The Case for Hydrogen Combustion

UK Hydrogen and Fuel Cell Association Position Paper

Key messages

Hydrogen is essential to the UK Government's energy independence and net zero ambitions and hydrogen combustion forms an important and complementary part of creating demand for hydrogen energy.

The UK has a wealth of existing skills, talent and jobs that could easily transfer and make us globally leading in hydrogen combustion if this opportunity is embraced. UK companies across the hydrogen combustion supply chain will benefit from growth of the sector, as well improving the UK's overall export performance.

R&D focused on continuous improvement is needed to deliver even more efficient, fit for purpose engines across a wide range of applications where electrification is either just not practical or too expensive.

The use of existing knowledge and supply chains for hydrogen combustion can accelerate the transition because the barriers and cost for change are lower than elsewhere.

We need to act now to adapt existing regulations and standards to incorporate hydrogen use across the board.

Why Hydrogen Combustion?

Combustion is simply the process of burning something to generate energy. In our current day to day lives we combust a range of fossil fuels, such as natural gas to heat our homes, and petrol or diesel for our transport needs - a process that has been established for nearly 200 years (Natural Gas Museum).

The need to decarbonise and mitigate climate change has put the spotlight on combustion processes because the emissions from burning fossil fuels (hydrocarbons) are responsible for global warming. It is the carbon in these fuels that are burned today that are the root cause of the CO_2 emissions from the exhaust and tailpipes; the actual energy is released from the hydrogen molecules in the fuels. It stands to reason, therefore, that burning hydrogen directly (rather than in conjunction with the carbon) will not generate greenhouse gas emissions and presents an opportunity to facilitate the transition to Net Zero and deliver against the interim target of a 78% reduction in CO_2 emissions by 2035.

78%

target of a reduction in CO_2 emissions by 2035 can be greatly aided by burning hydrogen directly.

Burning hydrogen is not new. Hydrogen has been a well understood option as a combustion fuel for almost as long as combustion engines have been in operation. However, up until now the downsides of using a light gas, developing the supply chain and producing the pure hydrogen in the first place has meant that it "lost" out to more energy dense and accessible fuels such as diesel, petrol and natural gas. It is only now, when we understand the environmental imperative, that innovators are looking at hydrogen combustion to be part of the future solutions to decarbonisation. As a result, priorities for research and development are on demonstrating that hydrogen combustion engines can meet the energy efficiency and air-quality requirements of modern applications, where it will complement other zero-emission technologies (direct electric, battery electric and fuel cell electric) to meet our future energy needs.

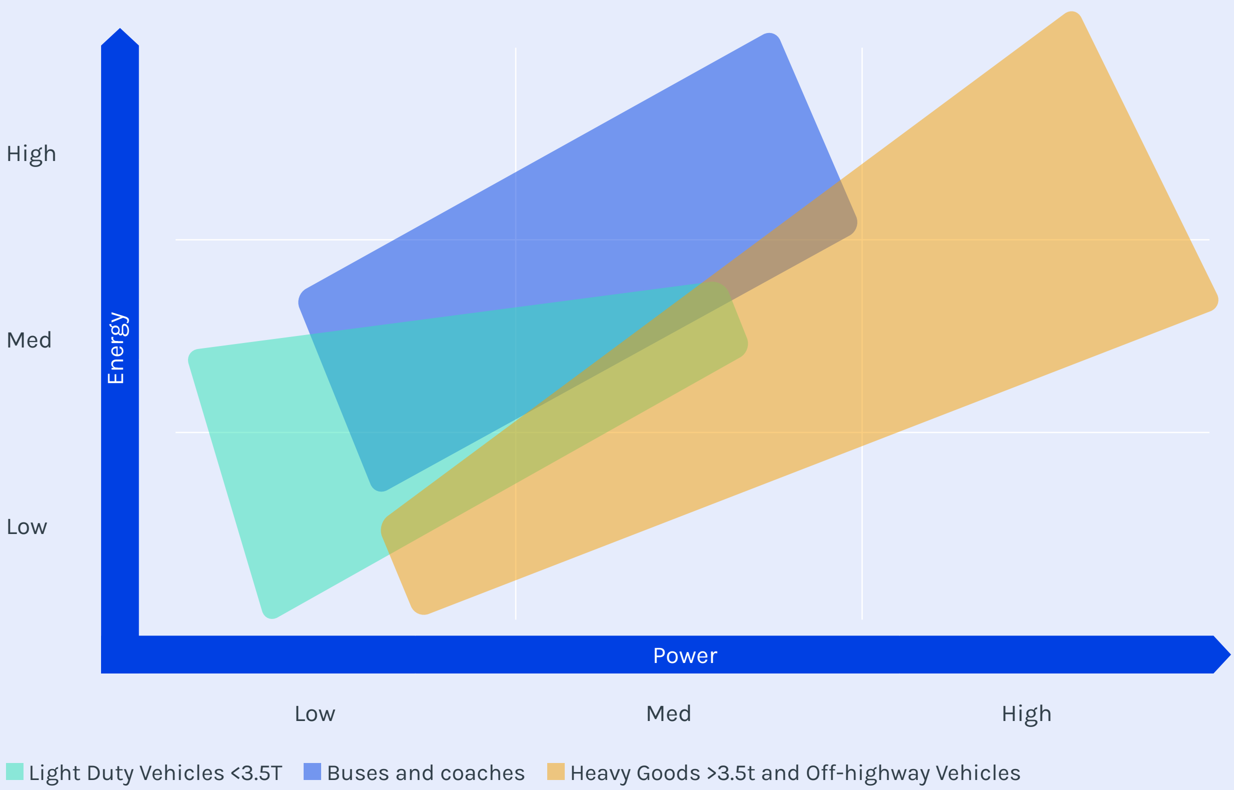
Given the deep understanding of combustion technologies, and the global scale of the capability to produce combustion-based equipment, machines and vehicles it is reasonable to assume that if this knowledge and the existing supply chains can be applied to using hydrogen, it will be possible to accelerate R&D and scale-up processes necessary to rapidly address the climate crisis. For domestic heating, where full electric solutions are challenging to implement as retrofits, or in transport applications where prolonged high-power loads present significant challenges for battery or fuel cell technology, hydrogen combustion will therefore have an important function in providing early commercially viable demands for hydrogen, helping to reduce CO_2 at a lower cost for transition than other options. In this way, it can bring synergies with current systems, and will complement the range of other solutions being developed for hydrogen.

Hydrogen Combustion in Transport

For transport, hydrogen combustion engines are typically most efficient under high loads. As can be seen in Figure 1, this positions them as an ideal solution to decarbonise heavy duty vehicles[1]. Research is already demonstrating that the efficiency of hydrogen combustion engines is approaching that of hydrogen fuel cells for trucks, tractors and construction equipment[2]. Added to this, the rugged design of the hydrogen combustion engine brings benefits in harsh environments in applications like construction where other technologies remain unproven.

From an air-quality perspective, whilst particulates and the other carbon related emissions are not a concern, managing NOx is. NOx can be minimised by operating the engine in conditions that minimise NOx generation,

Figure 1: Power and energy requirements for a range of heavy duty vehicles



(source: www.apcuk.co.uk/app/uploads/2021/09/https___www.apcuk_.co_.uk_app_uploads_2021_02_Exec-summary-Product-Roadmap-HGV-and-Off-highway-final.pdf - and add closing bracket

1 https://www.cummins.com/news/2022/01/27/examples-hydrogen-engines-mobility-and-transportation
2 https://cris.brighton.ac.uk/ws/portalfiles/portal/25512117/University_of_Brighton_Hydrogen_Report_2021.pdf

such as optimising the air fuel ratio and after-treatments (See Figure 2).

And from a life cycle emissions perspective, hydrogen ICEs require no / limited lithium and other scarce mineral resources and can be recycled using pre-existing supply chains.

The key is to design and adapt the technologies and approaches that have been learnt over many years, to drive efficiency and emission control for use with hydrogen. Existing standards and regulations need to be adapted to reflect the new fuel use. Because this does not require wholesale change, the regulatory change should be able to be implemented swiftly, providing there is the capability in place to do so.

Additional opportunities will become possible if these changes can be embraced. For example, there is potential for a lower specification for the quality of hydrogen used in an engine (at 97% purity) than in other applications; in some applications, this would open up a route to reduced cost of the fuel, as less purification expense is needed.

One of the significant R&D challenges for battery and fuel cell electric technologies is cooling, which has to be finely controlled to ensure the electrochemistry can function. Hydrogen combustion engines use conventional approaches to managing bi-product heat and maintaining the engine's performance - allowing the technology to tap into existing supply chain and costs for this aspect of the system engineering requirements across a diverse range of applications.

Purpose designed engines running directly on hydrogen are seen as one of the four truly zero-emission technologies to power vehicles[3] and can easily be adapted for scaled manufacturing through existing production lines in the UK.

Retrofit is also an option and could present the best chance to decarbonise a range of heavy-duty application cost-effectively within the timescales of climate targets. On a practical level, developing solutions that bring down the cost of decarbonisation for vehicle and machine operators by altering existing vehicles to run on hydrogen allows them to accelerate their transition within existing capital replacement programmes.

In the short- to medium-term hydrogen dual fuel offers the option of running an internal combustion engine on a diesel and hydrogen mix. If there is no hydrogen available, the equipment will continue to operate on diesel. This approach removes significant volumes of diesel, giving a direct reduction in tailpipe CO2 emissions and base load demand. With this technology, part-decarbonisation can be achieved while de-risking the case for adopting the new technology and the business change and investment needed to fully utilise a decarbonised fuel. Dual fuel works particularly well in a retrofit context as it allows manufacturers to choose an intermediary step in their journey to transition to a 'designed for hydrogen' future.

Beyond road transport, and particularly HGVs and similar, there are also opportunities for hydrogen combustion in maritime and rail applications. In the former, the steps needed to adopt hydrogen are far fewer than would be for zero carbon alternatives (known safety precedents for engines, maintenance and supply chains are already in place etc). Longer term, ammonia represents a low-cost hydrogen storage medium, and can be co-fired with hydrogen. For the latter, freight locomotives looks particularly attractive, whether via retrofits[4] or new engines. As before, these opportunities are complementary to fuel cells and electrification.

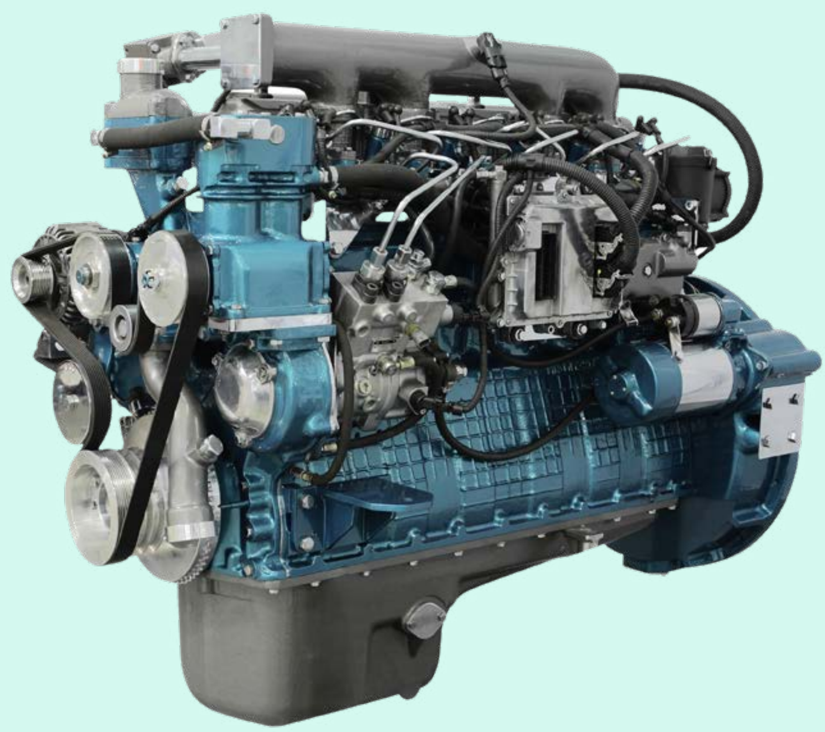
3 https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/how-hydrogen-combustion-engines-can-contribute-to-zero-emissions
4 https://www.smmt.co.uk/wp-content/uploads/sites/2/SMMT-Motor-Industry-Facts-Nov-2020.pdf

Figure 2: Engine modifications to optimise performance

Modified combustion system
Optimised compression ration and piston profile, updated piston rings

Material compatability
Upgrades to seals, hoses, valves, valve seats, lubricants

Fueling system
Injectors for manifold injection (PFI) or injection directly into the cylinder (IDI), spark plugs or HPDI injectors



Safety
Crank case ventilation, knock control

Emissions control
Options include water injection, ultra lean burn, exhaust gas recirculation, hydrogen optimised aftertreatment

Air path
Upgraded boosting, eg. turbocharger modification

Control
Upgraded control system

Hydrogen combustion for Industry and Heating

On the heating front, our current heating system accounts for 20% of UK CO2 emissions, and is a key area for decarbonisation if we are to meet our net zero targets. Hydrogen combustion for heat can help bring domestic decarbonisation while providing the benefit to end users of a similar experience compared to their current natural gas boilers with heating, hot water and cooking. Furthermore, through the repurposing of the UK's existing gas network, we can bring large scale demand for hydrogen[5] – helping realise commercially viable large scale hydrogen production – while creating a domestic heat network that requires similar skills, jobs and suppliers to those already servicing our gas networks.

Hydrogen combustion can decarbonise industrial processes too, enabling fuel switching to hydrogen throughout industrial clusters and regions. Industrial fuel trials are currently ongoing. For example, at Unilever's Port Sunlight factory, 100% hydrogen and a blend of natural gas and hydrogen will fire a boiler which provides steam for the production process[6]. Elsewhere, Budweiser is working with Protium to establish the first renewable hydrogen supply to a brewery. The project will see the Magor Brewery provided with zero carbon power and fuel for all of its operations.[7]

of UK CO2 emissions come from our current heating system

100%

hydrogen and a blend of natural gas and hydrogen will fire a boiler which provides steam for the production process at Unilever's Port Sunlight factory

5 https://cris.brighton.ac.uk/ws/portalfiles/portal/25512117/University_of_Brighton_Hydrogen_Report_2021.pdf
6 https://www.unilever.co.uk/news/2020/could-hydrogen-fuel-replace-natural-gas-on-an-industrial-scale/
7 https://hydrogen-central.com/budweiser-green-hydrogen-wales-brewery-uk-protium/

Current Market Situation

The UK has robust and long-standing excellence in combustion, ranging from supply chain through mechanical engineering expertise to skilled installers. On the transport side, the established UK automotive supply chain saw 11 engine manufacturers produce more than 2 million engines in 2019, of which over 6,000 were exported every day. The production lines used are already being considered for conversion to hydrogen combustion. UK supply-chain strengths also include high pressure tanks for the storage of hydrogen fuel in the vehicle, where the UK hosts end-to-end involvement in their production (APC). Allowing the switch of conventional fuels to low carbon hydrogen will safeguard this supply chain that is so vital to jobs in manufacturing regions across the UK.

6,000
engines were exported every day from the UK automotive industry

The UK's domestic heat industry saw £1.2 billion of boilers sold in 2018, the largest number in 10 years, half of which were produced in the UK. Current boilers are capable of operating with a 20% hydrogen blend with minor adjustments; this can provide an early market for hydrogen. To achieve greater hydrogen use in the gas grid, and offer further decarbonation, boiler manufacturers have developed 100% hydrogen boiler prototypes, and are working to offer these at prices similar to conventional boilers.

£1.2 bn
of boilers sold in the UK

Looking ahead, the UK's strong standing in the transport combustion sector is at risk. With a push away from mechanical engineering skills, we are at risk of losing this market position in favour of electric engineering skills while we witness China actively research hydrogen combustion technology and manufacturers across the EU develop hydrogen combustion solutions. The current non-qualifying status of hydrogen as a zero-carbon fuel for engines prevents subsidy and acts as a barrier to the near-term commercial viability that is required if we are to decarbonise heavy vehicles across all sectors. This stops fleet operators from pursuing cost-effective decarbonisation in the near term.

What needs to Happen

The UK Government's support for net zero has provided funding for projects across the hydrogen spectrum, particularly on the supply side. However, there has been limited coverage of hydrogen combustion, particularly on the transport side. For a zero-carbon hydrogen combustion industry to thrive in the UK, legislative support and funding is required now.

At a policy level, hydrogen combustion for transport faces a number of challenges. Firstly, it is not considered zero emission, which results in its exclusion from incentives in the UK and EU. Hydrogen combustion can achieve the CO_2 standard of <1g CO_2 /km and testing show that it can deliver ultra-low NOx emissions that are in practice below current background NOx levels.

Allowing inclusion in the subsidies associated with zero emissions technologies will incentivize the production of hydrogen combustion engines, as well as the uptake of retrofitted and purpose-built hydrogen internal combustion vehicles, and accelerate the overall transition.

'Allowing the inclusion of hydrogen combustion engines in the subsidies associated with zero emissions technologies will incentivize the production of hydrogen combusion engines'

For domestic heat through hydrogen combustion, BEIS should bring forward the decision date for hydrogen grid blending from 2026. Following the success of recent trials, bringing forward this date will also enable the transition to 100% hydrogen boilers more quickly, thus providing early demand for hydrogen in line with support planned to scale up supply.

While fuel switching to hydrogen combustion in industry offers significant opportunities for decarbonisation, current regulations are hindering progress. For example, the environmental permits for UK Mid-sized Combustion Plant are not well adapted for the combustion of hydrogen, notably where the volume of hydrogen may vary[8]. This is crucial because where hydrogen is used in a blend of between 5 and 20%, it may be the case that the actual hydrogen used on an hourly or daily basis changes. These standards require equivalent monitoring to that done for refineries, and is therefore excessively costly for SMEs who are the largest operators of combustion equipment covered under the permits. The standards for environmental permits also state that hydrogen combustion equipment should have a comparable level of NOx to natural gas, or lower. the standard is possible to achieve using flue gas recirculation. However given the positive environmental benefits it could be worth reviewing all the standards including those for biomass/and biogas to ensure that a level playing field is provided for all the relevant technologies.

'...given the positive environmental benefits it could be worth reviewing all the standards to ensure that a level playing field is provided for all the relevant technologies'

To accelerate progress, consideration should be given to the easing of restrictions surrounding monitoring. Action in this area will make the decarbonisation of industrial SME's more affordable in the near term. This measure should be aligned with the loosening of NOx restrictions to allow hydrogen combustion to compete evenly with Biomass and Biogas, while research continues on the removal of NOx from hydrogen combustion.

Finally, Universities do not have access to funding for the research into hydrogen combustion which will be key to enabling R&D and preventing a knowledge and skill gap from developing. Support for academic research will also help to accelerate wider progress such as the work that Cummins is involved in to reduce NOx emissions from hydrogen internal combustion.

If the current situation continues, there will be no internal combustion supply chain for transport in the UK past 2030 which will result in lost skills, jobs and export potential.

8 https://www.gov.uk/guidance/medium-combustion-plant-when-you-need-a-permit

What role should Government play?

There are two key sets of actions that Government can take to tackle the barriers described above and allow for the hydrogen combustion sectors for transport and heat to thrive: Support funding for Hydrogen combustion; and the implementation of legislation to allow hydrogen combustion to operate in the market.

Support funding for hydrogen combustion:

- Provide finance support for the retrofitting of legacy fleet vehicles across various applications.
- Provide finance support for the development and scale-up of purpose-built HGVs, boats and trains powered by hydrogen combustion.
- Ensure funding is available for R&D led studies from both academic institutions and private sector organisations.
- Commission R&D and real-world trials of hydrogen engines alongside hydrogen fuel cell-powered alternatives to build comparison data to support investment.

Implementation of Legislation:

- Allow the qualification of hydrogen combustion within Transport policy schemes to support the Net Zero transition
- Create a shared centre for knowledge on hydrogen for the different standards and regulatory bodies to reference and use this to ensure that the regulations and standards to support hydrogen combustion are in place, appropriate and able to be implemented.
- Commission a survey to identify how this sector might be supported by DfT and BEIS.
- Confirm the role hydrogen will play in domestic heating by 2024.

When pursued, these two set of actions will enable longstanding UK industries to thrive in the net zero transition, allow early and low-cost decarbonisation solutions across transport and heat, and help to establish an early market for hydrogen in the UK.

About the UK HFCA

The UK HFCA is the leading pan-UK hydrogen association, dedicated to supporting stakeholders across the entire value chain of both the Hydrogen sector and the Fuel Cell industry. Our 80+ members represent over 200,000 employees globally, with combined revenues over £400 billion, and cover the entire value chain from raw material sourcing, to supply chain and components, financing, professional services, B2B and consumer facing solutions. With over 15 years of experience, the UK HFCA is a leader in advocating for and accelerating the transition to Net Zero in the UK through the deployment of hydrogen and fuel cell solutions. Our mission is to help grow the industry and our members' activities in the UK and beyond, and achieve the best policy outcomes for the industry across the full range of applications and opportunities.

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- Pressure Tech
- Reynolds Logistics
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- Sustainable Working And Living Environments Ltd
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- creo construction
- Diffusion Alloys
- FAUN Zoeller
- Gen2 Energy
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- JREPrecision
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