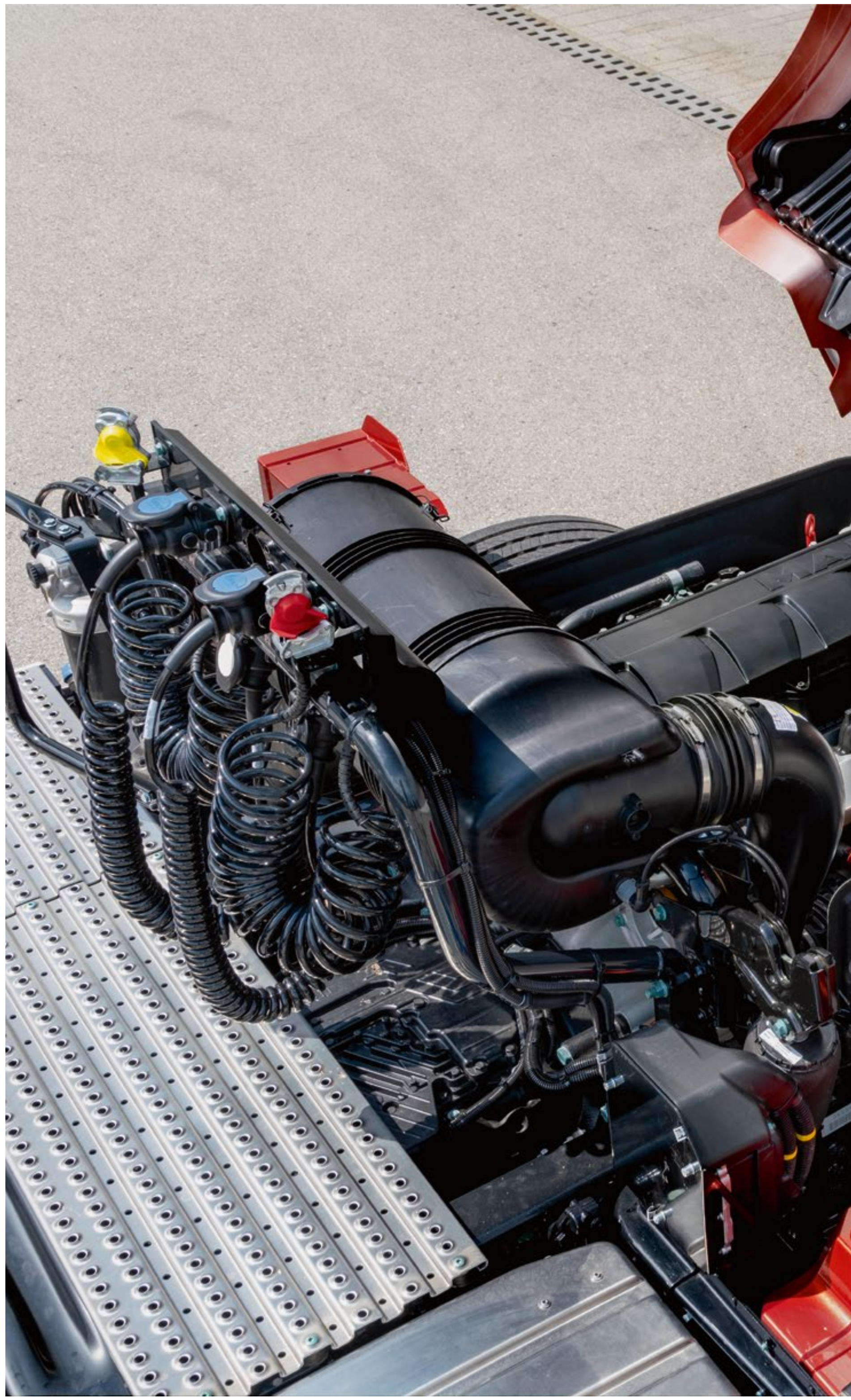
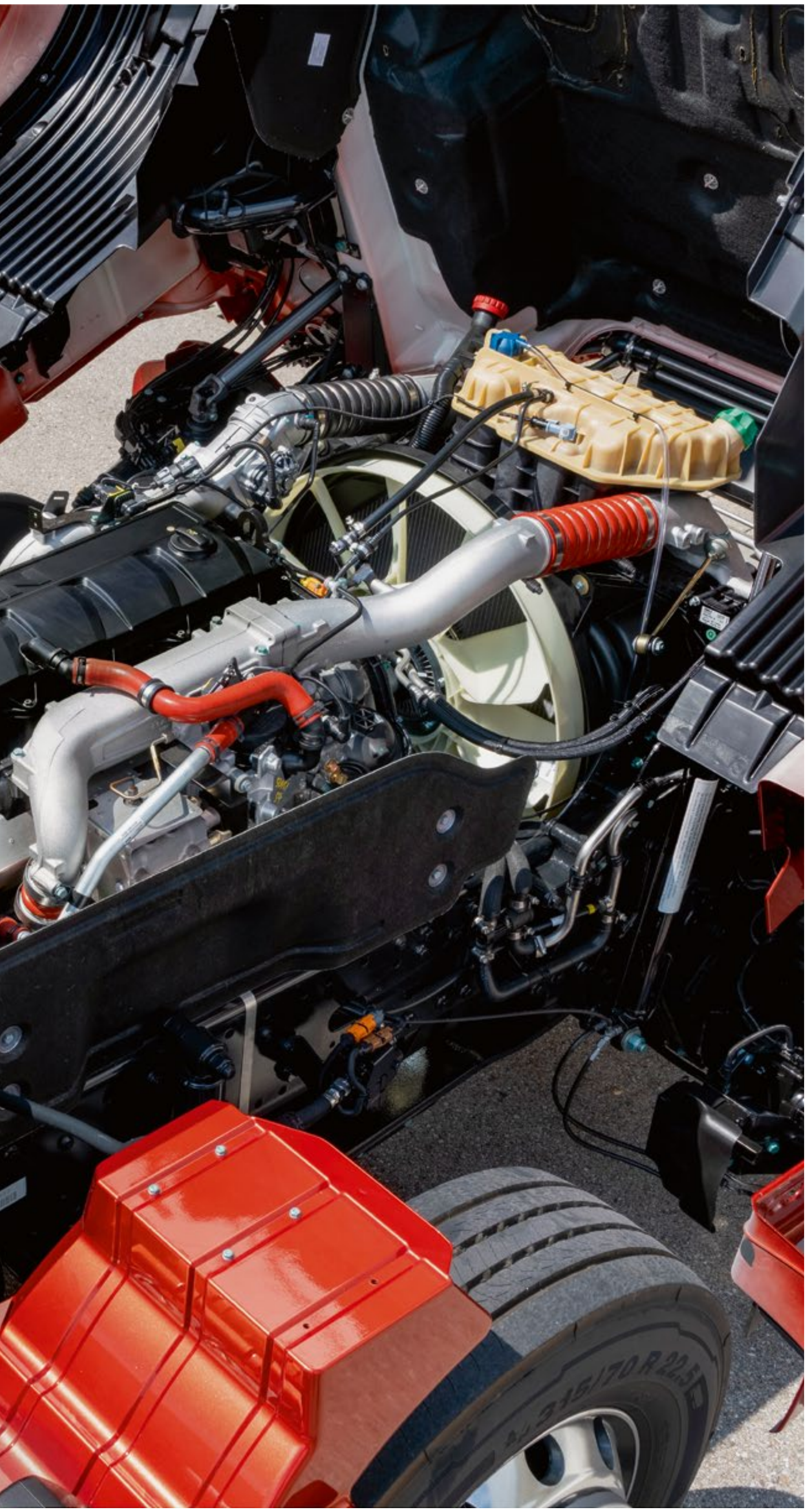
Advanced and Future-oriented Research on Compression-ignition Engines

Due to its outstanding efficiency, the diesel engine is the leader in many commercial applications. New technologies such as artificial intelligence or additive manufacturing can help to meet more stringent requirements for pollutant and CO_2 emissions. The scientific basis is being worked out in projects of the Research Association for Combustion Engines (FVV) and can be transferred into practice by the member companies.



1 OBJECTIVES

Since its foundation in 1956, the FVV has been coordinating research on CI internal combustion engines. Projects dealing with the CI combustion process were worked on in the planning group “Thermodynamics” until 2017, before being spun off into a dedicated group. This is not just the consequence of a considerable growth in the number of projects, but also reflects the changing significance of the diesel engine – due to its performance compared to other energy converters, it is increasingly being used again mainly in commercial vehicles, mobile machinery and stationary applications. In professional applications, which require the highest levels of efficiency, robustness and cost-effectiveness combined with high levels of continuous workload, there is a great potential to achieve further progress by using fundamentally new technologies. Pre-competitive collective research by the FVV can help to open up this potential to small and medium-sized enterprises (SMEs).



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Dr.-Ing. Christian Weiskirch is Head of Powertrain Development at Traton SE in Munich (Germany). In the FVV research area of engines he coordinates Planning Group 3 on Compression-ignition (CI) Engines.
"On the move towards zero-impact emission and climate-neutral powertrains we need a highly committed and application-oriented research platform such as that offered by the FVV."

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Prof. Dr.-Ing. Thomas Koch is Managing Director of the Institute of Internal Combustion Engines at the Karlsruhe Institute of Technology (Germany), supporting many FVV projects as a research and technology performer.
"Synthetic fuels along with hybridization and continuous further development down to the last detail are essential features of powertrain research for the next decades."

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Dr.-Ing. Reza Rezaei is Head of Advanced Engineering & Model-based Development of Commercial Vehicle Powertrains at IAV GmbH in Gifhorn (Germany).
"Hydrogen is regarded as one of the energy carriers of the future. All of us at the FVV are researching hydrogen combustion as a puzzle piece of sustainable mobility."

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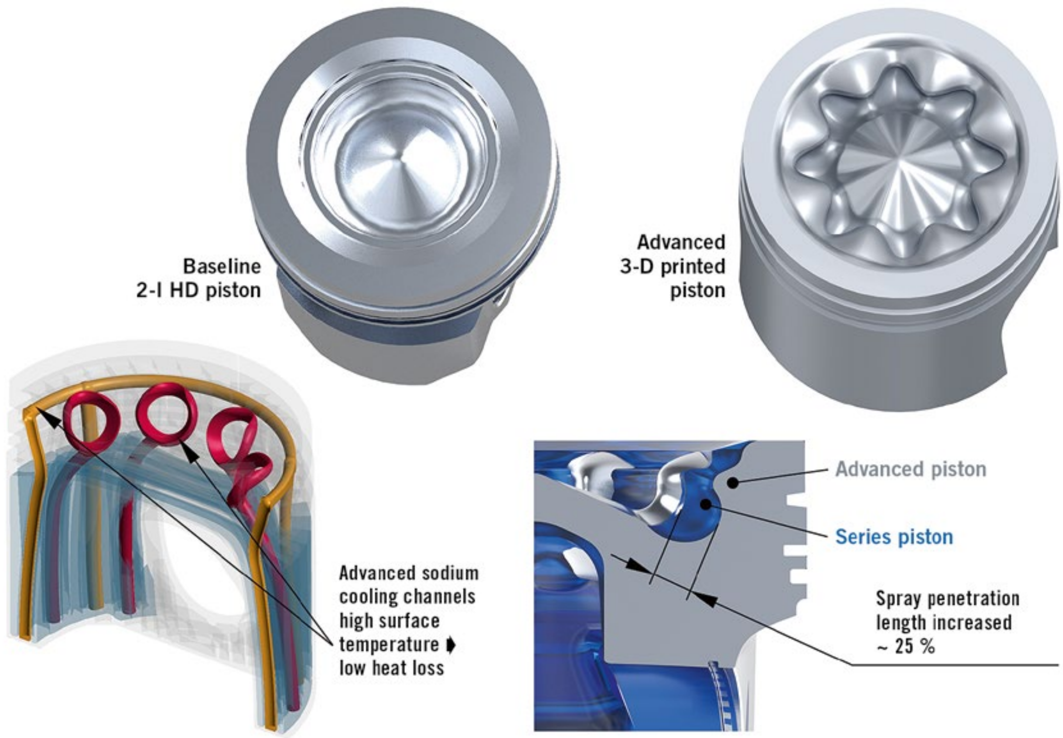

FIGURE 1 Bowl geometry and cooling channel design of a series-produced and an additively manufactured piston (© IAV)

The research landscape is currently shifting from a fundamental understanding of technical issues, such as in the area of the combustion process design, to an overall optimization of the powertrain system with regard to fuel consumption and emissions. The focus of the research must be on the CO_2 emission limit targets required by legislation, in perspective even complete climate neutrality. Since internal combustion can achieve this only by abandoning fossil fuels, the interaction of powertrain and energy source as a research topic gains considerable importance.

2 IMPLEMENTING AI IN ENGINE DEVELOPMENT

Ambitious CO_2 emission limit targets or indeed technological leaps toward full climate neutrality are associated with high development costs. In view of the increasing complexity, an ever higher proportion of these efforts is spent on the validation of both the measurements on test benches and full vehicle measurements. Commercial vehicles or large engines must run with a long operating time in order to be able to make valid statements about the long-term stable emission behavior. In addition, considerable amounts of data from real world operation are gathered via connected vehicles and aggregates, which in principle may contain important information for the development of next generation powertrains. In order to be able to evaluate large amounts of data more quickly, the use of Artificial Intelligence (AI) technologies is recommended.

In order to generally test the applicability, the FVV is launching the research project "AI Integration into the Development Toolchain" [1]. The methodology is to be validated on a hybridized CI engine-driven propulsion system, since such a powertrain is likely to represent the most challenging boundary conditions in terms of its transient emission behavior. The development of an algorithm, which is to be deployed in various development stages, will play an essential role for Reinforcement Learning (RL). Within the framework of a potential analysis, it will also be investigated to what extent AI would be useful for the adaptive control of hybrid drive systems during operation.

3 NEW PRODUCTION METHODS

The range in which a system optimum can be achieved for a series product is always limited by the manufacturability of the system components, whereby the production of a new design must not only be technically possible in principle but also economically feasible. Innovative manufacturing processes such as 3-D printing basically make it possible to produce components with new shapes.

The increased freedom in shaping can be used not only to further improve the efficiency of combustion engines, but also contribute to the adaption to innovative fuels that are relevant in terms of complying with any future more stringent emission limits for nitrogen oxides or CO_2.

An example of the incorporation of new production methods illustrates the FVV research project "Innovative HD Combustion System Design" [2]. This project, which is being carried out in interdisciplinary collaboration involving three research institutes, is based on the technical insight that the combustion process is significantly influenced by the piston bowl shape, **FIGURE 1**. Novel additive manufacturing processes allow fundamentally new degrees of freedom in piston design, both with regard to the bowl shapes and the cooling channels in the piston crown. Within the project, which was started in mid-2019, various additive piston geometries are being investigated on a single-cylinder research engine and geometry optimization is being carried out using numerical methods. In addition, it will be investigated to what extent the completely new bowl shapes can improve mixture formation and reduce emissions in terms of design. The influence of sodium cooling channels on wall temperature, wall heat losses and fuel consumption will also be analyzed numerically and experimentally.

4 OPERATION WITH CLIMATE-NEUTRAL FUELS

Against the background of global CO_2 emission limit targets, it is to be expected that fossil energy carriers will be fully substituted in the long term – some of the commercial vehicle manufacturers have already set themselves targets to reach complete climate neutrality. To achieve these, climate-neutral fuels could be used in combustion engines, especially for long-distance freight mobility. In recent years, the FVV has therefore already intensified its research on new engine technologies in interaction with synthetic fuels, looking at both blended and pure fuels [3].

At the very start of the production chain for such synthetic fuels there is almost always so-called green hydrogen, which is produced with the help of renewable energies. For this reason, the FVV is now also working on the fundamental principles of the reaction of hydrogen and oxygen in a so-called cold combustion process in the fuel cell in a new dedicated planning group [4].

The potential of hydrogen combustion in a CI engine is being investigated by the FVV in another new research project [5]. The guiding idea here is to substitute the ambient air with an inert working medium, in which the reacting gases (oxygen and hydrogen) are actively carried in a closed working gas circuit, **FIGURE 2**. This makes it possible to avoid the raw nitrogen oxide emissions that arise when ambient air is used. In particular, the project aims to investigate the extent to which the conversion of highly efficient combustion engines into electricity is economically viable in order to contribute to the stabilization of the electricity grid. The project serves to analyze the potential of the combustion process, the selection of an appropriate inert carrier medium and the basic questions of dimensioning.

5 TECHNOLOGY TRANSFER TO THE GAS ENGINE

The combustion of methane releases significantly lower CO_2 emissions in g/kWh than operations with gasoline or diesel fuels. In addition, synthetic methane can be produced from green hydrogen with relatively low conversion losses [6], thus allowing for a climate-neutral operation of engines and gas turbines. Cost-effectiveness and the demand for zero emissions, increasingly required by local authorities, pose major challenges for commercial mobile heavy-duty applications. Gas engines, although spark-ignited, have to overcome a similar conflict of objectives between efficiency and emissions reduction as is known from diesel engines.

A series of consecutive research projects on air path variability, coordinated by the FVV over the last 20 years, are showing that a technology transfer from diesel to gas engines is possible. In a project cluster started in 2003, the emission reduction potential of homogeneous diesel combustion for both passenger car and commercial vehicle engines was investigated. For commercial vehicle applications, it was found that a variable compression ratio is necessary in order to extend the load range of homogeneous diesel combustion, which is otherwise only of limited use, to a realistic size. The variation of the thermodynamic compression ratio by variable valve actuation seemed to be a more effective means than modifying the geometric compression ratio. Based not least on the knowledge gained in these pilot projects, the Technical University Braunschweig analyzed the use of air path variabilities on compression-ignition heavy-duty commercial vehicle engines in two consecutive projects. Thus it created a fundamental understanding of the influence of valve timing on efficiency and emission behavior [7]. Changing boundary conditions and new findings may therefore give rise to other new focal points of research

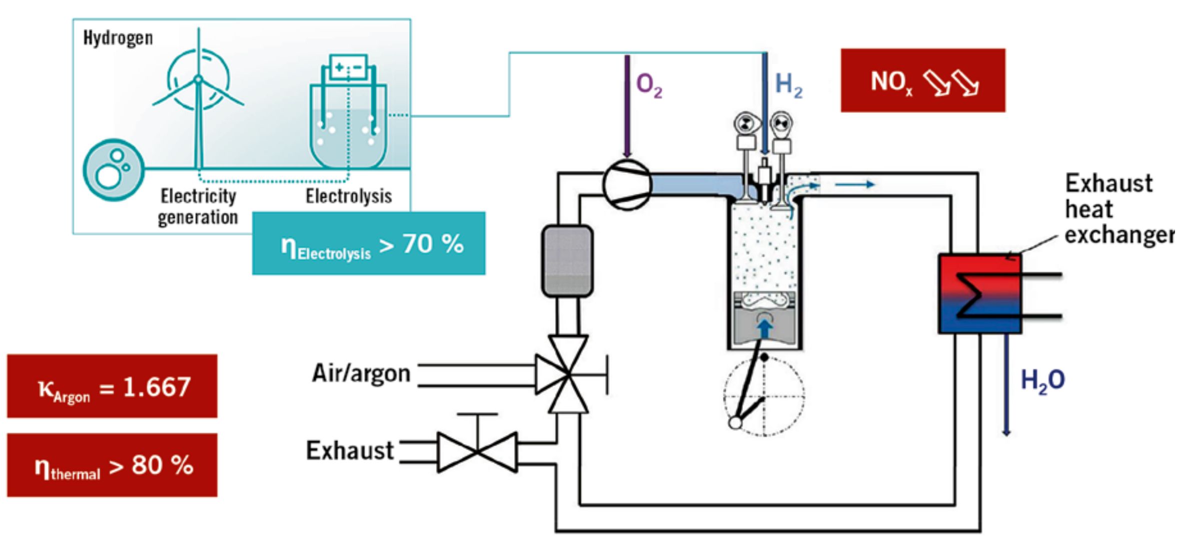

FIGURE 2 Schematic representation of hydrogen combustion using an inert car¬rier medium, source: Ehrler, T.: Zero-emission closed cycle engine for reconversion of green hydrogen. Dessau Gas Engine Conference, Dessau, 2019 (© Winterthur Gas & Diesel)

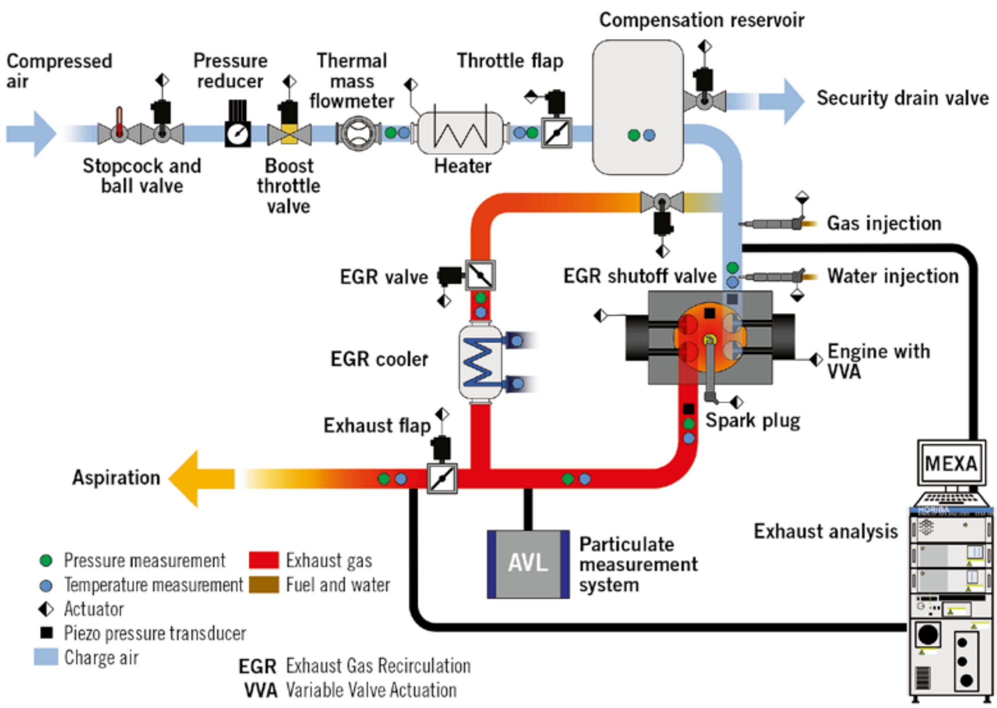

FIGURE 3 General test setup for the investigation of a stoichiometrically operated commercial vehicle gas engine with EGR and water injection (© TU Braunschweig)

within the FVV projects – here a switch has been made from a technology that controls the combustion processto more efficient engine temperature management.

A third project, "Potentials of Airpath Variabilities for Future Commercial Vehicle Gas Engines to Increase Efficiency and Reduce Emissions," which was launched at the beginning of 2019, is now dealing with how a fully variable valve train can be used to minimize the inherent efficiency disadvantage of a stoichiometric gas engine compared to a diesel engine [8]. Test bench measurements, **FIGURE 3**, are intended to prove that Miller valve control times can both reduce the throttling losses in the partload range and increase the knock limit at full load. In addition, the combination of the variable valve train with exhaust gas recirculation and water injection is being explored. In the best case scenario, such a gas engine could almost reach the efficiency of a diesel engine despite stoichiometric combustion, but with lower CO_2 emissions.

6 CONCLUSION

Due to the high energy density of gaseous and liquid fuels, internal combustion engines will continue to play a major role in the foreseeable future for long-distance and freight transport and as stationary energy converters. Basically, a CO_2-neutral operation with green hydrogen or synthetic fuels is possible, but in view of the higher production costs, research must continue to focus on overall system optimization. Engines with self-ignition can therefore be used wherever possible, provided that pollutant emissions are further reduced and efficiency is further increased.

Significant efficiency potentials can be realized by using new technologies such as AI or additive manufacturing. Innovative combustion processes and the further development of existing technologies such as variable valve actuation will be indispensable on the way forward to zero impact emissions and climate neutrality. With pre-competitive collective research projects, the FVV builds the bridges between science and application and thus ensures the competitiveness in the field of internal combustion engines.

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