MOBILITY & PRODUCTION

Fields of Expertise TU Graz

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Helmut Eichlseder, Mobility & Production

Source: Lunghammer – TU Graz

Despite the limited boundary conditions, we can again report on a wide range of activities and initiatives in the Field of Expertise Mobility & Production. The Faculty of Mechanical Engineering and Economic Sciences has launched an encouraging and broad-based research initiative on sustainable mobility of people and goods. Coordinated by Professors Hirz and Landschützer, several doctoral theses deal with questions of multimodal logistics processes, energy supply, drive technologies, etc. I am sure that we will be able to report on the results of these more often in the future.

Already in the past, some articles in our journal have pointed out the manifold research activities on hydrogen within our Field of Expertise. These activities in the field of production, storage and distribution of hydrogen as well as suitable energy converters and their application in mobility will be intensified in the near future.

One still existing good example in order to further develop hydrogen technologies and to accelerate knowledge transfer and market introduction is the H2GreenTECH project. It is supported by the European Regional Development Fund, was launched on March 1st by the Institute for Chemical Engineering and Environmental Technology together with the National Institute of Chemistry in Ljubljana, the Slovenian Ministry of Education, Science and Sport, Research Burgenland, Carinthia University of Applied Sciences and Austrian companies.

An important sector of hydrogen research is green mobility, especially the application in vehicle drivetrains, mostly in the form of fuel cells. In a research project of the Institute of Internal Combustion Engines and Thermodynamics, together with the Bosch company drivetrains based on hydrogen internal combustion engines were investigated and remarkable results were achieved, see the following report.

Last February a high-powered delegation from Graz University of Technology visited the partner University of Strathclyde in Scotland and was able to visit the substantially equipped laboratories for forming and friction welding. The strengthened scientific partnership is likely to cooperate in the digitalisation of such processes, e.g. in digital moulding, data analytics and likewise. For this the funding of the position of a PhD is in preparation.

Helmut Eichlseder, Peter Grabner, Klaus Schaffer:

Internal Combustion Engine – An Alternative Energy Converter for Hydrogen

Hydrogen is regarded as the energy carrier of the future. For mobility applications hydrogen has the potential to make an important contribution towards well-to-wheel and life-cycle CO_2 neutral mobility solutions. Usually the fuel cell is seen as the obvious energy converter, promising emission-free operation and high efficiency. The motivation for this research is a technology open assessment of whether and how hydrogen internal combustion engines (ICE) can represent an alternative for many applications.

Substantial arguments in favour of the application of hydrogen ICEs are existing manufacturing structures, robustness, low demands on fuel quality and a much more favourable cost situation, which could lead to a much faster penetration and development of the starting infrastructure. In some European countries, as well as in several important markets, e.g. Japan, Korea and China, a network of hydrogen refuelling stations exists and is currently expanding.

In the past few years, the Institute of Internal Combustion Engines and Thermodynamics has carried out intensive studies on this topic within the framework of bilateral activities with industrial partners, a large EU project and several FFG projects. These ranged from basic research to application in engine concepts and approved vehicles.

In cooperation with Robert Bosch GmbH the focus of the current project is on the achievable efficiency, emission >

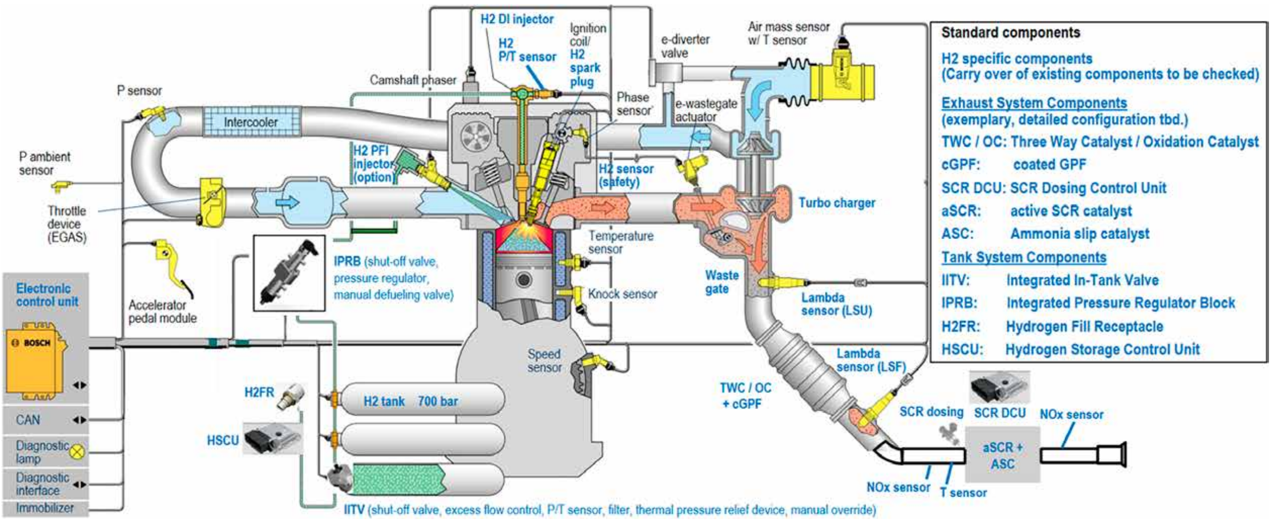

Figure 1: H2 ICE system chart for passenger cars and light commercial vehicles [1].

behaviour, power density and last but not least engine technology to be developed for this purpose. In particular, activities are concentrated on the evaluation of mixture formation, combustion and exhaust gas emissions for a H_2 ICE that is targeted for passenger car and light duty vehicle applications. The experiments are based on a 2.0 litre turbocharged SI engine that has been adapted for hydrogen operation with regard to fuel injection, ignition and turbocharging system. The results demonstrate significant functional potentials, e.g. with respect to specific torque, power and exhaust gas emissions, that have already been accomplished with relatively low development effort.

CONCEPT REALISATION

The derivation of the technical concept for a future H_2 ICE should be based as far as possible on the technical solutions for components and modular engine kits already available on the market and therefore carries the option to limit initial investment and additional costs. The specific properties of hydrogen as a fuel must be taken into account. Although hydrogen has a high gravimetric calorific value (120 MJ/kg), the power density is relatively low for concepts with external mixture formation (H_2 Port Fuel Injection) due to the low density (0.09 kg/m^3 at ambient conditions), so that the achievable specific torque and power are limited. The use of an internal mixture formation (H_2 Direct Injection) leads to significant improvements, especially if high H_2 mass flows can be realized. The very wide ignition limits (4 to 76 % by volume) in combination with a very high laminar flame speed enable an efficient homogeneous lean operation with lowest engine-out NO_x emissions. In order to expand lean operation to the highest possible specific loads and speeds, a capable turbocharging system is required, which provides very high air mass flows at relatively low exhaust gas temperatures (e.g. two-stage turbocharging with variable turbine geometry).

A gasoline engine with direct injection and turbocharging is therefore the preferred engine base for derivation and development of an H_2 ICE for passenger cars and light commercial vehicles. The components for a 700 bar hydrogen tank system can largely be taken from passenger car fuel-cell applications. Figure 1 shows the H_2 ICE system chart for passenger cars and light commercial vehicles.

EXPERIMENTAL RESULTS

A series-production gasoline engine with direct injection and turbocharging was used as the basis for the concept evaluation of our institute in cooperation with Robert Bosch GmbH. The engine was modified for operation with hydrogen so that either external mixture formation (PFI) or internal mixture formation (DI) can be applied.

With external hydrogen mixture formation in the intake ports (PFI) and homogeneous lean engine operation, comparatively high engine torque levels could be achieved for the examined configuration in the medium engine speed range. Using internal mixture formation (DI), engine operation with high excess air ratios is feasible in an even larger engine map range, since displacement of the intake air by hydrogen can be largely avoided with a corresponding H_2 direct injection strategy.

To cover the wide speed range of a gasoline engine, a two-stage turbocharging system with variable turbine geometry is required for both exhaust gas turbochargers to enable the full load curve shown (Figure 2). The low speed range in particular is a major challenge for design and control of the system in the examined configuration, since the required “small” turbocharger reaches its speed limit relatively quickly at higher engine speeds.

In PFI operation, a specific power of 60 kW per litre displacement, relatively high for external H_2 mixture formation, was achieved for the configuration examined (Figure 2 left). The specific torque reaches a value of about 150 Nm/l at 2000 rpm. These specific power and torque levels achieved without further optimisation already cover the requirements for a base engine variant.

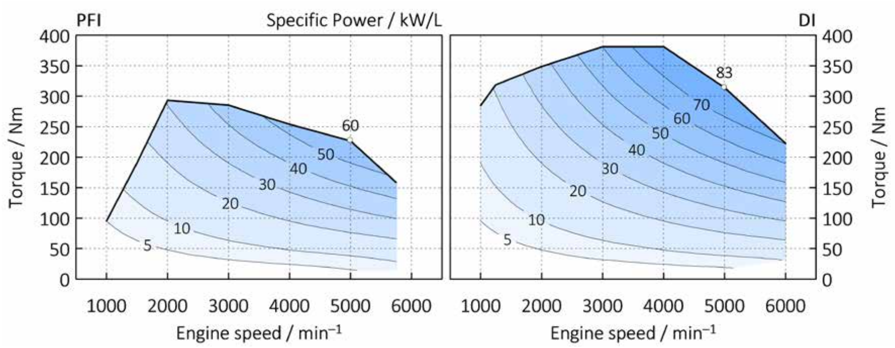

Figure 2: Torque and Specific power for PFI (Port Fuel Injection) and DI (Direct Injection) 2 litre engine.

Source: Institute of Internal Combustion Engines and Thermodynamics

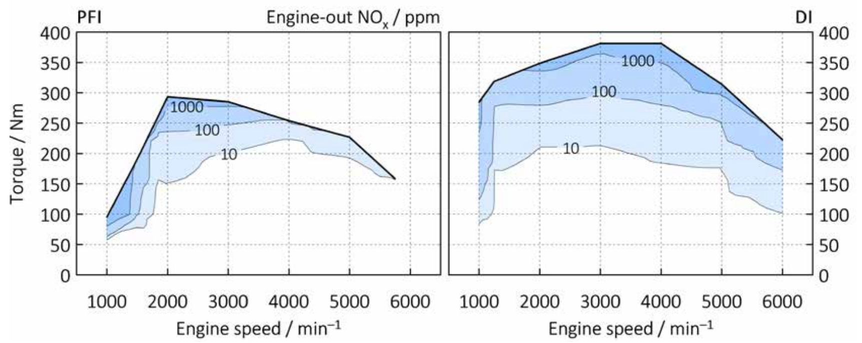

Figure 3: Engine-out NO_x emissions for PFI (Port Fuel Injection) and DI (Direct Injection).

Source: Institute of Internal Combustion Engines and Thermodynamics

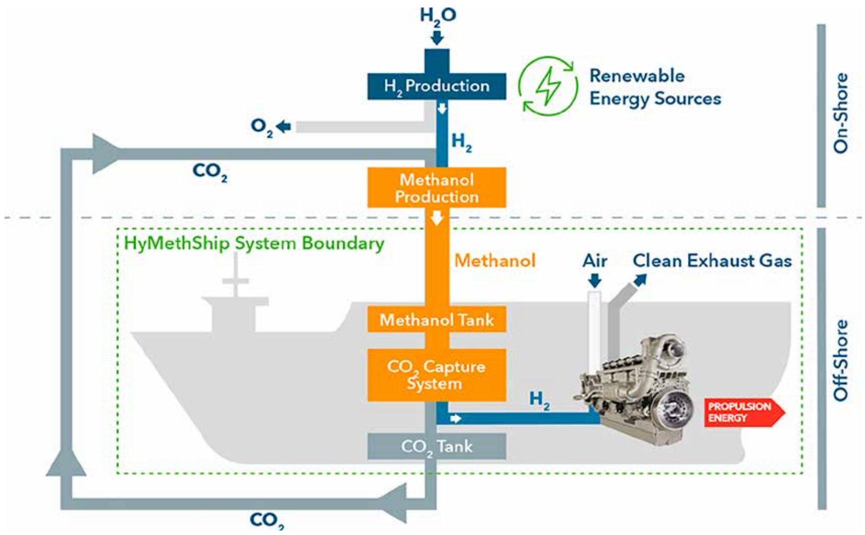

Figure 4: Project HyMethShip (hymethship.com) [2].

Particularly when integrated in hybrid powertrains, an attractive driving performance can already be accomplished using H_2 PFI engine solutions.

In DI operation, a specific torque of 191 Nm/l and a specific power of 83 kW/l were achieved (Figure 2 right). This already covers a significant proportion of the engine power variants offered today. By using a turbocharger configuration adapted for the high-speed range respectively, further improvements of specific power can be expected.

Nitrogen oxides (NO_x) are practically the only pollutants that can occur during hydrogen combustion in the engine. Even the engine-out NO_x emissions (Figure 3) could be kept at a very low level (< 10 ppm, corresponding to approx. 0.1 g/kWh for this engine) by the lean operation ($\lambda > 2.5$) in a significant engine map area. Extremely low tail-pipe emissions can therefore be expected with effective exhaust gas after-treatment. Particularly at low engine speeds, however, further improvements to the turbocharging system are required in order to be able to increase the excess air ratio for operation with lowest engine-out NO_x emissions via increased air mass flow.

OUTLOOK

A focus for further research is the systematic design and optimisation of the systems and components for the H_2 ICE that differ from the respective baseline powertrain. Here, the general target is an extensive use of existing modular engine kits and components as well as powertrain and vehicle architectures. Future H_2 ICE concepts are mainly integrated into electrified powertrains (e.g. full hybrid powertrains). In addition to advantages in efficiency and driving range, this results in attractive functional synergies and additional degrees of freedom for design and operating strategy which has to be taken into account. For example, the use of the synergies of an electrified powertrain for dynamic engine operation, as the provision of the necessary high boost pressures for lean operation would pose a particular challenge here. >

Furthermore, the development of an emission concept to represent a so-called zero-impact emission level is an essential task.

The hydrogen ICE is not restricted to vehicle mobility. In a large EU project (hymethship.com) [2] under the consortium leadership of the LEC and in cooperation with TU Graz, research activities are focused on an emission-free ship propulsion system.

[1] Pauer, T., Weller, H., Schünemann, E., Eichlseder, H., Grabner, P., Schaffer, K.: H2 ICE for Future Passenger Cars and Light Commercial Vehicles. 41th International Vienna Motor Symposium, Fortschrittberichte VDI, Reihe 12, 2020

[2] Zelenka, J., Wermuth, N., Lackner, M., Wimmer, A., Andersson, K., Veelken, H., Moeyaert, P., Jäger, B., Url, M., Lang, M., Huschenbett, M., Devalapalli, R., Sahnen, D., Grützner, J., Mair, Ch., Ellis, J.: The HyMethShip Project: Innovative Emission Free Propulsion for Ships, CIMAC World Congress, Vancouver, 2019

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Source: Lunghammer – TU Graz

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Source: Grabner - IVT

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Source: Grabner - IVT

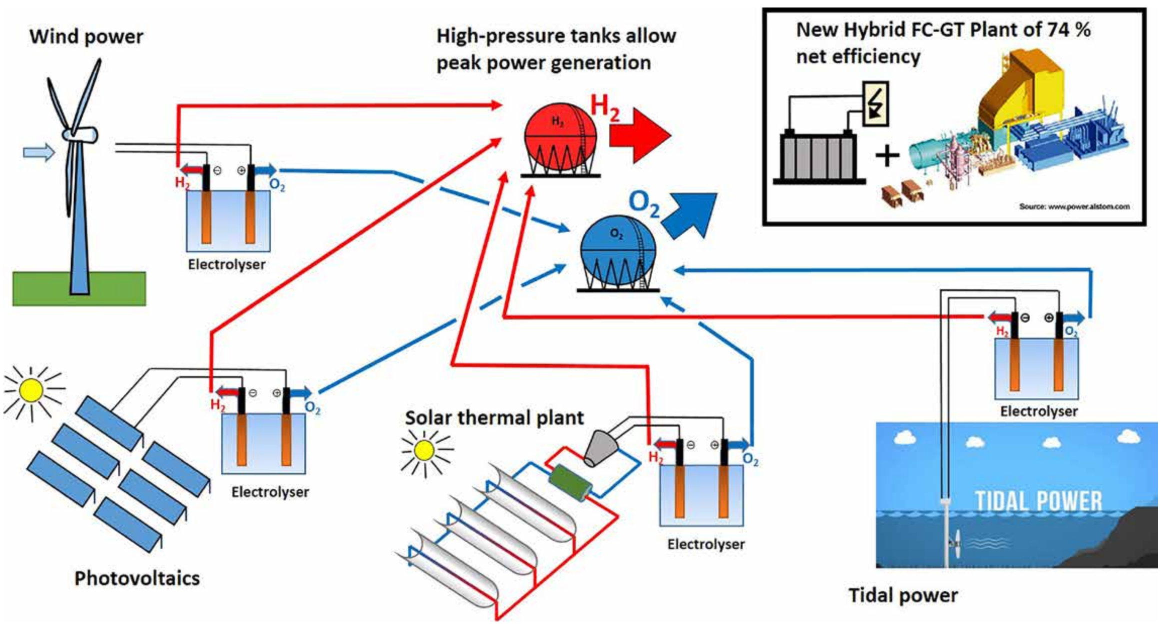

Figure 1: Scheme of a future energy system based on hydrogen as mean storage.
Source: Institute for Thermal Turbomachinery and Machine Dynamics