H2Accelerate

Hydrogen Internal Combustion Engines in Europe's Road Mobility Decarbonisation

Published on 28th October, 2025

Executive Summary

Hydrogen internal combustion engine vehicles (H_2-ICEVs) have recently seen increased interest culminating in their classification as zero-emission vehicles (ZEVs) under the updated Heavy-Duty Vehicles CO_2 standards in May 2024.[1] H_2-ICEVs present opportunities to accelerate European zero-emission vehicle deployment, and support the roll-out of hydrogen-refuelling infrastructure to meet the 2030 Alternative Fuels Infrastructure Regulation (AFIR) targets, by building on the existing experience of the automotive sector with ICE vehicles.

H_2-ICEVs are similar to their diesel equivalents, enabling OEMs to repurpose existing manufacturing infrastructure, supply chains, and engineering knowledge. As a result, H_2-ICEVs are projected to be the least capital-intensive zero-emission technology until BEV and FCEV markets reach higher maturity. The similarity between hydrogen and diesel combustion engines may also normalise the use of hydrogen fuel supporting the roll-out of FCEVs among end users in the future.

While some in the automotive sector see the role of H_2-ICEVs as a transition technology towards FCEVs, H_2-ICEVs are now also being considered as one of the zero-emission technologies of choice for certain, particularly high-load applications over a range of distances. For specific heavy load road and non-road mobile machinery (NRMM) applications, H_2-ICEVs offer great efficiency and robustness compared with alternative zero-emission technologies.

While H2-ICEVs can offer higher fuel efficiency in certain heavy-load on-road and off-road applications, fuel cell electric vehicles (FCEVs) remain the more fuel-efficient solution under typical road conditions and at lower loads. H_2-ICEVs are nonetheless expected to play an important role in the heavy duty road transport sector. Building on the existing fossil-fuel ICE manufacturing base, H_2-ICEVs are expected to be manufactured at scale before the end of the decade. As such, H_2-ICEVs will be important offtakers from Europe's first HRS networks and may present fuel suppliers with an opportunity to accelerate the roll-out of a broader HRS network. H_2-ICEVs and components can be locally produced, bolstering Europe's industry, supply chains, and skilled employment while also enhancing its regional autonomy.

Despite the opportunities presented by H_2-ICEVs and their classification as ZEVs, H_2-ICEVs are not yet classified equally with other zero-emission truck technologies. H_2-ICEVs have been excluded from incentivising mechanisms and, in

[1] Regulation (EU) 2024/1610.

some EU Member States, remain unable to refuel from existing HRS infrastructure through existing energy taxation legislation. To support H_2-ICEV deployment and accelerate decarbonisation, European policymakers must:

- **Ensure that hydrogen ICEVs are classified as zero-emission vehicles across all EU Member States.**
- **Ensure equal treatment of zero-emission vehicle technologies.** Hydrogen ICEs should be subject to the same incentives as other zero-emission technologies and must not be excluded from funding schemes for research or deployment of vehicles.
    - **Ensure that hydrogen used in an H_2-ICEV is subject to the same taxation and exemptions as hydrogen used in a FCEV, allowing both vehicles to refuel from the same HRS infrastructure.**
    - **Ensure that hydrogen trucks are included as eligible technologies for national and European zero-emission vehicle deployment projects.**
    - **Ensure Member States treat H2-ICEVs and FCEVs equally when implementing RED II/RED III certificates.**
    - **Research projects into hydrogen combustion engines should continue to be funded by European funding schemes such as Horizon Europe.**

H_2-ICEVs present a significant opportunity for Europe to deploy a zero-emission technology at scale before the end of the decade building on an existing expertise and maintenance base for fuel trucks. To pursue this opportunity, European policymakers must ensure that H_2-ICEVs receive equivalent subsidies and support as alternative zero-emission vehicles, namely fuel cell and battery electric vehicles.

Acknowledgements

The development of this paper was led by members of the H2Accelerate collaboration. The H2Accelerate collaboration has been formed by major players from the fuel supply and trucking industries to work together to accelerate the deployment of hydrogen-powered trucking in Europe.

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TotalEnergies | Shell | Hyundai Hydrogen Mobility | VOLVO

The collaboration would like to thank the following companies and associations for their support in the development of this paper:

ALLIANZ WASSERSTOFF MOTOR – Die Technikinitiative zur nachhaltigen Transformation | Hy24 | H2MOBILITY

acea – DRIVING MOBILITY FOR EUROPE | Global Hydrogen Mobility Alliance*

*the position expressed does not necessarily represent the full range of views or interests across the alliance.

Introduction

Following the revision of the EU's Heavy-Duty CO_2 Standards in May 2024, trucks producing under 3gCO_2/tkm are classified as zero-emission vehicles (ZEVs).[2] This revision has opened the door for Hydrogen Internal Combustion Engine Vehicles (H_2-ICEVs) to be classified as ZEVs while maintaining *"one of the most ambitious greenhouse gas standards for the heavy-duty vehicle sector globally." (ICCT, May 2024)*. H_2-ICEVs burn hydrogen in place of diesel and can achieve zero carbon emissions, producing instead a stream of water vapour. Like conventional fuel engines, H2-ICEVs produce only trace amounts of NOx, but these emissions can be effectively mitigated with existing aftertreatment technologies and be compliant with emission regulations.

Almost all major European truck OEMs now have H_2-ICEVs in development.[3] These vehicles are expected to play a role as either transitional technology driving demand for hydrogen ahead of FCEV roll-out, or for long-term use in specific use cases where H_2-ICEVs have advantages over other zero-emission technologies.[4] Despite these developments, H_2-ICEVs are yet to receive equal treatment with other zero-emission truck technologies. This paper will explore the role of H_2-ICEVs in Europe's zero-emission mobility transition and propose policy updates required to support the roll-out of this zero-emission technology.

H_2-ICEs will inherit expertise and manufacturing capacity from the established European automobile industry

H_2-ICEVs burn hydrogen in an internal combustion engine which operates in a similar manner to conventional diesel combustion engines, with limited modifications (e.g. the inclusion of spark plugs).[5] As a result, H_2-ICEVs can benefit from much of the knowledge, expertise and mass-manufacturing capacities of conventional diesel truck OEMs and offer a zero-emission trucking solution which is familiar to end-users. Further, the timelines for development and delivery of commercial H_2-ICEVs are shorter than their FCEV counterparts thanks to the mature starting point for ICE technology. Hydrogen ICEs are already entering pre-series production; MAN announced in April 2024 that they will launch a small series of 200 H2-ICEVs later this year (2025).[6] The maturity of ICE technology offers several benefits:

- **H_2-ICEs benefit from over 100 years of ICE technology research and development** – building on the existing knowledge base in ICE technologies, H_2-ICEs have already achieved tank-to-wheel efficiencies of 40-45%, similar to existing fossil-fuel ICEs.[5] In addition, the long-term performance of ICEs is well demonstrated, and engine degradation mechanisms are well understood, which will benefit H_2-ICEVs.
- **Manufacturers can adapt existing processes to develop H_2-ICE components** – engine architectures for H_2-ICEs are based on fuel engines and will utilise similar components.[7] As such, tier 1 suppliers and OEMs can adapt existing production processes at limited additional cost to develop

[2] Regulation (EU) 2024/1610.
[3] Based on results of the BMDV Clean Room report on climate friendly commercial vehicles – 2024.
[4] Based on results of the BMDV Clean Room report on climate friendly commercial vehicles – 2024.
[5] DESNZ - Hydrogen Delivery Council Report 2024 - Hydrogen Internal Combustion Engine sub-group
[6] MAN, April 2024 – Small truck series with hydrogen combustion planned for 2025.
[7] DESNZ - Hydrogen Delivery Council Report 2024 - Hydrogen Internal Combustion Engine sub-group

components for use in H_2-ICEs. As a result, H_2-ICEVs are projected to be the least capital-intensive zero-emission technology until BEV and FCEV markets reach higher maturity.[8] Furthermore, converting existing supply chains presents opportunities to ease the transition to zero-emission vehicles – for example, OEMs may be able to source components from the same suppliers, reducing uncertainty on the reliability of providers, delivery timelines, etc. and accelerating scaled production of vehicles through a secure supply chain.

- **Converting an existing knowledge base** – expertise in the maintenance and repair of ICEs is widespread across Europe. While retraining of maintenance staff for the servicing and repair of H_2-ICEs will be required, the similarity between fuel and hydrogen ICEs will enable a rapid conversion of the existing European expertise base. The large established maintenance network for conventional engines can efficiently support H2-ICEV deployment and service, offering business opportunities for workshops and garages. This is in contrast with fuel cells where the build-out of a knowledge base to service and repair these systems will require more extensive retraining of maintenance staff. **H_2-ICEVs will also help to normalise the use of hydrogen, preparing the route for mass roll-out of FCEVs** – by utilising hydrogen with a familiar technology, H_2-ICEVs provide fleet operators and end-users with exposure to the use of hydrogen without the additional uncertainty surrounding less familiar technologies (such as FCEVs).

By building on the existing manufacturing and knowledge base of fuel ICEs, H_2-ICEVs are able to achieve competitive vehicle capital costs and performance to existing diesel trucks. H_2-ICEVs offer the familiarity of an existing technology to end-users while facilitating broader adoption of zero-emission technologies.

H_2-ICEVs are emerging as the zero-emission technology of choice in certain applications

Under regular road operations, H_2-ICEVs are less fuel efficient than FCEVs. H_2-ICEVs can already achieve fuel efficiencies of between 9-10kg-H_2/100km – MAN 40 tonne H_2-ICEVs will achieve a range of up to 600km with a maximum fuel capacity of 56kg - a fuel efficiency of approximately 9.3kg-H_2/100km.[9] By contrast, FCEVs have already achieved fuel efficiencies of less than 8 kg- H_2/100km – Daimler Truck's GenH2 FCEV drove 1,047 km on less than 80kg of hydrogen in September 2023 - a fuel efficiency of below 7.6 kg-H_2 / 100km.[10] Depending on the payload, Daimler Truck also showed that in real customer operations FCEV can achieve operational fuel consumption between 6-8kg-H_2/100km.[11] Improved fuel efficiencies for both technologies are expected in the near future.

In some applications, H_2-ICEVs may be the most suitable zero-emission technology solution, creating specific long-term use cases for the technology. For example, H_2-ICEs are capable of more efficient performance than fuel cells in high engine-load applications.[12]

[8] Wang and Fulton (2024) – A comparative Review of Hydrogen Engines and Fuel Cells for Trucks
[9] 56 kg-H_2 / 600km = 9.3 kg- H_2 / 100km. MAN website, April 2024
[10] 80 kg-H_2 / 1047km = 7.6 kg-H_2 / 100km. Daimler Truck website, September 2023
[11] Five and a Half Times Around the World – Daimler Truck website, September 2025
[12] DESNZ Hydrogen Delivery Council Report 2024 - Hydrogen Internal Combustion Engine sub-group

For heavy engine-load applications, such as very heavy load trucks, H_2-ICEVs may therefore result in lower operational fuel costs for the vehicle operator than FCEVs.

For non-road mobile machinery (NRMM), such as farming, construction, and mining machines, machinery and vehicles are often subject to challenging working conditions, e.g. dust and particulates in the air, and uneven surface conditions leading to significant exposure to vibrations and shocks. Fuel cells currently require high purity fuel and air streams to prevent rapid cell degradation, which is challenging to guarantee in these environments.[13] Combustion engines have a well understood record of robust performance under these conditions.

H_2-ICEVs can drive hydrogen fuel consumption from early production hydrogen hubs and HRS.

The growing interest in H_2-ICEVs presents a valuable opportunity for hydrogen fuel suppliers to access greater fuel demand before 2030.

To invest in building HRS, operators will need confidence that sufficient demand for hydrogen fuel exists. At the same time, a pan-European HRS network must be developed ahead of 2030 to enable the deployment of series-manufactured fuel cell trucks, a crucial requirement for Europe to meet its road decarbonisation targets. To this end, the Alternative Fuel Infrastructure Regulation (AFIR) mandates that Member States establish hydrogen refuelling infrastructure by the end of 2030.

The higher technology readiness and more scalable manufacturing base of H_2-ICEVs means that these vehicles can drive offtake from HRS in the early years while FCEV deployment is scaled up. H_2-ICEVs are expected to play an important role in driving offtake from the early European HRS network.[14]

Classification of H_2-ICEVs as ZEVs is not yet complete at the Member State level

H_2-ICEVs are emerging as a competitive zero-emission solution for specific road and off-road applications and are expected to play an important role in driving hydrogen offtake from the early European HRS network. Despite this, the classification of H_2-ICEVs remains in regulatory limbo.

H_2-ICEVs are capable of meeting the classification for zero-emission trucks using today's technology. JCB reported on emissions from their hydrogen combustion engine, launched in March 2023. The JCB hydrogen engine produces under 1g-$CO_{2\text{-eq}}$/kWh under steady state conditions,[15] lower than the original HDV CO_2 standards classification for zero-emission vehicles, which has since been increased to 3g-CO_2/tkm threshold for zero-emission trucks. JCB has also already demonstrated the application of their H_2-ICE to trucks as well as NRMM.[16] Despite meeting the definition of zero-emission trucks, H_2-ICEVs are often set apart from other zero-emission trucks in policy and regulation:

[13] DESNZ – Hydrogen Delivery Council Report 2024 – Hydrogen Internal Combustion Engine sub-group
[14] BMDV Clean Room report on climate friendly commercial vehicles – 2024
[15] JCB hydrogen engine data shows circa 0.001 g of NO_x / kWh and zero CO_2 emissions are produced under stead state conditions (DESNZ – Hydrogen Delivery Council Report 2024 – Hydrogen Internal Combustion Engine sub-group). Assuming a CO_2-equivalent factor of 298 for NO_x (CBS.nl), this would yield CO_2-equivalent emissions of circa 0.298 g-CO_2-equivalent / kWh.
[16] In February 2023, JCB demonstrated the use of their H2-ICE engine within a 7.5 tonne truck.

- **H_2-ICEs have been subject to different taxation than fuel cell and battery electric technologies** – The Energy Taxation Directive (ETD), which was last updated in 2003, does not provide clear guidance on the classification of hydrogen fuels. Under the ETD, unclassified energy products (such as hydrogen) are expected to be taxed in line with classified products fulfilling a similar role.[17] Hydrogen used in an internal combustion engine has therefore been interpreted by Member State legislations, as being a direct alternative to fossil fuels and taxed in line with these products. In Germany for example, hydrogen used in combustion engines remains subject to an energy tax while hydrogen used in a fuel cell is tax exempt.[18] The taxation on hydrogen used in combustion engines should increase the price of hydrogen at the pump for these vehicles by €0.90/kg-H_2,[19] creating two pricing bands dependent on vehicle technology. As a result, H_2-ICEVs are not permitted to refill at existing H2Mobility HRS in Germany as the fuel supplied is not subject to the energy tax and these stations are not able to distinguish between fuel cell and H_2-ICE vehicles. While TEAL Mobility has developed fuel cards capable of distinguishing between H2-ICEVs and FCEVs, resolving the issue of access to HRS for H2-ICEs, the differential treatment leads to increased TCO costs for H2-ICEs and increased complexity for HRS operators.
- **H_2-ICEVs do not always qualify for zero-emission vehicle incentives** - the Austrian Zero-Emission Commercial Vehicles and Infrastructure (ENIN) funding programme provided €44m in funding to support the roll-out of projects deploying HRS and zero-emission trucks (N2 and N3) in 2024. H_2-ICEVs were excluded from applying for vehicle funding.[20] Additionally, the French AAP Ecosystèmes Territoriaux H2 programme has been modified to permit the inclusion of H2-ICEVs, but only when FCEVs are not available.

[17] Article 2.3 of the 2003 Energy Taxation Directive states that: "[non-specified energy products] shall be taxed according to use, at the rate for the equivalent heating fuel or motor fuel"
[18] German National Hydrogen Council – Statement January 2024.
[19] Hydrogen burned in a combustion engine is subject to an energy tax currently equivalent to €0.90/kg-H_2 and raising to €1.25/kg-H_2 in 2027 – H2 View, March 2025.
[20] Two rounds of calls for the Austrian ENIN funding programme were run in 2024, but H_2-ICEVs were excluded from funding.

Recommendations to support the roll-out of hydrogen internal combustion engine vehicles

Members of the H2Accelerate collaboration agree that H_2-ICEVs can play an important role in the decarbonisation of Europe's road and off-road sectors. The inconsistent treatment of this zero-emission technology, via exclusion from incentives such as tax exemptions and direct funding, places H_2-ICEVs at a disadvantage and risks slowing Europe's road mobility decarbonisation. The H2Accelerate collaboration recommends the following actions for European legislators to support the roll-out of H_2-ICEVs:

1. **Classification of hydrogen ICEVs as zero-emission vehicles across all EU Member States.**
2. **Equal treatment of zero-emission vehicle technologies.** Hydrogen ICEs should be subject to the same incentives as other zero-emission technologies and must be included in funding schemes for research or deployment of vehicles.
    a. **Ensure that hydrogen used in an H_2-ICEV is subject to the same taxation and exemptions as hydrogen used in a FCEV allowing both vehicles to refuel from the same HRS.**
    b. **Ensure that hydrogen trucks are included as eligible technologies for national and European zero-emission vehicle deployment projects.**
    c. **Ensure Member States treat H2-ICEVs and FCEVs equally when implementing RED II/RED III certificates.**
    d. **Research projects into hydrogen combustion engines should continue to be funded by European funding schemes such as Horizon Europe.**

These measures will allow the European automotive sector to take advantage of its well-developed expertise in combustion engine vehicles, while scaling up hydrogen production and refuelling infrastructure, and increasing end user acceptance of hydrogen as a fuel for freight transport.

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