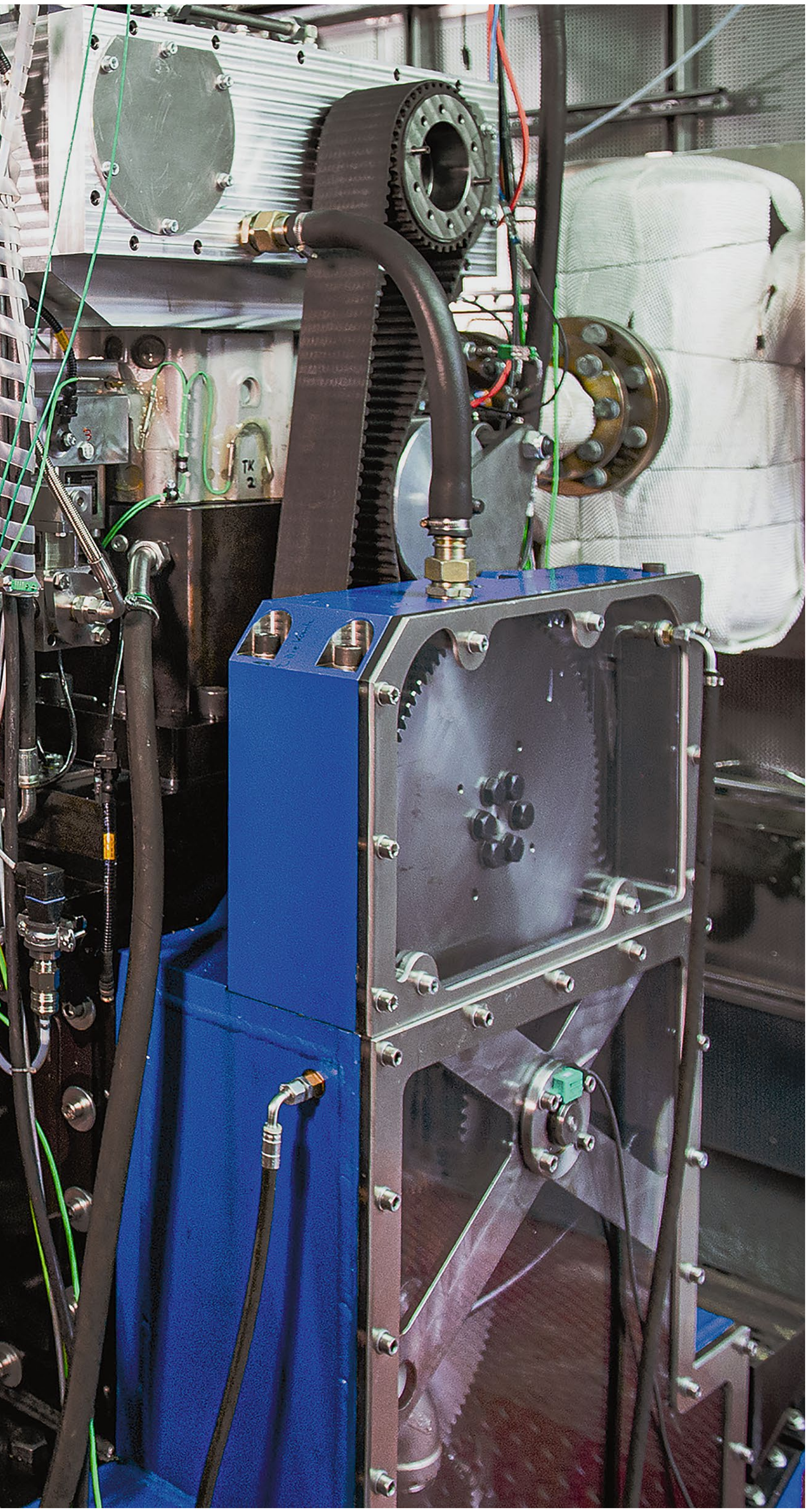
Industrial Engines as Power Systems – Research for Optimum System Design

The range of applications and the long service life of industrial engines call for research to reconcile climate neutrality and economic efficiency. The Research Association for Combustion Engines (FVV) promotes the use of climate-friendly energy sources, hybridization and fuel cells as alternative energy converters. There is one common challenge for the many different applications: The optimum is not achieved primarily through technical details, but rather through system design.

1 DIVERSITY

Industrial engines are used in a wide range of applications: in work equipment, construction and agricultural machinery, as emergency gensets, as combined heat and power plants, in mining, railways and watercraft. The power spectrum of currently produced four-stroke engines ranges from single-cylinder units with 1.5 kW to 10,000-kW marine engines, **TABLE 1**. With few exceptions, however, compression-ignition engines running on fossil fuel have been used to date. Even less than in the case of engines in road transport, defossilization can be achieved here via a general single alternative powertrain or a general single energy source, especially since the European engine manufacturers, who are without exception operating at a global scale, have to take into account different energy infrastructures in the world regions. Suppliers are therefore working across a broad spectrum on hybridization, full electrification, fuel cells, and combustion engines powered by synthetic fuels. In addition, the inter-



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VOICES OF THE FVV

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Dr.-Ing. Markus Schwaderlapp is Senior Vice President Research & Development at Deutz AG in Cologne (Germany). He is Member of the FVV's Board and Scientific Advisory Committee.
"The load profiles of industrial engines differ greatly. That is why we need a wide range of technology solutions on the road to a fully defossilized energy and transport system."

© Rolls-Royce Power Systems

Dr.-Ing. Martin Teigeler is Executive Vice President Research & Development at Rolls-Royce Power Systems AG in Friedrichshafen (Germany). He is Member of the FVV's Board and Scientific Advisory Committee.
"In the future, the true art of power supply will be to configure the perfect system for each application."

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Dr.-Ing. Sebastian Wohlgemuth took over as Head of Research & Development at Motorenfabrik Hatz GmbH & CO. KG in Ruhstorf (Germany) at the beginning of 2021. He is Member of the Scientific Advisory Committee of the FVV.
"Technology openness requires scientific evidence, such as that being developed in the FVV."

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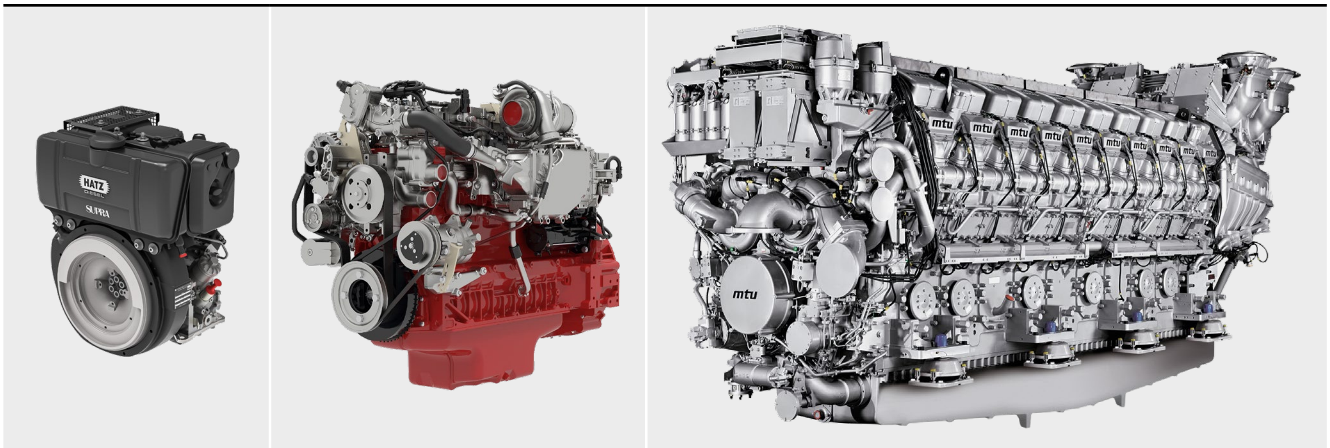

Hatz 1D90E	Deutz TCD 6.1 L6	MTU 8000 M91L
Air-cooled single-cylinder four-stroke engine	Water-cooled six-cylinder in-line engine	Water-cooled 20-cylinder V-engine
5.7 to 10.5 kW	180 kW	10,000 kW
0.722 l displacement	6.1 l displacement	347.4 l displacement

TABLE 1 Some examples of engine models currently on the market (© Hatz | Deutz | MTU)

nal combustion engine is expected to become even more efficient; however, the internationally inconsistent and partly application-specific exhaust gas legislation and different fuel qualities are contributing to even greater technical complexity.

For the diesel engine, increased power density and reduced pollutant emissions continue to be essential criteria. However, applications of solutions proven in road transport, such as Selective Catalytic Reduction (SCR) technology for nitrogen oxides, can lead to new research questions here. Engines running on gas have become very popular in some applications, such as distributed power and marine. For the gas engine, pre-competitive collective research in the FVV can answer questions about environmental compatibility in particular, for example with regard to methane slip, as well as seek strategies for higher power density. The latter also applies in particular to hydrogen operation. For new synthetic fuels, moreover, operating experience can be gathered on a broad basis; without collective research, this would hardly be possible for medium-sized suppliers in view of the variety of possible powertrain and fuel combinations.

In numerous applications, internal combustion engines are no longer to be regarded in isolation but as part of a hybridized energy supply system. This also applies to the fuel cell, insofar as mechanical energy is required in addition to electric power as their subsystem. While the concrete system design emerges in company-specific development, pre-competitively researched phenomena and simulation methods can strengthen the competitiveness of all players and at the same time accelerate the transition to carbon-neutral technologies.

2 FUTURE FUELS

A characteristic feature of industrial engines is their long service life, which is often more than 20 years and even longer. The targeted rapid defossilization of all sectors is in many applications only possible if a climate-neutral fuel is available. It can be assumed that one single novel energy carrier will not be enough to replace today's diesel fuel, but rather – depending on regional availability – a certain variety. When selecting suitable fuel alternatives, not only the influence on combustion and durability must be considered, but also their respective life cycle balance.

A detailed life cycle analysis for six energy sources and seven powertrains is being conducted by the FVV as part of the Fuel Study IV, which focuses on the defossilization of the transport sector [1]. Nevertheless, the study is also groundbreaking for industrial engines: It provides a methodology that is fundamentally transferable to other uses of synthetic fuels. However, it can be assumed that fuels completely independent of the transport sector will only be available for industrial engines in exceptional cases. A key feature of the Fuel Study IV is that it is based on the idea of the CO_2 residual budget and therefore considers the cumulative emissions over time for the use for alternative technologies. In addition, it consistently identifies the existing bottlenecks for individual production paths, differentiating between domestic and international production based on the division of labor. It is intended that the results of the study, which will be completed at the end of 2021, will be presented again in detail at a later date in MTZ.

3 COLD START OF GAS ENGINES

Due to the low carbon content in relation to its calorific value, gas as a fuel offers the opportunity to reduce CO_2 emissions from internal combustion engines, whereby the substitution of fossil natural gas with biogenic or synthetic methane can significantly improve the climate footprint of the engines. However, incomplete combustion after a cold start can lead to slip of the greenhouse gas methane as well as the formation of the

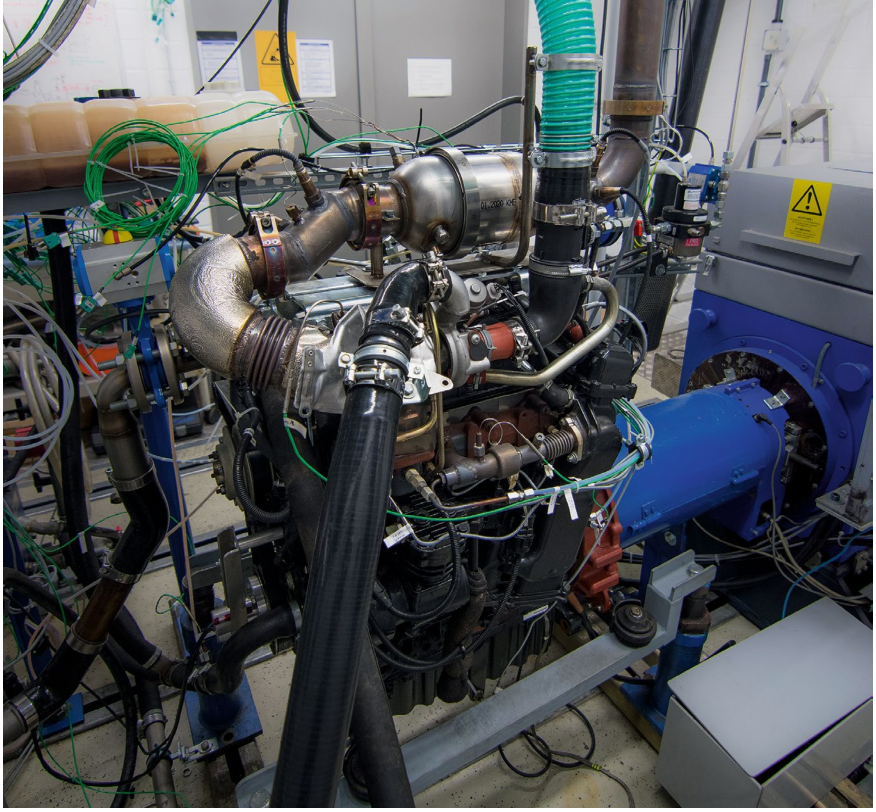

FIGURE 1 Deutz industrial gas engine with catalytic converter on the test bench (© LKV)

pollutant formaldehyde. One of the reasons for this is the high molecular stability of methane compared to long-chain hydrocarbons and the associated need for a higher ignition temperature. The conversion of CH_4 in an oxidation catalyst also requires higher temperatures, which makes complete conversion after a cold start even more difficult. Low CO_2 emissions from methane combustion are accompanied by high water concentrations in the exhaust gas. These lead to catalyst deactivation. As part of the FVV project "Cold Start CNG Catalyst," researchers from the universities of Cottbus-Senftenberg, Magdeburg and Rostock are investigating the cold start emissions of a passenger car and an industrial gas engine [2] in combination with a three-way and an oxidation catalyst. Extensive tests on the light-off behavior of the catalysts under various boundary conditions are first carried out on a synthesis gas test rig. In addition, the process of catalyst deactivation processes and various methods for reactivating are being investigated. Ammonia will be used as a reducing agent for the first time. In subsequent investigations on the engine test bench, several parameters are varied in the cold-start strategy of the engine control system, **FIGURE 1**. The Non-road Transient Cycle (NRTC) prescribed in Europe and the USA for pollutant measurements is used on the industrial engine, which differs significantly from load cycles in road transport. Based on the experimental investigations, a kinetic catalyst model is to be created that can be used for industrial developments in the future. The project is expected to be completed by the end of 2021.

4 SENSOR TECHNOLOGY FOR NEW FUELS

Synthetic and biogenic fuels can contribute to a rapid CO_2 reduction through blending. These blended fuels must also comply with the applicable standards. Nevertheless, a sensor that monitors fuel quality can increase operational reliability. This applies in particular to regions of the world with fluctuating fuel quality and to hybrid powertrains. For the electrified industrial engine, depending on the system configuration and mode of operation, the 90-day storage period that is decisive for the validity of DIN EN 590 can be exceeded.

The FVV project [3], which will run until the beginning of 2022, is investigating what a reliable sensor for e-fuels could look like, while at the same time being compatible in terms of measurement effort. Here, researchers at Coburg University of Applied Sciences are first identifying various synthetic fuels and analyzing their chemical composition. In parallel, a suitable aging apparatus for volatile fuels is being developed, in order to prepare a selection for the tests. From a previous research project [4], a di-electric and an optical sensor will be further developed to be able to measure the aged and unaged state of these fuels and their components. When the research is completed, all results will be recorded in a newly established database that will be available to other research projects.

5 UREA DEPOSITS

Wherever internal combustion engines are used in the future that operate with high excess air, exhaust gas purification by SCR is gaining importance. The basic principles were developed by a number of FVV projects in the 1990s and subsequently found widespread application in road vehicles. However, a 1 : 1 transfer to industrial engines is not possible due to the operating profile of these aggregates. A particular challenge is the deposition of unconverted urea in the exhaust system. Although this is well-known in principle from car and truck engines, it is particularly relevant due to the long service life of industrial engines. In the FVV project "Deposits from AdBlue II" [5], research performers at the Karlsruhe Institute of Technology (KIT) and the Vienna University of Technology are therefore jointly investigating the mechanisms that lead to the formation and build-up of solid deposits. While the previous project focused on modeling the fundamental physicochemical phenomena, the researchers in the current project [6] want to transfer the results obtained to the conditions in near-series exhaust systems, **FIGURE 2**. For the first time, the influence of surface quality in components – such as their roughness – on film formation is to be taken into account. The researchers also want to investigate how urea reacts with catalytic materials and how thick urea films (pools) behave in the hot exhaust gas stream. The findings will be used to improve the model created in the previous project. Results will be available in the first half of 2022.

6 PERSPECTIVES

Climate neutrality is an important corporate goal for many buyers of industrial engines – but it is expected not to

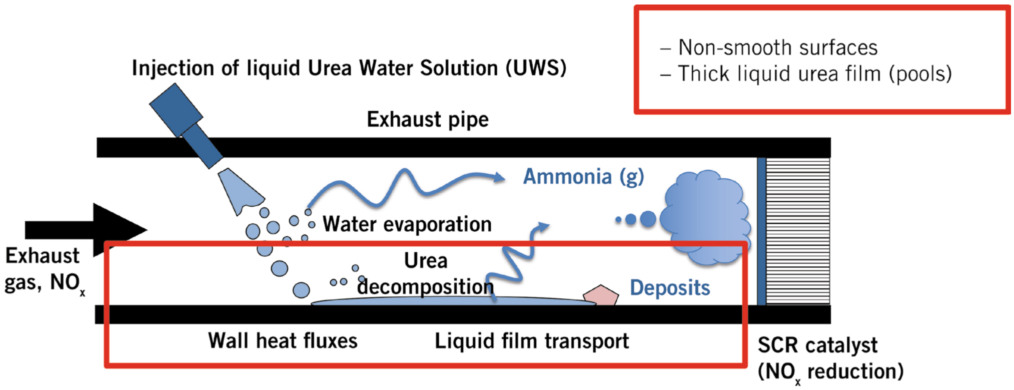

FIGURE 2 Formation mechanism for urea deposits in the exhaust gas (© ITC | IFA)

experience any restrictions in terms of reliability and service life. Hybridization, the switch to alternative operating materials or the use of fuel cells raise questions about aging behavior of the engines. This is related to the operating profile, which varies greatly depending on the application and the region of the world. Pre-competitive industrial collective research can gain insights into how aging processes and environmental conditions correlate. The transfer of knowledge that takes place within the framework of FVV projects also enables small and medium-sized companies in the supply industry to master the increasing technical complexity.

All industrial engines will become part of the Internet of Things (IoT) in the future. The remote diagnostics and predictive maintenance made possible thanks to networking have the potential to significantly reduce lifetime costs. Pre-competitive collective research may quickly reach its limits when it comes to exchanging operating data. However, methodological fundamentals offer enormous advantages for developers. Provisioning control unit data with the help of Artificial Intelligence (AI) or IoT-enabled sensor concepts are already on the FVV research agenda.

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