H2-INTERNAL COMBUSTION ENGINE

TNO's mission on HD transport

To achieve climate goals in 2030 and 2050 society has ambitious goals. In 2030 overall CO2 emissions must be reduced by 55% and in 2050 by 95%, all relative to 1990. Air quality standards will require vehicles to comply with post EURO 6/VI legislation.

Application of H2-ICE technology is one way in the mix of solutions that together must meet the targets mentioned above.

Why Hydrogen in ICE?

Reasons for H2-ICE to be an interesting line of powertrains development are the following:

1. No CO2 emissions from the fuel. Meeting EURO 6 and potentially EURO 7 without aftertreatment.
2. Cost efficient and Proven technology. Combustion engines are reliable. Production lines and service infrastructure already exist.
3. Geographic independence of the raw materials needed for production
4. No need for high purity of Hydrogen
5. Application of H2-ICE in a dual fuel fashion, but also as mono fuel will drive the market demand for hydrogen.

TNO and Hydrogen facilities

TNO is operating the Innovation Centre for Sustainable Powertrains (ICSP) in Helmond, The Netherlands. Four powertrain test cells are equipped with modern and latest equipment to test engines up to 700kW. In addition TNO has a Climate Altitude Chamber that can be used for vehicles and engines in climate conditions ranging from -45 to +55 degrees C, and to an altitude pressure relating to 4000m. The ICSP acts as a Technical Service for the European Market and is mandated to produce test reports that allow engines owners to operate on the road, or water.

Most importantly the ICSP since 2020 also has the infrastructure to test heavy duty engines with hydrogen. At the test facility the individual test cells are fed with compressed hydrogen fuel up to 350 bar. The hydrogen fuel is stored in a tube trailer. For realizing uninterrupted hydrogen flow, two trailers can be positioned near the test facility. The test cells can be equipped with both multi-cylinder (up to 700 kW) as well as single cylinder engines.

Fig. 1 Hydrogen infrastructure and test facilities at TNO in Helmond, The Netherlands. Compressed hydrogen is stored in tube trailer(s) feeding up to four individual test cells capable of running multi-cylinder engines up to 700 kW and heavy-duty single-cylinder engines.

Why TNO Traffic & Transport?

TNO is an internationally leading research organisation in the field of applied research, with successful performance results in the heavy-duty truck segment. We have a track record of more than 50 years in demonstration of innovative technical concepts for combustion engines running on fossil fuels and lately with a stronger focus on sustainable fuels.

TNOs experience with Engine Conversion

TNO has more than 50 years' experience with testing and converting combustion engines, and belonging technology together with partners. In 2020 we have accelerated to also experiment with the fuel hydrogen.

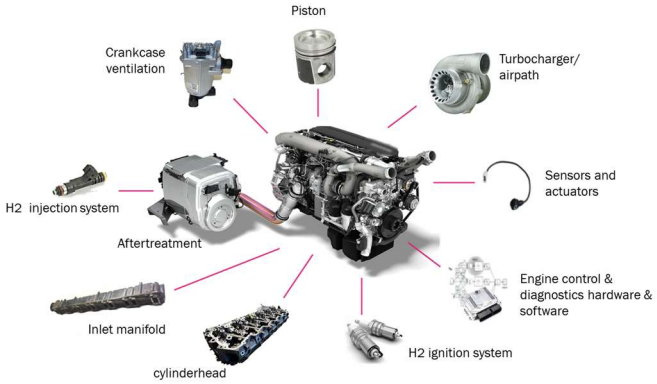

Fig. 2 Conversion of existing diesel or gas engine platforms to hydrogen impacts all main engine components.

The use of hydrogen impacts all main engine components. TNO supports OEMs and TIERs in their developments of dedicated hydrogen technology for ICE with main focus on combustion concept development, hydrogen/air mixing and controls & diagnostics. We have converted diesel engines to dual fuel and mono-fuel hydrogen engines. We have demonstrated emission out NOx emission levels below EURO VI, and we have demonstrated a BMEP of > 20 bar.

Experimental and numerical combustion engine research & development

TNO has designed and built its own single cylinder setup for experimental combustion research. The purpose is to have a flexible platform that can be used by OEMs and Tiers to experiment with innovative hardware components or with new combustion concepts. The platform is modular and highly flexible enabling cost-efficient and systematic evaluation of fundamental combustion parameters. It has a generic base on which OEM/TIER specific parts can be applied such as cylinder head, piston, valves, fuel system and ignition system.

The experimental developments are supported by numerical tools, ranging from detailed Computational Fluid Dynamics (CFD) simulations to phenomenological, physics-based in-cylinder combustion models and complete engine models for engine concept development and controls & diagnostics optimization.

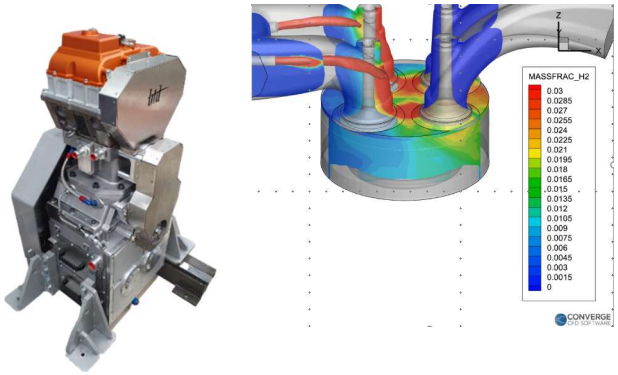

Fig. 3 Experimental and numerical tools used for fundamental hydrogen combustion research with on the left TNO's single-cylinder engine. CFD simulations (right) are e.g. used to investigate hydrogen/air mixing for Port Fuel Injected Spark Ignited hydrogen ICE targeting ultra-low NOx. .

In the current hydrogen combustion engine development phase, CFD simulations are an effective tool to research and develop key hydrogen combustion aspects. Here a key development area is to understand and optimize the interaction between the fuel injection system (PFI, DI, or High Pressure DI) and the combustion chamber geometry targeting low emissions, high efficiency and stable combustion.

TNO's proposition

TNO would like to get in touch with OEMs and TIERs to set up a proof of concept of a engine conversion to hydrogen. We will also be interested to establish a public funded project with industry partners in which we can experiment and test an innovative idea that could lead to a high efficient hydrogen engine. Program research topics could entail:

- Methods to improve BTE
- Methods to improve power density & transient response
- Methods to reduce engine-out NOx emissions

TNO track record

[1] Bekdemir, C., Doosje, E., Seykens, X., H2-ICE Technology Options of the Present and the Near Future, SAE paper 2022-01-0472, 2022

[2] Seykens, X., Doosje, E., Bekdemir, C., van Gompel, P., The hydrogen ICE for heavy-duty applications: Towards Ultra-low NOx Emissions, 43rd Vienna Motoren Symposium, 2022

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