12 https://gh2.org/countries
13 https://about.bnef.com/blog/2023-hydrogen-levelized-cost-update-green-beats-gray
14 https://www.hydrogeninsight.com/transport/hyundai-to-build-new-fuel-cell-plant-in-south-korea-amid-plans-to-expand-hydrogen-vehicles-business/2-1-1790875?zephr_sso_ott=BLUfTk

Differentiation in hydrogen ICE targets

Global approaches to tailpipe emission targets for transportation and logistics vehicles vary significantly. For instance, in the US State of California and the UK there are strict zero-emission tailpipe targets that need to be met by 2035. In contrast, the EU has taken a different approach, aiming for a 90% reduction in CO_2 emissions by 2040. The EU's approach supports a broader range of transition technologies, which may not deliver zero-tailpipe emissions, but still offer significant gains for decarbonisation and subsequently enable the adoption of hydrogen ICE vehicles.

Public-private partnership programmes

South Korean and Japanese governments have utilised public-private investment mechanisms for transitioning early-stage hydrogen technologies to market adoption.

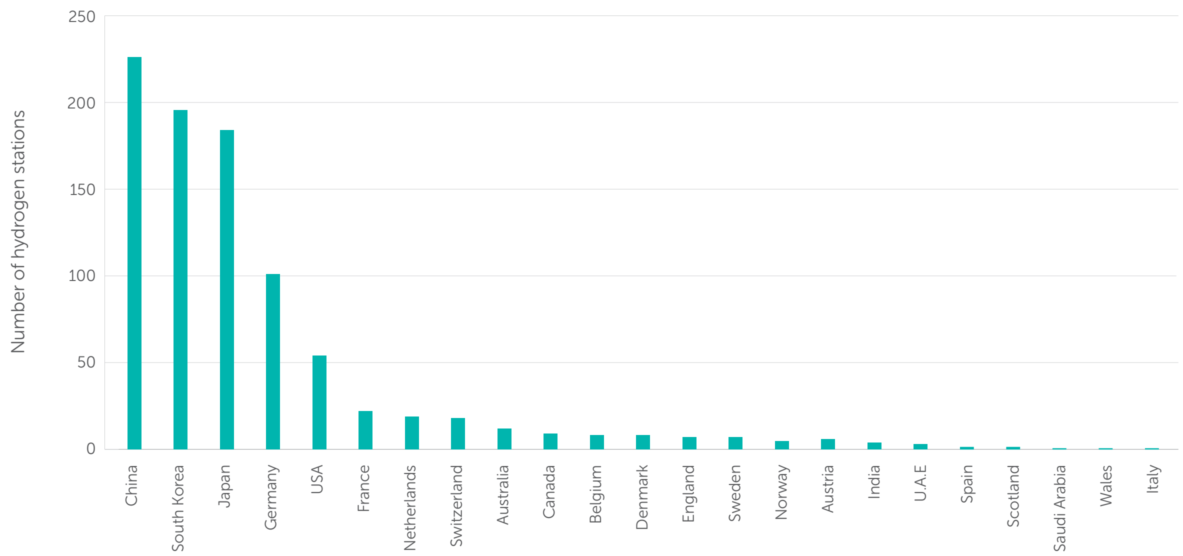
Refuelling stations and infrastructure support

Countries including; Germany, France, South Korea, and Japan, have invested heavily in developing a robust hydrogen refuelling infrastructure (see Figure 3). In turn, this supports ambitious targets they have set for the introduction of fuel-cell powered HDVs and buses. South Korea, for example, aims to have 300,000 FCEVs on its roads by 2030.

Wider challenges

Global market and geopolitical challenges, including the high cost of hydrogen production and distribution, and lack of fuelling infrastructure in the UK and USA, are hindering the wider adoption of hydrogen and hydrogen-powered vehicles. Competing technologies like BEVs and bio-fuels are also vying for market dominance.

Figure 3: Hydrogen fueling stations across the globe as of 2024



Source: Hydrogen Analysis Resource Center

Governments across the globe have introduced ambitious energy strategies and renewable energy policies, positioning hydrogen as a key component of the clean-energy portfolio to decarbonise challenging and harder to transition industries. The below chart offers an overarching view of hydrogen policy, targets and investment for several key regions.

Country	Goals	Approach	Key legislation acts that promote hydrogen	Hydrogen production carbon intensity target (CO_2-eq / kg H_2)	Investment
UK	10 GW of low-carbon hydrogen by 2030	Twin-track: electrolytic (green) and carbon capture-enabled (blue) hydrogen	The Energy Act 2023 National Wealth Fund Bill 2023	1.5 – 2.0	Up to £240 million on commercial development of new low-carbon hydrogen production projects in 2020s
Germany	10 GW electrolysis capacity by 2050	Green hydrogen from renewable energy	National Hydrogen Strategy 2023 German Hydrogen Acceleration Act (draft 2024)	3.38 (EU)	Total investment of €8 billion is to be made available by 2030 for hydrogen programme
Japan	Targeted 10% share of global electrolyser market	Public-private partnerships, financial commitments	Revised update on Hydrogen Basic Strategy in June 2023 Hydrogen Society Promotion Act in 2024 to improve public uptake of hydrogen	3.4	Over $400 million invested as part of the Japan Hydrogen Fund
South Korea	3 million FCEVs by 2040	Focus on FCEVs and large-scale stationary fuel cells	Hydrogen Economy Promotion and Hydrogen Safety Management Act 2023	4	250 billion South Korean Won to create national industrial complex specialising in hydrogen
France	6.5 GW by 2030, price target of hydrogen $1.60 per kg by 2030	Decarbonised hydrogen via electrolysis, nuclear power	The Plan of France 2030	3.38 (EU)	By 2030, €9 billion of public funding will be mobilised for the production of low-carbon hydrogen in France
USA	Large-scale clean hydrogen by 2050	National Clean Hydrogen Strategy and Roadmap	Inflation Reduction Act (note, there are uncertainties with Administration change)	4.0	In October 2023, the US Department of Energy announced a $7 billion injection to develop regional clean hydrogen hubs
China	Hydrogen energy industry by 2035	National and regional plans, renewable hydrogen	National Energy Law includes hydrogen for the first time alongside petroleum fuel	4.9	Total planned investment of hydrogen projects exceeded ¥470 billion in 2023
India	5 million metric green H_2 tonnes per annum by 2030	Green hydrogen and renewable energy generation	National Hydrogen Mission 2023	NA	$2.37 billion investment

Conclusions

1 Hydrogen fuel cells and hydrogen ICE are pivotal in decarbonising challenging transportation modes. By leveraging the strengths of FCEV and hydrogen ICE and implementing safe and efficient solutions for both the storage and refuelling of hydrogen, a wide range of use cases can be effectively addressed. The 2024 Automotive Council Mobility of People and Mobility of Goods Roadmaps provide further detail on where alternative propulsion types are best suited.

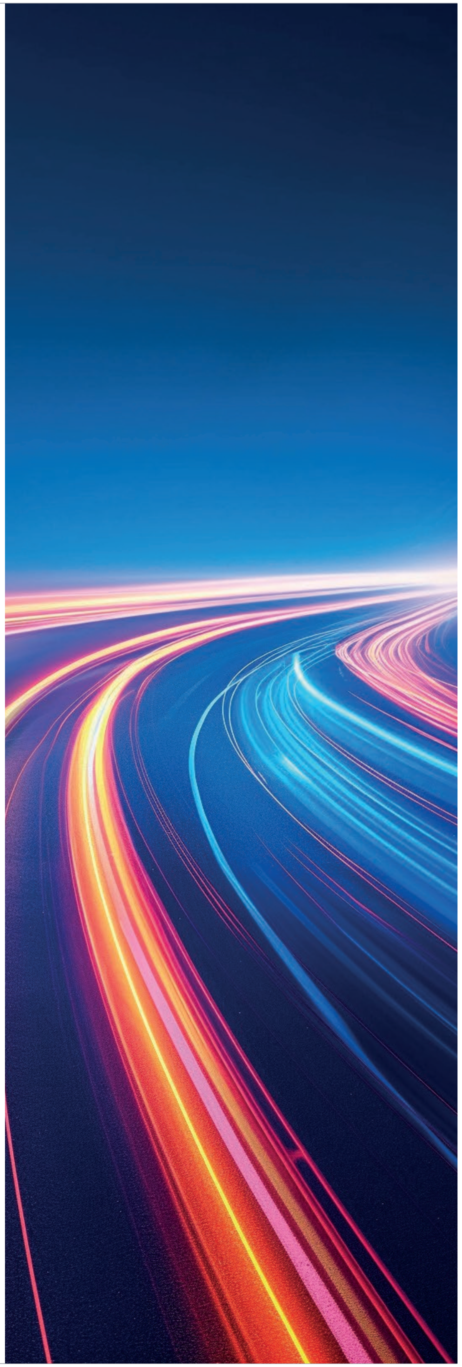
2 Emissions legislations like Euro Stage V, Euro 7 and EPA Tier 4, are crucial in shaping the industry's interest in hydrogen propulsion, driving significant investment in clean transport. Industry views and global policies must align to encourage future innovation and increased investments.

3 Hydrogen is globally recognised as a key solution for decarbonising hard-to-abate sectors, including HDVs and off-highway vehicles. Countries like Germany, France, South Korea, China, and Japan are advancing policies and strategies to promote hydrogen-based technologies.

4 There has been a targeted effort to generate clean hydrogen via carbon capture and renewable electricity through electrolysis. Challenges with scaling-up and hydrogen cost, hinder competitiveness.

5 A gap in emission mandates between the UK and EU may inhibit the growth of hydrogen ICE based technologies in the UK. The UK is well-positioned to leverage and exploit its existing expertise in legacy ICE and should look to upskill and pivot to hydrogen ICE-based applications, particularly for export markets.

6 The UK hydrogen supply chain has significant potential to grow and innovate, as discussed in the APC's HDV insight report 2024.[15]



15 https://www.apcuk.co.uk/knowledge-base/resource/uk-hdv-supply-chain-opportunities-to-2035/

Appendix

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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

Glossary

BEV	Battery electric vehicle
BSI	British Standards Institute
DESNZ	Department for Energy Security and Net Zero
EPA	Environmental Protection Agency
FCEV	Fuel cell electric vehicle
GW	Gigawatt
H_2 ICE	Hydrogen internal combustion engine
HAR	Hydrogen allocation rounds
HDV	Heavy-duty vehicle
HSE	Health and Safety Executive
ICE	Internal combustion engine
LCV	Light-commercial vehicle
NOx	Nitrogen oxides
NRMM	Non-road mobile machinery
OEM	Original equipment manufacturer
RDE	Real driving emissions
SCR	Selective catalytic reduction

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